Ginger
The Genus Zingiber

Edited by P.N. Ravindran and K. Nirmal Babu

Medicinal and Aromatic Plants — Industrial Profiles

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This volume is dedicated to Prof. V.L. Chopra, Member, Planning Commission, Government of India
(formerly BP Pal National Chair, Indian Council of Agricultural Research [ICAR]; Director General, ICAR; Secretary, Department of Agricultural Research and Education, Government of India);
a distinguished scientist, humanist, and research manager; an individual of rare distinction and qualities; for his guidance, encouragement, and support.

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Preface to the Series

There is increasing interest in industry, academia, and the health sciences in medicinal and aromatic plants. In passing from plant production to the eventual product used by the public, many sciences are involved. This series brings together information which is currently scattered through an ever-increasing number of journals. Each volume gives an in-depth look at one plant genus, about which an area specialist has assembled information ranging from the production of the plant to market trends and quality control.

Many industries are involved, such as forestry, agriculture, chemicals, food, flavor, beverage, pharmaceutical, cosmetics, and fragrance. The plant raw materials are roots, rhizomes, bulbs, leaves, stems, barks, wood, flowers, fruits, and seeds. These yield gums, resins, essential (volatile) oils, fixed oils, waxes, juices, extracts, and spices for medicinal and aromatic purposes. All these commodities are traded worldwide. A dealer's market report for an item may say "drought in the country of origin has forced up prices."

Natural products do not mean safe products, and account of this has to be taken by the above industries, which are subject to regulation. For example, a number of plants which are approved for use in medicine must not be used in cosmetic products.

The assessment of "safe to use" starts with the harvested plant material, which has to comply with an official monograph. This may require absence of, or prescribed limits of, radioactive material, heavy metals, aflatoxin, pesticide residue, as well as the required level of active principle. This analytical control is costly and tends to exclude small batches of plant material. Large-scale, contracted, mechanized cultivation with designated seed or plantlets is now preferable.

Today, plant selection is not only for the yield of active principle, but for the plant's ability to overcome disease, climatic stress, and the hazards caused by mankind. Such methods as *in vitro* fertilization, meristem cultures, and somatic embryogenesis are used. The transfer of sections of DNA is giving rise to controversy in the case of some end uses of the plant material.

Some suppliers of plant raw material are now able to certify that they are supplying organically farmed medicinal plants, herbs, and spices. The Economic Union directive CVO/EU No. 2092/91 details the specifications for the *obligatory* quality controls to be carried out at all stages of production and processing of organic products.

Fascinating plant folklore and ethnopharmacology leads to medicinal potential. Examples are the muscle relaxants based on the arrow poison, curare, from species of *Chondrodendron*, and the antimalarials derived from species of *Cinchona* and *Artemisia*. The methods of detection of pharmacological activity have become increasingly reliable and specific,

frequently involving enzymes in bioassays and avoiding the use of laboratory animals. By using bioassay-linked fractionation of crude plant juices or extracts, compounds can be specifically targeted which, for example, inhibit blood platelet aggregation, or have antitumor, or antiviral, or any other required activity. With the assistance of robotic devices, all the members of a genus may be readily screened. However, the plant material must be fully authenticated by a specialist.

The medicinal traditions of ancient civilizations such as those of China and India have a large armamentarium of plants in their pharmacopoeias which are used throughout Southeast Asia. A similar situation exists in Africa and South America. Thus, a very high percentage of the world's population relies on medicinal and aromatic plants for their medicine. Western medicine is also responding. Already in Germany all medical practitioners have to pass an examination in phytotherapy before being allowed to practice. It is noticeable that medical, pharmacy, and health-related schools throughout Europe and the United States are increasingly offering training in phytotherapy.

Multinational pharmaceutical companies have become less enamored of the single compound, magic-bullet cure. The high costs of such ventures and the endless competition from "me-too" compounds from rival companies often discourage the attempt. Independent phytomedicine companies have been very strong in Germany. However, by the end of 1995, 11 (almost all) had been acquired by the multinational pharmaceutical firms, acknowledging the lay public's growing demand for phytomedicines in the Western world.

The business of dietary supplements in the Western world has expanded from the health store to the pharmacy. Alternative medicine includes plant-based products. Appropriate measures to ensure their quality, safety, and efficacy either already exist or are being answered by greater legislative control by such bodies as the U.S. Food and Drug Administration and the recently created European Agency for the Evaluation of Medicinal Products based in London.

In the United States, the Dietary Supplement and Health Education Act of 1994 recognized the class of phytotherapeutic agents derived from medicinal and aromatic plants. Furthermore, under public pressure, the U.S. Congress set up an Office of Alternative Medicine, which in 1994 assisted the filing of several Investigational New Drug (IND) applications, required for clinical trials of some Chinese herbal preparations. The significance of these applications was that each Chinese preparation involved several plants and yet was handled as a *single* IND. A demonstration of the contribution to efficacy of *each* ingredient of *each* plant was not required. This was a major step toward more sensible regulations in regard to phytomedicines.

My thanks are due to the staff of CRC Press who have made this series possible and especially to the volume editors and their chapter contributors for the authoritative information.

Dr. Roland Hardman

Preface

Among the crops used by humankind, the history of spices is perhaps the most adventurous, the most fascinating, and the most romantic. In the misty distant past, when primitive humans were roaming around the forests in search of food and shelter, they might have tested and tasted many roots and leaves and might have selected those that were aromatic and spicy as being of special value, and might have used them to propitiate their primitive gods to save them from the raging storm, thunder, lightning, and rain. Out of the misty darkness of that distant past, the early civilizations evolved when humans settled down and started practicing agriculture. In all civilizations the aromatic plants were given special status, and many were probably used as offerings to gods. Gradually humans might have started using them for curing various illnesses, and in course of time spices and aromatic plants had acquired magical associations about their properties. Among all the civilizations, it was in the Indian and Chinese that profound knowledge gradually evolved on the use of plants and plant products for the treatment of human ills.

From the dawn of human civilization, spices were sought after as eagerly as gold and precious stones. Discovery of the spice land was one of the aims of all circumnavigations and the great explorations that the period of Renaissance witnessed. One such navigational venture in search of the famed land of spices and ivory reached the ancient Malabar Coast of India on May 20, 1498. Vasco da Gama discovered the sea route to India. The decades that followed witnessed the Portuguese establishment of trade relations with the Malabar Coast, and subsequently they emerged as powerful players in the game of power politics of the region. The landing of da Gama also witnessed the transition of medieval to the modern India and the rising of the global imperialism and colonial power struggles. The Portuguese and subsequently the Dutch, French, and finally the British established their supremacy over the spice trade in the centuries that followed.

Ginger has been valued as a spice and medicinal plant from ancient times both in India and in China. For the ancient Indians it was the *mahaoushadha* and *vishwabheshaja* (the great medicine, the universal cure, respectively). It was among the best-known crude drugs in the Chinese and Japanese systems of medicine too. Ginger is now used universally in traditional medicine as well as in modern medicine for the treatment of nausea and vomiting associated with pregnancy and for the prevention of travel and sea sickness. Many countries have approved ginger as a nonprescription drug for the prevention of motion sickness. It is also recognized as an anti-inflammatory drug useful in the treatment of rheumatoid arthritis and osteoarthritis, being on a par with many steroidal preparations.

Ginger plays a very significant role as a home remedy in that it is a sure cure for indigestion. It is indispensable in Chinese, Japanese, and Indian cooking, as well as in the cuisines of many South and Southeast and Far East Asian countries.

This book is the first comprehensive publication on ginger. It covers all aspects of ginger—botany, crop improvement, chemistry, biotechnology, production technology in the major producing countries, diseases, pests, harvesting, processing, products, economics and marketing, pharmacology, medicinal uses, uses as spice and flavorant. There is also a chapter on related, economically important species. The book comprises 17 chapters, each written by experts, giving an in-depth analysis of each aspect of ginger, followed by an extensive bibliography. We have tried to collect and collate as much information as possible about the subject presented in each chapter.

The editors of this volume have extensive experience in genetic resources conservation, botany, breeding, and biotechnology of ginger. As the former national co-coordinator of spices research in India, the senior editor, P.N. Ravindran, had the opportunity of associating with all the ginger research work being carried out in India, the only country having a strong research and development program on ginger. The value of this volume is enhanced considerably by the excellent and comprehensive review on ginger chemistry authored by Prof. Vernin and Prof. Parkyani. Prof. Kimura of Japan has authored a very valuable chapter on the pharmacology of ginger. The chapters on botany and crop improvement, biotechnology, diseases, processing, and marketing are also very extensive and authoritative. The production technologies of ginger differ in various producing countries. In order to give a full picture of the ginger production, three chapters have been included that represent the major producing countries from three regions: India, China, and Nigeria.

Research carried out during the past two decades led to the isolation of many chemical constituents of ginger and from the related taxa, some of which may be the basis for the medicinal properties of ginger. The medicinal uses of ginger in the Indian and Chinese systems of medicines have been presented in the chapter on medicinal properties and uses. The use of ginger in the kitchen as a spice and flavorant is also presented in a detailed chapter. A short chapter on the constraints and yield gaps is also included.

This book is targeted to the students and researchers in the areas of horticulture, agriculture, botany, medicinal plants, ginger producers, processors, exporters, and end users. We have tried very hard to select the best people available to author the chapters and also to gather as much information as possible. Collecting and collating such information was not easy, and many people and many organizations helped us. Prof. Roland Hardman, the General Editor of the Series on Medicinal and Aromatic Plants: Industrial Profiles, has kindly commissioned us to edit this book. He has been a source of help and inspiration, and supported us by the regular supply of updated literature searches and other advice. It was his goodwill that helped the senior editor, Dr. P.N. Ravindran, in getting the four volumes, including this one, edited. The editors, especially the senior editor, are extremely thankful to Prof. Hardman. We are also very much indebted to the publishers Taylor and Francis, London, and to the CRC Press, Boca Raton, Florida, for accepting the recommendation of Prof. Harman and for entrusting

the responsibility with us for editing this monograph. We are also extremely thankful to the CRC Press for publishing this first-ever international monograph on ginger.

We hope that this book will be invaluable to all those who are involved in the production, processing, marketing, and/or use of ginger. It is further hoped that it will kindle interest in this crop in the minds of the readers and will act as a catalyst for more research and developmental activities in solving the many problems besetting this wonderful spice and medicinal plant.

P.N. Ravindran
K. Nirmal Babu
Editors

Acknowledgments

The editors express their deep gratitude to all the chapter contributors to this monograph who found time to collaborate in its production. We are especially thankful to Prof. G. Vernin and Prof. G. Parkayni for preparing a magnificent chapter on the chemistry of ginger and to Prof. Ikuko Kimura and his colleagues for authoring the excellent chapter on the pharmacology of ginger. In spite of their manifold activities, they had the magnanimity of cooperating with us in the production of this first-ever monograph on ginger. We salute them in gratitude.

The editors are grateful to Prof. Roland Hardman, General Editor of the series Medicinal and Aromatic Plants: Industrial profiles, for commissioning us to edit this volume and for his constant help during its production. He helped by providing us with updates of literature searches and with valuable advice.

We are extremely grateful to Geetha S. Pillai and Minoo Divakaran for their devoted and committed help at every stage in the preparation of this volume. We are also thankful to many friends and colleagues who helped us during the preparation of this volume. Among them Mr. K.V. Thushar and Mr. Satheesh George deserve special mention. Dr Remashree helped us with some of the drawings included in the second chapter, for which we are very thankful to her.

In the preparation of this volume, especially that of the chapter on botany and crop improvement, we made use of the published information from diverse sources and by many authors, of course with full citation. Some of them are not with us now, but their contributions will continue to be remembered and studied by the students through this book for many a decade to come. We acknowledge with gratitude all these workers and salute them in reverence.

We place on record our appreciation to Arya Vaidya Sala, Kottackal, for permitting the senior editor to undertake the editing of this important monograph.

We have sincere appreciation to the publishers Taylor & Francis, London, and the CRC Press, Boca Raton, Florida, for giving us this opportunity to edit this first-ever monograph on ginger.

We are much indebted to the members of our families whose help, understanding, and love sustained us during the arduous work that we had to put forth during the preparation of this book. We thank all our well wishers and all those who helped us in the preparation of this book.

P.N. Ravindran
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Dec. 10, 2003

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1 Introduction

P.N. Ravindran and K. Nirmal Babu

Ginger is one of the most important and most widely used spices worldwide. Due to its universal appeal, ginger has spread to most tropical and subtropical countries from the China–India region, where ginger cultivation was prevalent probably from the days of unrecorded history. In ancient times ginger was more valued for its medicinal properties and played an important role in primary health care in ancient India and China. In European medicine ginger was also among the most highly valued of all mild carminatives and it was a component of many pharmaceutical preparations.

Ginger, botanically known as *Zingiber officinale* Rosc., belongs to the family Zingiberaceae and in the natural order Scitamineae (Zingiberales of Cronquist, 1981). The Latin term *Zingiber* was derived from the ancient Tamil root, *ingiver*, meaning ginger rhizome. The term *ingiver* spread to ancient Greece and Rome through the Arab traders, and from there to Western Europe. The present-day names for ginger in most of the Western languages were derived from this. Examples are *ingefaer* (Danish), *Gember* (Dutch), ginger (English), *Zingibro* (Esperanto), *harilik ingver* (Estonian), *inkivaari* (Finnish), *gingerbre* (French), and *ingver* (German) (Table 1.1). Some authors earlier thought that the term *Zingiber* was derived from the Sanskrit term *singavera* (Watt, 1872; Rosengarten, 1969; Purseglove et al., 1982), meaning antler-like or horn-shaped, indicating the shape of the rhizome. It is improbable because the Sanskrit language was not popular in the region in those days. Ginger was exported from the ancient Malabar Coast on the southwest coast of peninsular India, and the Arab traders might have used only the prevalent local Tamil name for trading the commodity. Mahindru (1982) was of the opinion that the original word for ginger was in all probability a pre-Dravidian one, and that it is found with minor variations in about 20 languages extending from China and the islands of the Pacific Ocean to England. In certain languages there are separate terms for fresh ginger and dried ginger, which indicate the importance of both commodities as well as the fact that they are put to uses that are often distinct and different (Table 1.2).

Fluckiger and Hanbury (1874) mentioned that, as early as the second century A.D., in Rome ginger was one among the very few items on which duty was levied at Alexandria, the port of entry. In subsequent periods, including the Middle Ages, ginger was on the list of privileged goods in the European trade and duty was levied for its trade. In England it must have been well known even prior to the Norman Conquest, for it is frequently named in the Anglo-Saxon beech-books of the eleventh century as well as in the Welsh "Physician of Myddvai" (Parry, 1969). During the thirteenth and fourteenth centuries, next to pepper, ginger was the commonest and most precious of spices, costing nearly seven scrolling per pound, or about the price of a sheep. The merchants of Italy during the thirteenth and fourteenth centuries knew three kinds of ginger: *belledi, colombino,* and

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Table 1.1 Names of ginger in various languages

Language	*Common name*
Pharm.	Rhizoma Zingiberis
Arabic	Zanjabil
Assamese	Ada
Bengali	Ada
Brazilian	Mangaratia
Burmese	Gin, Gyin sein, Khyen-seing, Ginsi-kyaw
Chinese	Jeung, Sang keong, San geung, Chiang, Jiang, Keong, Shen jiang, Gan jinang, Shengjiang
Czech	Zázvor
Danish	Ingefær
Dutch	Gember, Djahe
English	Ginger
Esperanto	Zingibro
Estonian	Harilik ingver
Ewe	Nkrawusa, Nkrama, Nkrabo, Agumetakui
Fante	Akakadur, Tsintsimir, Tsintsimin
Farsi	Jamveel, Zanjabil
Finnish	Inkivääri
French	Gingembre
Ga-Dangme	Kakaotshofa, Odzahui
German	Ingwer
Gujarati	Adhu (fresh), Sunth, Shuntya (dried)
Hausa	Chitta, Afu
Hebrew	Zangvil
Hindi	Adi, Adrak (fresh), Sonth (dried)
Hmong	Kai
Hungarian	Gyömbér
Icelandic	Engifer
Indonesian	Jahé, Aliah, Jae, Lia
Italian	Zenzero, Zenzevero
Japanese	Shouga; Myoga (Z. mioga) , Kankyo, Shoukyo, Kinkyo
Kannada	Alla (fresh), Sunthi (dried)
Kashmiri	Sho-ont
Khmer	Khnehey, Khnhei phlung
Laotian	Khing
Malay	Halia, Atuja, Jahi, Keong phee, Kong Keung
Malayalam	Inchi (fresh), Chukku (dried)
Marathi	Alha, Aale (fresh), Sunth, Shuntya (dried)
Norwegian	Ingefær
Nzema	Sinziminli
Oriya	Ada, Adraka
Persian	Shangabir, Zangabi
Polish	Imbir
Portuguese	Gengibre
Romanian	Ghimbir

Russian	Imbir
Sanskrit	Adraka (fresh), Shunthi (dried), Shringaveran, Sringaaran, Nagara
Scandinavian	Ingefaer
Singhalese	Inguru
Spanish	Jengibre
Swahili	Tangawizi
Swedish	Ingefära
Tagalog	Luya
Tamil	Ingee, ingiver, chukku (dried)
Telugu	Allam
Thai	Kinkh, Khing-daen
Tibetan	Gamug, Sga smug, Sman-sga
Turkish	Zencefil
Twi	Akakaduru, Kakaduru
Urdu	Adraka
Vietnamese	Gung, Sinh khuong

Compiled from various sources

Table 1.2 Names of fresh and dried ginger in some languages

Language	*Plant*	*Fresh*	*Dried*
Hindi	Adrak	Adrak, Adhruka	South, Saindhi
Bengalese	Ada	Adrok	Sont
Assamese	Ada	Adrak	Sonth
Punjabi	Ada, Adrak	Aunjbel	Sanjzabil, South
Marathi	Adu, Aale	Alen, Alem, Adrak	Sonth, Sunta, Sunt
Gujarati	Adu, adhu	Adu, Adhu	Sunt
Tamil	Inji	Inji, Ingiver	Chukku
Malayalam	Inchi	Inchi	Chukku
Telugu	Allam	Allam	Sonthi
Kannada	Sunthi	Hasisunthi	Vana sunthi
Burmese	Khyenseing	Ginsin	Ginsi-khaiv
Singapore	Ingru	Ammuingru	Velicha-ingru
Sanskrit	Adraka, Sringavara	Ardrakam	Vishva-bhishakam Nagara, Sunti Mahaushadha.
Arabic	–	Sanjzabile-ratal	Sanjzabile-Yabis
Persian	–	Zanjzabil-tar	Zanjzabil-Khushk

Compiled from various sources

micchino. *Belledi* is an Arabic word meaning “country” and was probably the common ginger. *Colombino* referred probably to Columbum, Kollom, or Quilon, an ancient port on the southern Malabar Coast, and *micchino* denoted the ginger brought from Mecca (which again goes from the Malabar Coast only) (Watt, 1872, Mahindru, 1982). The

literature also indicates that ginger preserved in syrup (called green ginger) was also imported to the Western World during the Middle Ages and was regarded as a delicacy of the choicest kind. In Zanzibar on the east coast of Africa, ginger is regarded as auspicious, which is absolutely necessary to the Savaras tribe for their religious and marriage functions.

Ginger is mentioned in the Koran (76: 15–17): "Round amongst them (the righteous in paradise) is passed vessels of silver and goblets made of glass ...a cup, the admixture of which is ginger." In the Middle Ages ginger was considered to be so important a spice that the street in Basle where Swiss traders sold spices was named *Imbergasse*, meaning "Ginger Alley" (Rosengarten, 1969). In Henry VIII's time, ginger was recommended against plague. It was during that time that "gingerbread" became popular, and it became a favourite of Queen Elizabeth I and her court. The legend is that around 2400 B.C. a baker on the Isle of Rhodes near Greece prepared the first gingerbread. Shortly thereafter the recipe found its way to Egypt, where the Egyptians savored its excellent flavor and served it on ceremonial occasions. The Romans distributed ginger bread to all parts of the empire (Farrell, 1985).

During the Middle Ages and until the end of the nineteenth century English tavern keepers used to have ground ginger in constant supply for thirsty customers to sprinkle on top of their beer or ale and then stir into the drink with a red-hot poker (Rosengarten, 1969). The Western herbalists and naturalists knew the great qualities of ginger as confirmed by the well-known British herbalist John Gerad. He writes in his herbal (1577) that "ginger is right good with meat in sauces," and says that this spice is "of an eating and digesting quality, and is profitable for the stomach, and effectively opposeth itself against all darkness of the sight, answering the qualities of pepper" (Parry, 1969).

Ginger in India

In ancient India, ginger was not significant as a spice, but it was *mahabheshaj*, *mahaoushadhi*, literally meaning the great cure, the great medicine. For the ancient Indian, ginger was the god-given panacea for a number of ailments. That may be the reason why ginger found a prime place in the ancient Ayurvedic texts of Charaka *(Charaka samhita)* and Susruth *(Sushrutha samhita).* In *Ashtangahridyam* of Vagbhatt (a very important ancient Ayurvedic text), ginger is recommended along with other herbs for the cure of elephantiasis, gout, extenuating the juices, and purifying the skin from all spots arising from scorbutic acidities. Ginger is also recommended when exotic faculties were impaired due to indigestion.

The earliest mention of ginger cultivation is probably by Rabbi Benjamin Tudella, who traveled between 1159 and 1173 A.D., and gave an account of spices grown on the west coast of India. Tudella gives a vivid description of the place and trade in spices as well as cultivation of spices in and around the ancient port of Quilon in the State of Kerala (Mahindru, 1982). Marco Polo (A.D. 1298), in his famous travelogue, writes: "good ginger also grows here and is known by the name of Quilon ginger. Pepper also grows in abundance throughout the country" (translation by Menon, 1929). Another traveler, Friar Odoric (A.D. 1322), writes. "Quilon is at the extremity of pepper forests towards the south. Ginger is grown here, better than anywhere else in the world and in huge quantities." In those days Calicut, Cochin, Aleppey and Quilon were the ports through which all the spices were traded with the Western World. Nicolo Contai (A.D. 1430)

describes Calicut as the "Spice Emporium of the East." He described it as a maritime city of 8 miles in circumference, a notable emporium for the whole of India abounding in pepper, aloe, ginger, and a large kind of cinnamon, myrobalans, and zedoary. Linschotten (1596) gives a very interesting account of the spices. He states that ginger grew in many parts of India, but the best and the most exported grew on the coast of Malabar. He described the method of cultivation and preparation that appear to be similar to the present-day practices. Linschotten also wrote about the ginger trade and mentioned that ginger was mainly brought to Portugal and Spain from the West Indies, indicating the fact that the Portuguese were successful in cultivating ginger extensively in Jamaica and the adjoining West Indies Islands. Fluckiger and Hanbury (1874) writes: "it [ginger] was shipped for commercial purposes from the Islands of St. Domingo as early at least as 1585 and from Barbadoes in 1654. Reny (1807) mentions that in 1541, 22053 cwt of dry ginger was exported from West Indies to Spain" (Watt, 1872).

The most significant event in the history of the spices trade was the landing of Vasco da Gama on the west coast of India. Da Gama started from Lisbon in Portugal, arrived at Mozambique in March 1498, and from there he reached Mlinde by the end of April. The king of Mlinde advised da Gama to sail to Calicut and arranged an Arab pilot to help him. This Arab brought the Portuguese across the Arabian Sea in 20 days, and on May 17, 1498, da Gama anchored at Kappad, a hamlet near Calicut. Following this, a wave of expeditions arrived on the west coast of India (known at that time as the Malabar Coast), and the trade with Europe flourished. The arrival of the Portuguese also signaled the end of the Arab monopoly on the spices trade. Da Gama again came to India commanding an armada of 15 ships. By using all the techniques of intimidation, he entered into an alliance with the king of Cochin and secured all the rights of the spices trade from him. Subsequently in 1513 A.D., a treaty was signed with the king of Calicut (known as Zamorin), ending the decade-long fight between the two. By this treaty Portugal got the license to trade spices freely, although under the ineffectual supervision of the Zamorin government. However, there was no restriction in procuring ginger directly from the growers (Mahendru, 1982).

When the Portuguese started exporting spices directly to Europe, they forced the growers to cultivate almost every inch of land with pepper and ginger. This helped the growers in a way, as they were free from the bondage of a few big merchants. But the Portuguese could not continue alone for long. The Dutch arrived on the scene and they drove out the Portuguese practically from the entire west coast. The Dutch controlled the spices trade on the west coast of India only for a short while, as they concentrated more on East Indies. The powerful Travancore king defeated them. As time rolled on, the spices trade ultimately passed on to the British in the decades that followed.

When these developments were going on in the west coast, the north of India was under the rule of the Mogul emperor Akbar. Under the Mogul rule spices cultivation in the north and western India improved considerably. The spread of Mogul dishes also demanded a considerable quantity of various spices. Ginger was an important constituent of most of these dishes, both vegetarian and nonvegetarian. *Ain–i–Akbari*, written by Abdul–Fazl, Akbar's prime minister, is a truthful account of the period, in which he presents the details of various dishes in vogue among the Moguls (*Ain* 24). In *Ain* 27(f) he records the market prices of spices. Ginger was comparatively cheaper than many other spices—dried ginger was four dinars per seer, and fresh ginger was 2.5 dinars. He mentioned that pickled green ginger was available at 2.5 dinars per seer. Ginger was thus a common man's spice, unlike black pepper and saffron (Mahindru, 1982).

Ginger was being grown on the west coast (the present-day Kerala) of India from time immemorial, and later on its cultivation spread to various other parts, mainly to Bengal and northeastern India. Buchanan (1807), who journeyed through the heartlands of various kingdoms that existed in southern India, made many references on the cultivation of various spices, including ginger, on the Malabar Coast. Ridley (1912) gives a detailed description of agricultural practices prevalent in nineteenth-century India. About ginger and turmeric, he quoted from the work *A Hand Book of Agriculture* written by N. Mukherjee: "The planting of ginger and turmeric was preferred under the shade of orchard trees. . . .The output of ginger was 2500 pounds per acre. . . .Green ginger was sold at rupees four for 25 pounds. The cost of cultivation worked out to about rupees 250 per acre."

In other words, the farmer got Rs.166 per acre (66.4%) as profit from ginger. The quantity of rhizomes required for planting was estimated as 100 pounds per "bigha" (1600 sq. yards). Harvested ginger was processed before being sold in the market. Different methods were followed in the processing of ginger in different regions. In Maharashtra (Khandesh region), the processing was done as follows:

> The rhizomes were dug up, cleaned of dirt and roots and boiled in a wide mouthed vessel, and then dried. After drying for a few days, the rhizomes were steeped in a diluted limewater, sun dried and again steeped in a stronger limewater and buried for fermentation. Later the rhizomes were dried and marketed. This product was known as "Sonth." (Watt, 1872)

The practice adopted in Bengal was: "Ginger was first brushed with a hand brush to remove dirt and steeped overnight in lime water; subsequently rinsed in clear water and dried slowly on a brick oven." The Bengal province in those days extended to the Himalayan hills, and ginger cultivation was prevalent in these areas. Campbell, who wrote the *Agricultural and Rural Economy of the Valley of Nepal,* states that ginger was carefully grown in Nepal and the produce "is reckoned by the people of the neighboring plains of Tirhoot and Sarun of very highest flavor and superior to the produce of their own country" (Watt, 1872). Watt also gives details of cultivation prevalent in these regions.

Sir Baden Powell, the legendary founder of the Boy Scout movement, reported the following practice:

> The rhizomes were dried up by placing them in a basket suspended by a rope and shaking for two hours everyday for three days. Later on these were sun dried for eight days and again shaken in the basket and re-dried for 48 hours in the basket itself. This removed the scales and skins, making the produce suitable for marketing (Watt, 1882).

In the nineteenth century in Bombay province, ginger was processed by peeling the rhizome with a piece of metal or tile and later drying it in the sun.

The Cochin ginger (ginger that came from the Cochin principality and exported from Cochin) was processed similarly to the Bombay ginger. Harvested rhizomes were heaped for a few days and then washed thoroughly to remove dust and soil. The outer skin was peeled off using a bamboo splinter, washed again, and dried in the sun. Sometimes the

dried ginger was heaped in limewater for a few hours and redried to improve the appearance.

A *bigha* of ginger crop yielded 10 mounds fit for sale at the rate of Rs. 6 per mound. The prevailing rate for ginger during the end of the nineteenth century was: Bengal Rs. 10.6 per cwt; Bombay Rs. 9.9 per cwt; Sind Rs. 11.6 per cwt. In Madras Province (including the Cochin region) ginger was available at 20 paise per kilogram (Mukherjee, quoted by Ridley, 1912).

It is also of historical importance to record the first detailed chemical studies on ginger by J.O. Thresh (Year Book of Pharmacy, 1879, 1881, and 1882). He analyzed a sample of Cochin ginger that was found to contain (in percent): volatile oil—1.350, fat (wax) resin—1.205; neutral resin—0.950; α and β resins—0.865; gingerol—0.6; substance precipitated by acids—5.35; mucilage—1.45; indifferent substance precipitated by tannins—6.8; extraction soluble in spirits of wine, not in ether or water—0.28; alkaloid—trace; metarabin—8.12; starch—15.79; pararabin—14.4; oxalic acid—0.427; cellulose—3.75; albuminoides—5.57; vasculose etc.—14.4630; moisture—13.53; and ash—4.8.

Centers of Cultivation

Ginger is not known to occur in the truly wild state. It is believed to have originated in Southeast Asia, but was under cultivation from ancient times in India as well as in China. There is no definite information on the primary center of domestication. Because of the easiness with which ginger rhizomes can be transported long distances, it has spread throughout the tropical and subtropical regions in both hemispheres. Ginger is indeed the most widely cultivated spice (Lawrence, 1984).

The main ginger growing countries are: India, China, Jamaica, Taiwan, Sierra Leone, Nigeria, Fiji, Mauritius, Indonesia, Brazil, Costa Rica, Ghana, Japan, Malaysia, Bangladesh, Philippines, Sri Lanka, Solomon Islands, Thailand, Trinidad and Tobago, Uganda, Hawaii, Guatemala, and many Pacific Ocean islands.

India and Other South Asian Countries

India is the largest producer of ginger; the annual production is about 263,170 tons from an area of about 77,610 hectares, contributing approximately 30 to 40% of the world production. The productivity is low, at about 3,428 kg/ha. Out of the total production, 10 to 15% is exported to about 50 countries around the world. The crop occupies the largest area in the state of Kerala (19%), followed by Orissa (17%) Meghalaya (12%), West Bengal (12%), and Arunachal Pradesh (6%). Kerala and Meghalaya together account for nearly 40% of the country's production (Table 1.3). In terms of productivity, Arunachal Paradesh stands first with 7,164 kg/ha, followed by Meghalaya (5,139 kg/ha), Mizoram (5,000 kg/ha), and Kerala (3,428 kg/ha). During 1999–2000 India exported 8,773 tons of ginger valued at Rs. 306 million, out of which dry ginger contributed Rs. 199.2 million.

Nigeria

In Nigeria large-scale cultivation of ginger began in 1927 in southern Zaria, especially within Jemma's federated districts as well as in the adjoining parts of the plateau. Nigeria has tried to widen the genetic base of the crop through introduction of ginger cultivars,

Table 1.3 Area under ginger cultivation in the world

Ginger area harvested (ha)	*Year*		
	1999	2000	2001
Bangladesh	6,879	6,879	7,290
Bhutan	350	350	350
Cameroon	1,370	1,370	1,370
China	17,750	19,170	20,700
Costa Rica	110	361	361
Dominica	45	45	45
Dominican Republic	400	400	400
Ethiopia	150	150	150
Fiji Islands	65	65	65
India	80,000	80,000	80,000
Indonesia	10,200	10,600	10,600
Jamaica	180	180	180
Kenya	65	55	55
Korea, Republic of	4,255	4,255	4,255
Madagascar	8	8	8
Malaysia	1,000	1,000	1,000
Mauritius	50	170	170
Nepal	1,400	1,400	1,400
Nigeria	166,800	174,000	174,000
Pakistan	78	78	78
Philippines	4,700	5,000	5,000
Reunion	30	30	30
Saint Lucia	25	25	25
Sri Lanka	2,000	2,000	2,000
Thailand	12,000	12,000	12,000
Uganda	50	50	50
United States of America	140	110	150
World	310,100	319,751	321,732

Source: FAOSTAT Database

mainly from India. Currently, Nigeria is one of the largest producers and exporters of split-dried ginger. The annual production is around 90,000 metric tons from an area of 17,400 ha.

Jamaica

In Jamaica, ginger is grown in the hills of the South Central Parish of Manchester and in the Christiana Area Land Authority. There is also some production in the border parishes of Clarendon, Trelawny, and St. Elizabeth as well as in the hills of St. James, Hanover, and Westmoreland in the northwest. The area under ginger was about 65,000 to 70,000 acres in the past (Prentice, 1959), but now the area has dwindled considerably and the current production is below 1,000 tons.

Fiji

In Fiji, the early European settlements introduced ginger as an export crop in 1890. The Indian migrants started large-scale cultivation later. The major production areas are Suva peninsula, especially in Tamarua, Colo-Suva, and Tacinua districts. Ginger has also spread to Sawani, Waibu Nabukaluka, and Viria districts. The area under cultivation is around 1,000 hectares.

Ghana

In Ghana the early attempts at growing ginger were not successful, but with the launching of the Economic Recovery Programme in 1983, ginger cultivation was promoted by the government. Large-scale production was taken up in the Kadzebi district. The production touched 80,000 tons in 1990. However, production declined in subsequent years. The current production is very meager—below 1,000 tons.

Australia

Ginger became a commercial crop in Queensland (Australia) during the Second World War. In 1920 a farmer introduced ginger to Buderim, a small town north of Brisbane in Queensland, which has been the center of ginger production ever since. The growers are concentrated in Buderim, Nambour, North Arm, and Eumundi. The production was over 6,200 tons in 1974. The production figure has increased since, and the entire production is processed into preserved ginger and other ginger products. However, ginger production declined later, and currently ginger occupies very little area, and the production is processed mainly by the famous Buderim Ginger Co. into more than 100 products.

Sierra Leone

Sierra Leone remained a ginger producer for over 100 years. Ginger is grown along the railway lines around Freetown, Bola, Kennama, Pendemba, and Njala, as well as in the Mayamba district and parts of East Kano. Sierra Leone ginger was traditionally known as African ginger. It is less aromatic but is more pungent than other commercial gingers (Lawrence, 1984).

Mauritius, Trinidad, and Tobago

In Mauritius ginger is grown in all districts on the island, although most of the production comes from Pamplemousses and Flacqdisbiets. Guajana has a small-scale ginger production in the northern–western region. The current production is around 500 metric tons in Mauritius.

In Trinidad and Tobago ginger is a traditional spice that is grown mixed with other crops.

Southeast Asia

Southeast Asia is a major ginger production region. Ginger production in this region comes mainly from China, Thailand, Taiwan, Korea and Vietnam. China is the largest producer, followed by Thailand, Korea, and Vietnam. China cultivates ginger in an area ranging from 50,000 to 80,000 hectares. Ginger is cultivated in the provinces of Shandong, Guangdong, Zhejiang, Anhui, Jiagxi, and Hubai. The largest variability in

ginger is seen in China, where many distinctly different morphotypes have been identified. Available figures indicate a production of 2,40,000 tons. China consumes internally the major share of ginger produced, with many ginger products being available in the markets.

Taiwan has only 3,000 to 4,000 hectares under ginger, and the produce is marketed mainly as vegetable ginger. It is grown as an intercrop with tea or as a pure crop on hill slopes.

Thailand and Korea also produce ginger for internal consumption. Thailand produces about 30,000 tons of ginger from a 12,000-hectare area. The Republic of Korea has a ginger area of around 4,200 hectares and produces about 8,000 metric tons of ginger.

Indonesia

Indonesia is another important producer, having a ginger area of over 10,000 hectares and production around 77,000 metric tons. Ginger cultivation here is concentrated in the Java-Sumatra islands.

Sri Lanka

In Sri Lanka ginger is grown as a mixed crop with turmeric, cocoa, coffee, jack, arecanut, coconut, or green vegetables mostly in a haphazard way. It is cultivated mostly in the central eastern provinces in Yatinurwara, Harispatta, Siambolagoda and Girijama. Ginger production is mostly used up by local consumers, mainly for the manufacture of ginger beer and ginger ale.

Philippines

In the Philippines ginger is produced in Las Banos, Laguna, Tanavan, Bantagas, Silag, and Carite. The current area under cultivation is about 5,000 hectares and production is around 29,000 metric tons.

Many other countries, such as Nepal, Bangladesh, Bhutan, Cameroon, Costa Rica, Kenya, Reunion Islands, and the United States, produce small quantities of ginger for home consumption (Table 1.3 and Table 1.4).

According to the Food and Agriculture Organization, ginger production is looking bright because harvesting areas and production have increased, and are estimated to enlarge in the coming years (Anon, 2003).

Research and Development Efforts

Although a spice crop of global use, the research and development (R&D) efforts on ginger have not been commensurate with its importance. Research on ginger was initiated only in the second half of the last century, but only in a rudimentary manner. In India the first research project was started in 1953 at four centers: Kandaghat (in the former Punjab, now in Himachal Pradesh), Targaon (Maharashtra), Thodupuzha, and Ambalavayal (both in Kerala). However, these programs ended with the termination of the respective projects. Later, spice research was taken over by the Indian Council of Agricultural Research (ICAR) and ginger was brought under the purview of the All India Coordinated Spices and Cashew Improvement Project, which was started in 1971. However, the research programs were mainly adaptive trials. In 1975 ICAR set up the Regional Station of Central Plantation Crops Research Institute (CPCRI) at Calicut in

Table 1.4 World ginger production (Mt)

	Year		
	1999	*2000*	*2001*
China	201,128	228,056	240,000
Bangladesh	38,000	38,000	42,000
Bhutan	3,100	3,100	3,100
Cameroon	7,430	7,500	7,500
Costa Rica	1,225	4,375	4,400
Dominica	100	100	100
Dominican Republic	1,500	1,500	1,500
Ethiopia	450	400	400
Fiji Islands	2,500	2,500	2,500
Ghana	60	65	65
India	270,000	275,000	275,000
Indonesia	70,100	71,900	77,500
Jamaica	620	620	620
Kenya	200	150	150
Korea, Republic of	7,950	7,950	7,950
Madagascar	30	30	30
Malaysia	2,500	2,500	2,500
Mauritius	116	498	500
Nepal	4,200	4,200	4,200
Nigeria	90,000	90,000	90,000
Pakistan	28	28	28
Philippines	28,000	29,000	29,000
Reunion	900	500	500
Saint Lucia	60	60	60
Sri Lanka	8,000	8,000	8,000
Thailand	30,000	30,000	30,000
Uganda	120	120	120
United States of America	7,300	6,120	7,350
Zambia	100	100	100
World	775,717	812,372	835,173

Source: FAOSTAT Database

Kerala to do research on spices, and ginger became a major mandate crop in this center. The research programs were further strengthened with the setting up of an independent All India Coordinated Research Project on Spices with headquarters at Calicut in 1986. Under this project research on ginger was going on mainly at the Y.S. Parmar University of Horticulture and Forestry at Nauni, Solan (Himachal Pradesh) and at the High Altitude Research Station at Pottangi under the Orissa University of Agriculture and Technology. Some multilocational and adaptive trials were also going on in a few other centers. The upgradating of the regional station at Calicut to a National Research Centre for Spices in 1986 and later to The Indian Institute of Spices Research (IISR) in 1995 led to further strengthening of the R&D programs. At the IISR, research programs on

ginger are going on in areas such as: (1) genetic resources collection, conservation, characterization and documentation; (2) crop improvement; (3) disease and insect pest management; (4) agronomic management; (5) postharvest technology and quality evaluation; and (6) biotechnology. The research activities in India led to the development and release of seven high-yielding cultivars of ginger, establishment of a germplasm of about 650 accessions, development of management practices for diseases and insect pests, evolution of various agronomic and nutrient management schedules, evolution of post-harvest technology and storage aspects, development of biotechnological tools for improvement of ginger, and establishment of an in vitro gene bank. Apart from these applied aspects, basic studies on taxonomy, anatomy, cytology, and sterility, etc., have also been conducted.

In Nigeria ginger research is being carried out at the National Root Crops Research Institute, where the programs are mainly centered on developing agronomic and fertilizer schedules, storage of seed ginger, and management of diseases. A crop improvement program has not progressed much, probably due to the narrow genetic base.

In China ginger research programs are mainly concentrated in universities such as Shandong University, where basic physiological studies on ginger have been carried out. Many universities in southern China (where ginger cultivation is located) have research programs on ginger. However, the language barrier is affecting the spread of the research results to other parts of the world.

Earlier some research programs existed in Queensland, Australia, when ginger cultivation was prevalent in that area. However, with the decline of cultivation the research programs also came to an end. Both in China and Australia (and also in Thailand and Taiwan), a large number of ginger-based products are popular in the market. Many studies must have been done for the development of these products. Occasional research papers on ginger also appear from many other countries around the world.

Uses of Ginger

Ginger is a unique plant—a spice that is used universally. The ancient Indians considered ginger as the *mahaoushadha* (the great medicine), and it is the raw material for certain soft drinks and a variety of sweetmeats. The plant thus possesses a combination of many attributes and properties. Ginger contains volatile oil, fixed oil, pungent compounds, resins, starch, protein, and minerals. The characteristic organoleptic properties are contributed by the volatile oil and nonvolatile solvent-extractable pungent compounds. Among the many components, alpha Zingiberene is the predominating component of the oil. Gingerol and shogaol are the pungency-contributing components. The refreshing aroma and the pungent taste makes ginger an essential ingredient of most world cuisine and of the food processing industry. The solvent-extracted oleoresin is available in convenient consumer packs. Ginger powder is also an ingredient in many *masala* mixes. In Western countries ginger is used, for example, in gingerbread, biscuits, cakes, puddings, soups, and pickles. Ginger ale, ginger beer, and ginger wine are widely used soft drinks. Ginger is one of the most widely used medicinal plants in the traditional Indian, Chinese, and Japanese systems of medicine. According to the Indian system (Ayurveda), ginger is carminative and digestive. It is believed to be useful in anorexia, in dyspepsia, and for the suppression of inflammation. Dry ginger is useful in dropsy, otalgia, cephalgia, asthma, cough, colic, diarrhea, flatulence, nausea, and vomiting. Pharmacological

studies have indicated the usefulness of ginger in preventing nausea and vomiting associated with chemotherapy, pregnancy, travel, and seasickness. Ginger also has antiplatelet activity, hypolipidemic activity, and an anxiolytic effect. It is an ingredient in many Ayurvedic preparations and is a folk cure for indigestion, fever, colic, and any ailment associated with the digestive system.

Ginger is also an important drug in the Chinese and Japanese systems of medicines. In the Chinese Materia Medica, ginger is indicated, for example, for the treatment of vomiting, diarrhea, light-headedness, blurred vision, dyspepsia, tremors, decrease in body temperature, and high blood pressure. In the Chinese and Japanese systems of medicine the dry and fresh gingers constitute two different drugs that are used for different purposes (Benskey and Gamble, 1986).

Future Outlook

In spite of the research efforts, productivity of ginger remains low in countries like India and Nigeria. The gap existing between the national productivity level of, say India, and that of the productivity reported in China is vast—3.8 t/ha and 70 t/ha, respectively. Many constraints are limiting the production and productivity of ginger, chief among them being the diseases caused by fungi and bacteria and various insect pests. Many of the producing countries have no product development programs based on ginger. On the other hand, countries like Australia, Thailand, Japan, and China have a large number of ginger-based products. The Buderim Ginger Company in Queensland, Australia, produces more than 100 ginger products. A dynamic product development agenda is essential for any producing country to offset the frequent price fall of the raw and dried ginger. Moreover, a network of small-scale industries involved in the manufacture of ginger products will ensure a good farm price for the product and help in the growth of ginger production.

Ginger will continue to be used worldwide in a vast variety of dishes, and will remain as the only spice used widely for the preparation of an array of sweetmeats. Ginger is also the only spice widely used in the manufacture of soft drinks. No doubt the importance of ginger can hardly decline in the future. However, due to overproduction or underproduction, the market prices can fluctuate widely, with the consequent impact being felt in the production and earning figures of the producing countries.

It is also necessary that the producing and consuming countries join hands in alleviating the serious constraints facing ginger production. Such a global effort will have much beneficial fallout in many areas of ginger production and utilization, thereby helping eventually in the growth in production, productivity, and utilization and finally to a healthy, prosperous global ginger economy.

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2 Botany and Crop Improvement of Ginger

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The genus *Zingiber* of the family Zingiberaceae is distributed in tropical and subtropical Asia and Far East Asia and consists of about 150 species. Zingiberaceae is of considerable importance as a "spice family." Besides ginger this family includes turmeric, cardamom, large cardamom, grain of paradise, and several others having economic and medicinal importance. Zingiberaceae was earlier divided into the subfamilies Costoideae and Zingiberoideae, which were later given independent family status as Costaceae and Zingiberaceae. Three tribes were recognized in the subfamily Zingiberoideae by workers such as Peterson (1889) and Schumann (1904); and the genus *Zingiber* was included in the tribe Zingibereae along with *Alpinia*, *Amomum,* and others. This tribe is characterized by the absence of lateral staminodes or staminodes that are united to the labellum, in comparison with tribe Hedychieae, in which the lateral staminodes are well developed. Later Holttum (1950) removed *Zingiber* from Zingibereae and renamed it as Alpinieae; his argument was that *Zingiber* is closer to the genera under the Hedychieae as their lateral staminodes appear as lobes at the base of the labellum, whereas in *Alpinia* these staminodes are well developed. Many later workers accepted the opinion of Holttum. Burtt and Smith, however, felt that the contention of Holttum is nomenclaturally incorrect and proposed that *Zingiber* should be in an independent tribe (Burtt and Smith, 1983).

The first documentation of ginger was by Van Rheede (1692) in his *Hortus Indicus Malabaricus* (Vol. 11), the first written account of the plants of India. Van Rheede described the cultivated ginger (*Z. officinale*) under the local name *inschi (inchi*). The Indian species was first botanically described by Roxburg (1810), who reported 11 species, and placed them in two sections based on the nature of the spike: Section 1. spikes radical and Section 2. spikes terminal.

Baker (1882) has carried out an exhaustive survey of the Zingiberaceae of Indian Peninsula for *The Flora of British India* (J.D. Hooker). In this he recognized four sections:

1. Cryptanthemum Horan—Spikes are produced directly from the rhizome and are very short and dense; peduncle very short (11 species)
2. Lampuzium Horan—Spikes produced from the rhizome on more or less elongated peduncles with sheathing scariose bracts (10 species)
3. Pleurantheis Benth—Spike peduncle arising from the side of the leafy stem (1 species)
4. Dymczewiczia (Horan) Benth—Spikes terminal on the leafy stem (2 species)

This subgeneric classification was accepted by later workers including Schumann (1904) in his revision of Zingiberaceae.

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Zingiber Boehmer

Boehmer and Ludwig, Def.Gen.Pl.89,1760, nom.cons; Benth.&Hook.f.Gen.Pl. 3,646,1883; Baker in Hook.f.Fl.Br.India,7,243,1892; Schum.in Pflanzen.Zng.165,1904. Type species: *Z. officinale.*

Holttum (1950) provided the following description for the genus.

Rhizomes as or near surface of the ground, bearing leaf shoots close together. Leaf shoots short to moderately tall, often with many leaves. Leaves thin in texture, never very large (rarely to 50 cm long), sessile or with quite short petioles, the ligule short to long deeply bilobed or entire. Inflorescence on a separate shoot without normal leaves (rarely at the apex of the shoot); scape usually erect, short or long, clothed with two-ranked sheaths that are sometimes colored red; spike short or long, slender or thick, cylindrical, ovoid, or tapering to a narrow apex, elongating gradually. Bracts fairly large, usually brightly colored, red or yellow, usually thinly fleshy, closely imbricating or with apices free, margins plane or inflexed. One flower in the axil of each bract; flowers fragile or short lived. Bracteoles one to each flower, facing the bract, thin and narrower than bract, usually persisting and enclosing the fruit, split to the base, never tubular.

Calyx thin, tubular spathaceous usually shorter than the bracteole, but sometimes longer. Corolla tube slender, usually about as long as the bract; dorsal lobe usually broader than the others, erect, narrowed to the tip, and hardly hooded; edges inflexed, lateral lobes usually below the tip and on either side of it, sometimes joined partly together by their adjacent sides and to the tip; color usually white or cream. Labellum deeply three-lobed (the side lobes representing staminodes), or rarely the side lobes hardly free from the mid lobe, side lobes erect on either side of the stamen, mid lobe shorter than or not greatly longer than the lateral corolla lobes, its apex usually retuse or cleft; color cream to white or more or less deeply suffused with crimson or purple. Filament of stamen short and broad, anther rather long, narrow; connective prolonged into a slender curved beak-like appendage as long as the pollen sac, with inflexed edges, containing the upper part of the style. Stigma protruding just below the apex of the appendage, not thickened, with a circular apical aperture surrounded by stiff hairs. Stylodes usually slender and free, not surrounding the base of the style. Ovary glabrous or hairy, trilocular with several ovules in each loculus. Fruit with a fleshy wall when fresh, more or less leathery when dry, smooth, or hairy, enclosed by the persistent bract or bracteole, dehiscent loculicidally within the persistent bracts. Seed ellipsoid, black or dark brown, covered by a thin saccate white aril with irregularly lacerate edges.

The main distinguishing features of the genus are: (1) long, curved anther-appendage embracing the style, (2) the three-lobed lip (the side lobes are staminodes, which are relatively broad and fused more or less to the mid lobe or lip proper), and (3) the relatively large bracts, each with a single flower and a nontubular bracteole, more or less imbricating on a lengthening inflorescence (*Z. clarkei* from Sikkim is an exception that has two to four flowers to each bract). The bracts are often but not always colored; in some species, they change color as they grow older. The color of the lip is an important distinguishing character.

The genus contains 150 species: 34 species have been reported from China (Shu, 2003) and 24 species from India (Baker, 1882). The main centers of diversity are South China; Malaysia; Northeast India, Myanmar region, and the Java–Sumatra region of Indonesia; Shu (2003) has recently revised the Chinese species. The only species extensively used as flavoring for food is the true ginger, *Z. officinale.* Some species like *Z. zerumbet* and

Z. cassumunnar are well known for their uses in native medicine. *Z. mioga* is used as a spice and its flower buds are in great demand in Japan as a vegetable.

Zingiber officinale Rosc.

Roscoe, New arrangements of the plants of the monandrian class usually called "Scitaminea," Trans. Linn. Soc. 8:348, 1807; Valeton, Bull. Buitenz, 2nd Ser., xxvii, 128, 1818; Fluckiger and Hanbury, Pharmacographia, 574, 1874; Engler, Pflanzenw.Ost.-Afrikes and Nachbargebiete, B. Natzpflanzen,.264,1895; Schumann, Zingiberaceae, in Das Pflanzenrich, 4,46,170,1904.

Inschi, Rheede, Hort. Malabaricus, 11,23–25, 1692.

Rhizome entirely pale yellow within or with a red external layer. Leafy stems to about 50 cm tall, 5 mm diameter, glabrous except for short hairs near base of each leaf blade; leaf blades commonly about 17 by 1.8 cm; rather dark green, narrowed evenly to slender tip; ligule broad, thin, glabrous, to 5 mm tall, slightly bilobed. Scape slender, to 12 cm tall, the upper sheaths with or without short leafy tips; inflorescence approximately 4.5 cm long and 15 mm diameter; bracts approximately 2.5 by 1.8 cm; green with pale submarginal band and narrow translucent margin; margins incurved, lower bracts with slender white tip. Bracteoles as long as bract; calyx with ovary 12 mm long; corolla tube 2.5 cm long, lobes yellowish, dorsal lobe 18 by 8 mm (flattened), curving over the anther and narrowed to the tip, laterals narrower. Lip (mid lobe) nearly circular, approximately 12 mm long, and wide, dull purple with cream blotches and base, sidelobes about 6 by 4 mm; free almost to the base, colored at mid lobe; anther cream, 9 mm long, appendage dark purple, curved, 7 mm long (Holttum, 1950). The species is sterile and does not set seeds (Figure 2.1, Figure 2.2, and Figure 2.3).

Taxonomical notes: Roscoe (1807) described *Z. officinale* from a plant in the Botanic Garden at Liverpool as "*Bracteis ovato-lanceolatis, laciniis corolla revolutis, nectario trilobato*" and referred to *Amomum zingiber* Willd. Sp.Pl 1:p6. Willdenow (1797) extended Linnaeus description "*Amomum scapo nude, spica ovata*" with "*squamis ovatis, foliis lanceolatisbad apicem margine ciliates*." Linnaeus's (1753) *Amomum zingiber* is the basionym for the species. The genus *Amomum* of Linnaeus is a nomenclatural synonym of the conserved generic name, *Zingiber* Boehm (Burt and Smith, 1968). The specific epithet *zingiber* could not be used in the genus *Zingiber*. Thus, *Z. officinale* was adopted as the correct name for ginger. The specimens available in most herbaria are without flowers, and it is assumed that Linnaeus based his description on the account and figure given by Rheede in *Hortus Malabaricus.* The figure given by Rheede (Vol., 11, plate 12, 1692) is the designated lectotype of the species *Z. officinale* Rosc. (Jansen, 1981).

The species epithet *officinale* was derived from Latin, meaning "work shop," which in early Latin was used to mean pharmacy, thereby implying that it had a medicinal use.

Morphology and Anatomy

The ginger plant is a herbaceous perennial grown as an annual crop. The plant is erect, has many fibrous roots, aerial shoots (pseudostem) with leaves, and the underground stem (rhizome). The roots of ginger are of two types, fibrous and fleshy. After planting, many roots having indefinite growth grow out of the base of the sprouts. These are the fibrous roots, and the number of such roots keeps on increasing with the growth of

Figure 2.1 A ginger plant showing aerial shoots and inflorescence.

tillers. These fibrous roots are thin, have root hairs, and their function is mainly absorption of water and nutrients. As a ginger plant grows further, several fleshy roots of indefinite growth are produced from the lower nodes of the mother ginger and primary fingers. These roots are thicker, milky white in color, with few root hairs, and no lateral roots. Such roots carry out the functions of support as well as absorption (Figure 2.4).

During the initial growth, the apical bud of the rhizome piece planted grows out and becomes the main tiller or mother tiller. As this tiller grows, its base enlarges into a rhizome. This is the first formed rhizome knob and is often called the mother rhizome. From either side of the mother rhizome, branches arise and they grow out and become the primary tillers (Figure 2.5). The bases of these tillers become enlarged and develop into the primary fingers. The buds on these primaries develop in turn into secondary tillers and their bases into secondary fingers. The buds on the secondary fingers in turn can develop into tertiary tillers and tertiary fingers.

The aerial shoots have many narrow leaves borne on very short petioles and with sheaths that are long and narrow, and the overlapping sheaths produce the aerial shoot. A pair of ligules is formed at the junction of leaves and sheath. The leaves are arranged in a distichous manner.

Ginger is a subterranean stem (rhizome) modified for the vegetative propagation and storage of food materials. The stem has nodes with scale leaves and internodes. Except for the first few nodes, all the nodes have axillary buds. When the rhizome bit is used for planting ("seed rhizome" or setts), there may be one or more apical buds on it; however, normally only one bud becomes active. When large pieces are used, more than

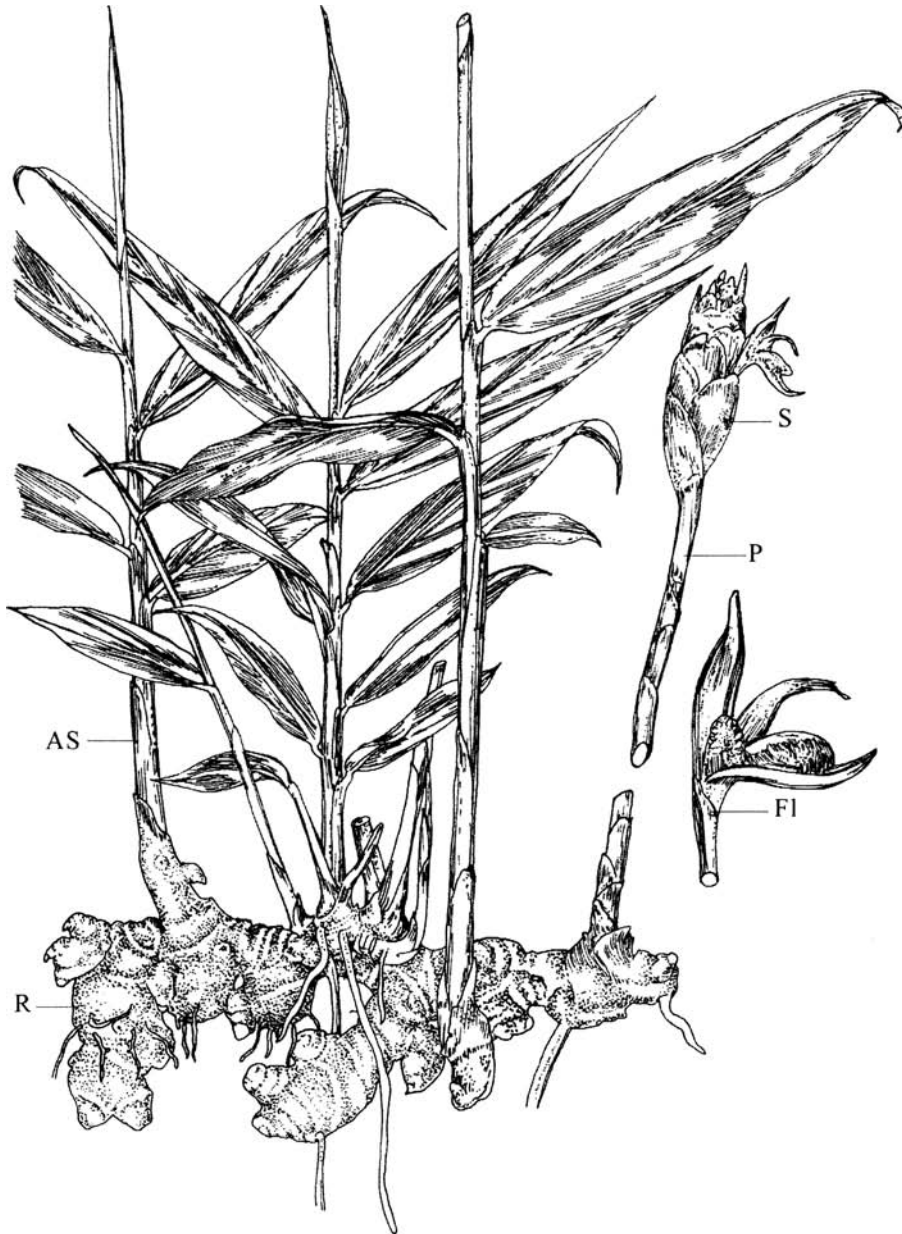

Figure 2.2 Sketch of the ginger plant showing the origin of shoots, inflorescence, and flower. AS: Aerial shoot, R: Rhizome, Fl: Flower, P: Peduncle (scape), S: Spike.

one bud may develop simultaneously. If more than one branch from the parent rhizome is responsible for the ultimate growth and development of the adult rhizome, the branches of the mature rhizome lie in the same plane (Shah and Raju, 1975a).

The pattern of rhizome branching is illustrated in Figure 2.6. The main axis developing from the apical bud, which is the first developing branch, has 7 to 15 nodes, which later

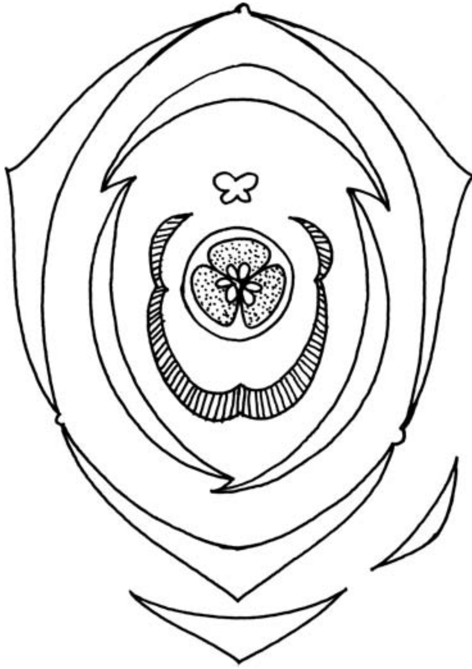

Figure 2.3 Floral diagram of ginger flower.

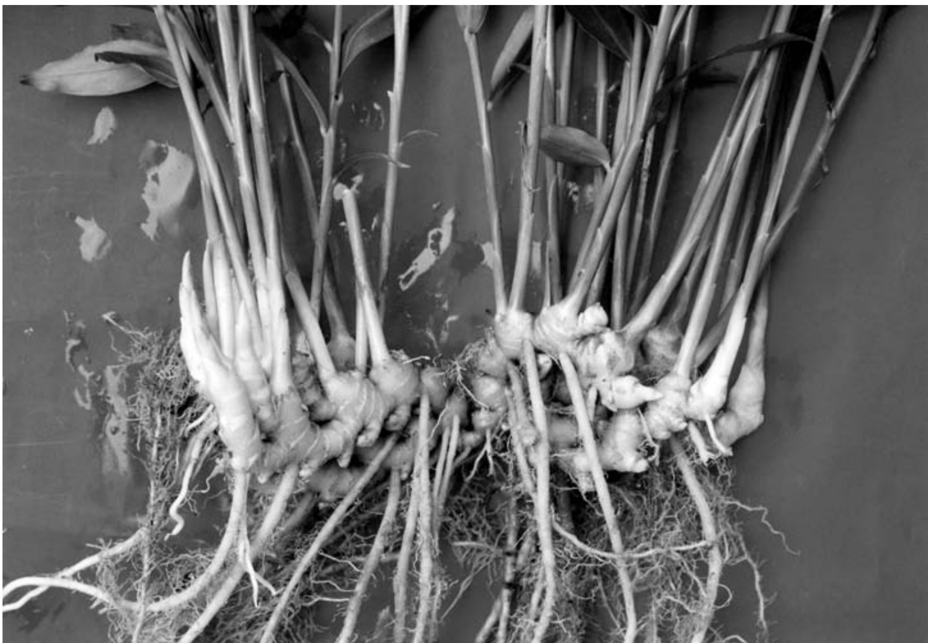

Figure 2.4 Ginger rhizome showing two types of roots—thick, white fleshy roots and the fibrous roots with root hairs.

Figure 2.5 Ginger rhizome showing the conversion of branch apices into aerial shoots.

becomes an aerial shoot. Once this axis becomes aerial, the subsequent growth of the rhizome is due to the development of the axillary buds situated above the first two to three nodes of the underground main axis. These axillary branches are plagiotropic and then they quickly show orthotropic growth at their distal region and subsequently become aerial shoots (see Figure 2.5). The same pattern of growth is continued for successive branches to form a sympodial growth pattern. A few axillary buds at the distal end of the branch remain dormant. The number of primary branches may be two, three, or four. These primary branches arise on either side of the main axis. Subsequent development of the secondary, tertiary, and quaternary branches are on the abaxial side of the respective branches. Irrespective of the number of primary branches, the subsequent branches lie in the same plane, although alteration of this scheme is seen sometimes. A mature rhizome may consist of 6 to 26 axillary branches with foliage leaves or only with sheath leaves and they show negative geotropic response (Shah and Raju, 1975a).

The number of nodes in each rhizome branch varies. The main axis (mother rhizome) and the subsequent branches (primaries) have 6 to 15 nodes. The internodal length of the rhizome branches ranges 0.1 to 1.5 cm, and varies even in a single branch. The internodal length is more in secondary, tertiary, and quaternary branches, and in the aerial stem it ranges from 3 to 7 cm. In the underground stem the nodes have scale leaves that ensheath and protect the axillary buds. These scale leaves fall off or may be lost, so that in mature rhizomes only the scars remain. Young scale leaves have pointed tips that help in penetration of soil.

The distal few nodes of the rhizome have sheath leaves. At the early stage of development they lack any apparent slit due to the overlapping of their margins. Later a longitudinal slit is formed through which the shoot tip projects. After the development of 6 to 12 scale leaves and 3 to 5 sheath leaves, the foliage leaves are produced. A foliage

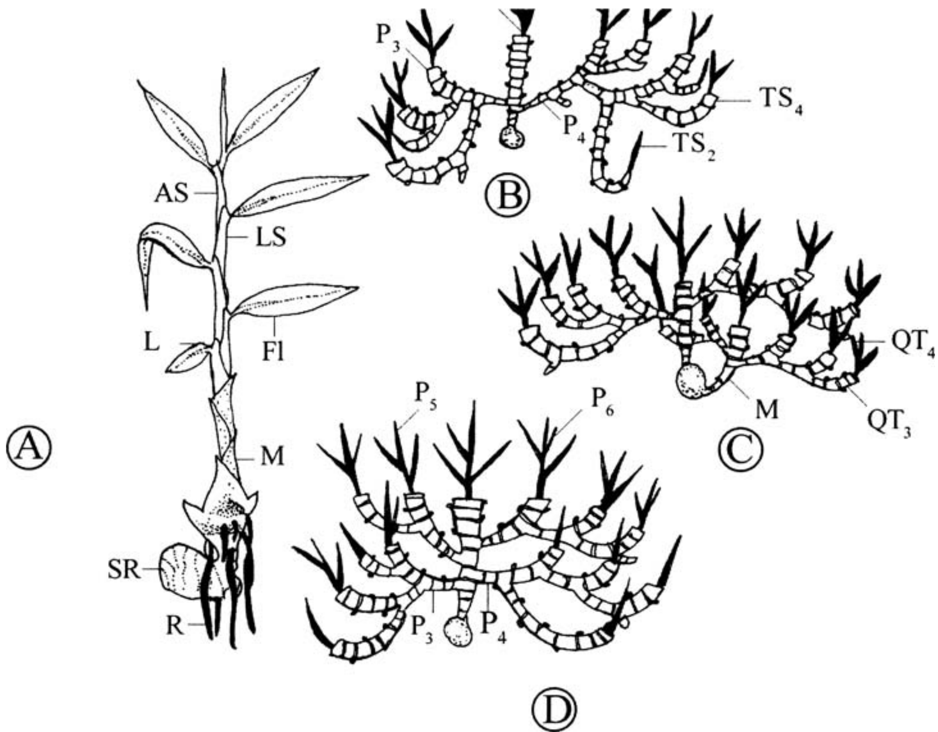

Figure 2.6 Growth pattern of the ginger rhizome.
A. Habit. B. Typical mode of growth pattern (nodes are represented by dark horizontal lines and dormant buds by a black spot). C. Two main axes developing from the seed rhizome, and their subsequent branches developing in the same plane. D. A main axis with four primary branches and their subsequent branches developing in the same plane. (Source: Shah and Raju, 1975a.)

leaf consists of a leaf sheath, a ligule, and an elliptical–lanceolate blade. The leaf sheath is about 15 to 18 cm and lamina about 12 to 15 cm long. Above its region of insertion, the sheath encircles the internode; and from the side opposite to its origin up to the ligule, the sheath is open longitudinally. A distinct mid rib is present only in the lamina. The phyllotaxy of the scale leaves on the rhizome and foliage leaves on the aerial stem is distichous, with an angle of divergence of about 180°. Within the bud, leaves have imbricate aestivation (Shah and Raju, 1975a).

Rhizome Anatomy

The early studies on the anatomy of ginger were carried out mainly by the pharmacognosists, and they concentrated on the officinal part, the rhizome, either dry or fresh (Futterer, 1896). A comprehensive survey on the anatomy of the plants belonging to Zingiberaceae was that of Solereder and Meyer (1930), in their classical work *Systematische Anatomie der Monocotyledonen* (Systematic Anatomy of the Monocotyledons). They provided anatomical notes on 18 genera and some 70 species (Tomlinson, 1956). Later Tomlinson (1956) supplemented the information and filled in the gaps. However, no information was available on the developmental anatomy. Some studies were carried out

by Pillai et al. (1961), Aiyer and Kolammal (1966), and Shah and Raju (1975b). More recently, Ravindran and colleagues investigated the developmental anatomy of rhizomes, oil cells, and associated aspects (Remashree et al., 1997; 1998, 1999; Ravindran, 1998). The following discussion is based on the studies of the above workers.

The transection of a fresh, unpeeled rhizome is almost circular or oval, about 2 cm in diameter, with the outline almost regular. The TS shows a light-brown-colored outer border and a central zone 1.2 cm in diameter marked off by a yellowish ring from an intermediate cortical zone. A distinct continuous layer of epidermis is generally present, consisting of a single row of rectangular cells; in some cases, it may be ruptured. Within this is the cork, varying in thickness from 480 to 640 μm and differentiated into an outer region 300 to 400 μm in thickness, composed of irregularly arranged, tangentially elongated, slightly brown-colored cells, and an inner zone of 6 to 12 regular rows of thin-walled rectangular to slightly tangential elongated cells arranged in radial rows. They measure 30 × 30 to 114 × 48 μm. (*Note*: Cork tissue develops after the harvest and during storing. So when a rhizome is cut soon after harvest, one may not encounter much cork tissue.) A cork cambium is not evident. Inner to the cork is the cortex that is about 4 mm in thickness, composed of thin-walled large hexagonal to polygonal parenchymal cells. The cortical cells are heavily loaded with starch grains. These grains are large, simple, and ovoid, in length varying from 15 to 65 μm. Scattered within the cortex are numerous oil cells that contain large globules of yellowish-green color. The outermost three to five rows of cortical cells are not rich in oil contents. Many scattered, collateral, closed vascular bundles are present, of which the greater number is seen in the inner cortical zone. The large bundles are partially or entirely enclosed in a sheath of septate fibers, whereas the smaller bundles are devoid of any fiber. Each vascular bundle consists of phloem, composed of small thin-walled polygonal cells with well-marked sieve tubes and xylem composed of one to nine vessels with annular, spiral or reticulate thickenings. These vessels have a diameter varying from 21 to 66 μm. In the enclosing sheath of fibers the number of cells varies very much. There are 4 to 48 fibers or occasionally more. These fibers are very long, but less than 1 mm, have a diameter from 10 to 40 μm, and are not straight, but undulate in character. The inner limit of the cortex is marked by a single-layered endodermis composed of thin-walled rectangular cells, much smaller than the cortical cells, with their radial walls slightly thickened and free from starch grains. The endodermis is lined by a pericycle composed of a single row of thin-walled slightly tangentially elongated cells devoid of any starch grains.

The stele that forms the bulk of the rhizome consists of parenchymal cells similar to those of the cortex, with starch grains and oil globules and a large number of irregularly scattered vascular bundles. Just within the pericycle a number of very small vascular bundles are arranged in a ring. These bundles have only one to three vessels and a small phloem. No fibers are present enclosing these small bundles. Generally, the vascular bundles present within the stele are slightly larger than those present in the cortex. The stele contains more oil cells and starch grains than the cortex (Aiyer and Kolammal, 1966).

Rhizome Enlargement

Rhizome enlargement in ginger is by the activity of three meristematic zones. Very early in the development of the rhizome, a zone of meristematic cells is formed at the base of a young scale leaf primordium of developing rhizome. These meristematic cells develop

into the primary thickening meristem (PTM) and procambial stands. The meristematic activity of the PTM is responsible for the initial increase in the width of the cortex. The second type is the actively dividing ground parenchyma. The third type is the secondary thickening meristem (STM), in which fusiform and ray initials are clearly visible. The STM develops just below the endodermoidal layer.

At a lower level in the rhizome from the shoot bud apex, the PTM can still be identified. The scattered vascular bundles are developing from the PTM or procambial cells. Such groups of cells can be identified by the plane of cell division. The differentiation of procambial cells into vascular tissue takes place at different stages of rhizome growth. Unlike in many monocots, in ginger rhizome there is a special meristematic layer along with the endodermoidal layer, and this layer consists of cambium-like cells. The cells are thin-walled and arranged in a biseriate manner. In certain loci, where the vascular bundles develop, these cells are elongated with tapered ends and appear similar to the fusiform initials with an average of 62.34 μm length and 8.12 μm width in mature stages. Between these fusiform initials, some cells show transverse divisions to form ray initials. The presence of the cambium-like layer is an important feature in rhizome development. From this layer inverted and irregularly distributed groups of xylem and phloem are formed along the intermediate layer. The cells outer and inner to the cambial layer become filled with starch grains.

Development of Oil Cells and Oil Ducts

Oil cells are present in the epidermis or just below the epidermis of the leaf, petiole, rhizome, and root. In the rhizome, oil cell initials are present in the meristematic region. They are spherical and densely stainable. The initiation of oil cells and formation of ducts occurs in the apical parts of shoots and roots and starts much before the initiation of vascular elements. Secretory ducts are formed both schizogenously and lysigenously (Remashree et al., 1998; Ravindran et al., 1998).

Schizogenous Type

The schizogenous type of secretory duct originates in the intercalary meristem of the developing regions. The ducts are initiated by the separation of a group of densely stained meristematic cells through dissolution of the middle lamella. Concurrent separation of the cells leads to the formation of an intercellular space bordered by parenchymal cells. These ducts anastomose and appear branched in longitudinal section. Further separation of the bordering cells along the radial wall leads to widening of the duct lumen.

Lysigenous Type

The lysigenous type of duct formation is more frequent in the meristematic region, but occurs in mature parts too. There are four stages involved in its development: initiation, differentiation, secretion, and quiescence. These steps are a gradual process that occurs acropetally (Figure 2.7).

Initiation and differentiation: In shoot apex, the meristematic cells are arranged in tiers. In between these cells, certain cells in the cortical zone are distinguishable from the rest by their large size, dense cytoplasm and prominent nucleus (see Figure 2.7A). Such cells act as the oil cell mother cell. Anticlinal and periclinal divisions of these cells result in

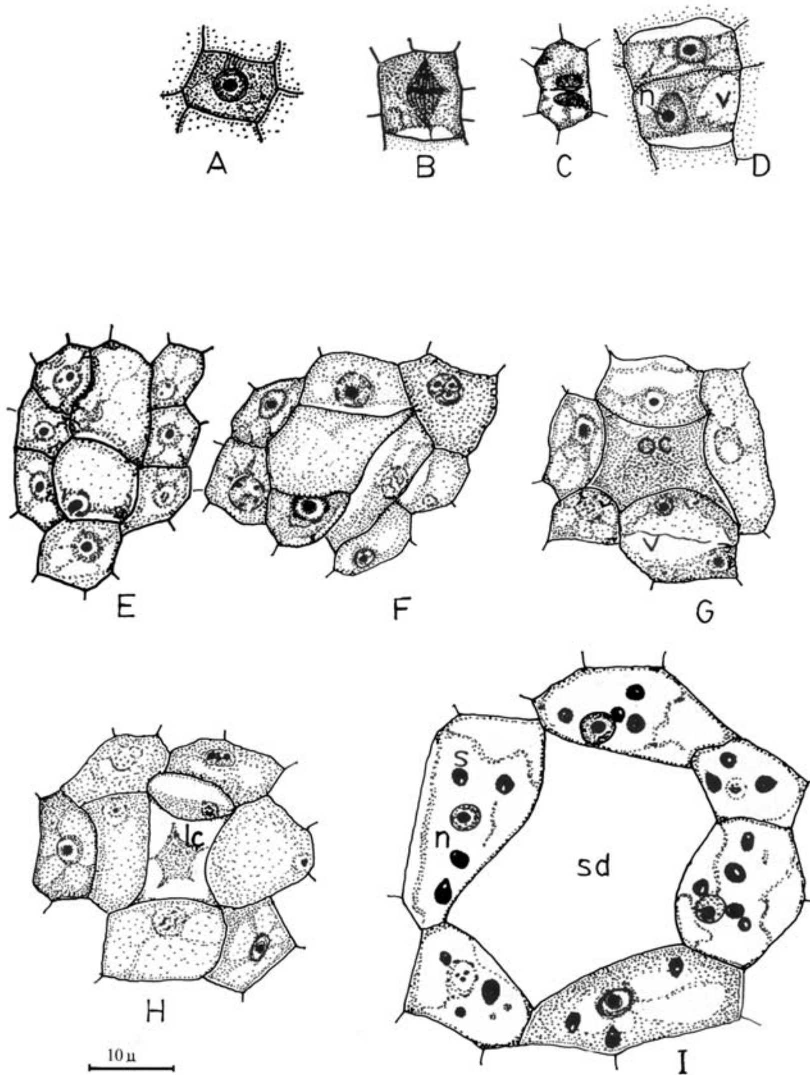

Figure 2.7 Ontogeny of oil cell in ginger: lysigenous development.
A. Oil cell mother cell. B–D. Division of mother cell. E. Nuclear disintegration of central cell. F. Nuclear disintegration (note the deformed cell). G. Cytoplasmic condensation. H. Darkening of cell contents and increase in vacuolation. I. Mature oil duct with scanty cytoplasm (lc, lysing cell; n, nucleus; oc, oil cell; sd, secretory duct; s, starch grain; v, vacuole).

a group of oil cell initials (see Figure 2.7B–E). Cyloplasmic vacuolation initiates in the oil cells at a distance of about 420 μm from the shoot apex. Subsequently the surrounding cells also enlarge in size, showing cytoplasmic and nuclear disconfigurations (see Figure 2.7E, F). Further development leads to the disintegration of nuclear content of the central cell, which stretches toward the intercellular space. Later the central cell disintegrates

and the contents spill into the cavity thus formed (see Figure 2.7I). This process that takes place in adjacent cells leads to the formation of a duct. The duct can be either articulated or nonarticulated, and becomes gradually filled up with the cell contents of the lysed cells. Once the lysogeny of the central cell is completed, the adjacent cells also lyse gradually in a basipetal manner, resulting in the widening of the duct lumen. These stages occur between 1500 and 3000 μm from the apex.

Secretion: The differentiated oil cells start a holocrine type of secretion and expel their contents into the duct. Then the next cell (in acropetal order) becomes differentiated into an oil cell and starts elimination of its contents followed by lysis. Simultaneously the primary tissues continue to become differentiated into new oil cells and reach the secretory stage. The secretion fills the duct in young stages, but the quantity becomes reduced gradually, and finally the ducts appear empty. This could happen because of the diffusion of oil basipetally and radially; such oil particles are deposited in the cells and can be seen as black masses inside cells as well as in the intercellular space. Such stages are noticed about 3,250 μm from the shoot tip (Ravindran et al., 1998; Remashree et al., 1999).

Quiescence: In the mature rhizome the ground parenchyma does not undergo further division and differentiation into the duct. In this stage the cells adjacent to the duct become storage cells, containing numerous starch grains and large vacuoles. An empty cell or cells with distorted cytoplasm appear along the duct lumen. Quiescence and secretory stages are visible from the third month onward after planting. In primary tissues the oil duct development is schizogenous, whereas further development proceeds both schizogenously and lysigenously.

Root Apical Organization

The root apical organization in ginger together with many other zingiberaceous taxa was first reported by Pillai et al. (1961). They found that the structural organization of ginger root apex differs from that of other taxa (such as *Curcuma, Elettaria,* and *Hedychium*). In ginger, all zones in the root apex are originated from a common group of initials. From the rim of this common group, calyptrogen, dermatogen, periblem, and plerome become differentiated. Raju and Shah (1977) also reported a similar observation in ginger and turmeric. The following discussion is adapted from Pillai et al. (1961).

The root cap is not differentiated into columella and a peripheral zone, and hence there are no separate initials for these regions. The cells in this region are arranged in vertical superimposed files. The cells arise by the activity of a meristem, which can be easily differentiated from the rest of the region. Pillai et al. (1961) named this meristematic region columellogen. In transections, the cells of the columella form a compact mass of polygonal cells in the center with the cells of the peripheral region arranged in radiating rows around it.

In the root body two histogens could be distinguished: (1) the plerome concerned with the formation of stele and (2) the protoderm–periblem complex concerned with the formation of the outer shell to the stele including periblem and dermatogen. The protoderm–periblem complex is located outside the plerome and is composed of a single tier of cells. The cells of this zone located on the flanks exhibit T-divisions, which help the tissue to widen out. Periblem consists of the initials of the cortex extending from the hypodemis to the endodermis. The hypodermis arises from the inner layer of the

protoderm–periblem initials. The cells composing this tissue vacuolate earlier than the outer cells of the cortex.

Endodermis differentiates from the innermost periblem cells. Outside the plerome dome all cells of the periblem exhibit T-divisions initially but later in development show anticlinal divisions, and the endodermis is differentiated at that time.

Plerome has at its tip a group of more or less isodiametric cells. On the sides of the plerome dome is the uniseriate pericycle. Near the dome, cells take less stain because of their quiescent nature. The metaxylem vessel elements with wider lumens can be seen near the plerome dome. The isodiametric cells at the very center of the plerome divide like a rib meristem to give rise to the pith. In transections passing near the tip of the plerome dome, the initials can be distinguished as a compact mass of isodiametric cells surrounded by radiating rows of periblematic cells.

Cytophysiological Organization of Root Tip

The root tip can be distinguished into two zones on cytophysiological grounds:

1. The quiescent center: This zone is found at the tip of the root body, characterized by its cells having (a) cytoplasm highly stained with pyronin-methyl green and hematoxylin, (b) smaller nuclei and nucleoli, (c) cell divisions less frequent, and (d) vacuolation noticeable in most.

The median longisection of this group of cells is in the shape of a cup with the rim forward. The above characteristics show their state of rest and are called the quiescent center. This zone includes cells belonging to all the structural histogens of the root body (i.e., not structurally delimitable). It gradually merges with the zone outside, the meristematic zone. Raju and Shah (1977) studied the root apices of ginger, mango ginger, and turmeric with azure B staining to localize DNA and RNA contents in order to identify the quiescent center. A quiescent center was present in all the three cases as indicated by the light stainability of its cells. In longisection the quiescent center resembles an inverted cup.

2. The meristematic zone: This zone is shaped like an arch surrounding the quiescent center on the sides of the root body. The cells of this zone have the following features:

a. cytoplasm deeply stained with pyronin-methyl green and hematoxylin.
b. divides more frequently
c. have larger nuclei and nucleoli
d. vacuolation is absent or not prominent

The meristimatic zone includes the cells of all the structural histogens of the root body.

The percentage of cell division is much lower in the quiescent center compared to the meristematic zone. This character combined with the response of these cells to stains such as pyronin-methyl green indicates that these cells are in a state of comparative repose and hence are not synthesizing nucleic acids (Pillai et al., 1961). The distance between the tip of the root body and the nearest mature phloem element, which carries the metabolic products required by the active cells, was reported to be 480 to 490 μm. This led to the suggestion that the cells at the tip of the root body go into quiescence because of the dearth of sufficient metabolites (Pillai et al., 1961).

Ontogeny of Buds, Roots, and Phloem

The ontogeny of ginger was studied by Shah and Raju (1975b), Remashree et al. (1998), and Ravindran et al. (1998). In a longisection, the shoot apex is dome shaped with a single tunica layer, below which the central mother cell zone is present. The flank meristem is situated on either side of the central mother zone. The leaf is initiated from the outer tunica layer and from the flank meristem. The shoot apical organization and acropetal differentiation of procambial strands are closely related to the phyllotaxy. At an even lower level basipetally in the rhizome axis, additional inner cortical cells are produced by a lateral PTM or procambium in which the resulting cells are radial rows.

The nature of the shoot apex: Shah and Raju (1975b) investigated the nature of the shoot apex in ginger. In the shoot apex in all stages, a single layer of tunica occurs, showing only anticlinal divisions. Cytohistological zonation based on staining affinity is not observed at any stage. The distal axial order (cr) includes the central group of corpus cells dividing periclinally and anticlinally and the overlying cells of the tunica (Figure 2.8). The peripheral zone (pr_1) is concerned with the initiation of the next leaf primor-

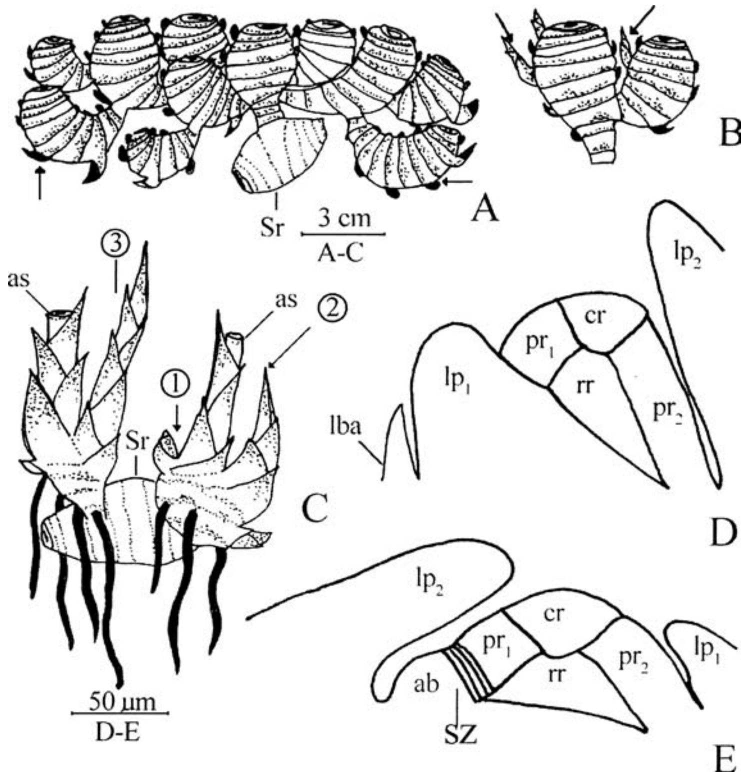

Figure 2.8 Ontogeny of shoot apex: (A) dormant rhizome with stage 1 root apices; (B) rhizome with stage 2 shoot apex; (C) rhizome with stages 5, 6, and 7 root apices; (D) aerial apex showing topographical zonation; (E) rhizome apex showing topographical zonation.
ab, axillary bud; as, aerial shoot; cr, central zone; lba, leaf base; lp_1, lp_2, leaf primordium; pr_1, pr_2, peripheral zone; rr, inner aerial zone; sr, seed rhizome; sz, shell zone. (Source: Shah and Raju, 1975.)

dium and formation of the leaf sheath on the opposite side. It is delimited by the shell zone on the rhizome apices, which appears as an arc of narrow cells in median longitudinal section. The peripheral zone (pr_2) is associated with the initiation of the next leaf primordium. In the rhizome apices it is also associated with the initiation of the axillary buds. As the phyllotaxy is distichous, this zone is opposite to pr_1 in median longisections. Pith cells differentiate in the inner axial zone (rr).

Shah and Raju (1975b) recognized seven developmental stages of the apical bud. In stage one (dormant apex), the shoot apex lies in a shallow depression, the apex measures 116 to 214 μm by 45 to 70 μm. A few cells toward the flank showed increased concentrations of DNA as evidenced by dense staining. Some cells of pr_1 and pr_2 (see Figure 2.7) showed dense stainability for C-RNA (cytoplasmic RNA). The outer corpus cells show peripheral divisions. In stage two, the apex is dome shaped and its width and height are 94 to 165 μm and 35 to 75 μm, respectively. Zones pr_1 and pr_2 show denser histological staining than cr and rr zones. A biochemical zonation is present at pr_2 that shows deep staining for DNA. The apex at stage three measures 76 to 140 μm in width, and 53 to 86 μm in height and is dome shaped. The cells of the inner axial zone are vacuolated. The shoot apex dome at stage four is 140 to 160 μm high and 90 to 116 μm wide. Outer corpus cells are vertically elongated. At stage five, the apex is a low dome having 214 to 248 μm height and 53 to 75 μm width. Cells of the pr_2 zone show dense staining. The apex of stage six is prominently dome shaped having a width of 169 to 200 μm and height of 87 to 96 μm. During stage seven, the underground branch reaches the soil level. The shoot apex is 91 to 112 μm in width and 134 to 167 μm in height.

In ginger all the underground branches show a negative geotropic response. Two kinds of apices are found in ginger: (1) the apices are low dome and surrounded by either scale leaves or leaf bases, and (2) they are dome shaped and raised on an elongated axis. In the base of the rhizome apices, cells derived from the inner axial zone elongate tangentially and contribute to the widening of the axis. In certain cases these cells extend up to the base of the axillary buds. In a dormant apex they are thick walled and contain starch grains. These cells are distinct in the dormant or early active rhizome apex and constitute latitudinal growth meristem. During vascular differentiation a few cells of this meristem develop into procambium. During subsequent development of the rhizome apex the cells derived from the inner axial zone elongate and contribute to the pith.

Procambial differentiation: The peripheral or flank meristem divides periclinally and produces parenchymal cells. Some of the cells are distinguishable from the rest by deeper stainability, smaller size, less or no vacuolation, and darkly stained nuclei. These are the procambial initials and each such group contains 15 to 20 cells. Later these cells elongate, vacuolation increases, and they develop gradually into sieve tubes. Protophloem differentiation precedes that of protoxylem. The collateral differentiation of phloem and xylem with parenchymal bundle sheaths becomes distinct after an intermediate stage of random differentiation of the bundles. Ultimately the vascular bundles are found scattered in parenchymal ground tissue. In transection, an endodermoidal layer is also visible during the development (Remashree et al., 1998; Ravindran et al., 1998).

Axillary Bud

The development of leaves and scale leaves that encircle the shoot apex in ginger rhizomes is in a clockwise direction. The axillary bud meristem is first discernible in the axillary

position on adaxial sides of the third leaf primordium from the apical meristem as a distinct zone by the stainability of the constituent cells and multiplane division of the cells in the concerned peripheral meristem sectors. The axillary buds thus originate as a cellular patch in the adaxial side of a leaf or scale leaf of the node. In a fully developed axillary bud the cytohistological zones akin to the main shoot apex can be distinctly observed. The development of a new rhizome is by the enhancement of a dormant axillary bud, which acts just like the main shoot apex. The procambial cells and the ground meristem cells divide and parenchyma as well as vascular tissues add thickness to the newly enhanced axillary bud. Likewise, many buds become active during favorable conditions, each of which produces secondary or tertiary rhizomes. The axillary buds show vascularization by the activity of the procambial strands of the mother rhizome and procambial cells originated from the differentiation of parenchymal cells.

Development of the Root

The adventitious root primordia become differentiated endogenously from the endodermoidal layer of the rhizome. Roots always develop just below the nodal region. Transection of the rhizome reveals that the endodermoidal layer and the pericycle become meristematic and undergo periclinal and anticlinal divisions resulting in a group of root initials. This is in direct connection with the vascular ring situated beneath the endodermoidal layer. The root primordia are of the open type, having common initials for the cortical meristem, root cap, and protoderm. The actively dividing and deeply staining central cylinder shows vascular connections with the rhizome vasculature. As the enlarging root primordia emerge through the cortex, the cortical cells are crushed and torn apart. Normally, these roots originate from the lateral or opposite side of the axillary bud and scale leaf.

Phloem

As a rule there is no secondary growth in monocots. However, the rhizome structure of ginger gives evidence of both primary and secondary growth having a well-developed endodermoidal layer and cambium. The vascular bundles are collateral, closed, and scattered in the ground parenchyma. The phloem element consists of the sieve tube, companion cells, parenchyma and fiber.

Sieve tube: Phloem cells originate from a group of actively dividing procambial cells of PTM. These cells can be distinguished from the surrounding cells by their meristematic activity, stainability, and size of the nucleus. During development, a procambial cell elongates and becomes thick walled with cytoplasm and a prominent nucleus; this is the sieve tube mother cell. It undergoes a longitudinal unequal division, and the resulting smaller cell gives rise to the companion cell. This cell continues to divide, forming four to eight cells. The large cell is the sieve cell. It has cytoplasm and nucleus in early stages, which degenerate during its development into the sieve tube. During further development, the vacuolation increases and the cytoplasm shrinks and appears like a thread along the wall. At the same time, the nucleus disintegrates and the cell assumes the features of the enucleated sieve tube element. The transverse wall of the sieve tube changes to simple sieve plates with many pores and with very little callose deposition.

The first sieve tube element can be distinguished at a distance of 720 to 920 μm from the shoot apex.

In the ginger rhizome, four to eight companion cells per sieve tube element are arranged in vertical lines with transverse end walls. They may vary from 18 to 32 μm in length and 7 to 19 μm in width. The sieve tube elements are arranged end to end to form columns of sieve tubes. The length of a sieve tube element varies from 57.5 to 103.8 μm, the average being 76.8 μm. The width varies from 5.29 to 10.35 μm, the average being 8.76 μm (Remashree et al., 1998). At the early stage of development, the slime body is present in the sieve tube, which appears to be amorphous but homogeneous. Later the slime body disintegrates.

In ginger, development of sieve tube is pycnotic, similar to the second type of nuclear degeneration reported by Esau (1969) and Evert (1984). The sieve element passes through a "fragmented multinucleated stage," a unique feature in the ontogeny of the multinucleated sieve tubes as reported by Esau (1938).

Phloem parenchyma: The phloem parenchymal cells are comparatively larger than the companion cells and smaller than normal cortical parenchymal cells. The increase in size of the phloem element is proportional to the growth of the rhizome. Some older phloem parenchymal cells become lignified into thick phloem fibers.

Anatomical Features of Ginger in Comparison with Related Taxa

Many species-specific anatomical variations were noted in the genus *Zingiber*. These variations were presented in a comparative study of ginger and three other species (Ravindran et al., 1998). The salient features are given in Table 2.1, which presents the important anatomical similarities and differences among the four species: *Z. officinale, Z. roseum, Z. zerumbet,* and *Z. macrostachyum.* Ginger has distinct anatomical features compared to other species, such as the absence of periderm, short-lived functional cambium, the presence of xylem vessels with scalariform thickening, helical and scalariform type of xylem tracheids, scalariform perforation plate, outer bundles with a collenchymatous bundle sheath, and high frequency of oil cells. The oil cell frequency was found to be 17.8/mm^2 in ginger, whereas the corresponding frequency in the other species was 9.5, 5.3, and 2.8/mm^2 in *Z. zerumbet, Z. macrostachyum*, and *Z. roseum,* respectively. Species differences were also noticed in fiber length, fiber width, and fiber wall thickness. Histochemical studies indicated that *Z. zerumbet* has greater amount of fibers than the others.

In general, xylem elements in *Zingiber* consist mainly of tracheids and rarely of vessels. The secondary wall thickening in the tracheids of ginger is of two types, scalariform and helical. The rings, or helices, are arranged either in a loose or dense manner. The helical bands are found joined in certain areas giving ladder-like thickening. The width of helical tracheids is less than that of scalariform tracheids. Similar tracheids are present in *Z. macrostachyum*, whereas in *Z. zerumbet* and *Z. roseum,* only scalariform thickening occurs (Ravindran et al., 1998). Xylem vessels occur in ginger and not in other species. Snowden and Jackson (1990), while studying the microscopic characters of ginger powder, recorded that the vessels are fairly large, reticulately thickened, less commonly spirally, and annularly thickened.

Table 2.1 Comparative anatomy of four species of *Zingiber*

Tissue	*Z. officinale*	*Z. roseum*	*Z. zerumbet*	*Z. macrostachyum*
Epidermis	Single layered	Single layered	Single layered	Single layered
Periderm	Absent	Periderm with lenticel	Periderm present	Absent
Cortex (outer cylinder)	Not wide	Not wide	Not wide	Wide
Endodermis	Present	Present	Present	Present
Casparian strips	Present	Present	Present	Present
Cambium	Present	Not found	Not found	Not found
Central cylinder	Wider than the outer zone	Wider than the outer zone	Comparatively less wider than the outer zone	Not wider than the outer zone
Number of vascular bundles	Less in the outer cylinder than in the inner zone	Less in the outer zone than in the inner zone	Less in the outer zone than in the inner zone	More in the outer cylinder than the other 3 species but lesser than the inner zone
Nature of vascular bundles	Collateral closed	Collateral closed	Collateral closed	Collateral closed
Vascular bundles distribution	More toward inner cortex and scattered in the central zone	More toward inner cortex and scattered in the central zone	More bundles in the middle cortex and number of bundles is very less compared to other 3 species	Bundles are arranged in two rows in the middle cortex and only a few bundles in the inner cortex and the bundles are uniformly distributed in the central zone.
Pith	Present	Present	Present	Present
Xylem elements	Vessels, tracheids, and fibers	Tracheids, fibers	Tracheids, fibers	Tracheids, fibers
Vessels	Vessels few with scalariform/reticulate thickening	Not found	Not found	Not found
Xylem tracheids thickening	Helical and scalariform type	Scalariform	Scalariform	Helical and scalariform
Perforation plate	Scalariform type	None	None	None
Phloem	Sieve tube, companion cells, phloem parenchyma and phloem fiber	Sieve tube, companion cells, phloem parenchyma and phloem fiber	Sieve tube, companion cells, phloem fiber, and phloem parenchyma	Sieve tube, companion cells, phloem fiber, and parenchyma
Metaxylem width	Outer zone 57 μm Inner zone 84 μm	20 μm 53 μm	25 μm 53 μm	32 μm 76 μm
Bundle sheath	Outer vascular bundles possess collenchymatous bundle sheath	Absent	Absent	Collenchymatous sheath is present only in outer bundles
Oil cell frequency	Very high	Least	High	Less
Curcumin cell	None	Present	Present	None

Leaf Anatomical Features

Ginger leaves are isobilateral. The upper epidermal cells of leaf are polygonal and predominantly elongated at right angles to the long axis of the leaf. In the lower epidermis the cells are polygonal and irregular, except at the vein region, where they are vertically elongated and thick walled. The epidermal cells in the scale and sheath leaves (the first two to five leaves above the ground are without leaf blades) are elongated and parallel to the long axis of the leaf. Oil cells in the upper and lower epidermis are rectangular, thick walled, and suberized. Unicellular hairs are present in the lower epidermis of the foliage leaves. Occasionally, a hair is present at the polar side of the stomata.

Ginger leaves are amphistomatic. A distinct substomatal chamber is present. Stomata are either diperigenous or tetraperigenous. Occasionally, anisocytic stomata are also observed. The subsidiary cells are completely aligned longitudinally with the guard cell. The lateral subsidiary cells may divide to form anisocytic stomata. Occasionally, three to five lateral subsidiary cells are formed by further division (Raju and Shah, 1975).

The guard cells on the foliage leaves are 40.6 μm long, whereas those on the sheath and scale leaves are 28.9 μm long. The stomata on the scale leaves and rarely on the sheath leaves show pear-shaped guard cells with a large central pore. The nuclei of the guard cells are smaller than those in the subsidiary cells. Raju and Shah (1975) also reported the uncommon wall thickening at the polar ends of the guard cells. This wall thickening may be restricted to the outer wall at the polar regions or may also be extended to the common inner cell wall.

Tomlinson (1956) gave a brief note on the petiolar anatomy of ginger. The short petiole shows a swollen pulvinus-like appearance. A transection just above the pulvinus shows typical structure with two bundle arcs, air canals, and collenchyma. A transection through the pulvinus shows a different structure. Here air canals and assimilating tissue are absent, there is extensive hypertrophy of ground tissue parenchymal cells, and abundant deposition of tanniferous substances. The most striking feature according to Tomlinson (1956) is the collenchymatous thickening of the cells of the bundle sheath, Below the pulvinus the structure is again normal as that of the above pulvinus region.

Table 2.2 gives the comparative leaf anatomical features of four species of *Zingiber.* The stomata are tetracyclic in all the species. The first two subsidiary cells are parallel to the guard cells and the other two lie at right angles. In *Z. officinale*, *Z. roseum,* and *Z. macrostachyum* there is a special thickening in the upper and lower sides of the guard cell, but *Z. zerumbet* showed some extra thickening on the corners of subsidiary cells. The stomatal index was higher in *Z. zerumbet.* Guard cells were the largest in *Z. zerumbet*, followed by *Z. officinale* and *Z. macrostachyum.* In *Z. roseum* the guard cells were shorter and broader.

Stomatal ontogeny: Raju and Shah (1975) described the structure and ontogeny of stomata of ginger. Here the differentiation of a guard cell mother cell or a meristemoid occurs by an asymmetrical division of protodermal cells. The meristemoid is distinguished from the adjacent protodermal cells by its small size, dense stainability of cytoplasm, and less vacuolation. The anticlinal wall of the meristemoid appears lightly stained with periodic acid–Schiff (PAS) reaction than the lateral walls of the epidermal cell and the meristemoid. The epidermal cell on either side of the meristemoid divides to form a small subsidiary cell. This epidermal cell shows dense stainability for nuclear DNA. The young lateral subsidiary cells are smaller than other epidermal cells. Later the meristemoid

Table 2.2 Leaf anatomical characteristics in four species of ginger

Tissues	*Z. officinale*	*Z. macrostachyum*	*Z. zerumbet*	*Z. roseum*
Epidermis	Upper larger than the lower	Both epidermis equal	Both epidermis equal	Both epidermis equal
Hypodermis	2 layers on upper side, one layer on lower side	2-layered on both sides	2-layered on both sides	Upper cells are larger, lower cells smaller
Mesophyll palisade	Single layered on upper side	No palisade tissue	No palisade tissue	Single layered on upper side
Spongy tissue	3–4 layers, closely packed	4–5 layers, loosely packed	4–6 layers, loosely packed	4–5 layers, closely packed
Air cavities	Absent in lamina, present in the mid rib region	Present in the mesophyll tissue and more in the mid rib region	Few cavities in lamina, more in the mid rib region	Absent in lamina, present in the mid rib
Vascular bundle sheath	Present on both sides and extend to both epidermis	Present on both sides and extend to upper epidermis only	Present on both sides and extend to upper epidermis only	Present on both sides and extend to both epidermis
Stomatal Index Range, Mean, Std. deviation	5.8–8.9, 7.45, 1.4	7.8–10.3, 8.15, 1.08	8.9–13.2, 10.23, 1.4	8.01–12.03,9.11, 1.2

divides to form a pair of guard cells. The epidermal cells that are lying at the polar region of the guard cell may divide and occasionally completely abut the stomatal complex and appear as subsidiary cells (Raju and Shah, 1975).

Anatomical Features of Dry Ginger

In commercial ginger rhizome (peeled dried rhizome), the outer tissue consisting of cork, epidermis, and hypodermis is scraped off. So the transections of processed rhizome consist of cortex, endodermis, pericycle, and the central cylinder or the vascular zone. The epidermis (of dry unpeeled ginger) is frequently disorganized, consisting of longitudinally oblong rectangular cells; the hypodermis consists of a few layers of parenchymal cells. The cork consists of several layers of oblong–rectangular, thin-walled suberized cells. The cortex is made of (1) thin-walled parenchymal cells containing plenty of starch grains, (2) brown-colored oleoresin and oil cells scattered throughout the cortex, and (3) fibrovascular bundles. There is an unbroken endodermis made of tangentially elongated cells with thickened suberized radial walls. Below the endodermis there is a pericycle that consists of an unbroken ring of tangentially elongated cells.

The central cylinder consists of an outer and an inner zone. In the outer zone adjoining the pericycle there is a vascular bundle zone without fibers. Fibrovascular bundles and oleoresin cells occur in the central zone of the central cylinder. The ground tissue of the central cylinder consists of thin-walled parenchymal cells containing starch.

The fibrovascular bundles are large. In longisections the fibers are long with moderately thick walls and a wide lumen. The vessels are large and scalariform, except in the vascular bundle zone adjoining the pericycle, where large reticulate vessels, scalariform vessels, and some special vessels occur.

Starch grains are present in abundance. The granules are ovate and many are characterized by a protuberance at one end. They vary in size to about 45 μm in length and 24 μm in width. Under polarized light the granules exhibit a distinct cross through the hilum at the tapering end (Parry, 1962).

Microscopic Features of Ginger Powder

Ginger rhizome powder is pale yellow or cream in color with a pleasant, aromatic odor and a characteristic and pungent taste. The diagnostic characteristics of ginger powder given by Jackson and Snowden (1990) are:

1. The abundant starch granules are mostly simple, fairly large, flattened, oblong to subrectangular to oval in outline with a small pointed hilum situated at the narrower end; infrequent granules show very faint transverse striations. Compound granules with two components occur very rarely.
2. The fibers usually occur in groups and may be associated with the vessels; they are fairly large and one wall is frequently dentate; the walls are thin and marked with numerous pits, which vary from circular to slit shaped in outline; very thin transverse septa occur at intervals. The fibers give only a faint reaction for lignin.
3. The vessels are fairly large and usually occur in small groups associated with the fibers; they are reticulately thickened, frequently showing distinct, regularly arranged rectangular pits, and are often accompanied by narrow, thin-walled cells containing dark brown pigment; a few smaller, spirally or annularly thickened vessels also occur. All the vessels give only a faint reaction for lignin.
4. The oleoresin cells in uncleared preparations are seen as bright yellow ovoid to spherical cells occurring singly or in small groups in the parenchyma.
5. The abundant parenchyma is composed of thin-walled cells, rounded to oval in outline with small intercellular spaces; many of the walls are characteristically wrinkled; the cells are filled with starch granules or oleoresin. Occasionally, groups of parenchyma are associated with thin-walled tissue composed of several rows of collapsed cells.

Floral Anatomy

Rao et al. (1954), Rao and Pai (1959, 1960), and Rao and Gupta (1961) studied the floral anatomy of the members of Scitamineae, in which a few species of *Zingiber* were also included. The floral anatomy of *Z. ottensi, Z. macrostachyum, Z. cernuum,* and other *Zingiber* species was reported by these workers. Because of the basic similarities in floral characters, it is presumed that the floral anatomical features will also be identical. The following discussion is based on the reports of the above-mentioned workers. The floral anatomical features of *Z. cernuum* (which is different from *Z. officinale* only by the absence of staminodes) are given in Figure 2.9. The peduncle contains two rings of vascular bundles with a few strands in the central pith. The inner ring gives off three dorsal bundles of the carpels outward and the latter then divide into three large strands alternating in position with the dorsal bundles of the carpels. The central strands unite

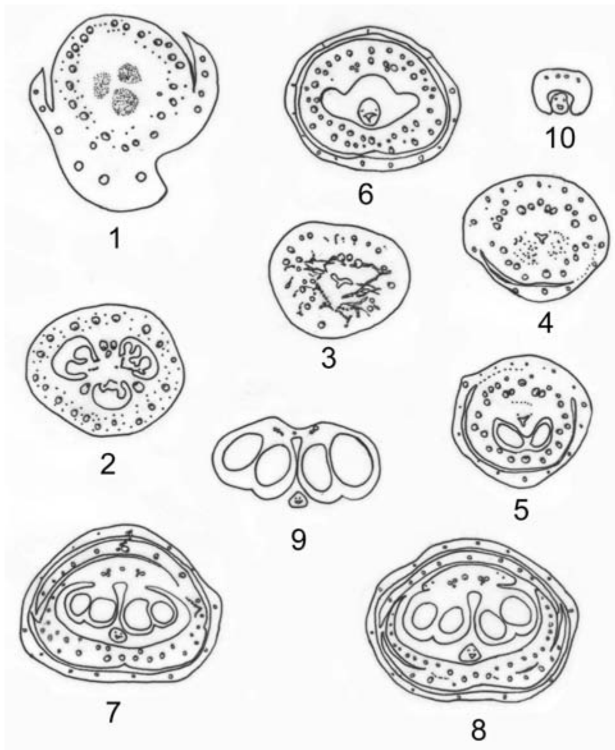

Figure 2.9 Floral anatomy of *Z. cernuum*. 1–10, different stages in the development of floral vasculature (for explanation, see text).

first into one bundle for a short length and fuse with the vascular tissue immediately to the outside. The three large bundles divide first into smaller inner placental bundles and a large outer parietal bundle. The placental bundle may branch off almost at its base. The parietal bundle travels into the septa and sends a few outward branches into the ovary wall. The placental bundles in the axile area bear the ovular traces. The posterior parietal bundle is larger and divides even at a lower level than the other two into two or three. A transverse section through the basal part of the ovary at this level shows: (1) a comparatively thick ovary wall in which there are numerous vascular bundles almost irregularly scattered, (2) in each of the three septa there is a prominent bundle that may divide into two, and (3) in the placental zone there are 6 to 10 strands that bear traces for the ovules. Most of the potential bundles are exhausted in supplying the ovules while one or two may fuse with the nearest parietal bundle. The loculi extend for a considerable distance above the ovuliferous zone, and in this terminal part of the ovary the number of bundles in the ovary wall is reduced by fusions among themselves, and all of them form almost a single ring near the level where the loculi end. Just on the top of the ovary, the three parietal strands, which have already divided into two or three bundles, extend laterally and form a broad network-like cylinder of vascular tissue. This network establishes vascular connections (anastamoses) with the peripheral bundles. The three loculi continue upwards into a Y-shaped stylar canal. After the anastamosis the vascular tissue directly forms (1) an outermost ring of about 15 small bundles for the calyx, (2)

a next inner ring of about 25 larger strands for the corolla and androecial members, and (3) toward the center a number of small scattered strands arrange somewhat in the form of an arc. Two stylar traces are given off from the two margins of this arc-like group and they stand close to the two arms of the Y-shaped stylar canal. The numerous small bundles, arranged at first as an arc, break up into two groups, which supply the two epigynous glands present in anteriolateral positions. The tubular basal parts of the calyx containing the sepal traces referred to earlier are at first separated, and at the same level, the two epigynous glands also separate. A very short distance above, the style also separates.

The basal part of the floral tube contains a ring of vascular bundles, an additional bundle in the median posterior position, and a pair of closely placed bundles on either side. The median posterior strand and the double strands on either side constitute the supply to the functional stamen. One of the component bundles of each double strand divides into two in such a way as to result in a third bundle that lies toward the inner side with its xylem pointing to the outside. On the anterior side of the floral tube, the vascular bundles divide and form two rings, whereas on the posterior face, external to the stamen traces, there is only one ring of bundles. The latter are for the labellum, whose margins are fused for a short distance with those of the filament. The outer ring of bundles is for the corolla.

The flat filament receives: (1) a small median bundle; (2) a triple strand on either side of it, the constituent bundles of which more or less fuse together; and (3) two or four minute strands toward either margin. The lateral triple strands are opposite the line of attachment of the anther lobes to the filament. The minute marginal traces disappear quickly, leaving only a small median bundle and the two lateral large composite ones. These run in parallel manner upward, and the composite strands of each lateral group fuse together more or less completely, so that the anther connective contains a small median and two large lateral bundles. Above the level of the anther, the connective is continued upward as a narrow flat plate with margins incurved and enclosing the style. Each of the two composite lateral strands becomes smaller and divides into two. Thus, in the terminal part of the filament, five bundles are present, of which one is the median one. The median bundle fades out first, leaving a pair of bundles on either side. The bundles of each pair then fuse together giving only two bundles, which run right up to the tip and disappear.

The style receives only two traces and these run throughout its length without any branching. The styled canal is narrow, Y-shaped, the arms of the Y pointing to the posterior side. Toward the tip the arms of the stylar canal spread out so that the canal appears as a curved slit in transverse sections. It then widens out into a large canal, which opens freely to the outside. The two vascular bundles of the style become more prominent in this terminal part and then disappear (Rao and Pai, 1959).

Floral Biology

Ginger flowers are produced in pedicled spikes arising directly from the rhizomes. The oval or conical spike consists of overlapping bracts, from the axils of which flowers arise, each bract producing a single flower. The flowers are fragile, short-lived, and surrounded by a scariose, glabrous bracteole. Each flower has a thin tubular corolla that widens up at the top into three lobes. The colorful part of the flower is the labellum, the petalloid

stamen. The labellum is tubular at the base, three lobed above, pale yellow outside, dark purple inside the top and margins, and mixed with yellow spots. The single fertile anther is ellipsoid, two celled, cream colored, and dehisces by longitudinal slits. The inferior ovary is globose, the style is long and filiform, and the stigma is hairy. Flowering is not common, and is probably influenced by climatic factors and photoperiod. On the west coast of India (Kerala), most cultivars flower if sufficiently large rhizome pieces are used for planting. When rhizomes are left unharvested in pots, profuse flowering occurs in the next growing season. Flowering is also reported from the east coast of India (Bhubaneswar in Orissa). However ginger does not usually flower or flowers very rarely in the growing areas of such locations as Himachal Pradesh, Utter Pradesh, West Bengal, and Northeast India. Holttum (1950) reported that ginger seldom, if at all, flowers in Malaysia. Flowering is reported from south China, but not from north China, and also from Nigeria. In general ginger does not flower under subtropical or subtemperate climatic conditions. Japanese workers reported that flowering leads to yield reduction. Ginger is shown to be a quantitative short-day plant (Adaniya et al., 1989).

Jayachandran et al. (1979) reported that the flower bud development took 20 to 25 days from the bud initiation to full bloom and 23 to 28 days to complete flower opening in an inflorescence. Flower opening takes place in an acropetal succession. Anthesis is between 1.30 and 3.30 P.M. under the west coast conditions of Kerala. Anther dehiscence almost coincides with the flower opening. The flower fades and falls on the next day morning. There is no fruit setting.

Das et al. (1999) reported floral biology in four cultivars of ginger (Bhaisey, Ernad Chernad, Gurubathan and Turia local). They found that anthesis under greenhouse and field conditions took place at around 1:00 to 2:00 P.M., under the coastal Orissa situations. Flowers were hermaphroditic with pin- and thrum-type incompatibility, and dehisced pollen grains did not reach the stigma. Selfing and cross-pollination did not produce any seed set.

Self-Incompatibility

Dhamayanthi et al. (2003) investigated the self-incompatibility system in ginger. They reported that heterostyly with a gametophytically controlled self-incompatibility system exists in ginger. Flowers are distylous, there are long ("pin") and short ("thrum") styles. The "pin" type has a slender style that protrudes out of the floral parts, which are short, covering not even half the length of the style. The stigma is receptive before the anthesis, whereas the anthers dehisce after 15 to 20 hours. The anthers are situated far below and hence the pollen grains cannot reach the stigma. In case of the "thrum" style, the stigma is very short and the staminodes are long and facing inward. However, the occurrence of thrum styles is very rare among cultivated ginger. According to the above-mentioned workers, this heterostyly situation may be a contributing factor to the sterility in ginger. However, this may not be very important as almost all cultivars are the pin type and pollination is entomophilous, mostly by honeybees. Dhamayanthi et al. (2003) have also reported inhibition of pollen tube growth in the style, and this was interpreted to be due to incompatibility. Adaniya (2001) reported the pollen germination in a tetraploid clone of ginger, 4 × Sanshu. Pollen germination was highest at around 20°C and pollen tube growth in the style was greatly enhanced at 17°C. At this temperature, the pollen tubes penetrated into the entire length of the style in

66.7% of the styles analyzed. Pollen stored for 3 hours at a relative humidity (RH) of 40 to 80% completely lost its viability, whereas pollen incubated at 100% RH retained relatively high germinability. When the RH was low, the pollen tube in the style stopped growing. Hence for pollen to germinate and grow in the stylar tissue, relatively low temperature (approximately 20°C) and 100% RH are essential.

Embryology

The embryology of ginger has not been investigated critically so far, and it is rather amazing that such an economically important species has been ignored by embryologists. One possible reason may be the absence of flowering and seed set in ginger in most growing regions. However, some information is available on a related species, *Z. macrostachyum*. The embryological features of the genera in Zingiberaceae are similar, and hence the information on *Z. macrostachyum* may as well be applicable to ginger.

The embryo sac development follows the *Polygonum* type (Panchaksharappa, 1966). The ovules are anatropous, bitegmic, and crassinucellate and are borne on an axil placentation. The inner integument forms the micropyle. In the ovular primordium the hypodermal archesporial cell cuts off a primary parietal cell and a primary sporogenous cell (Figure 2.10). The former undergoes anticlinal division. The sporogenous cell enlarges into a megspore mother cell, which undergoes meiosis forming megaspores. The chalazal spore enlarges and produces the embryo sac. Its nucleus undergoes three successive divisions resulting in a eight-nucleate embryo sac. Prior to fertilization in *Z. macrostachyum,* the synergids and antipodals degenerate. The fate of the nuclei in the embryo sac of ginger (which is a sterile species) is not known. However, some studies have indicated a postmeiotic degeneration of the embryo sac (Pillai, personal communication).

Cytology, Cytogenetics, and Palynology

Mitotic Studies

The chromosome number of ginger was reported as 2n = 22 by Moringa et al. (1929) and Sugiura (1936). Darlington and Janaki Ammal (1945) cited a report from Takahashi who claimed 2n = 24 for *Z. officinale*. A more detailed study was carried out by Raghavan and Venkatasubban (1943) on the cytology of three species, *Z. officinale*, *Z. cassumunnar,* and *Z. zerumbet,* and all three had the somatic chromosome number of 2n = 22. Based on the differences in ideogram morphology, the above-mentioned workers concluded that the chromosome morphology of *Z. officinale* was different from the other two species. Janaki Ammal (Darlington and Janaki Ammal, 1945) reported two "B" chromosomes in certain types of ginger in addition to the normal complement of 2n = 22. Chakravorti (1948) also found 2n = 22 in ginger. He concluded that in view of the normal pairing of 11 bivalents in species like *Z. cassumunnar* and *Z. zerumbet*, *Z. mioga* having a somatic chromosome of 2n = 55 is to be considered a pentaploid (Table 2.3).

Sharma and Bhattacharya (1959) reported the widespread occurrence of an inconsistency in chromosome numbers in several species of Zingiberaceae including *Z. officinale*. Sato (1960) carried out karyotype studies of 24 species belonging to 13 genera and concluded that the basic number of the genus *Zingiber* is x = 11 and that *Z. mioga*

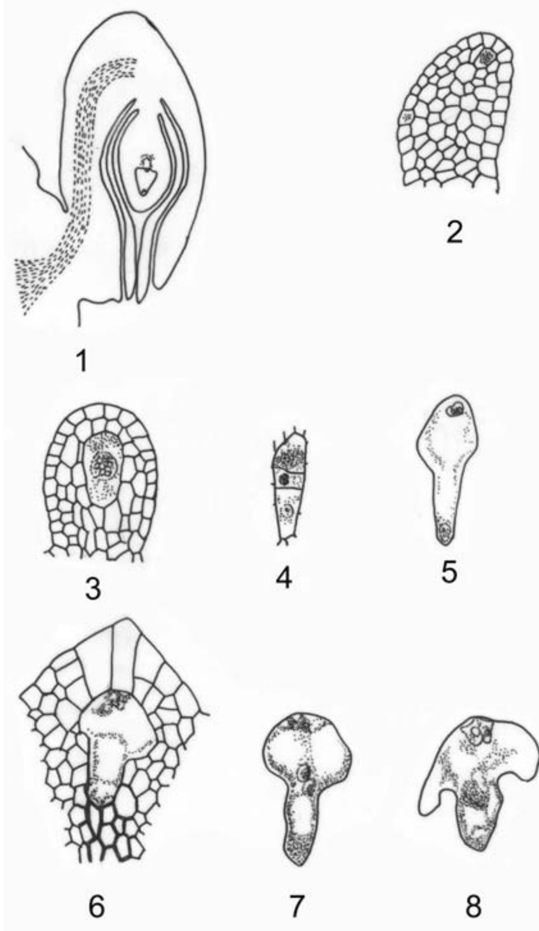

Figure 2.10 Embryology of ginger (*Z. macrostachyum*). 1–8, stages in the development of the embryo sac (for details see text).
1. L.S. of the anatropous ovule. 2. L.S. ovule showing archesporial cell. 3. L.S. ovule with meagspore mother cell. 4. T-shaped tetrad. 5, 6. 4- and 8-nucleate embryo sacs. 7, 8. Organized embryo sacs. Note the degenerated synergids and antipodals in 8.

having 2n = 55 is a pentaploid. Ramachandran (1969) studied the cytology of five species of *Zingiber* (*Z. macrostachyum, Z. roseum, Z. wightianum, Z. zerumbet,* and *Z. officinale*) and found a diploid number of 2n = 22 in all species. He found evidence of structural hybridity involving interchanges and inversions in ginger. Mahanty (1970) studied the cytology of Zingiberales. He reported 2n = 22 for Z. *spectabile* and *Z. cylindricum* and concluded that the genus *Zingiber* appears to be much more correctly placed in Hydychieae than in the Zingibereae.

Ratnambal (1979) investigated the karyotype of 32 cultivars of ginger (*Z. officinale)* and found that all of them possess a somatic chromosome number of 2n = 22 (Figure 2.11). The karyotype was categorized based on Stebbins's classification (Stebbins, 1958), which recognizes three degrees of differences between the longest and the shortest chromosome of the complement and four degrees of differences with respect to the

Table 2.3 Chromosome reports on *Zingiber*

Species	*n*	*2n*	*Reference*
Z. officinale		22	Suguira (1936)
		22	Moringa et al. (1929)
		22	Raghavan and Vankatasubban (1943)
		22	Chakravorthi (1948)
		22	Sharma and Bhattacharya (1959)
		22 + 2B	Darlington and Janaki Ammal (1945)
		24	Takahashi (1930)
	11	22	Ramachandran (1969)
	11	22	Ratnambal (1979)
Z. roseum	11	22	Ramachandran (1969)
Z. wightianum	11	22	Ramachandran (1969)
Z. spectabile		22	Mahanty (1970)
Z. cylindricum		22	Mahanty (1970)
Z. cassumunnar		22	Raghavan and Venkatasubban (1943)
		22	Ratnambal (1979)
Z. clarkei		22	Holttum (1950)
Z. ottensi		22	Holttum (1950)
Z. mioga		55	Moringa et al. (1929), Sato (1948)
Z. zerumbet	11	22	Ratnambal (1979)

proportion of the chromosome that are acro-, meta-, and telocentric. An asymmetrical karyotype of "1B" was found in all cultivars except in cvs. Bangkok and Jorhat, which have a karyotype asymmetry of 1A (Ratnambal, 1979). The karyotypes of various cultivars exhibited only minor differences (Table 2.4.). The total chromosome length varied from 22.4 μm in cv. Jorhat to 37.4 μm in cv. China. The length of the longest chromosome ranged between 2.8 μm (in cv. Jorhat) and 4.8 μm (in cv. China). The length of the shortest chromosome ranged between 1.2 μm (in cv. Rio de Janeiro) to 2.2 μm (in cv. China).

Ratnambal (1979) used the karyotype data in a generalized distance-D^2 statistics analysis. Based on the D^2 values, the cultivars were grouped into different clusters. Thirty-two cultivars fell into eight groups, A–H (Table 2.5). The relative distance between each group is a measure of the extent of divergence of the cultivars constituting the group. Cultivars Tafingiwa, Jamaica, Rio de Janeiro, Thinladium, Thingpuri, Maran, and Himachal Pradesh did not fall into any cluster, indicating their independence as well as divergence from the rest of the cultivars. *Z. zerumbet* and *Z. casummunar* did not fall into any group, but *Z. machrostachyum* fell into group B. It was also seen that geographical distances did not influence the clustering. This is expected in a strictly vegetatively propagated species, the planting materials that have been transported from

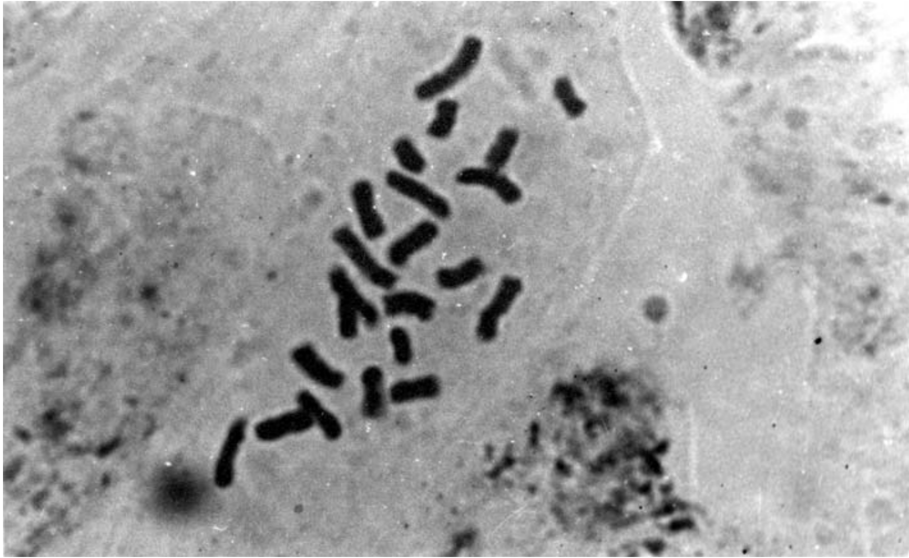

Figure 2.11 Mitotic metaphase showing 2n = 22 chromosomes.

Table 2.4 Karyotype variability in ginger cultivars

Sl. No.	*Karyotype character*	*Range*	*Cultivars with lowest and highest values*
1.	Total chromatin length (μm)	22.4–37.4	cv. Jorhat, cv. China
2.	Length of longest chromosome (μm)	2.8–4.8	cv. Jorhat, cv. China
3.	Length of shortest chromosome (μm)	1.2–2.2	cv. Rio de Janeiro, cvs. China and Poona
4.	No. of median chromosomes	1–9	cv. Jugijan, cvs. Mananthody and Arippa
5.	No. of submedian chromosomes	2–10	cv. Mananthody, cv. Jugijan
6.	No. of subterminal chromosomes	0–2	cvs. Kuruppumpadi, Poona, and Himachal Pradesh.
7.	No. of satellite chromosomes	1	In all cultivars
8.	Type of symmetry	1A	cvs. Jorhat and Bangkok, species *Z. macrostachyum, Z. zerumbet*, and *Z. casumunnar*
		1B	In all other cultivars

Source: Ratnambal (1979).

region to region and between countries. The karyotype of the cultivars remained relatively asymmetrical because of the lack of recombination and evolution by sexual processes.

Ratnamabal (1979) investigated the cytology of three species that are closely related to ginger. In *Z. zerumbet* the total chromatin length in the haploid compliment was 25.6 μm. The absolute length of individual chromosomes ranges from 2.9 to 1.6 μm. Six of 11 chromosomes have median centromeres and the remaining have submedian centromeres. Four chromosomes are long, four medium, and three short. The third chromosome with a median centromere has a satellite attached to its long arm. In *Z.*

Table 2.5 Grouping of ginger cultivars based on D^2 analysis of karyotype data

Group	*Cultivars in the group*
A	China, Assam, Burdwan
B	Wynad, Kunnamangalam, Sierra Leone, Kuruppumpadi, Jugidan, Jorhat
C	Narasapattam, Poona.
D	Arippa, Tura
E	Eranad, Manjeri, Nadia, Uttar Pradesh
F	Wynad local, Valluvanadu
G	Taiwan, Bajpai, Bangkok, Vengara
H	Eranad Chernad, Thodupuzha

Source: Ratnambal (1979).

macrostachyum the total chromatin length of the haploid complement is 29.6 μm. The absolute length of individual chromosomes varies from 3.5 to 1.9 μm. Chromosomes 1, 2, 4, 5, and 9 have submedian centromeres; 3, 6, 10, and 11 have median centromeres; and 7 has terminal centromeres. The second chromosome had a satellite on its longer arm. *Z. cassumunnar* had a total chromatin length of 24.7 μm; the individual chromosomes length varied from 2.9 to 1.6 μm. The karyotype is characterized by one subterminal, two submedian (one of which is satellited), and eight median chromosomes. There were three long, three medium, and five short chromosomes. In all three species the type of asymmetry is reported as being IA.

Das et al. (1998) carried out karyotype analysis and 4C DNA estimation in eight ginger cultivars. They recognized five types of karyotypes occurring in these cultivars.

Type A. Large- to medium-sized chromosome with primary and secondary constrictions nearly submedian in position, respectively

Type B. Large- to medium-sized chromosome with two constrictions, one in the submedian position and other in the subterminal position

Type C. Small-sized chromosome with nearly median to median primary constriction with satellite bodies on the long arm

Type D. Medium- to small-sized chromosome with nearly submedian primary constriction

Type E. Medium-sized chromosomes with nearly submedian primary constriction

All the types of karyotypes are found in the cvs. Bhitarkata local, Himachal Pradesh, and Tura. The A type was present in all the cultivars except in cvs. Raipur local and Wynad. The C type chromosome was common in all the cultivars except in cvs. Maran, Nadia, S-557, and Tura. D and E types were found in all the cultivars. The total chromosome length ranged from 64.80 μm in cv. S.557 to 98.12 μm in cv. Wynad. Total chromosome volume was from 84.35 μm^3 in S.557 to 1126.36 μm^3 in Wynad.

The 4C DNA varied significantly in different cultivars of ginger; from 16.234 picogram (pg) in cv. S.537 to 22.934 pg in cv.Wynad. The average chromosome length and volume ranged from 2.94 to 4.46 and 3.83 to 5.74 μm^3, respectively. The nuclear DNA content was directly proportional to the total chromosome volume, which in turn was

positively correlated with the chromosome length. The variability in DNA amount has been attributed to loss or addition of highly repetitive DNA sequence rather than the adenine-thymine (AT) or guanine-cytosine (GC) rich sequences in a genome, which reached a certain level and became stabilized during microevolution and gradual selection (Das et al., 1998).

Meiosis

Ratnambal (1979) and Ratnambal and Nair (1981) studied the process of meiosis in 25 cultivars of ginger. These cultivars exhibited much intercultivar variability in meiotic behavior. Cultivars like Karakkal formed only bivalents, whereas in cv. Taiwan two hexavalents, one quadrivalent, and three bivalents were present. Univalents were very common and much variability was noticed in respect of their number (Figure 2.12a, b). The presence of multivalent and chromatin bridges was found to be a common feature in most cultivars studied by Ratnambal (1979). The presence of multivalents in a diploid species indicates structural hybridity involving segmental interchanges, and four to six chromosomes are involved in the translocations as evidenced by quadrivalents and hexavalents. This structural hybridity might be contributing to the sterility in ginger.

Ratnambal (1979) also reported two to six univalents in various cultivars; the lowest was in the cv. Mananthody and the highest in cv. Karakkal. The number of univalents observed at metaphase 1 was more than that in diakinesis, and this has been attributed to the precocious separation of one or two bivalents. Most of these univalents end up in the formation of micronuclei and are lost subsequently. This leads to the production of gametes with deficiency and is likely to lead to sterility. A high percentage of abnormalities has been observed during the first and second divisions, as well as in the tetrad stage. The bridges noticed were presumed to be due to inversion heterozygosity or from chromosomal breakage and reunion in the early stage of meiosis. Unequal breakage of bridges at anaphase might be leading to the production of gametes with duplications and deficiencies (Ratnambal, 1979).

Structural chromosomal aberrations occurred at all stages of microsporogenesis in ginger. The predominant aberrations were laggards, bridges, and fragments at anaphase I; laggards, bridges, and fragments, irregular chromosome separation, and irregular cytokinesis at anaphase II; and micronuclei and supernumerary spores at the quartet stage (Table 2.6). Ratnambal (1979) had shown a positive linear regression between pollen sterility and chromosomal aberrations at anaphase II and aberrant quartets. Structural chromosomal aberrations have been attributed as the cause of sterility in ginger. But how such a diploid species as ginger came to acquire a complicated meiotic system that led to chromosomal sterility is not well understood. A hybrid origin followed by continuous vegetative propagation can be one reason for the abnormal chromosomal behavior (Ratnambal, 1979). Beltram and Kam (1984) studied meiotic features of 33 species in Zingiberaceae, including nine species of *Zingiber*. They observed various abnormalities such as aneuploidy, polyploidy, and B chromosomes. They also confirmed the diploid nature of the Malysian Zingiber ($x = 11$) and the pentaploid nature of the Japanese ginger, *Z. mioga*.

Das et al. (1998) studied meiosis and sterility in four cultivars (Bhaisey, Ernad Chernad, Gorubathany, and Thuria local) and reported a 30.35 to 40.5% meiotic index in them. Pollen mother cells showed incomplete homologous pairing at metaphase 1 and spindle

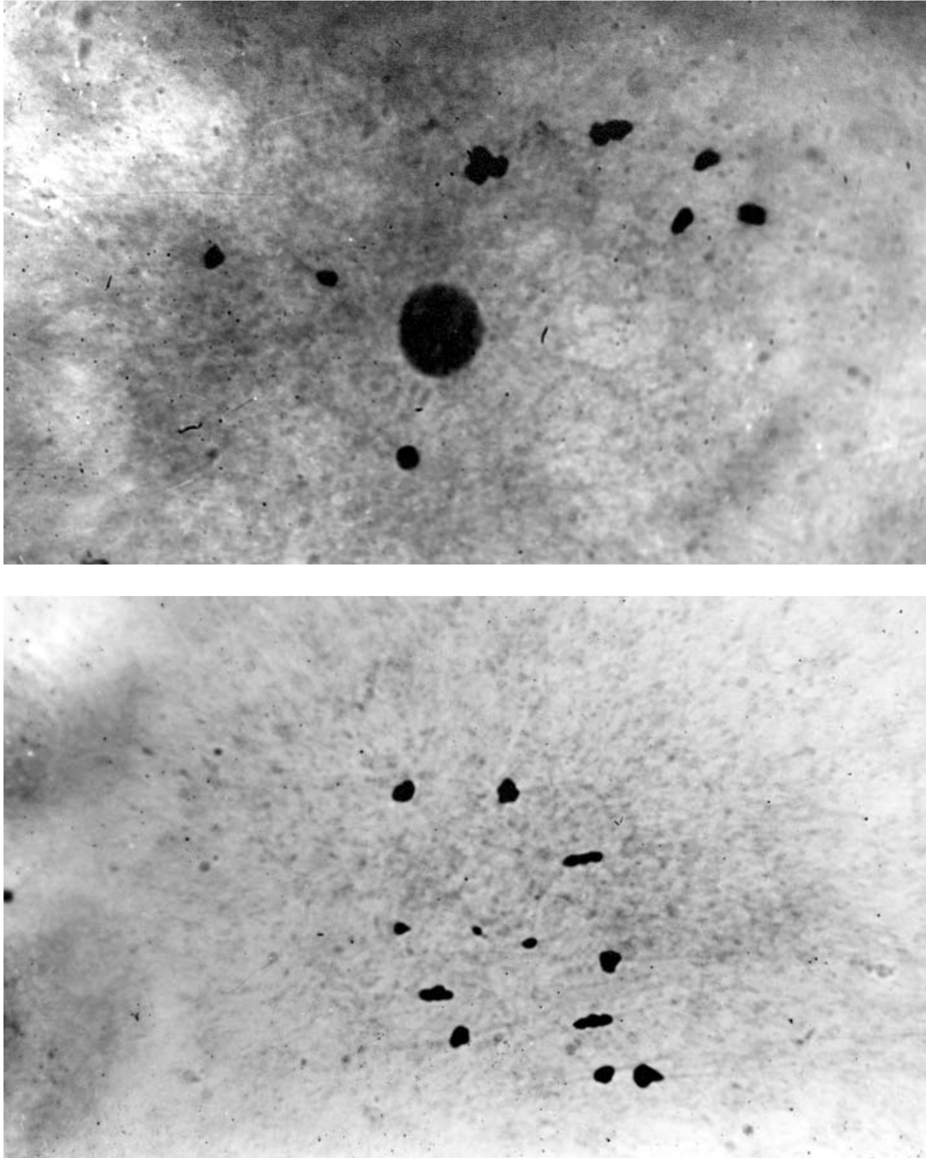

Figure 2.12 (a) Meiosis (diakinesis) showing multivalents. (b) Meiotic metaphase showing multivalents and univalents.

abnormalities (e.g., late separation, laggards, sticky bridges) at anaphase 1, leading to high pollen sterility. Das et al. (1999) felt that the sterility might be due to nonhomology of bivalents, with irregular separation of genomic complements leading to sterile gamete formation. The absence of germination pores on the pollen grains has also been indicated as an impediment to seed set.

Table 2.6 Chromosomal abnormalities and pollen sterility in ginger cultivars

Sl. No.	*Cultivars*	*Percentage of PMCs with anaphase I abnormalities*	*Percentage of PMCs with Metaphase II abnormalities*	*Abnormal tetrads*	*Percentage of pollen sterility*
1	China	31.0	45.8	52.9	81.0
2	Bangkok	33.3	51.7	42.9	82.0
3	Taiwan	8.1	40.0	51.9	82.8
4	Sierra Leone	47.2	55.1	52.2	85.0
5	Tafingiwa	11.0	34.4	48.8	82.9
6	Jamaica	11.6	30.2	54.2	54.4
7	Rio de Janeiro	17.6	71.2	70.6	90.2
8	Wynad local	5.5	39.4	37.9	76.7
9	Kunnamangalm	15.4	70.7	80.5	91.4
10	Mananthodi	21.1	60.2	42.2	82.5
11	Kuruppampadi	24.5	30.8	39.7	79.6
12	Eranad Manjeri	18.0	26.9	30.3	74.2
13	Eranad Chernad	21.4	41.5	56.7	84.4
14	Valluvanadu	20.0	39.4	33.8	85.6
15	Thodupuzha	9.8	69.2	61.2	86.4
16	Vengara	3.2	20.6	51.9	84.0
17	Karakkal	20.7	58.3	48.7	85.7
18	Uttar pradesh	32.9	67.0	58.8	86.1
19	Bajpai	34.2	61.4	5.5	85.5
20	Assam	38.4	61.2	51.6	78.5
21	Jorhat	18.7	81.1	79.4	88.7
22	Thingpuri	21.4	47.2	24.3	84.0
23	Jugidan	19.7	72.4	83.2	88.8
24	Burdwan	23.1	24.6	47.9	79.6
25	Maran	19.4	76.6	71.2	79.3
26	*Z. zerumbet*	28.4	19.3	15.2	9.0
27	*Z. casummunnar*	23.0	28.1	18.3	4.7

PMC, Pollen mother cells. Source: Ratnambal (1979).

Pollen Morphology

The earlier investigators (Stone et al., 1979; Zavada, 1983; Dahlgren et al., 1985) were of the opinion that the pollen grains of the family are exineless, possessing a structurally complex intine (Hesse and Waha, 1982). However later studies indicated that in the majority of the Zingiberaceae an exinous layer does exist, although it is poorly developed in many taxa (Kress and Stone, 1982; Skvaria and Rowely, 1988; Chen, 1989). Recent palynological studies have demonstrated differences in pollen structure between sections of *Zingiber*. The Sect. Zingiber has spherical pollen grains with cerebroid sculpturing, whereas Sect. Cryptanthium has ellipsoid pollen grains with spirostriate sculpturing (Liang, 1988; Chen, 1989).

The pollen of Zingiberaceae is usually classified as inaperturate, but *Zingiber* is an exception. Some workers described *Zingiber* pollen as monosulcate (Zavada, 1983; Dahlgren et al., 1985; Mangaly and Nair, 1990), whereas others reported the pollen as being inaperturate (Liang, 1988; Chen, 1989). Theilade et al. (1993) made a detailed study of pollen morphology and structure in 18 species of *Zingiber*. The pollen is spherical or ellipsoidal. The spherical pollen grains have a cerebroid or reticulate sculpturing. The grains are 55 to 85 μm in diameter. The elliptical pollen grains (in Sect. Cryptanthium) have a spirostriate sculpturing. The grains are 110 to 135 by 60 to 75 μm. The pollen grains have 2 to 3 μm thick coherent exine. The intine consists of two layers, a 5 μm thick outer layer and 2 to 3 μm thick inner layer adjacent to the protoplast. The outer layer is radially striated; the inner layer has a distinct, minute fine structure. No apertures are present. It has been indicated that the entire wall functions as a potential germination site (Hesse and Waha, 1982; Kress and Stone, 1982). Nayar (1995) studied germinating pollen grains of 22 taxa in Zingiberales including *Z. roseum* and *Z. zerumbet* and reported that the pollen grains possess an exine containing sporopollenin. Inside this layer there is a well-defined lamellatted cellulosic layer (described as the outer layer of intine by earlier workers), which is the medine. The intine is membraneous and consists of cellulose and protein and is in fact the protoplasmic membrane. At germination a solitary pollen tube develops that has the protoplasmic membrane (intine) as its wall and pierces the outer layers smoothly even in the absence of a germpore or aperture (Figure 2.13).

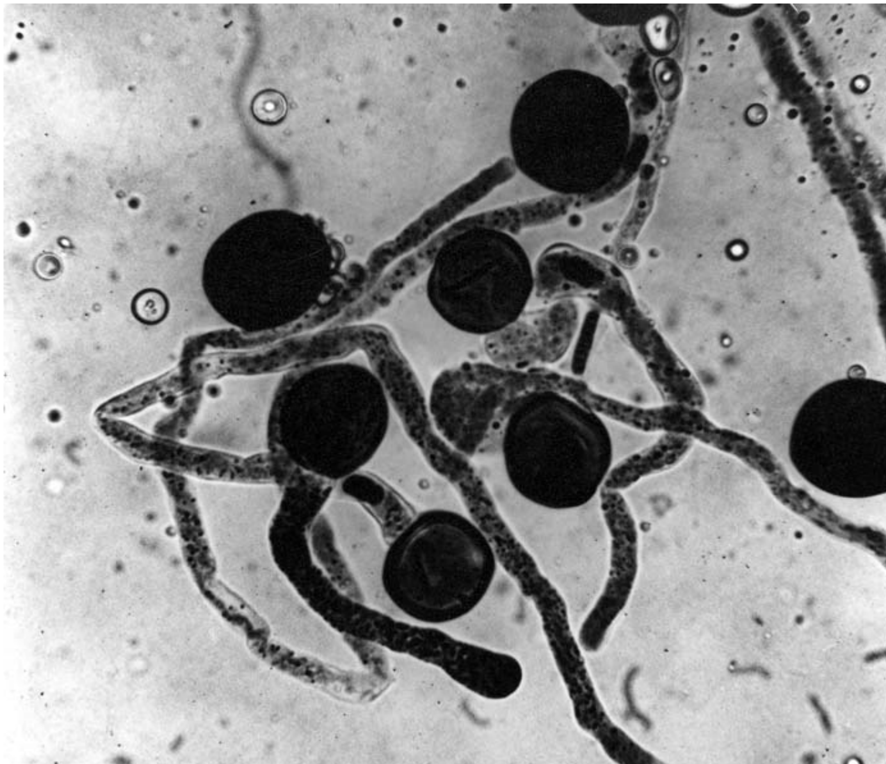

Figure 2.13 Germination of pollen grains.

The stainability percentage ranges from 14.7 (cv. Thingpuri) to 28.5 (in cv. Pottangi and China). Usha (1984) reported 12.5 and 16.4% stainability in cvs.Rio de Janeiro and Moran, respectively. Pollen germination ranged from 8 (cv. Sabarimala) to 24% (Moran) (Dhamayanthi et al., 2003). Pillai et al. (1978) reported 17% pollen germination in cv. Rio de Janeiro. The pollen tube growth under in vitro was maximum in cv. China (488 μm) and minimum in cv. Nadia (328 μm). The number of pollen tubes ranged from 6.5 (in cv. Nadia) to 16.7 (in cv. Varada) (Dhamayanthi et al., 2003).

Physiology of Ginger

Effect of Day Length on Flowering and Rhizome Swelling

Ginger is grown under varying climatic conditions and in many countries in both hemispheres. It is generally regarded as being insensitive to day length. Adaniya et al. (1989) carried out a study to determine the influence of day length on three Japanese cultivars (Kintoki, Sanshu, and Oshoga) by subjecting the plants to varying light periods in comparison with natural daylight. In the three cultivars, as the light periods decreased from 16 to 10 hours, there was inhibition of vegetative growth of shoots and the underground stem. The rhizome knobs became more rounded and smaller. As the day length increased to 16 hours, the plants grew more vigorously and the rhizome knobs were slender and larger and active as new sprouts continued to appear. When the light period was extended to 19 hours, there was reduction in all growth parameters, and it was on a par with the 13-hour light period. It seems that the vegetative growth was promoted by a longer light period up to a certain limit, whereas rhizome swelling was accelerated under a relatively short day length (Table 2.7). The results also suggested that a relatively short day length accelerated the progression of the reproductive growth, whereas relatively long day length decelerated it. Ginger is therefore described as a quantitative short-day plant for flowering and rhizome swelling (Adaniya et al., 1989). These workers have also observed intraspecific variations in photoperiodic response; cv. Sanshu responded most sensitively, and Kintoki was more sensitive than Oshoga. They concluded that such an intraspecific response to the photoperiod could be related to their traditional geographical distribution; Kintoki and Sanshu are early cultivars adapted to the northern part (Kanto district) and Oshoga is a late cultivar adapted to the south (Okinawa to Shikoku districts).

Sterling et al. (2002) studied the effect of photoperiod on flower bud initiation and development in *Zingiber mioga* (myoga, or Japanese ginger). Plants grown under long-day conditions (16 hours) and short-day conditions (8 hours) with a night break produced flower buds, whereas those under short-day conditions (8 hours) did not. This failure of flower bud production under short day was due to abortion of developing floral bud primordia rather than a failure to initiate inflorescences. It was concluded that although for flower development in myoga a quantitative long-day requirement must be satisfied, flower initiation was day neutral. Short-day conditions also resulted in premature senescence of foliage and reduced foliage dry weight.

Chlorophyll Content and Photosynthetic Rate in Relation to Leaf Maturity

Xizhen et al. (1998c) investigated the chlorophyll content, photosynthetic rate (Pn), MDA content, and the activities of the protective enzymes during leaf development. Both chlorophyll content and Pn increased with leaf expansion and reached a peak on

Table 2.7 Effect of photoperiod on the growth of underground parts

Cultivar	*Day length (h)*	*No. of rhizome knobs*	*Weight of rhizome (g)*	*Weight of a rhizome knob (g)*	*No. of primary roots*	*Percentage of swollen primary roots (%)*
Kintoki	10	27.0a[y]	75.2b	2.71b	39.8d	19.9a
	ND[x]	30.4a	118.2a	3.80a	127.0c	3.9b
	13	30.6a	102.0ab	3.15b	154.8bc	0.6c
	16	29.9a	128.5a	4.33a	204.4a	—
	19	28.5a	99.3ab	3.50a	184.9ab	—
Sanshu	10	26.7c	58.3c	2.18c	41.3d	2.3a
	ND	39.6b	151.4b	3.82b	77.1b	2.5a
	13	47.5a	152.1b	3.26b	55.0cd	0.5b
	16	45.2ab	212.3a	4.64a	146.7a	—
	19	27.8c	123.2b	4.48a	74.5bc	—
Oshoga	10	11.2b	68.9c	6.15b	26.9b	0.7a
	ND	13.8ab	190.4ab	13.80a	44.4a	0.5a
	13	15.9a	215.9a	13.58a	49.6a	—
	16	12.8ab	195.6ab	15.28a	44.6a	—
	19	10.8b	146.7b	13.58a	40.2a	—

Values followed by the same letters are not significantly different.
[x]Natural day length decreased from 13.46 h (June 29) to 10.41 h (Nov. 29)
[y]Mean separation with in cultivars by Duncan's multiple range test, 5% level.

the 15th day and then declined gradually (Table 2.8). In the first 40 days of leaf growth, the malondialdehyde (MDA) content of leaves remained constant and SOD (superoxide dismutase) activity showed a little decrease. After 40 days, the MDA content increased markedly and SOD activity dropped substantially. Peroxidase (POD) and catalase activities exhibited a steady increase during 60 days. Xizhen et al. (1998) concluded that senescence of ginger leaf sets in when leaf age reaches about 40 days.

Xizhen et al. (1998) also studied the photosynthetic characteristic of different leaf positions, and reported that the Pn of midposition leaves was the highest followed by the lower leaves and Pn was lowest in upper leaves. The light compensation point of different leaf positions was from 18.46 to 30.82 $\mu mol/m^2s^{-1}$; it was highest in midposition leaves and lowest in lower leaves. The light saturation point ranged from 624.8 to 827.6 $\mu mol/m^2s^{-1}$, the values were 624.8, 827.6 and 799. 5 $\mu mol/m^2s^{-1}$, respectively, in upper, middle, and lower leaves. CO_2 compensation points in upper, middle, and lower position leaves were 163.8, 29.6 and 71.4 µl/l, respectively. CO_2 saturation in upper, middle, and lower leaves were 1543.3, 1499.0 and 1582.0 µl/l. The diurnal variation of Pn in different leaf positions gave a double peak curve, the first peak was at about 9:00 A.M. and the second appeared from 1300 to 1400 hours.

Stomatal Behavior and Chlorophyll Fluorescence

Dongyun et al. (1998) studied the chlorophyll fluorescence and stomatal behavior of ginger leaves. Ginger leaves were enclosed individually in cuvettes and studied to find

Table 2.8 Changes of chlorophyll content and photosynthetic rate during development of ginger leaves

Leaf age (days)	*Chlorophyll content(mg · g^{-1})*	*Pn (μmol m^{-2} · s^{-1})*
1 day	1.80	6.11
5 days	1.98	7.58
10 days	2.02	9.16
15 days	2.58	10.30
20 days	2.56	0.20
25 days	2.43	9.86
30 days	2.47	8.54
35 days	2.51	8.69
40 days	2.56	8.48
45 days	2.30	7.62
50 days	2.01	7.11
55 days	1.89	6.65
60 days	1.77	6.21

Source: Xizhen et al. (1998b).

out the relationship between photosynthesis and changes in microclimate. Stomatal conductance (gsc) increased and was saturated at relatively low values of high intensity (400 μmol^{-1}). At different leaf temperatures, gsc peaked at 29°C, but transpiration (tr) increased with increasing irradiance and temperature. Increasing external CO_2 concentrations caused gsc to increase but were relatively insensitive to increasing soil moisture availability until a threshold was reached (0.5 to 2 g/g). At a soil moisture content of 2 to 3.5 g/g, gsc increased approximately linearly with increasing tr. Fluorescence (Fv/Fm, electron transfer in PS II) decreased with increasing photon flux density (PFD). In leaves exposed to high PFD and different temperatures, Fv/Fm was the lowest at 15°C, and the highest at more than 25°C. In leaves exposed to low PFD, Fv/Fm remained at a similar value over all temperatures tested.

Photosynthesis and Photorespiration

Zhenxian et al. (2000) measured, using a portable photosynthetic system and a plant efficiency analyzer, the photosystem inhibition of photosynthesis and the diurnal variation of photosynthetic efficiency under shade and field conditions. There were marked photoinhibition phenomena under high light stress at mid-day. The apparent quantum yield (AQY) and photochemical efficiency of PS II (Fv/Fm) decreased at midday, and there was a marked diurnal variation. The extent of photoinhibition due to higher light intensity was severe in the seedling stage. After shading, AQY and Fv/Fn increased and the degree of photoinhibition declined markedly. However, under heavier shade, the photosynthetic rate declined because the carboxylation efficiency declined after shading.

Shi-jie et al. (1999) investigated the seasonal and diurnal changes in photorespiration (Pr) and the xanthophyll cycle (L) in ginger leaves under field conditions in order to understand the role of L and Pr in protecting leaves against photoinhibitory damage. The seasonal and diurnal changes of Pr and L of ginger leaves were marked, and Pr showed diurnal changes in response to PFD, and its peak was around 10:00 A.M. to

12:00 noon. Pr declined with increasing shade intensity. The L cycle showed a diurnal variation in response to PFD and xanthophyll cycle pool. Both increased during the midday period, and peaked around 12:00 noon. The results, in general, indicated that Pr and the xanthophyll cycle had positive roles in dissipating excessive light energy and in protecting the photosynthetic apparatus of ginger leaves from midday high-light stress.

Xizhen et al. (2000) have also investigated the role of SOD in protecting ginger leaves from photoinhibition damage under high-light intensity. They observed that on a sunny day the photochemical efficiency of PS ll (Fv/Fm) and AQY of ginger leaves declined gradually in the morning, but rose progressively after 12:00 noon. The MDA content in ginger leaves increased but the Pn declined under midday high-light stress. SOD activity in ginger leaves increased gradually before 1400 hours, and then decreased. At 60% shading in the seedling stage, Fv/Fm and AQY of ginger leaves increased but the MDA content, SOD activity, and Pn decreased. Pn, AQY, and Fv/Fm of ginger leaves treated with diethyldithio carbamic acid (DDTC) decreased whether shaded or not, but the effect of DDTC on shaded plants was less than that on unshaded plants. These workers concluded that midday high-light intensity imposed a stress on ginger plants and caused photoinhibition and lipid peroxidation. SOD and shading played important roles in protecting the photosynthetic apparatus of ginger leaves against high light stress.

Xizhen et al. (1998a) have investigated the effect of temperature on photosynthesis of ginger leaf. They showed that the highest photosynthetic rate and apparent quantum efficiency was under 25°C. The light compensation point of photosynthesis was in the range of 25 to 69 μmol.m^{2}s^{-1}; it increased with increasing temperature. The light saturation point was also temperature dependent. The low-light saturation point was noted at temperatures below 25°C. The CO_2 compensation point and the saturation point were 25 to 72 and 1343 to 1566 μl/l, respectively, and both increased with the increase in leaf temperature.

Xianchang et al. (1996) studied the relationship between canopy, canopy photosynthesis, and yield formation in ginger. They found that canopy photosynthesis was closely related to yield. In a field experiment using a plant population of 5,000 to 10,000 per 666.7 m^2 area, they had a yield increase from 1,733 to 2,626 kg. The Pn increased from 8.16 (μmol CO_2 m^{-2} 1 (ground) s^{-1}) to 14.66; the leaf area index from 3.21 (m^2/m^2) to 7.02 m^2/m^2 (Table 2.9). The unit area of branches (tillers) and leaf area index were over 150/m^2 and 6 m^2/m^2, respectively, in the canopy of the higher yield class. The canopies over 7,000 plants per 666.67 m^2 satisfied these two criteria and among them there were no significant differences in height, tillers, leaf area index, canopy photosynthesis, and yield. Diurnal changes in the canopy Pn showed a typical single-peak curve, which was different from the double-peak curve obtained from the single-leaf Pn.

Effect of Growth Regulators

Studies have been carried out to find out the effect of various growth regulators on ginger growth, flowering and rhizome development. The main aims of such studies are to break the rhizome dormancy, to induce flowering and seed set, and to enlarge the rhizome followed by increased yield. Islam et al. (1978) studied the influence of 2-chloroethyl phosphonic acid (ethrel or ethephon) and elevated temperature treatments. Exposure of ginger rhizome pieces to 35°C for 24 hours or to 250 ppm ethrel for 15 min caused a

Table 2.9 Effect of plant density on growth, photosynthesis, and yield of ginger

Plant density (per 66.67 m^2)	*Plant ht. (cm)*	*Tillers (no/m^2)*	*Leaf area index (m^2/m^2)*	*Photosynthetic rate ($\mu mol\ CO^2\ m^2$ (ground) $\cdot s^{-1}$)*	*Yield (kg/666.7 m^2)*
5,000	62a*	103a	3.21a	8.16a	1733.42a
6,000	64a	122b	4.25b	10.17b	1948.25b
7,000	67a	138c	5.31c	12.23c	2211.22c
8,000	73b	152d	6.15d	14.56d	2637.17d
9,000	74b	159d	6.63d	14.78d	2614.95d
10,000	74b	163d	7.02d	14.66d	2626.13d

[a]Same letters are not statistically significant

Source: Xianchang et al. (1996).

Table 2.10 Effect of temperature and ethrel on germination and early growth of ginger

Growth parameters	*Day 16 Pretreated*			*Day 23 Pretreated*		
	Control	*35°C*	*Ethrel*	*Control*	*35°C*	*Ethrel*
Shoots plus swollen buds (%)[a]	70.4	76.8	91.8***	86.2	81.4	92.6
Total length of shoots per rhizome piece (m)	2.63	3.49*	4.23***	3.72	5.36	6.83***
Length of longest shoot per rhizome piece (cm)	1.48	1.90*	2.36***	2.28	3.23	4.36*
Shoots having roots (%)	9.43	13.73	34.63***	25.83	41.83**	46.93**
Total number of roots per seed piece	2.45	2.78	9.81***	5.95	9.12	13.54**

Source: Islam et al. (1978), [a]Expressed as percentage of total number of shoots, swollen buds, and visible but apparently dormant buds; *, **, *** denotes significant differences from control treatment at P = .05, P = .01, and P = .001, respectively.

substantial increase in shoot growth during the first 23 days of growth (Table 2.10). Ethrel was more effective in increasing the number of roots per rhizome piece by a factor of 4.0 and the number of shoots having roots by a factor of 3.7 (both at day 16). Relatively low concentrations of ethrel (less than 250 ppm) were sufficient to produce maximum responses in terms of shoot length parameters, although significant increases in the number of shoots per seed piece, the number of rooted shoots, and the total number and length of roots per seed piece occurred even up to the highest concentrations of 1,000 ppm studied by Islam et al. (1978). Treatment of ethrel was found to be effective in reducing the variability in root growth, but shoot growth variability had increased particularly at concentrations below 500 ppm.

Furutani and Nagao (1986) investigated the effect of daminozide, gibberellic acid (GA_3), and ethephon on flowering, shoot growth, and yield of ginger. Field-grown ginger plants were treated with three weekly foliar sprays of GA_3 (0, 1.44 and 2.88 mM); ethephon (0, 3.46, and 6.92 mM), or daminozide (0.3, 13, and 6.26 mM). GA_3 inhibited

flowering and shoot emergence, whereas ethepon and daminozide had no effect on flowering but promoted shoot emergence. Rhizome yields were increased with daminozide and decreased with GA_3 and ethephon.

Ravindran et al. (1998) tested three growth regulators—triacontanol, paclobutrazole, and GA_3—on ginger to find out their effect on rhizome growth and developmental anatomy. Paclobutrazole- and triacontanol-treated rhizomes resulted in thicker walled cortical cells compared to GA_3 and control plants. The procambial activity was higher in plants treated with triacontanol and paclobutrazole. In the cambium layers, the fusiform cells were much larger in paclobutrazole-treated plants. Growth-regulator treatment did not affect the general anatomy, although dimensional variations existed. The numbers of vascular bundles were more in plants treated with paclobutrazole and triacontanol. Paclobutrazole-treated plants exhibited greater deposition of starch grains than other treatments. The fiber content in the rhizome was less in GA_3-treated rhizome. A higher oil cell index and higher frequency oil cells were observed in paclobutrazole-treated rhizome (Table 2.11). GA treatment also led to considerable increase in the number of fibrous roots.

Growth-Related Compositional Changes

Baranowski (1986) studied the cv. Hawaii for 34 weeks and recorded the growth-related changes of the rhizome. The solid content of the rhizome increased throughout the season, but there was a decline in the acetone extractable oleoresin content of dried ginger. However, the oleoresin content on a fresh weight basis was roughly constant (Table 2.12).

The (6)-gingerol content of ginger generally increased with the age of the rhizome on a fresh weight basis (Table 2.13) These results indicate the basis for the gradual increase in pungency with maturity. On a dry weight basis, gingerol generally exhibited a linear increase with maturity up to 24 weeks, followed by a steady decline through the rest of the period. The results, in general, indicate that it may be advantageous to harvest ginger early (i.e., by 24 weeks) for converting to various products.

Table 2.11 Effect of triacontanol, paclobutrazol, and GA_3 on rhizome characters of ginger

Treatment	*Mean internodal length aerial stem (cm)*	*Mean leaf length (cm)*	*Mean internodal length of rhizome (cm)*	*Mean rhizome girth (cm)*	*Mean oil cells per mm^2*	*Crude fiber content (%)*
Control	2.3	1.9	5.2	6.8	18.3	2.2
Tria-contanol	1.9	2.0	4.0	7.8	12.3	2.4
Paclobutrazole	0.8	1.8	0.7	4.6	22.2	2.6
GA_3	4.8	3.2	4.4	8.6	17.8	1.8

GA_3, gibberellic acid.

Source: Ravindran et al. (1998).

Table 2.12 Changes in yield and composition of ginger Hawaiian rhizomes during growth

			*Oleoresin (%)***	
Weeks after planting	*Wt.* (kg)*	*Solids (%)*	*Dry wt basis*	*Fresh wt basis*
12	0.1	6.4	18.7a	1.20a
16	0.5	5.1	19.7a	1.00c,d
18	0.4	4.9	18.4a	0.90d
20	0.8	5.3	16.8b	0.89d
22	0.9	5.7	16.7b	0.95c,d
24	1.5	6.1	15.4c	0.94c,d
26	3.0	7.0	14.7c,d	1.03b,c
28	3.4	8.8	13.6d	1.20a
30	3.7	9.2	12.1e	1.04a,b
32	3.1	10.4	10.0f	1.04b,c
34	5.0	13.8	7.1g	0.99c,d

*Average of four plants, cleaned rhizomes
**Means separated by Duncan's multiple range test (P = .05)
Figures followed by the same letters are not significantly different.

Source: Baranowski (1986).

Table 2.13 Changes in (6)-gingerol content during growth

Weeks after planting	*Wet weight basis (ppm)*[a]	*Dry weight basis* ($ppm * 10^{-3}$)[a]
12	597	9.3
16	964	18.9
18	708	14.5
20	723	13.6
22	871	15.3
24	1001	16.4
26	1039	14.8
28	1184	13.5
30	1110	12.1
32	1238	11.9
34	1547	11.3

[a]Means separated by Duncan's multiple range test (P = 0.05)

Source: Baranowski (1986).

Genetic Resources

The history of domestication of ginger is not definitely known. However, this crop is known to have been under cultivation and use in India and China for the last 2,000 years or even more. China is probably the region where domestication had started, but little is known about the center of origin, although the largest variability exists in China. Southwestern India, known as the Malabar Coast in ancient times, traded ginger with the Western World from ancient times, indicating its cultivation. This long period of

domestication might have played a major role in the evolution of this crop that is sterile and propagated solely vegetatively. Ginger has rich cultivar diversity, and most major growing tracts have cultivars that are specific to the area; and these cultivars are mostly known by place names. Cultivar diversity is richest in China. In India the diversity is more in the state of Kerala and in the northeastern region of India. Being clonally propagated, the population structure of this species is determined mainly by the presence of isolation mechanisms and the divergence that might have resulted through the accumulation of random mutations. At present, more than 50 ginger cultivars possessing varying quality attributes and yield potential are being cultivated in India, although the spread of a few improved and high-yielding ones are causing the disappearance of the traditional land races. The cultivars popularly grown (cultivar diversity) in the various ginger-growing states in India are given in Table 2.14. Some of these cultivars were introduced into India, and the cultivar Rio de Janeiro, an introduction from Brazil, has become very popular in Kerala. Introductions such as China, Jamaica, Sierra Leone, and Taffin Giwa, are also grown occasionally.

Among the ginger-growing countries, China has the richest cultivar diversity. The important cultivars grown in China are given in Table 2.15. Less important ones are Zaoyang of Hubei province, Zunji big white ginger of Giuzhou, Chenggu yellow ginger of Shaxi, Yulin round fleshy ginger of Guangxi, Bamboo root ginger and Mian yang ginger of Sichuan, Xuanchang ginger of Ahuii, Yuxi yellow ginger of Yunnan, and Taiwan fleshy ginger. Many of these cultivars have unique morphological markers for identification.

In general, the cultivar variability is much less in other ginger-growing countries. Tindall (1968) reported that there were two main types of ginger grown in West Africa. These differ in color of the rhizome, one with a purplish red or blue tissue below the outer scaly skin, whereas the other has a yellowish white flesh. Graham (1936) reported that there were five kinds of ginger recognized in Jamaica known as St. Mary, Red eye, Blue Tumeric, Bull blue, and China blue. But Lawrence (1984) reported that only one cultivar is grown widely in Jamaica. According to Ridley (1915), three forms of ginger were known in Malaysia in earlier days: halyia betel (true ginger), halyia bara, or padi, a smaller leaved ginger with a yellowish rhizome used only in medicine; and halyia udang, red ginger having red color at the base of the aerial shoot. A red variety of ginger, *Z. officinale* var. *rubra* (also called pink ginger), has been described from Malaysia, in which the rhizome skin has a reddish color. A variety "withered skin" also has been reported. In Philippines two cultivars are known, the native and the Hawaiian (Rosales, 1938). In Nigeria the cv. Taffin Giwa (Bold, yellow ginger) is the common one, the other being Yasun Bari, the black ginger.

In Japan the ginger types are classified into three groups: (1) small-sized plants with many tillers and a small rhizome, (2) medium-sized plants with an intermediate number of tillers and a medium-sized rhizome, and (3) large-sized plants with fewer tillers and larger rhizomes. The common cultivars included in these groups are Kintoki, Sanshu, and Oshoga, respectively. A stabilized tetraploid line of Sanshu (4x Sanshu) is also being cultivated in Japan (Adaniya, 2001). In addition, *Z. mioga* (Japanese ginger) is also grown in Japan for spice and vegetable purposes. In Queensland, Australia, ginger was an important crop in earlier times. The ginger cultivars might have been introduced there, although the exact source is not known. The local cultivar, known as Buderim local, is the most commonly grown. Australia earlier introduced cultivars from Japan, Hawaii,

Table 2.14 Major ginger-growing states in India and their popular cultivars indicating the diversity in ginger

State	*Cultivar name*	*Specific trait/character*	*Reference*
Kerala	Rio de Janeiro (32.55 t/ha—fresh)	High yield	Thomas (1966);
	Burdwan, Jamaica	High yield	Muralidharan and Kamalam (1973)
	Nadia (28.55 t/ha—fresh) & 6.54 t/ha—dry), Maran, Bajpai, and Narasapattam	High yield	AICSCIP (1978); Khan (1959)
	Rio de Janeiro and Kuruppumpady	Ratoon crop	Sree Kumar et al. (1980)
	SG-666	Fresh rhizome	Rattan (1989)
	Rio de Janeiro (21.80 t/ha—fresh; 3.27t/ha—dry), Assam (17.23 t/ha—fresh), Maran (3.27 t/ha—dry), and Thingpuri (2.79 t/ha—dry)	High yield	Muralidharan (1973)
	Thingpuri, Rio de Janeiro, and China	High yield	Sreekumar et al. (1980)
	IISR-Varada (22.6 t/ha)		Muralidharan (1973)
	IISR-Mahima (23.2 t/ha) and IISR-Rejatha (22.4 t/ha)	Wider adaptability High yield	Sasikumar et al. (2003)
	V_2E_5-2 (33.83 t/ha), Rio de Janeiro (27.38 t/ha), Ernadan (25.11 t/ha), and Mananthavady (22.94 t/ha) (green ginger)	High yield	Pradeep Kumar et al. (2000)
Himachal Pradesh	Himachal Selection, Rio de Janeiro	High yield	Jogi et al. (1972)
	SG-646 and SG-666	High yield	Rattan (1989)
	Kerala local (3.76 t/ha) and B-1 (3.83 t/ha), Himachal selection (local) (10.9 t/ha) and Kerala local (9.6 t/ha)	Fresh ginger	Arya and Rana (1990)
	SG-534 (10.35 t/ha), V_1E_8-2 (8.92 t/ha), Acc. No. 64 (8.9 t/ha)	High-altitude areas	AICRPS (2000)
Assam	Nadia (6.7 t/ha) & Chekerella (5.7 t/ha)	High fresh rhizome yield	Aiyadurai (1966); Saikia and Shadeque (1992)
Nagaland	Thinladium, Nadia, and Khasi local (>30 t/ha)	High fresh rhizome yield	Singh et al. (1999)
Orissa	SG-666	High fresh rhizome yield	Rattan (1989)
	Rio de Janeiro and China (239 g/plant), Vingra selection, Ernad Manjeri, U.P., Thingpuri, Kuruppampadi, Wynad Kunnamangalam Thingpuri (2.20 t/ha)	High yield	Mohanty et al. (1981) Panigrahi and Patro (1985)
	V_1E_8-2 (25.13 t/ha) V_3S_1-8 (22.12 t/ha)	High-altitude area	AICRPS (2000)
Andhra Pradesh	IISR-Varada	High-altitude area	Naidu et al. (2000)

Karnataka	Himachal Pradesh (19.97 t/ha), Jorhat (18.88 t/ha), Wynad local (18.68 t/ha)	High fresh rhizome yield	Gowda and Melanta (2000)
Meghalaya	Tura (26.69 t/ha), Poona (25.04 t/ha), and Basar local (24.88 t/ha)	Midhills area	Chandra and Govind (1999)
West Bengal	Gurubathan (27.9 t/ha) Acc. No. 64 (18.93 t/ha)	High yield	AICRPS (2001)
Madhya Pradesh	V_3S_1-8 (17.4 t/ha)	High yield	AICRPS (1999)

Table 2.15 Ginger varieties commonly grown in China

Sl. No.	*Category/Type*	*Varieties/Cultivars*
1.	Sparse seedling type	Gandzhou (sparse ringed, big fleshy ginger) Shandong Laiwu (big ginger)
2.	Dense seedling type	Guangzhow (dense-ringed fleshy ginger) Zhejiang (red-claw ginger)
3.	Edible medicinal type	Fujian red bud Hunan yellow heart Chicken claw ginger Xingguo ginger
4.	Edible processed type	Guangzhou (fleshy) Fuzhou ginger (purplish shoot) Tongling (white ginger) Fujian bamboo ginger Zunyi (big white ginger) Leifeng ginger
5.	Ornamental ginger examples	Laishe ginger Flower ginger Tea ginger Strong ginger Hengchum ginger Hekou ginger
6.	Other cultivar examples	Zaoyang (Hubei Province) Zunji big ginger (Giuzhou) Chenggu Yellow (Shaxi) Yulin round fleshy (Guangxi) Bamboo root ginger (Sichuan) Mianyang (Sichuan) Xuanchang (Ahuii) Yuxi yellow (Yunnan) Laiwu slice ginger (Shandong) Yellow claw (Zhejiang) Taiwan fleshy (Taiwan)

and India. Recently the Buderim Ginger Co. (2002) has released the first tetraploid commercial variety, called Buderim Gold, for cultivation in Queensland. *Z. mioga,* the myoga ginger, introduced from Japan, is also grown commercially for its unopened flower buds, which are a vegetable delicacy.

In many cases, the major production centers are far from the areas of origin of the crop concerned (Simmonds, 1979). This is true of ginger as well: the Indo/Malayan region is very rich in Zingiberaceous flora (Holttum, 1950). Considering the present distribution of genetic variability, it is only logical to assume that the Indo/Malayan region is probably the major center of genetic diversity for *Zingiber*. It may be inferred that geographical spread accompanied by genetic differentiation into locally adapted populations caused by mutations could be the main factor responsible for variations encountered in cultivated ginger (Ravindran et al., 1994). In India the early movement of settlers across the length and breadth of the Kerala state and adjoining regions, where the maximum ginger cultivation is found, and the story of shifting cultivation in northeastern India (the second major ginger-growing sector in India), are well-documented sociological events. The farmers invariably carried small samples of the common crops that they grew in their original place along with them and domesticated the same in their new habitat—in most cases, virgin forestlands. Conscious selection for different needs such as high fresh ginger yield, good dry recovery, and less fiber content over the years has augmented the spread of differentiation in this crop. This would have ultimately resulted in the land races of ginger of today (Ravindran et al.,1994).

Conservation of Ginger Germplasm

Major collections of ginger germplasm are maintained at the Indian Institute of Spices Research (IISR), Calicut, India, and the Research Institute for Spices and Medicinal Crops, Bogor, Indonesia. In India serious efforts are being made for conservation of ginger germplasm. At present, the ginger germplasm conservatory at IISR consists of 645 accessions that include exotic cultivars, indigenous collections, improved cultivars, mutants, tetraploids, and related species (IISR, 2002). In addition, 443 accessions are being maintained at different centers of the All India-Coordinated Research Project on Spices and the National Bureau of Plant Genetic Resources (NBPGR), Regional Station, Thrissur (AICRPS, 2001 Table 2.16). The major constraints involved in the conservation of the germplasm of ginger are the two soil-borne diseases: rhizome rot caused by *Pythium* spp. (such as *P. aphanidermatum, P. myriotylum,* and *P. vexans*) and the bacterial wilt caused by *Ralstonia solanacearum* (*Pseudomonas solanacearum*). Added to this, infection by leaf fleck virus is also posing serious problems for conservation. These diseases are extremely difficult to control or prevent under field conditions. Hence, in the National Conservatory for ginger at IISR, ginger germplasm is conserved in specially made cement tubs under 50% shade, as a nucleus gene bank to safeguard the material from deadly diseases and to maintain the purity of germplasm from adulteration,which is very common in field plantings. Each year, part of the germplasm collection is planted out in the field for evaluation and characterization (Ravindran et al., 1994). The collections are harvested every year and replanted in the next season in a fresh potting mixture. On harvesting the rhizomes, each accession is cleaned and dipped in fungicide and insecticide for protection and stored in individual brick-walled cubicles lined with sawdust or sand in a well-protected building.

In Vitro Conservation

In vitro conservation of ginger germplasm is a safe and complementary strategy to protect the genetic resources from epidemic diseases and other natural disasters. This is also an excellent method to supplement the conventional conservation strategies. Conservation

Table 2.16 Germplasm collections of ginger in India.

Sl.no	*Institute/University*	*No. of accessions*	*Reference*
1.	Indian Institute of Spices Research, Calicut	645	IISR (2002)
2.	Orissa University of Agriculture and Technology, Pottangi, Orissa	172	AICRPS (2003)
3.	Dr. Y.S Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh	271	AICRPS (2003)
4.	Rajendra Agricultural University, Dholi, Bihar	103	-do-
5.	Uttara Bangala Krishi Viswa Vidyalaya, Pundibari, West Bengal	31	-do-
6.	Narendra Dev University of Agriculture and Technology, Kumarganj, Faizabad, Uttar Pradesh.	29	-do-
7.	Indira Gandhi Krishi Viswa Vidyalaya, Regional Station, Raigarh	35	-do-
8.	National Bureau of Plant Genetic Resources, Regional Station, Thrissur, Kerala	173	Ravindran et al. (2004)
9.	Department of Horticulture, Sikkim	58	Kumar (1999)
10.	Central Agricultural Research Institute, Port Blair, Andamans	33	Shiva et al. (2004)

of ginger germplasm under in vitro conditions by slow growth was standardized at IISR, Calicut (Geetha et al., 1995; Nirmal Babu et al., 1996; Geetha, 2002). By this method, ginger could be stored up to one year without subculture in half-strength Murashige and Skoog (MS) medium with 10 gl^{-1} each of sucrose, and mannitol in sealed culture tubes. The survival of such stored material is around 85%. At IISR, over 100 unique accessions of ginger are being conserved under in vitro gene bank as medium-term storage of germplasm (Ravindran et al., 1994; Geetha, 2002). The possibility of storage at relatively high ambient temperatures (24–29°C) by subjecting the ginger and related taxa to stress factors was explored by Dekkers et al. (1991). The increase in the subculture period was better with an overlay of liquid paraffin. After one year, 70 to 100% survival was seen.

Ravindran and coworkers (Anon. 2004) standardized the use of synthetic seeds in conservation. Synthetic seeds, developed with somatic embryos, encapsulated in 5% sodium alginate gel could be stored in MS medium supplemented with 1 mgl^{-1}. g/l can be substituted for gl^{-1} throughout the chapter (and also in other chapters) Benzyl adenine (BA) at 22 ± 2°C for 9 months with 75% survival. The encapsulated beads on transfer to MS medium supplemented with 1.0 mgl^{-1} Benzylaminopurine (BAP) and 0.5 mgl^{-1} Naphthalene acetic acid (NAA), germinated and developed into normal plantlets (Sajina et al., 1997). The conservation of germplasm through microrhizome production was also investigated and it was found that microrhizomes can be induced in vitro when cultured in MS medium supplemented with higher levels of sucrose (9 to 12%). Such microrhizomes can be easily stored for more than one year in culture. Six-months-old microrhizomes can be directly planted in the field without any acclimatization. The microrhizomes can thus be used as a disease-free seed material and for propagation, conservation, and exchange of germplasm (Geetha, 2002). This microrhizome technology is amenable for automation and scaling up.

Cryopreservation is a strategy for long-term conservation of germplasm (Ravindran et al., 1994). Efforts are going on at IISR and NBPGR for developing such strategies. Cryopreservation of ginger shoot buds through an encapsulation-dehydration method was attempted by Geetha (2002). The shoot buds were encapsulated in 3% sodium alginate beads and pretreated with 0.75 M sucrose solution for 4 days and dehydrated in an air current from laminar airflow and then immersed in liquid nitrogen. Beads conserved like this on thawing and recovery exhibited 40 to 50% viability. The cryopreserved shoot buds were regenerated into plantlets. The studies carried out at IISR showed that vitrification and encapsulation-vitrification methods are more suitable for the cryopreservation of ginger shoot buds (Nirmal Babu, unpublished data).

Characterization and Evaluation of Germplasm

A clear knowledge of the extent of genetic variability is essential for formulating a meaningful breeding strategy. Under a low-variability situation, selection programs will not yield worthwhile benefits. In any vegetatively propagated species the extent of genetic variability will be limited unless samples are drawn from distinctly different agroecological situations. Studies on genetic variability for yield and associated characters in ginger indicated the existence of only moderate variability in the germplasm. Little variability exists among the genotypes that are grown in the same area; however, good variability has been reported among cultivars that came from widely divergent areas.

Ravindran et al. (1994) characterized 100 accessions of ginger germplasm based on morphological, yield, and quality parameters. Moderate variability was observed for many yield and quality traits (Table 2.17). Tiller number per plant had the highest variability, followed by rhizome yield/plant. Among the quality traits, the shogaol content recorded the highest variability, followed by crude fiber and oleoresin. None of the accessions possessed resistance to the causal organism of leaf spot disease, *Phyllosticta zingiberi.* Quality parameters such as dry recovery and oleoresin and fiber contents

Table 2.17 Mean, range, and CV (%) for yield attributes and quality traits in ginger germplasm

Character	*Mean*	*Range*	*CV (%)*
Plant height (cm)	59.2	23.1–88.6	19.00
Leaf no./plant	37.1	17.0–52.0	18.22
Tiller no./plant	16.8	2.80–35.5	45.90
Leaf length (cm)	23.8	17.0–36.5	10.90
Leaf width (cm)	2.6	1.90–3.70	10.80
Days to maturity	226.0	214–236	13.5
Dry recovery (%)	21.7	14.0–28.5	14.3
Rhizome yield/plant (g)	363.1	55.0–770.0	39.3
Crude fiber (%)	4.31	2.1–7.0	23.3
Oleoresin (%)	6.1	3.2–9.5	21.7
Gingerol (%) in oleoresin	19.9	14.0–27.0	15.2
Shogaol (%) in oleoresin	4.1	2.7–7.5	24.3

Source: Ravindran et al. (1994).

are known to vary with the soil type, cultural conditions, and climate (Ravindran et al., 1994).

Mohanty and Sarma (1979) reported that expected genetic advance and heritability estimates were high for the number of secondary rhizome and total root weight. Genetic coefficient of variation was high for weight of root tubers. Rhizome yield was positively and significantly correlated with number of pseudostems (tillers), leaves, secondary rhizome fingers, tertiary rhizome fingers, total rhizome, plant height, leaf breadth, girth of secondary rhizome fingers, and number and weight of adventitious roots. Studies indicated that straight selection was useful to improve almost all characters except the number of tertiary fingers and straw yield. Rattan et al. (1988) reported that plant height was positively and significantly correlated with number of leaves, leaf length, rhizome length, rhizome breadth, and yield per plot. The number of leaves per plant was positively and significantly related to rhizome length, breadth, and yield. The rhizome length was also related to rhizome breadth and yield. Positive correlation of rhizome weight with plant height, number of tillers, and leaf number was reported by Sreekumar et al. (1980). Mohanty et al. (1981) observed a significant varietal differences for all the characters except for the number of tillers per plant and number of leaves per plant. Pandey and Dobhal (1993) observed a wide range of variability for most of the characters studied by them. Rhizome yield per plant was positively associated with plant height, number of fingers per plant, weight of fingers, and primary rhizome.

At IISR, Sasikumar et al. (1992b) studied 100 accessions of ginger germplasm for variability, correlation, and path analysis. They found that rhizome yield was positively correlated with plant height, tiller and leaf number, and leaf length and width (Table 2.18). Plant height also had a significant and positive association with leaf and tiller number as well as length and width of leaf. The association of leaf number with tiller number, leaf length, and leaf width was also positive and significant. Tiller number had a significant negative association with dry recovery. Leaf width had a positive significant association with dry recovery.

Table 2.18 Character associations in ginger

Character	*Leaf no.*	*Tiller no.*	*Leaf length*	*Leaf weight*	*Days to maturity*	*Dry recovery*	*Rhizome/ plant*
Plant ht.	0.69*	0.32**	0.59**	0.51**	0.12	0.18	0.47**
Leaf no.		0.26**	0.56**	0.36**	0.01	0.07	0.38**
Tiller no.			0.30*	0.13	0.03	0.29**	0.26**
Leaf length				0.42**	0.04	0.04	0.49**
Leaf width					0.01	0.42**	0.23**
Days to maturity						0.06	0.03
Dry recovery							0.10

** Significant at 1% level.

Source: Sasikumar et al. (1992b) .

Yadav (1999) reported a high genotypic coefficient of variation for length and weight of secondary rhizomes, weight of primary rhizomes, number of secondary and primary rhizomes, and rhizome yield/plant. High heritability coupled with high genetic advance as a percentage of mean was observed for plant height, leaf length, suckers per plant, number of mother and secondary rhizomes, weight of primary rhizome, and rhizome yield per plant, indicating that desirable improvement in these traits can be brought about through straight selection. Plant height followed by number of tillers per plant and leaf length had a maximum direct effect on rhizome yield (Singh, 2001).

Nybe and Nair (1982) suggested that morphological characters are not reliable to classify the types, although some of the types can be distinguished to a certain extent from rhizome characters. All the morphological characters were found to vary among types except for breadth of leaf, leaf area index, and number of primary fingers. Manmohandas et al. (2000) found that all the cultivars differed significantly in tiller number and leaf number. Yield stability analysis revealed the superiority of cvs. Ernad and Kuruppumpadi as they expressed high mean yield, nonsignificant genotype-environment interaction and stability in yield.

Biochemical Variability

Oleoresin of ginger is the total extract of ginger containing all the flavoring principles as well as the pungent constituents. The oleoresin contains two important compounds—gingerol and shogoal—that contribute to the ginger pungency. On long-term storage, gingerol becomes converted to shogoal. The quality of ginger thus depends on the relative content of gingerol and shogoal. Zachariah et al. (1993) classified 86 ginger accessions into high-, medium-, and low-quality types based on the relative contents of the quality components (Table 2.19). There are many ginger cultivars with high oleoresin, a few them, such as Rio de Janeiro, Ernad Chernad, Wynad, Kunnamangalam, and Meppayyur, also had a high gingerol content. The intercharacter association showed a positive correlation with oleoresin, gingerol, and shogoal.

Shamina et al. (1997) investigated the variability in total free amino acids, proteins, total phenols, and isozymes, using 25 cultivars. Moderate variations were recorded for total free amino acids, proteins, and total phenols. Isozyme variability for polyphenol oxidase, peroxidase, and SOD was reported to be low, indicating only a low level of polymorphism.

The information available from various studies on germplasm evaluation is summarized in Tables 2.20 and 2.21.

Table 2.19 Range, mean, and coefficient of variance in ginger cultivars for the quality components

Quality constituents	*Range*	*Mean*	*CV%*
Oleoresin (%)	3.2–9.5	6.1	21.5
Gingerol (%) (in oleoresin)	14–25	19.9	15.0
Shogaol (%) (in oleoresin)	2.8–7.0	4.1	23.7

Source: Zachariah et al. (1993).

Table 2.20 Evaluation of ginger germplasm for rhizome yield and its attributes

Character/trait	*Variety/Cultivar/Accession*	*References*
1. High yield (fresh and dry)	U.P, Rio de Janeiro, Thingpuri, Karakkal, Suprabha, Anamika, Jugijan	Mohanty and Panda (1994)
	SG-646 (Kerala) (159 g/plant) and SG-666 (H.P) (151 g/plant)	Rattan (1989)
	Rio de Janeiro, Suprabha, Suruchi, Suravi, Jugijan, Thigpuri, Wynad local, Himachal, Karakkal, Varada, Maran Acc. Nos. 64, 117 and 35	Sasikumar et al. (1994)
	Rio de Janeiro (Av. 21 t/ha—fresh, Maran (Av. 20 t/ha, 4.40 t/ha—dry), Nadia (Av. 19 t/ha—fresh, 3.80 t/ha—dry), Narasapattam (Av. 3.80t/ha-dry)	Paulose (1973)
	Rio de Janeiro (32.55 t/ha), China (16.76 t/ha), Ernad Chernad (15.84 t/ha)	Thomas (1966)
	Wynad (9.0 kg/3 m^2, SG-700, SG-705, and BDJR-1226 (7.5–7.7 kg/3 m^2), V_2E_4-5, and PGS 43 (7.8 kg/3 m^2)	AICRPS (1999, 2000, 2001)
	SG-876, SG-882 (9.2 kg/3 m^2)	
2. Bold rhizome	China, Taffingiva, SG-35	
	Varada, Gurubathan, Bhaise, China, Acc. Nos. 117, 35, 15, 27, and 142	Sasikumar et al. (1994, 1999)
3. Slender rhizome	Suruchi, Kunduli local	Mohanty and Panda (1994)
4. Short duration	Sierra Leone	Mohanty and Panda (1994)
5. High dry recovery (%)	Tura local—2 (29.7%)	Mohanty (1984)
	Tura (28%)	Sreekumar et al. (1982)
	Thodupuzha (22.6%), Kuruppampadi (23.0%) and Nadia (22.6%)	Nybe et al. (1982)
	Tura and Maran	Nair (1969); Muralidharan (1972); CPCRI (1973)
	Tura (22.07%), Thinladium (21.03%), and Jorhat (20.60%)	Muralidharan (1973)
	Vengara (25%), Ernad (24.37%), Himachal Pradesh, and Sierra Leone (23.12% each)	Thomas (1966)
	Zahirabad, Jorhat local, Kuruppampadi, Ernad, Suruchi, Maran, Assam, China, Mowshom, Thingpui, Varada, Acc. Nos. 27, 117, 204, and 294	Sasikumar et al. (1994, 1999)
	SG-685	AICRPS (2000)
6. High oleoresin (%)	Assam (9.3%) and Manathody (9.2%)	Krishnamourthy et al. (1970); Natarajan et al. (1972)
	Kuruppampadi (7.1%)	Muralidharan (1972)
	Rio de Janeiro (10.5%), Maran (10.0%) and Wynad local (9.1%)	Nybe et al. (1980)

Table 2.20 (Continued)

Character/trait	*Variety/Cultivar/Accession*	*References*
	Rio de Janeiro (10.8%)	Sreekumar et al. (1980)
	Wynad, Kunnamangalam, Ambalavayalan, Ernad, Santhing Pui, Rio de Janeiro, Kuruppampadi, Himachal, Varada, and China	Sasikumar et al. (1994)
	Rio de Janeiro, Wynad, Kunnamangalam, Meppayur, Santhing Pui (Manipur-1), Ernad, Erattupetta, Tamarassery local, PGS-33, and PGS-11 (> 7.4%)	Zachariah et al. (1993)
	Acc. Nos. 14 (9.0%) and 118 (6.0%)	
	Nadan Pulpally, Nadan, and Acc. No.57	Sasikumar et al. (1999)
	Acc. Nos. 110, 582, 236, 388, 414, 6, and 3 (6.2–8.9%)	Zachariah et al. (1999)
	V_1S_1-8, BDJR-1226, and Chanog-ll (8.3 to 8.7%)	AICRPS (1999)
7. High Essential oil (%)	Mananthody (2.2%)	Krishnamurthy et al. (1970); Lewis et al. (1972)
	Karakkal, (2.4%), Rio de Janeiro (2.3%), Vengara (2.3%), and Valluvanad (2.2%)	Nybe et al. (1982)
	Elakallan and Sabarimala	
	Acc. Nos. 118 (2.6%) and 14 (2.5%)	
	Pulpally, Sabarimala, Nadan Pulpally, and Thodupuzha	Sasikumar et al. (1999)
	Acc. Nos. 418, 399, 389, 205, 110, 236, 104, and 296 (2.9–3.2%)	Zakariah et al. (1999)
	BLP-6, SG-723, BDJR-1054, SG-55, and Maran (2.0 to 2.8%)	AICRPS (1999)
	Shilli, Bangi, Himgiri, Acc. No. 64, V_1E_4-4 PGS-23, and SG-706	AICRPS (2000)
8. Low crude fiber (%)	China (3.4%), UP (3.7%), Himachal Pradesh (3. 8%), Nadia (3.9%)	Nybe et al. (1982)
	Tura (3.5%)	Sreekumar et al. (1980)
	China (3.43%), Ernad (4.43%)	Thomas (1966)
	Zahirabad, Kuruppampadi, Mizo, PGS-16, China, UP, Nadia, Poona, and Jamaica	Sasikumar et al. (1994)
	Acc. Nos. 287 (3.0%), 288, 22 and 18 (3.2%)	
	Varada, Acc. Nos. 15 and 27	Sasikumar et al. (1999)
	Poona (4.62%), Nadia (4.84%), and Thinladium (5.01%)	Jogi et al. (1972)
	Acc. Nos. 419, 386, 415, 200, 110, and 336 (2.2–3.3%)	Zachariah et al. (1999)
9. High yield of dry ginger (t/ha)	Rio de Janeiro, Maran (3.27 t/ha), and Thingpuri (2.79 t/ha)	Muralidharan (1973)
	Maran (Av. 4.40 t/ha), Nadia (Av. 3.80 t/ha), Narasapattam (Av. 3.80 t/ha)	Paulose (1973)

10. High gingerol and shogaol	Wynad, Kunnamangalam, Ambalavayalan, Ernad, Thing Puri, and Rio de Janeiro	Sasikumar et al. (1994)
	Mizo, Nadia, Maran, Ernad, Kada, and Narianpara (high gingerol—22% of oleoresin); Rio de Janeiro, Santhing Pin (Manipur-1), PGS-37, S-641, Maran, Erattupetta, Nadan Pulpally, Jorhat local, PGS-16, Mizo and Nadia (high shogaol)—5% of oleoresin)	Zachariah et al. (1993)
	Baharica and Amaravathy	Sasikumar et al. (1999)
11. High zingiberene and (6)-gingerol	Baharica and Amaravathy	Sasikumar et al. (1999)

Data collected from various sources.

Table 2.21 Screening of ginger germplasm against pest and disease incidences

Character/trait	*Variety/cultivar/accession*	*Reaction*	*References*
A. Reaction to pests			
1. Shoot borer	Rio de Janeiro	Tolerant	Nybe et al. (1980)
2. Rhizome scale	Wild-2	Least infestation	Mohanty (1984)
	Anamika	Least incidence	Sasikumar et al. (1994)
3. Storage pest	Varada, Acc. Nos. 215 and 212	Resistant	
4. Root-knot nematode	Valluvanad, Tura and H.P	Least infestation	Charles and Kuiyan (1981)
	Acc. Nos. 36, 59 and 221	Resistant	
B. Reaction to diseases			
1. Rhizome rot	Jorhat and Sierra Leone	Least incidence (11.25%)	AICSCIP (1975)
	Maran	Least infection	Nybe and Nair (1979)
	Narasapattam	Least susceptible (1–20%)	Mohanty (1984)
	Burdwan-1, Anamika, Poona and Himachal	Less susceptible	Sasikumar et al. (1994)
	BDJR-1226, Jamaica, BLP-6	Less susceptible	AICRPS (1999)
2. Bacterial wilt	V_2E_5-2, Rio de Janeiro	Least incidence	Pradeepkumar et al. (2000)
3. Leaf spot	Taffingiva, Maran Bajpai and Nadia	Most tolerant	Nybe and Nair (1979)
	Maran and Kunduli local	Less susceptible	Sasikumar et al. (1994)

Path Analysis

The partitioning of phenotypic correlation between yield and morphological characters into direct and indirect effects by the method of path coefficient analysis revealed that plant height exhibited a high direct effect as well as high indirect effect in the establishment of correlation between yield and other morphological characters (Ratnambal, 1979; Nair et al., 1982). Rattan et al. (1989) indicated that number of leaves per plant had maximum direct contribution to yield per plant, followed by rhizome breadth.

Das et al. (1999) reported very high positive direct effects of stomatal number, leaf area, leaf number, and plant height on rhizome yield; leaf temperature, relative humidity of leaves; stomatal resistance and rate of transpiration showed negligible effects. The direct effect of leaf number on rhizome yield was very high (0.631), and this trait is recommended for use as a selection criterion for improving rhizome yield. The study of Pandey and Dobhal (1993) revealed that the strongest forces influencing yield are weight of fingers, width of fingers, and leaf width. Singh et al. (1999) grouped 18 cultivars into three clusters under Nagaland conditions based on D^2 analysis. The major forces influencing divergence of cultivars were rhizome yield per plant and oleoresin and fiber contents.

Sasikumar et al. (1992b) carried out path analysis using 100 accessions of ginger. They reported that plant height followed by leaf length exhibited the highest direct effect on rhizome yield. Dry recovery had a negative direct effect on yield. All other direct effects were negligible. The highest indirect effect was for leaf number through plant height followed by leaf length, again through plant height. In turn, plant height exerted a moderately good indirect effect on rhizome yield. Moderate indirect effects were also noticed in the case of leaf width (through plant height), and leaf length and leaf number (through leaf length). However, these workers noticed a residual effect of 0.8217, thereby indicating that the variability accounted for in the study was only 18%. They concluded that plant height should be given prime importance in a selection program as this character had positive and significant correlation as well as a good direct effect with rhizome yield.

Multiple regression analysis by using morphological characters indicated that the final yield could be predicted fairly accurately by taking into consideration plant height, number of leaves, and breadth of last fully opened leaf at the 90th and 120th days after planting (Ratnambal et al., 1982). Rattan et al. (1989) found that to improve yield per plant, emphasis should be given to the number of leaves per plant and rhizome length by using partial regression analysis. Rai et al. (1999) reported that higher rhizome yields were strongly associated with chlorophyll-a, carbohydrate, and lower polyphenol levels in the leaf. Leaf protein contents showed significant correlation with carbohydrates and the chlorophyll a:b ratio. The chlorophyll a:b ratio also showed a highly positive correlation with the leaf carbohydrate content. However, polyphenols showed a significant positive correlation with chlorophyll-b and carotenoids with chlorophyll-a and chlorophyll-b.

Crop Improvement

Crop-improvement work in ginger is constrained due to the absence of seed set. As a result, clonal selection, mutation breeding, and induction of polyploidy were the crop-improvement methods employed. More recently, somaclonal variations arising through

the callus regenerating system is also being made use of in crop-improvement work. Most of the work in this area was carried out in India. The major breeding objectives are: high yield, wide adaptability, resistance to diseases (such as rhizome rot, bacterial wilt, and *Fusarium* yellows), improvement in quality parameters (oil, oleoresin), and low fiber. Work in this area is carried out mainly at the IISR, Calicut, the AICRPS center at the High Altitude Research Station, Pottangi, under the Orissa University of Agriculture and Technology and at the AICRPS center at the Y.S. Parmar University of Horticulture and Forestry at Solan (Himachal Pradesh).

Crop-improvement work carried out so far has been confined mainly to germplasm collection, evaluation, and selection. A large number of collections have been assembled at the IISR, and these collections have been evaluated for yield and quality characters. In addition, a few introductions from other countries have also been made use of for breeding work. Some of the indigenous cultivars have been known to be high yielding and of good quality. In general, variability was found to be limited in cultivars grown in the same region, but wider variability is met within cultivars growing in geographically distant locations.

Khan (1959) reported the high yielding capacity of cv. Rio de Janeiro. In a trial with 18 cultivars, the yield of Rio was double of that of cv. China under Kerala conditions (Thomas, 1966). Kannan and Nair (1965), Thomas and Kannan (1969), and Muralidharan and Kamalam (1973) also found that cv. Rio de Janeiro was superior to other cultivars with respect to yield; however the percentage dry ginger was lower than that of cv. Moran. Randhawa and Nandpuri (1970) evaluated 15 cultivars for four years, and reported that none could out-yield the local cultivar (Himachal) under the colder climate of Himachal Pradesh. Jogi et al. (1972) also reported that the local cv. Himachal produced the highest yield, followed by cv. Rio de Janeiro.

The trials carried out at Kasaragod under the All India Coordinated Research Project indicated the high-yield potential of cvs Rio de Janeiro, Burdwan, and Jamaica (AICSCIP, 1978). In Assam cv. Nadia out-yielded other cultivars (Aiyadurai, 1966).

Nybe et al. (1982) evaluated 28 cultivars for fresh and dry rhizome yield and noted significant differences among them. Fresh rhizome yield was highest in the case of cv. Nadia, followed by cvs. Moran, Bajpai, and Narasapattam. Cv. Nadia also gave the highest yield of dry ginger. Sreekumar et al. (1982) found that cvs Rio de Janeiro and Kuruppumpadi were the best yielders.

Muralidharan (1973) studied the varietal performance of ginger in Wynad, Kerala, and concluded that the cv. Rio de Janeiro gave the highest fresh ginger yield, whereas the dry ginger yield was lowest in this cultivar. Dry ginger yield was highest in cv. Tura. Cvs. Moran, Nadia, and Thingpui are the other high yielders and were more or less on a par with cv. Rio de Janeiro. This worker recommended cv. Rio for fresh ginger production and cvs. Moran, Nadia, and Thingpui for dry ginger production.

Evaluation and Selection for Quality

Jogi et al. (1972) evaluated 14 cultivars and reported that the fiber content ranged from 4.62 (cv. Poona) to 6.98% (cv. Narasapattam). Cv. Karakkal was lowest in dry recovery followed by cvs. Wynad local and Rio de Janeiro. Cv. Rio had the highest oleoresin, whereas cv. Karakkal had the highest oil. Crude fiber was least in cvs. Nadia and China.

Nybe et al. (1982) evaluated 28 cultivars and reported that cvs. Rio de Janeiro and Moran had the highest oleoresin content, 10.53 and 10.05%, respectively. Essential oil was highest in Karakkal (2.4%) and crude fiber was highest in Kuruppumpadi (6.47%).

Sreekumar et al. (1982) found that the dry ginger recovery ranged from 17.7% in cv. China to 28.0% in cv. Tura. Cultivars having more than 22% dry recovery (cvs. Moran, Jugijan, Ernad Manjeri, Nadia, Poona, Himachal Pradesh, Tura, and Arippa) are suitable for dry ginger production.

Breeding Strategies

Conventional Method: the Clonal Selection Pathway

The clonal selection pathway has been the most successful breeding method in the absence of seed set. The steps involved are: collection of cultivars from diverse sources and their assemblage in one or more locations, evaluation of cultivars for superiority in yield, quality or stress resistance, selection of promising lines, replicated yield trials in multilocations, selection of the best performer, its multiplication and testing in large evaluation plots and finally release. For a cultivar to be released, it should give a yield increase of 20% or more over the ruling standard cultivar (Figure 2.14). This strategy has been used successfully for evolving the present day cultivars, which have been developed mainly for higher yield adaptability and quality (Table 2.22).

Table 2.22 Elite cultivars developed and released

Cultivar name	*Pedigree*	*Mean yield t/ha*	*Dry recovery (%)*	*Oil content (%)*	*Oleoresin (%)*	*Crude fiber (%)*	*Mean days to maturity*
Suprabha	Selection from Kunduli local	16.6	20.5	1.9	8.9	4.4	230
Suruchi	Induced mutant of Rudrapur local	11.6	23.5	2.0	10.0	3.8	220
Suravi	Selection from germplasm	17.5	23.0	2.1	10.2	4.0	225
IISR Varada	Do	22.6	19.5	1.7	6.7	3.3	200
IISR Mahima	Do	23.2	23.0	1.7	4.5	3.3	200
IISR Rajitha	Do	22.4	19.0	2.4	6.2	4.0	200
Himgiri	Clonal selection from Himachal Local	14.0	20.6	1.6	4.3	6.0	230
Buderim gold[a]	Induced tetraploid of cv. Queensland Local	NA	NA	NA	NA	NA	NA
4x Sanshu[b]	Induced tetraploid of cv. Sanshu	NA	NA	NA	NA	NA	NA

[a]Developed by the Buderim Ginger Co., in Queensland, Australia. Reported to be high yielder, having plumpy rhizomes.

[b]Developed in Japan, reported to be high yielding, and is cultivated commonly. More information on yield and quality are not available.

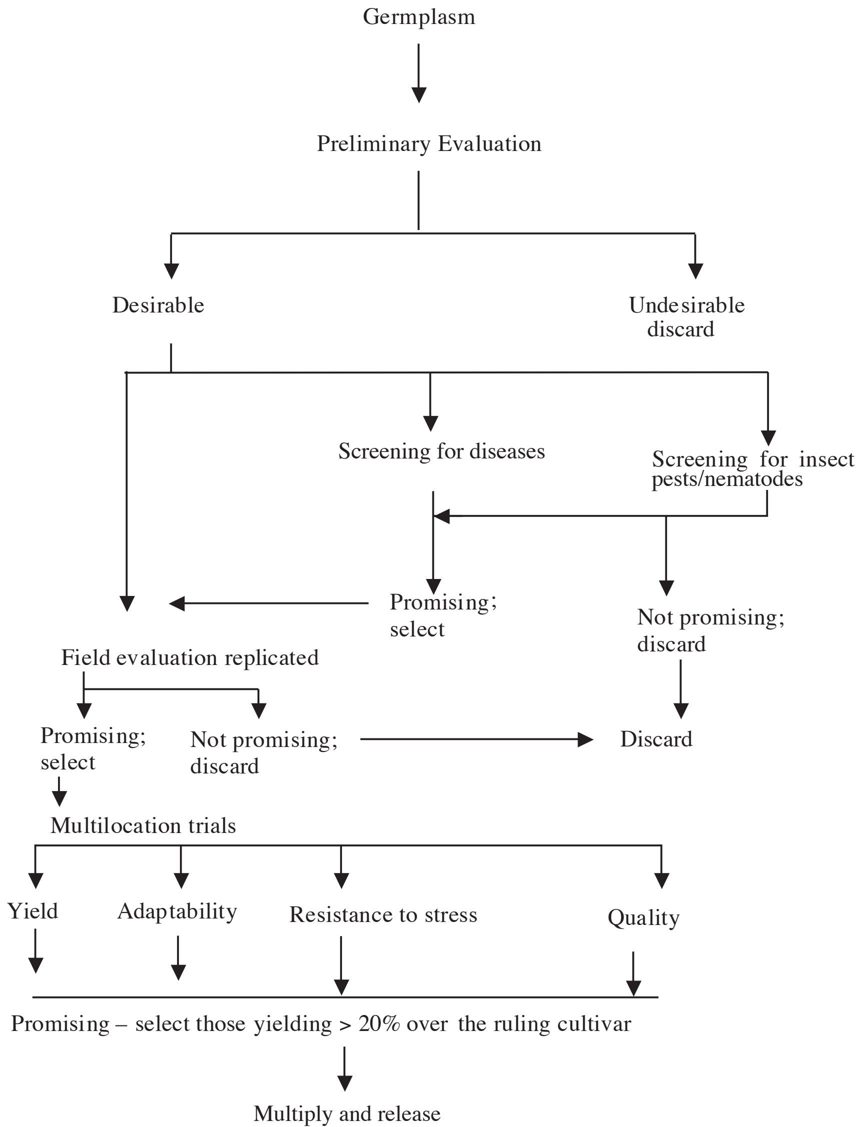

Figure 2.14 Breeding strategy—the clonal selection pathway.

The general breeding objectives in most breeding programs have been: high yield, high quality, resistance to fungal and bacterial pathogens, bold rhizomes, high dry recovery, and low fiber content. Resistance to *Pythium* (the causal organism for rhizome rot) and *Ralstonia solanacearum* (bacterial wilt pathogen) has so far not been encountered.

In one such selection program carried out at the IISR, Calicut, 15 cultivars short listed from germplasm evaluation were tested in replicated trials for four years in five locations (Table 2.23). This effort led to the selection of Varada, one of the most important ruling cultivars at present in south and central India (see Figure 2.14).

The data presented in Table 2.23 also demonstrate the influence of genotype–environment interaction. The quality characters of these accessions are given in Table 2.24.

Table 2.23 Yield and dry recovery of ginger at different locations

Accession Number	*Mean fresh yield (kg/3 m² bed)*					*Dry recovery (%)*			
	Peruvan-namuzhi	*Muvatt-upuzha*	*Amaba-lavayal*	*Peechi*	*Niravi-lpuzha*	*Peruvan-namuzhi*	*Ambal-avayal*	*Peechi*	*Niravil-puzha*
51	9.5	9.43	6.28	7.17	11.08	19.5	24.0	24.0	16.0
64	11.17	11.5	7.38	9.83	11.0	21.0	23.0	24.0	20.0
141	9.83	9.83	6.78	8.00	10.0	20.5	18.00	20.0	19.0
251	12.33	8.17	6.09	8.83	9.47	20.0	23.0	19.0	19.5
222	10.17	8.0	5.17	7.83	6.92	20.5	22.0	22.0	22.0
63	10.83	9.0	6.87	7.67	10.83	18.5	21.0	1.0	14.0
151	11.0	9.27	6.30	8.17	8.10	20.0	19.0	24.0	20.0
53	11.0	10.33	6.41	9.83	9.60	20.0	15.0	20.5	19.4
11	10.6	9.0	6.47	7.17	9.67	17.5	14.0	20.5	19.5
249	10.1	10.0	6.00	8.33	9.16	17.5	17.0	20.5	20.5
65	9.83	10.5	5.33	7.33	11.0	20.0	20.0	21.5	20.0
250 (Himachal)	10.17	10.5	6.10	8.16	10.23	21.0	22.5	25.0	21.4
293 (Suprabha)	11.17	9.67	7.25	7.83	11.28	18.5	15.0	19.0	15.1
295 (Maran)	10.17	8.83	7.23	9.0	7.36	21.5	19.0	20.0	22.2
252 (M puzha)	11.0	8.83	6.70	8.16	7.83	20.0	16.0	19.0	19.27
CD	0.62	0.51	0.54	0.745	0.90				
CV	47.48	17.19	11.27	12.1	12.6				

Source: IISR Annual report, 1994–1995.

In another trial for increasing the rhizome size, 15 bold rhizome accessions short listed from the germplasm were tested in multilocation plots (Table 2.25). Based on the overall superior performance, accessions 35 and 107 were selected, multiplied, and released for cultivation under the names IISR Rejatha, and IISR Mahima, respectively (Sasikumar et al. 2003) (Figure 2.15).

Clonal selection programs for crop improvement were carried out at the High Altitude Research Station in Potangi, Orissa, and at the Department of Vegetable Crops at the Y.S. Parmar University of Horticulture and Forestry in Solan (Himachal Pradesh). The former came out with the selections, Suprabha, and Suravi and the latter with the selection, Himgiri.

Mutation Breeding

Ginger is not amenable to any conventional recombination breeding programs due to its sterility. Induction of variability through mutations, chemical mutagens, ionizing radiations, and tissue culture (somaclonal variations) has been tried by a few workers (Gonzalez et al., 1969; Raju et al., 1980; Giridharan, 1984; Jayachandran, 1989; Mohanty and Panda, 1991; Nirmal Babu, 1997). The general scheme for a mutation

Table 2.24 Yield, dry recovery, and quality of promising ginger accessions at IISR

Accession no.	*Quality*		
	E. Oil (%)	*Oleoresin (%)*	*Crude fiber (%)*
51	2.1	6.8	5.7
64	1.9	6.0	5.4
141	1.9	6.5	4.0
251	2.4	9.0	6.6
222	2.0	7.0	3.9
63	2.3	7.0	4.9
151	2.0	7.0	6.0
53	2.5	9.9	5.1
11	2.0	7.0	4.0
249	2.4	9.0	3.5
65	2.7	8.0	5.3
H.P local	1.2	5.8	8.5
Suprabha	1.9	6.3	4.4
Maran	2.0	7.5	6.1
M. Puzha local	1.9	6.3	NA
CD (P = 05)			

Source: IISR Annual report (1993–1994).
NA: Value not available

Table 2.25 Yield and recovery of bold rhizome selections

Accession no.	*1996*		*1997*		*1998*
	Mean Yield (fresh)	*Dry recovery (%)*	*Mean yield*	*Dry recovery (%)*	*Yield*
117	13.5	22.0	9.9	25.5	11.0
35	14.7	17.5	11.9	21.2	14.7
49	12.3	22.0	10.3	21.3	9.3
27	13.0	22.0	11.3	26.3	11.8
3573	5.0	23.0	9.6	25.5	7.0
142	7.8	23.0	6.9	26.8	12.7
15	9.6	19.5	13.1	24.8	9.7
415	12.3	22.0	11.4	24.3	10.8
116	7.3	15.0	10.6	22.0	8.2
294	12.2	22.0	10.5	27.0	9.8
204	11.4	23.0	10.9	25.5	9.3
64	13.2	19.5	11.4	24.3	12.5
179	13.0	23.0	10.9	26.5	11.7
71	8.5	21.5	7.4	23.8	10.3
244	13.1	17.5	9.9	22.0	10.7
CD%	1.13	—	1.86	—	1.22

Source: IISR Annual Report (1997, 1998, 1999).

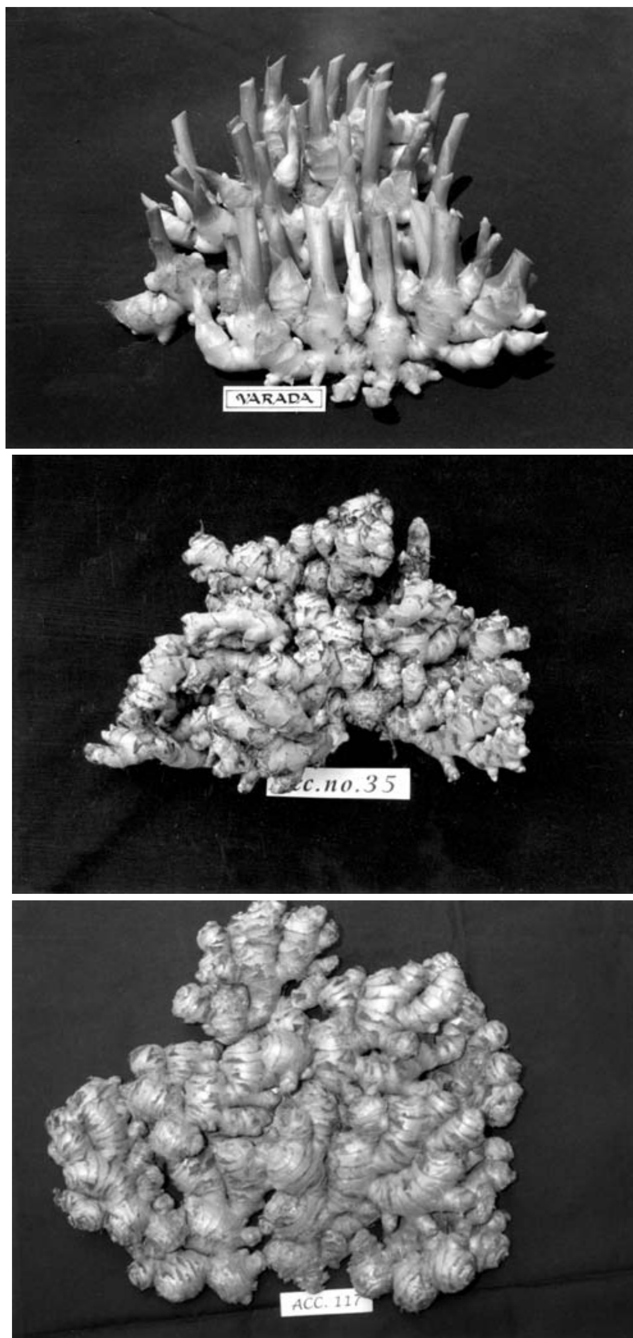

Figure 2.15 Improved selections of ginger (a) IISR Varada, (b) Acc. 117, (c) Acc. 35.

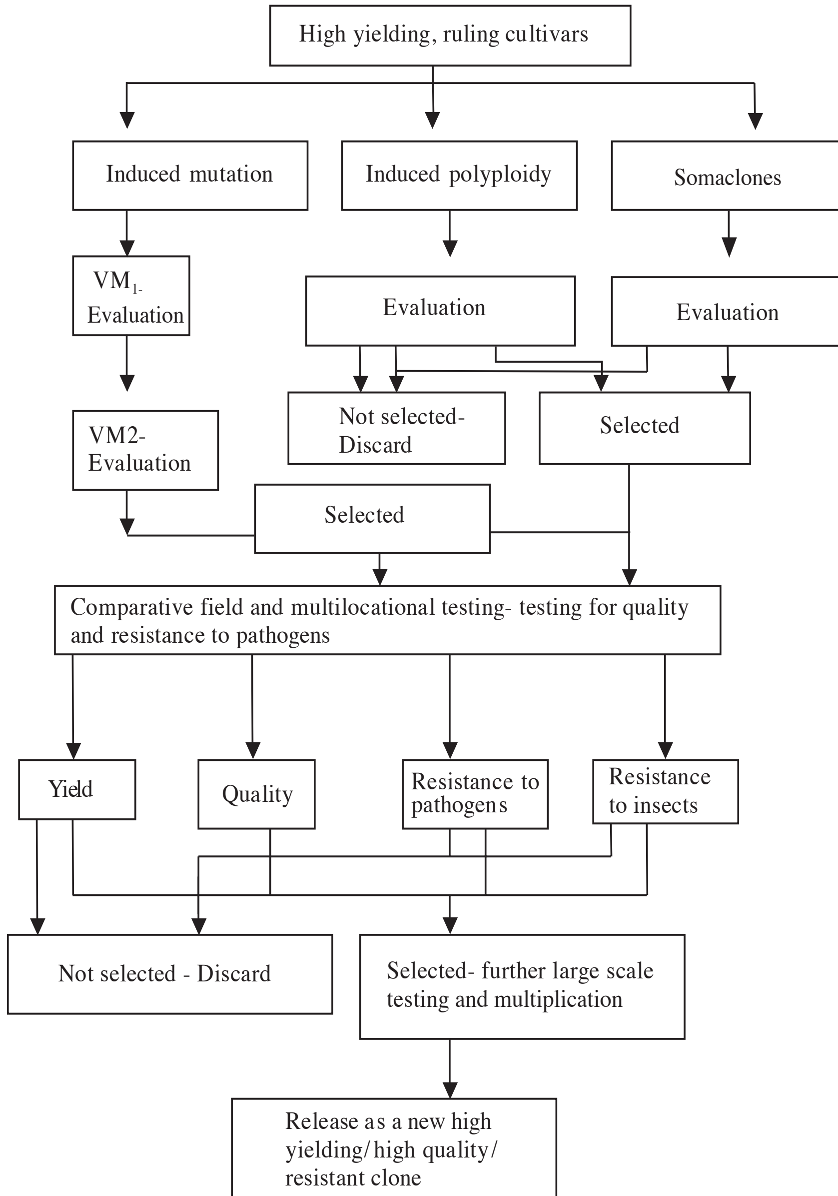

Figure 2.16 Breeding strategy—the unconventional pathway.

breeding program is given in Figure 2.16. Rhizome bits were treated with chemical mutagens or irradiated with gamma rays. Ginger buds are sensitive to irradiation and the LD_{50} was reported to be below 2 Krad. The LD_{50} (50% lethal dose) for germination was reported to be between 1.5 and 2.0 Krad (Giridharan, 1984). Jayachandran (1989) treated the cv. Rio de Janeiro with gamma rays at 0.5 to 1.5 Krads and Ethylmethane sulfonate (EMS) at 2.0 to 10.0 mM and studied VM_1-VM_3 generations with a view to isolate useful mutants. This study revealed that the percentage of sprouting, survival, and the height of plants decreased as the mutagen dose increased. The LD_{50} in the study

for sprouting and survival was between 0.5 and 1.0 Krad of gamma rays and below 8 mM of EMS.

Mutagen treatment affected tiller production; in 1.5 Krad gamma rays there was 45% reduction, whereas in 10 mM EMS there was 61% reduction in tiller production. The mutagen treatment did not affect pollen fertility or improve seed set. Rhizome yield was affected in a dose-dependent manner.

Jayachandran (1989) analyzed the VM2 generation and found a significant reduction in plant height as the dose increased. The mean tiller number indicated transgression to either side of the controls. Similarly, the mean rhizome yield in the VM2 generation indicated shifts in both the directions, with the lower doses of the mutagens giving positive shifts and the higher doses giving negative shifts. The variation in rhizome yield ranged from 1 to 1,320 g/plant. This same worker found that lower doses of gamma rays (0.5 and 0.75 Krad) and EMS (2 to 4 mM) are more effective in inducing wider variations. Screening against the soft rot pathogen, *Pythium aphanidermatum,* and bacterial wilt (caused by *Ralstonia solanacearum*) did not reveal any change in pathogenic susceptibility. Jayachandran (1989) observed that the effects of mutagen treatment in the subsequent generations vanished, indicating the operation of strong diplontic selection.

Nwachukwu et al. (1995) irradiated rhizomes of two Nigerian cultivars (Yatsun Biri and the yellow ginger Tafin Giwa) with 2.5 to 10 Gy gamma rays (Gy—Gray—is the unit of absorbed dose; 1 Gy = 100 rads). In these cultivars the GR50 (50% growth reduction) was found to be at 5 and 6 Gy in Tafin Giwa and Yatsun Biri, respectively, and LD_{50} was found to be 8.75 Gy for both cultivars.

Mohanty and Panda (1991) reported the isolation of a high-yielding mutant from the VM_3 generation. They used EMS, sodium azide, colchicine, and gamma rays as mutagenic agents and five cultivars (cv. UP, Rio de Janeiro, Thingpui, PGS-10, and PGS-19) were treated and studied in VM_1, VM_2, and VM_3 generations. Twenty promising individual clumps ("mutants") were selected for evaluation. One of them (V_1K_1-3) gave the highest yield of 22.08 t/ha, which was significantly higher than the top yielding variety, Suprabha. Six top yielders were further tested in comparative yield trials and multilocation trials—the results indicated the superiority of V_1K_1-3 and have been subsequently released for cultivation under the name Suravi.

The genotype differences were consistent over the locations tested, and V_1K_1-3 was out yielding the others in all locations. This line has a dry recovery of 23%. The rhizomes are plumpy with cylindrical fingers having dark glazed skin and dark yellow flesh with bulging oval tips and finger nodes that are covered with deep brown scales. This genotype has oil content of 2.1%, oleoresin content of 10.2%, and crude fiber content of 4.0%.

Tashiro et al. (1995) studied induced isozyme mutations to find out the possible use of isozyme analysis as markers for detecting mutants at an early stage or under an in vitro culture system. They used the cvs. Otafuku, Kintoki, and Shirome Wase and excised shoot tips were treated with 5 mM methyl nitrosourea (N-methyl-N-nitrosourea-MNU) for 5 to 20 minutes and cultured on MS medium supplemented with 0.05 mg NAA and 0.5 mg BA/l. Regenerated plants were analyzed for locating mutations in the following isozymes: glutamate dehydrogenase (GDH), glutamate-oxaloacetate transaminase (GOT), malate dehydrogenase (MDH), 6-phosphogluconate dehydrogenase (6-PGDH), phosphoglucomutase (PGM), and shikimate dehydrogenase (SKDH). Analysis of the untreated control gave uniform isozyme profiles for all the three cultivars. Five of 21 MNU-treated plants had isozyme profiles that differed from the basic pattern of GOT, 6-PGDH, PGM and SKDH. All these isozyme mutants expressed morphological

variations such as multiple shoot formation, dwarfing, and abnormal leaves. The results indicated that treating shoot tips with MNU and then culturing them in appropriate media can recover mutants and that isozyme analysis is a good technique in detecting the mutation rate, and hence is useful in mutation breeding programs.

Polyploidy Breeding

Induced polyploidy has been tried in ginger for introducing variability, for improving pollen and ovule fertility, and for improving growth and yield. Ratnambal et al. (1979) reported induction of polyploidy in the cv. Rio de Janeiro through colchicine treatment. The tetraploids showed stunted growth and had reduced length and breadth of leaves. However, in this case a stable polyploid line could not be established and all the plants reverted to diploidy in the succeeding generations.

Ramachandran et al. (1982) and Ramachandran and Nair (1992) reported successful production of stable tetraploid lines in cvs. Maran and Mananthody. The polyploids were more vigorous than the diploids and flowered during the second year of induction. The stable tetraploid lines ($2n = 44$) had larger, plumpy rhizomes and high yield (198.7 g/plant). However, the essential oil content was lower (2.3%) than the original diploid cultivar. There was considerable increase in pollen fertility in the tetraploids. These tetraploids are maintained in the germplasm collection at IISR, Calicut.

Adaniya and Shirai (2001) induced tetraploids under in vitro conditions by culturing shoot tips in MS solid medium containing BA, NAA, and 0.2% w/v colchicine for 4, 8, 12, and 14 days and transferred the shoot tips to medium without colchicine for further growth. More tetraploids were recovered from buds cultured for eight days. Induced tetraploid line of the cultivars (4x Kintoki, 4x Sanshu, and 4x Philippine cebu1) were later transferred to the field where they flowered. These tetraploids produced pollen with much higher fertility and germinability than the diploid plants (0.0 to 1% in the diploid plants as against 27.4 to 74.2% in the tetraploids).

The commercial ginger company in Queensland, Australia, Buderim Ginger Co., has developed and released for cultivation a tetraploid line from the local cultivar. This line, named Buderim Gold, is much higher yielding and has plump rhizomes that are ideally suitable for processing (Buderim Ginger Co., 2003). Nirmal Babu (1996) developed a promising line of cv. Maran from somaclonal variants. This line is high yielding with bolder rhizomes and taller plants (Figure 2.17). In addition to somaclonal variation, other biotechnological approaches have been initiated for evolving disease-resistant genotypes (for details, see Chapter 4).

The breeding strategies currently in use will not be useful to solve many of the serious problems besetting the ginger crop. In spite of extensive search, no genes resistant to *Pythium* rot, *Fusarium* wilt, or bacterial wilt could be located in the germplasm. The absence of sexual reproduction and seed set imposes a severe constraint on our efforts to develop resistant cultivars. Recourse to biotechnological approaches may be useful. However, no effort is going on in this field in a concerted manner anywhere in the world. Resorting to r-DNA technology by using resistance genes to the target pathogen from other crop plants can be a viable alternative for evolving resistant ginger plants. Until such genetically modified ginger cultivars are available, one has to rely on disease avoidance through efficient phytosanitation, through crop rotation, and by the use of biocontrol organisms. However, the ginger breeders and biotechnologists around the world should put their brains together to evolve a future action plan to solve the difficult problems and constraints to which this crop is currently being subjected.

Figure 2.17 High-yielding somaclonal variant.

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3 Chemistry of Ginger

Gaston Vernin and Cyril Parkanyi

Ginger has been cultivated and processed in China, where it is used as folk medicine, for more than 3,000 years. Originally from China and India, it has spread to tropical and subtropical areas around the world: southeastern Asia, Japan, Taiwan, Fiji, Oceania (Tahiti), Indonesia, Java, Sri Lanka, Bangladesh, Australia (Queensland), South America, Jamaica, Brazil, Argentina, Africa (Nigeria, Ivory Coast, Sierra Leone, Burkina Fasso), Mauritius, Réunion islands, and elsewhere. By steam distillation or extraction with supercritical carbonic dioxide, ginger rhizome gives an essential oil with a high content of mono-, and sesquiterpene derivatives (α-zingiberene). By extraction with solvents, an oleoresin containing the pungent principles of ginger (gingerols, shogaols, and related compounds) is obtained, as well as the essential oil. Other constituents are vitamins, carbohydrates, lipids, carboxylic acids, amino acids, and minerals. Ginger oil finds much use in food and drink industry; for example, ginger ale, ginger beer, and various cookies and desserts. The oil is also used in small quantities by the cosmetic, pharmaceutical, and perfume industry. It is valued for its pleasant aromatic, more or less lemon-like fragrance. It is also described as possessing pungent, spicy, or camphoraceous aromas. Rhizomes are used as stimulants, eupeptics, and carminatives. Ginger capsules can be used to relieve tiredness, to relieve the effects of overwork, to aid digestion, to reduce sexual insufficiency, and to treat motion sickness. With other spices, such as pepper, cloves, cinnamon, cassia, mace, nutmeg, pimento and cardamon, ginger constitutes about 90% of the world trade in spices. Owing to its interesting medicinal and flavoring properties, ginger has been widely studied and several reviews have been published (Connell, 1970; Opdyke, 1974; Lawrence, 1977, 1978, 1983, 1984, 1988, 1995, 1997; Imagawa, 1981; Akhila and Tewari, 1984; Ho et al. 1989; Rosella et al., 1996; Germer and Franz, 1997; Ho et al., 1999; Kikuzaki, 2000; Metz and Cupp, 2000; Afzal et al., 2001; Nakatani and Kikuzaki, 2002.

In this chapter, extraction and analytical methods of identification of nonvolatile and volatile compounds of ginger of various origins as well as their precursors are reviewed and updated. Finally, mass spectra of some characteristic compounds, based on our SPECMA 2000 data bank, are reported.

Composition of Ginger Rhizomes

The following composition was reported by Natarajan et al. (1972) for ginger rhizomes from Kerala (India): essential oil (1 to 2.7%), acetone extract (3.9 to 9.3%), crude fiber (4.8 to 9.8%), and starch (40.4 to 59%). Percentages of volatile oil and nonvolatile extract for ginger from various countries have been reported by Akhila and Tewari (1984) (see Table 3.1).

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Table 3.1 Percentages of volatile and nonvolatile extracts of ginger from various countries*

	Percentages (w/w)	
Origin	*Volatile oil*	*Nonvolatile extract*
Cochin (India)	2.2	4.25
Sierra Leone	1.6	7.2
Jamaica	1.0	4.4
Nigeria	2.5	6.5

*Akhila and Tewari, (1984)

Some years later, Haq et al. (1986) studied the composition of ginger from Bangladesh. They found that the rhizomes contain:

- Essential oil (4%, on the basis of rhizomes dried at 60° C for 8 hours, and 0.8% on raw rhizome basis).
- Mixture (10 to 16%) of mainly sesquiterpene hydrocarbons, based on dried ginger.
- Ash (6.5%).
- Proteins (12.3%) and water soluble proteins (2.3%).
- Starch (45.25%).
- Fat (4.5%) including free fatty acids (acid number: 10.38, as oleic acid: 5.2). Achinewhu et al. (1995) reported free fatty acid (as % [dry matter] oleic acid) content and peroxide number (peroxide value) of ginger from Nigeria as 0.48 ± 0.04 and 3.2, respectively.
- Phospholipids (traces) determined from the petroleum extract.
- Sterols (0.53%)
- Crude fiber (10.3%)
- Cold alcoholic extract (7.3%) as oleoresin
- Vitamins (see Table 3.2)
- Reducing sugars (glucose, fructose, arabinose), traces.
- Water solubles (10.5%)
- Minerals (in g/100 g): Ca (0.025), Na (0.122), K (0.035), Fe (0.007), P (0.075), Mg (0.048), Cl (1.5 ppm), F (5.0 ppm).

Content of elements in ginger was reported by Zaidi et al. (1992) and Afzal et al. (2001) (see Table 3.3)

In summary, ginger rhizomes contain two kinds of products:.

- Volatile compounds constituting the essential oil
- Nonvolatile (or heavy) products (Sku et al., 2001) including oleoresin (gingerols, shogaols, and related products that are the pungent principles of ginger) and the other usual organic and inorganic compounds found in foods. The high content of vitamin C, manganese, and iron should be noted.

Characteristics of two kinds of fresh Brazilian ginger rhizomes have been reported by Taveira Magalhaes et al. (1997) (see Table 3.4).

Table 3.2 Vitamins in ginger rhizome powder from Bangladesh*

Vitamin		*Percentage in powder*
Thiamine		0.035
Riboflavin		0.015
Niacin		0.045
Pyridoxin		0.056
Vitamin C		44.0
Vitamin A		Traces
Vitamin E		Traces
	Total	44.15%

*Haq et al., (1986)

Table 3.3 Inorganic elements in trace amounts in ginger*

Element	*Amount, μg.g⁻¹ dry weight basis*	*Element*	*Amount, μg.g⁻¹ dry weight basis*
Cr	0.89	Hg	6.0 $ng.g^{-1}$
Ma	358	Sb	39
Fe	145	Cl	579
Co	18 $ng.g^{-1}$	Br	2.1
Zn	28.2	F	0.07
Na	443	Rb	2.7
K	12.900	Cs	24 $ng.g^{-1}$
As	12 $ng.g^{-1}$	Sc	42 $ng.g^{-1}$
Se	0.31	Eu	44 $ng.g^{-1}$

*Zaidi et al., (1992)

Table 3.4 Characteristics of fresh Brazilian rhizomes*

Compounds	*Origin*	
*(g/100 g of dry material)***	*Gigante*	*Calpira*
Proteins	5.55–13.84	7.23–7.70
Ether extracts	3.24–8.35	3.60–7.29
Carbohydrates	76.82–84.86	78.54–81.62
Fiber	5.50–11.72	9.56–13.17
Ash	4.30–7.99	6.94–7.08
Alcoholic extract	1.66–6.01	5.42–8.01
Volatile extract (E.O.)	0.40–2.68	1.49–2.64
Nonvolatile extract	2.02–5.99	2.11–4.65

*The moisture content ranged from 80 to 90 percent.
**Taveira Magalhaes et al., (1997)

Okwu (2001) reported the chemical evaluation, nutritional and flavoring potential of ginger stem (see Table 3.5).

Ginger possesses a high nutritional value. However, α-amino acids, reducing sugars, and vitamin C can give rise to Maillard reaction upon heating (similarly as in other

Table 3.5 Various data on the overall composition of ginger stem and ginger oil

*Minerals**		*Minerals*	
P (in g/100 g dry matter)	0.11 +/− 0.01	Na (%)	0.04 +/− 0.2
Mg (%)	0.80 +/− 0.10	K (%)	1.00 +/− 0.50
Ca (%)	0.50 +/− 0.10	N (%)	2.50 +/− 0.01
Miscellaneous	*Percentage*	*Miscellaneous*	*Percentage*
Moisture	16.10 +/− 0.10	Carbohydrates	57.00 +/− 0.77
Ash	9.52 +/− 0.02	Fiber	4.53 +/− 0.05
Fat/oil	17.20 +/− 0.10	Food Energy (FE)**	400.56 g/cal.
Protein N x 6.25%	15.69 +/− 0.06		
Various indices for the ginger oil			
Iodine number (mg/100 g)	87.60+/− 0.10		
Peroxide number (mg/g oil)	9.80 +/− 0.10		
Saponification number (mg/KOH/g oil)***	4.80 +/− 0.20		
Acid number (mg/COOH/g oil)	190.74 +/− 0.10		

Okwu (2001)
*They were determined according to AOAC methods (1984).
**FE was estimated using the equation:
FE = (% crude protein × 4) + (% lipids × 9) + (% carbohydrates × 4)
***The saponification number was obtained by the William's method. The iodine number was determined by the Strong and Koch's method. The acid and peroxide numbers were calculated using the Pearson's method.

foods) with the formation of off-flavors (mainly heterocyclic compounds) and the formation of melanoidins (Vernin et al., 1992; Rogacheva et al., 1998). Ginger does not contain aflatoxin (Martins et al., 2001).

Extraction, Separation, and Identification Methods

Extraction Methods

All these extraction methods have been reviewed by Van Beek (1991).

Besides the usual hydrodistillation, steam distillation, leaching, and pressing, extraction with supercritical carbon dioxide also has been widely used in the last 20 years for essential oils. For example, solvent extraction with acetone gives the ginger oleoresin, which contains the essential oils as well as the pungent principles and other nonvolatile compounds present in ginger. When compared with other methods, it gives the best results (Zhou et al., 1994; Roy et al., 1996; Yu et al., 1998; He et al., 1999; Zang et al., 2000).

Hydrodistillation and Steam Distillation

Hydrodistillation is principally used for laboratory purposes in a glass, copper, or steel reactor connected to a cooling and decanting flask. Krishnamurthy et al. (1970) studied

the water-distilled oil from green and dry ginger. Green ginger oil has a more spicy odor and is considered superior to the oil from dry ginger. This is probably due to the greater amount of α-zingiberene in green oil. Since green ginger is perishable, the distillation must be done locally. More α-zingiberene and smaller amounts of other sesquiterpene alcohols are present in green oil than in the oils from Cochin and peeled ginger.

Steam distillation, an old and well-known method, is commonly used for commercial isolation of ginger oils. Yields ranged from 0.2% to 3% according to the origin and the state of the rhizome (fresh or dried) (Krishnamurthy et al., 1970; Connell, 1971; Anzaldo et al., 1986; Van Beek et al., 1987; Ekundayo et al., 1988). It leads to high levels of monoterpenes and low amounts of nonvolatile compounds, in part by thermal degradation of gingerols giving rise to straight-chain aldehydes and 2-alkanones (Badalyan et al., 1998).

Solvent Extraction

This method is used to obtain oleoresin extracts. Several solvents have been recommended. Oleoresin from Australian ginger rhizhome was prepared by acetone or ethanol extraction of dried ground ginger. Gingerols constituted about 33% of the freshly prepared oleoresin. It decomposes to afford shogaols and zingerone (see § 3.5). Ethyl ether, acetone, and hexane were used by Mathew et al. (1973), Jo (2000), and Nishimura (2001), respectively, as well as pentafluoropropane (Hill et al., 1999) and heptafluoropropane (Dowdle et al., 2002). Antioxidant compounds in ginger rhizome from Korea were extracted using ethyl acetate from a crude methanol extract and separated by thin-layer chromatography (TLC). Ethyl acetate was also used by Harvey (1981). Dry root ginger from Jamaica (1.5 g) was crushed and left to stand with ethyl acetate for 30 min. The solution was filtered and evaporated to dryness to yield 200 mg of oil. This was dissolved in 20 mL of ethyl acetate to give the stock solution. A kinetic study of extraction of gingerols using acetone as solvent was carried out by Spiro and Kandiah (1989). The drawbacks and advantages of the method were reviewed by Koedam (1987) and Bicchi and Sandra (1987).

Solid-Phase Microextraction (SPME) Method

Solid-phase microextraction from the sampling in aromatic analysis was carried out by Faulhaber and Shirey (1998). They described an extraction and desorption process and method of solid-phase microextraction (SPME) for fruit, juice drinks, peppermint oil in chocolate, spearmint oil, gum ginger oil, and citrus oil. The latter method was presented as a quick and solvent-free alternative to conventional extraction methods.

Extraction by Supercritical Carbon Dioxide

For almost 20 years, supercritical carbon dioxide has been employed for extraction of natural products and particularly for ginger powder and other spices (Meyer-Warnod, 1984; Chen et al., 1986, 1987; Chen and Ho, 1988; Naik and Maheshwari, 1989). It is used mainly because supercritical carbon dioxide is safe, noncombustible, inexpensive, odorless, colorless, tasteless, nontoxic, and readily available solvent. Its low viscosity enables it to penetrate the matrix to reach the material extracted, and its low latent heat of vaporation and high volatility mean that it can be easily removed without leaving a solvent residue. Several reviews have been devoted to the CO_2 extraction of essential oils

(Moyler et al., 1994; Meireles and Nikolov, 1994). According to Moyler et al. (1994), a distinction must be made between subcritical liquid CO_2 ($SLCO_2$) and supercritical fluid CO_2 ($SFCO_2$). In the first process, temperature and pressure ranged between 0 and 10° C and 50 to 80 bar, respectively. It is mainly used selectively to extract essential oils from ground plants. Supercritical CO_2 is not currently used commercially to extract flavor oleoresins because of cost constraints. However, some supercritical CO_2 is available commercially. Brogle (1982) showed that a fractionated extract can be obtained by reducing the pressure of a CO_2 solution of a supercritical extract while still in the condenser. Insoluble components such as waxes, resins, and alcohols can be separated to give an essential oil similar to that of the subcritical CO_2 extract. A third method consists of using CO_2 with entraining solvents such as ethanol in order to obtain a specific flavor profile. The apparatus is generally used for 500 to 600 kg of powdered ginger under a blanket of CO_2 gas to prevent surface oxidation. Liquid CO_2 at low temperature is pumped around the circuit and the extract is collected in a condenser evaporator. The pressure is released, extract trapped, and the CO_2 recycled. By varying the temperature and pressure during extraction, the flavor and odor components can be selectively extracted (Roy et al., 1996). Chen et al. (1986) extracted freeze-dried ginger powder with liquid CO_2 (600 to 700 psi) for 48 hours. The oil was fractionated into a hydrocarbon fraction and oxygenated fractions by using silica gel column chromatography. Each fraction was then analyzed by gas chromatography (GC) on a Carbowax 20 M capillary column (60 m $\times$ 0.32 mm i.d.). Previously, Chen et al. (1986) also analyzed the oil by TLC on silica gel and high-performance liquid chromatography (HPLC) on a reverse phase column. The ginger oil had both the pungent and aromatic properties of ginger. Two cultivars of ginger from Korea were treated by simultaneous steam distillation and CO_2 extraction (Kim et al., 1991). The oil from this latter process (6.96%) was fractionated into one hydrocarbon fraction and another oxygenated hydrocarbon fraction by using silica gel column chromatography. Each fraction was analyzed by GC and GC/mass spectrometry (MS).

Pellerin (1991) compared the extracts of Indian ginger root obtained by the conventional processes (steam distillation and hexane extraction) and that obtained by supercritical CO_2 extraction (see Table 3.6).

Table 3.6 Gas chromatography (GC) comparison of some sesquiterpene hydrocarbons and zingerone obtained from Indian ginger extracts by three different extraction methods*

	Percentages (%)		
Volatile Compound	*Steam distillation*	*Supercritical CO^2*	*Hexane*
ar-Curcumene	10.0	3.7	2.3
α-Zingiberene	44.0	19.6	12.1
β-Zingiberene	8.0	3.4	2.0
β-Bisabolene	8.3	3.7	2.4
β-Sesquiphellandrene	17.8	7.9	4.9
Total	88.1%	38.3%	23.7%
Zingerone	0.8	0.7	0.3

*According to Pellerin (1991)

These results show a great difference in the sesquiterpene hydrocarbons percentages between steam distillation and supercritical CO_2 extraction, particularly for α-zingiberene. Several cooked dishes (soup, fish, poultry) were seasoned with ginger prepared by the same three methods. Tasters commented favorably on the flavor balance and fresh characteristics of food seasoned with a supercritical CO_2 extract of ginger. In a study of a Fijian ginger oil extracted with CO_2, the content of gingerols increased with rising CO_2 pressure (Zhou et al., 1994). A two-stage separation of (6)-gingerol was proposed by Yonei et al. (1995). The first step was carried out under various pressures of 7.9 to 10.9 MP_a at a constant temperature of 333°K and the second step conditions were kept the same as those for the first stage step, that is, extraction by high-pressure CO_2 from the dried rhizome. Roy et al. (1996) studied the extraction rate of oil from freeze-dried ginger with supercritical carbon dioxide as a function of solvent, flow rate, particle size, temperature, and pressure. The extraction curves were independent of flow rate in a plot of oil yield versus extraction time. This indicated that the extraction process is controlled by intraparticle diffusion within a particle of ginger root. The extraction rate increased as the particle size decreased due to a decrease in the diffusion path. The higher temperature favoured the extraction at 10.8 MP_a (crossover effects). Extraction of Australian ginger root with CO_2 and ethanol entrainer was carried out by Badalyan et al. (1998). The proportion of oleoresin in the extract depended on extraction conditions. The recovery of oleoresin was greater with entrainer, high solvent feed ratio, and higher pressure but showed little variation with temperature over the range studied (9 to 35° C). GC analyses revealed that latter fractions of extracts contained a higher proportion of oleoresin components. The use of ethanol as cosolvent maintained recoveries at pressures lower than required with pure CO_2.

A method comprising drying of ginger, crushing to obtain ginger powder, subjecting it to supercritical CO_2 fluid extraction at 32 to 65° C and 12 to 40 MP_a, and separating to obtain ginger oil resin containing active ingredients (i.e., gingerols, shogaols, and gingerone), was patented by Li (1999). Another procedure using a series of separators was patented by Yao et al. (2000). The effective components from 435 g ginger powder were extracted by supercritical CO_2 at 80° C and 45 MP_a.

The separation conditions were as follows:

1. 60° C and 25 MP_a in the first separator (1.1 g of ginger wax was obtained).
2. In the second separator, temperature and pressure were 70° C and 20 MP_a, respectively (2.1 g of hot gingerin was obtained).
3. In the third separator 9.2 g of ginger essential oil was isolated at 60° C and 14 MP_a, and in the final separator, 33.5 g water was separated at 15° C and 3.5 MP_a.

The effects of extraction pressure (25 MP_a), temperature, time (2 hours), CO_2 flow rate (0.09 $l.h^{-1}$), water control (15%), and material size (40 to 60 μm) on the extraction rate of ginger oleoresin from China were explored under industrial conditions (Zhang et al., 2001). Other methods have been published by Yu et al. (1998) and Wen et al. (2001).

In conclusion, the supercritical carbon dioxide extraction has many advantages over normal extraction methods for the following reasons:

1. Shorter extraction time
2. Lower energy consumption
3. Better quality of sensory properties

The selective solubility of components in CO_2 enables it to extract all the useful aromatics from a flavoring source. However, according to Van Beek (1991), its use should be limited in the industry because of the high pressures needed and the high cost of the appropriate apparatus.

Analytical and Isolation Methods

Before 1970, fractional vacuum distillation, analytical and preparative chromatographic procedures such as column chromatography (CC), TLC, GC, and chemical methods were used. These procedures have been extended to HPLC, high-performance gas chromatography (HPGC) (associated or not associated with specific detectors), direct vaporization in the GC apparatus, and dynamic headspace techniques.

Liquid Column Chromatography

Liquid column chromatography is the oldest method used in organic chemistry since Tswett's discovery in 1906. Essential oils from ginger can be fractionated on a silica gel column into a hydrocarbon fraction and an oxygenated fraction. Elution solvents are nonpolar hydrocarbons such as pentane, and for the latter a mixture of pentane with ether (2:1, v/v) or acetone (4:1, v/v), respectively (Van Beek, 1991). Thus essential oils with removed terpenes can be obtained on a large scale. However, terpenes containing a furan ring such as perillene and rosefuran found in ginger oil occur in both fractions. More polar compounds such as aliphatic acids can be eluted with a more polar solvent (pentane/ethanol: 9:1 v/v). Chromatographic procedures on alumina were used by Herout et al. (1953) for the isolation of some sesquiterpene hydrocarbons: (+)-ar-curcumene, bisabolene, farnesene, and α-zingiberene. But this class of compounds was better separated by column chromatography on silver nitrate–treated supports (Smith and Ohlson, 1962). Balladin and Headley (1999) isolated essential oil and pungent principles of West Indian ginger by liquid chromatography using silica gel (70 to 230 mesh) and a mixture of petroleum ether (60 to 80° C) and diethyl ether (3:7 v/v) as the mobile phase. They isolated seven fractions: the first 15 mL contained the very volatile and less polar compounds present in the extracted oleoresin from the sun-dried ginger rhizome; that is, the essential oil accounts for 25.6% (wt/wt) of the total oleoresin charge to the column. The next 5 mL aliquot was without any compound. The following 25 mL contained the shogaol fraction and represented 47.3% of the sample. The next 5 mL aliquot was without any compound. The following 35 mL contained the gingerol fraction and represented 27.1% of the sample. Each fraction was subjected to GC/MS and HPLC/MS analyses. Two techniques of column chromatography have been used by Zarate et al. (1992) to separate pungent principles of ginger: vacuum and flash chromatography, with toluene/methanol (16:10 v/v) as the mobile phase. Whereas flash chromatography is not very successful for separation of these compounds, vacuum chromatography is more rapid and effective.

Purification and characterization of cysteine proteinase from fresh ginger rhizome has been carried out by column chromatography using diethylaminoethyl (DEAE)-cellulose and Sephadex G 75 (Kitamura and Naguno, 2000). Two CPI fractions of 11,000 to 11,800 and 15,500 to 16,000 molecular weights were recorded. Both fractions showed potent papain inhibitory activities and were stable at <40 to 60° C, but the activities decreased and disappeared when exposed to higher temperatures.

Thin-Layer Chromatography

Since the time Stahl published his work (1962), TLC, a fast, easy, and inexpensive method, has been widely used in organic chemistry (Vernin, 1970). Unfortunately, the method is unsuitable for complex mixture analysis such as essential oils. However, it is adequate for the preparative separation of some compounds or a set of compounds having the same retention times (R_t). The extract after solvent extraction can be submitted to GC and GC/MS analyses. Quantitative determination by ultraviolet (UV) densitometry can also be used in a simple case. Analyses for the ginger oleoresin have been reported by Connell (1970) using TLC on silica gel plates with hexane-diethyl ether mixtures as eluent. Quantitative determination by densitometry allowed him to separate three main groups: gingerols, shogaols essential oils, and more polar and heavy compounds as a trailing. Some sesquiterpene hydrocarbons were separated by TLC on silica gel plates treated with silver nitrate (Connell, 1970). Analysis of gingerol compounds of raw ginger and its paste was carried out by TLC (Jo, 2000). Antioxidant compounds in ginger rhizomes from Korea, extracted with ethyl acetate from crude methanol extract, were separated through TLC. Ten phenolic antioxidant bands were visualized through color reactions using ferric chloride, potassium ferrocyanide, and 1,1-diphenyl-2-picrylhydrazyl (DPPH) and were purified through preparative TLC and HPLC. Among them, five antioxidants were identified as (4)-, (6)-, and (10)-gingerols and (6)-shogaol on the basis of their molecular weight determination through LC/MS. As shown in experiments using DPPH free radicals, (6)-gingerol and PT_4-HPS were revealed to be more efficient than BHT (butylated hydroxytoluene). Total gingerol content (determined through reversed phase HPLC) in rhizomes of different ginger varieties varied significantly. Two varieties collected in Korea (HG 55) and in Brazil (HG 52) showed the highest content.

High-Performance Liquid Chromatography

HPLC has supplanted the TLC for the preparative separation of essential oil compounds and for the quantitative determination of important and heavy compounds. Two examples have been given for ginger oil by Van Beek (1991). The first example concerns the separation of the more important sesquiterpene hydrocarbons of ginger oil from India, accounting for 70% of the oil. The following conditions were used: a 25×1 cm column fitted with 5μm C-18 silica gel reversed phase eluted with $MeCN/H_2O$ (88:12) with a flow rate of 4 mL/min, and UV detection at 215 and 245 nm. After the four preparative runs, ar-curcumene was obtained in $>99\%$ purity and (E,E)-α-farnesene in 84% purity. Other sesquiterpene hydrocarbons (β-sesquiphellandrene, α-zingiberene, β-bisabolene) have been separated under different analytical conditions. Two fractions were collected. The first consisted of 53% α-zingiberene, 19% β-bisabolene, and 9% β-sesquiphellandrene. They were further purified by means of preparative capillary GC. Using a reversed

phase system: HPLC column 15 × 0.46 cm fitted with Microsorb 5 μm C-18 silica gel, solvent: MeCN/H_2O (6/1, 1 mL.min$-^1$) to MeCN/H_2O (0.5/5 in 30 minutes) and a detection UV at 236 nm, the geranial and neral content of any ginger oil can be measured in minutes (the minimum detectable quantity was 1 ng) (Van Beek, 1991). Other compounds detected were: myrcene, β-phellandrene, (E,E)-α-farnesene, and β-sesquiphellandrene + α-zingiberene. The comparison by HPLC of the extracts of Indian ginger root obtained by the conventional methods and that obtained by supercritical CO_2 shows that steam distillation is not suitable for the extraction of the pungent principles of ginger oleoresin. The supercritical CO_2 method gives better results than the hexane extracts (see Table 3.7) (Pellerin, 1991). Paradol has not been taken into account.

A quantitative method by HPLC of pungent principles of ginger was developed by Yoshikawa et al. (1994). The content of (6)-, (8)-, and (10)-gingerols, (6)- and (8)-shogaols, 6-dihydrogingerdione, and galanolactone in 20 kinds of rhizomes originating from China, Taiwan, Vietnam, and Japan, and fresh ginger root cultivated in Shizuoka Prefecture of Japan were examined. It was found that Japanese and fresh ginger root contained gingerols, shogaols, 6-dehydrogingerdione, and galanolactone as the major constituents.

A HPLC method was developed by Sane et al. (1998) to study the geographical variation in the ginger samples obtained from different states of India with respect to their gingerol and ginger oil content. Analyses of gingerol compounds of raw ginger and its paste were carried out by a combination of TLC and HPLC with Licrosorb RP-18 column by Jo (2000). (6)-, (8)-, and (10)-Gingerols were identified by HPLC/MS, and nuclear magnetic resonance (NMR). The content of (6)-, (8)-, and (10)-gingerols were 635.3, 206.3, and 145.7 mg %, respectively, in raw ginger (from Korea). They were 418.2, 142.6, and 103.3 mg % in ginger paste, respectively. Another HPLC method was applied by Chen et al. (2001) for the determination of pungent constituents in ginger and to evaluate ginger extracts obtained by supercritical CO_2 or anhydrous alcohol extraction. The effective content of pungent constituents was 13.84 and 1.46%, respec-

Table 3.7 HPLC comparison of gingerols and shogaols obtained from Indian ginger extracts by three different extraction methods*

	Percentages (%)		
*Pungent principle***	*Steam distillation*	*Supercritical CO_2*	*Hexane*
(6)-Gingerol	0.2	16.4	0.9
(8)-Gingerol	0.3	3.1	0.7
(10)-Gingerol	—	3.8	0.8
(6)-Shogaol	0.3	2.8	6.3
(8)-Shogaol	—	—	1.6
Total	0.8%	26.1%	10.3%

*According to Pellerin (1991).

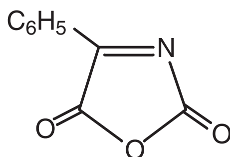
**The supercritical CO_2 method gives better results than the hexane extraction.

tively. Ginger oleoresins extracted by CO2 were of especially high quality and contained higher amounts of natural gingerols and related compounds.

Gas Chromatography

Both analytical and preparative GC have undergone a considerable development since the discovery by James and Martin in 1952. For about 20 years, stainless steel–packed columns with various polar and nonpolar stationary phases (3 to 15%) on silica gel GC (80 to 100 mesh) were used, which were later replaced by capillary columns (high-resolution GC [HRGC]). Ginger oils were first analyzed on packed columns (Jain et al., 1962; Nigam et al., 1964; Connell and Sutherland, 1966; Humphrey, 1970; Harvey, 1981) on, for example, Reoplex 400, silicone nitrile, Apiezon M and L, Carbowax 400 and 20 M, and SE 30. Monoterpenes of ginger oil have been analyzed using Reoplex 400 at 70° C and Carbowax 400 at 144° C as stationary phases (Connell, 1970). Apiezon L and M have been also used at isothermal or programmed temperature. The same authors reported the separation of five sesquiterpenes: ar-curcumene, α-zingiberene, (−)-β-sesquiphellandrene and *trans*-β-farnesene on a packed column (6 feet × 1/8 inch i.d.) containing 15% of Apiezon M on silica gel GC (80 to 100 mesh). The pungent constituents of ginger were analyzed as trimethylsilyl derivatives by Harvey (1981) using a 3% silicone SE 30–packed column (100 to 120 mesh), GC Q, programmed from 100 to 300° C at 4° C/min, with nitrogen at 30 mL/min as the carrier gas. Injector (FID) and detector temperature were kept at 300° C. TMS derivatives were used in a combination of chemical reactions (lithium aluminium hydride reduction, deuterium exchange, deuterium exchange reduction, oxidation). Capillary GC chromatogram on Carbowax 20 M of Japanese ginger oil was reported by Masada (1976).

Gas chromatograms of an Indian ginger oil with a high citral content were obtained with DB-1 and DB-Wax capillary columns (Van Beek, 1991). On the nonpolar column (DB-1), a good separation of monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, and oxygenated sesquiterpenes was found. However, limonene, β-phellandrene, and 1,8-cineole overlap. On the polar column (DB-Wax), the three latter compounds were well separated, but oxygenated monoterpene and sesquiterpene hydrocarbons were poorly separated. Application of GC in the analysis of essential oils was clarified by a commitee (1993). A rapid and simple isolation of α-zingiberene from ginger oil was developed by Millar (1998). A sesquiterpene-enriched fraction was treated with the dienophile 4-phenyl-2,5-oxazolinedione **A,** which selectively formed a Diels-Alder adduct with zingiberene.



A

The adduct was purified by flash chromatography and then hydrolyzed to afford zingiberene in good yield (99% of purity). Quality assessment of flavors and fragrances by HPGC has been widely used (Mosandl, 1992).

Enantiomers also can be separated by capillary columns coated with β-cyclodextrin derivatives. Thus, Takeoka et al. (1990) separated sesquiterpene hydrocarbons using a permethylated β-cyclodextrin (PM-β-CD) as GC stationary phase. Sesquiterpenes include ar-curcumene, α- and β-bisabolenes, δ- and β-elemenes, α-copaene, δ-cadinene, *cis*- and *trans*-calamenenes, and bicyclogermacrene. Four years later, Koenig et al. (1994) separated the two enantiomers of ar-curcumene and β-bisabolene in ginger oil, using a fused capillary column coated with heptakis (2,3-O-methyl-6-O-t-butyldimethylsilyl-β-cyclodextrin in polysiloxane OV-1701 (50% w/w). The column temperature was 115° C and carrier gas:hydrogen (0.5 bar). The chromatogram shows that ar-curcumene exists in the (+) form, whereas β-bisabolene contains the two enantiomers (+) and (−) in equal quantity. Enantiomeric separation of the characteristic aromatic compounds in fresh rhizomes of Japanese ginger was carried out using the off-line multidimensional GC (MDGC) system and confirmation of the odor character of each enantiomer by GC/olfactometry (Nishimura, 2001). GC has been widely used for preparative purposes as well. Packed columns giving poor separation were replaced by megabore columns that are wide-bore capillary columns (WBCCs) of 0.5 to 0.8 mm i.d. coated with thick films of 3 to 5 μm of stationary phases. Van Beek (1991) reported the quantitative separation of some sesquiterpene hydrocarbons (SQHCs) using a 30 m/3 μm DB-1 megabore column. From a SQHC fraction containing α-zingiberene (69%), β-bisabolene (19%), β-sesquiphellandrene (9%), and minor compounds (3%), and obtained by preparative HPLC and then injected several times in the WBCC, β-bisabolene could be obtained sufficiently pure for ^{1}H- and ^{13}C-NMR analyses. β-Sesquiphellandrene was purified as well. This type of column is also useful in the sniffing method (at the end of the column).

Other GC Methods: Dynamic Headspace

The thermal desorption cold trap injector (TCT) was used as a part of the off-line multidimensional GC (MDGC) system. It was shown that the TCT can be used not only for headspace analysis, but also as a part of an MDGC system. Direct vaporization of a pulverized sample of ginger can be subjected to heating at 250° C for 1 minute in a vaporizer directly connected to the GC on a GC/MS apparatus. Out of 54 constituents, 25 were identified (Chen et al. 1987). They found little decomposition regardless of the heating time and temperatures and a similar composition with the essential oil obtained from the same sample. GC of headspace vapor from dry ice–cooled trap of low-boiling compounds from steam-distilled ginger was reported by Kami et al. (1972). The identification of peaks was carried out by comparing the retention time with authentic samples. The identification was supported by a chemical reaction including 2,4-dinitrophenylhydrazones (for carbonyl compounds), 3,5-dinitrobenzoates (for aliphatic alcohols), a mercuric complex (for sulfide derivatives), and hydroxamic acid (for monoterpenes). They were analyzed directly or after regeneration by TLC, GC, and combined GC/MS.

The GC dynamic headspace is a very suitable technique and useful to analyse liquid or solid aromatic materials and has been widely used in flavors and fragrances. It uses an inert gas (helium or nitrogen) to flush a small flask containing the aromatic product

for 10 to 15 minutes at room temperature. Volatile compounds are trapped on Tenax GC and then thermally desorbed at 250° C for a few seconds in the capillary column, under the usual conditions. De Pooter et al. (1985) used this technique for ginger powder, and the GC pattern was quantitatively similar to that of the corresponding essential oil prepared by hydrodistillation.

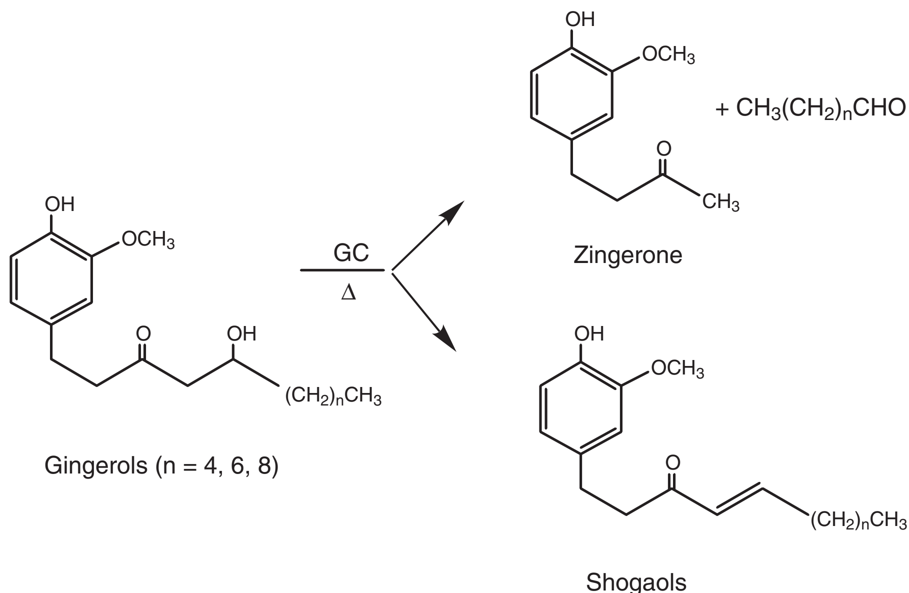
It is an excellent and powerful method for the comparison of different samples of ginger powders from different origins. The method can be indirectly used with a separated flask connected to a Tenax GC trap (in glass or stainless steel). Volatiles are extracted by solvent extraction (ethyl ether). The extract after evaporation of the solvent is then injected in the GC column and GC/MS apparatus.

GC Artefacts

Under gas chromatographic conditions, gingerols are decomposed into zingerone, aldehydes, and shogaols according to Scheme 3.1.

Hexanal and minor amounts of the other aldehydes and zingerone were also formed on treatment with hot alkali of an extract of gingerols obtained by dry column chromatography. Connell (1970) used two packed columns (3 ft × 1/8 inch): 1.6% SE 30 at 188° C and Apiezon M at 200° C on Embacel, respectively.

Chen et al. (1987) used HPGC on Carbowax 20 M and OV-1 columns to study the thermal degradation products of gingerols in steam-distilled oil from ginger. Significant higher concentrations of aliphatic aldehydes (C_6 to C_{12}) and 2-alkanones in the steam-distilled sample confirmed that thermal degradation of nonvolatile gingerols occurred during steam distillation. On the other hand, during steam distillation or hydrodistillation



Scheme 3.1 Thermal degradation of gingerols during gas chromatography. (adapted from Connell (1970))

artifacts can be formed either by hydrolysis of labile esters or by isomerization (or rearrangement) of some hydrocarbons. In the headspace technique, these artifacts will be greatly diminished (Van Beek, 1991). Examples of artifact formation by chromatographic techniques (GC, LC, GC/MS) have been reviewed by Garnero and Tabacchi (1987).

To conclude this section, it should be pointed out that packed columns should be strongly discouraged owing to the limited number of separated compounds (about 40). This problem can be partially alleviated by using better performance capillary columns of two different polarities and specific detectors for compounds containing nitrogen and sulfur atoms. Even in this case, some peaks overlap. Thus, it is necessary to proceed to a prefractionation of the ginger oil on a short column of silica gel in a hydrocarbon and an oxygenated fraction using pentane (or hexane) and pentane/ether (2:1 v/v) as solvents, respectively. Each fraction is again analyzed by GC and GC/MS. The method does not require a large amount of product (20 to 50 μL).

Gas Chromatography/Mass Spectrometry Coupling (GC/MS)

Since 1967, HRGC and GC/MS coupling have been successfully used in the analysis of essential oils in general, and particularly in the analysis of ginger oils. The most important papers are summarized in Table 3.8.

Table 3.8 Principal publications on ginger (Zingiber officinalis Roscoe) essential oils according to their origin

Origin	*Extraction/Identification methods**	*Author(s) (year)*
India	Steam distillation/GC/MS Steam distillation/GC/MS Steam distillation/GC	Nigam et al. (1964) Natarajan et al. (1972) Mitra (1975)
India (Kerala)	Steam distillation Steam distillation Steam distillation Dynamic headspace/GC/MS Steam distillation/GC (EO yield: 1.4 –2.6%)	Natarajan et al. (1972) Lawrence (1983) Narayanan and Mathew (1985) De Pooter et al. (1985) Hou and Louling (1989) Gopalam & Ratnambal (1989)
India/Australia	Steam distillation/GC/MS	Erler et al. (1988)
India/China	Steam distillation/GC/MS	Vernin and Parkanyi (1994)
West India	Steam distillation/GC/MS	Balladin and Headley (1999)
China (Szechuan)	Steam distillation/GC; TLC	Chen and Guo (1980) Lin & Hua (1987)
China	Dynamic headspace/CO_2 supercritical/GC/MS; RI; thermal treatment Steam distillation/GC/MS Different methods/CC;MS Steam distillation (dry and fresh rhizomes)/GC/MS; UV; TLC	Chen et al. (1986–1987) Ye et al. (1989) Yu et al. (1998) Li et al. (2001)
Taiwan	Steam distillation//CO_2 supercritical/CC; GC; GC/MS	Chen and Ho (1988)
Sri Lanka (Chinese variety)	Steam distillation/GC/MS; RI	McLeod and Pieris (1984)
Vietnam	Steam distillation/GC; GC/MS	Van Beek et al. (1987)

Japan	Steam distillation/GC; GC/MS; SIM	Tanabe et al. (1991)
Philippines	Hydrodistillation (yield: 0.2–1%)/TLC; GC;IR	Anzaldo et al. (1986)
Malaysia	Steam distillation/GC	Ibrahim and Zakaria (1987)
Korea	CO_2 supercritical/GC/MS	Kim et al. (1992)
Fiji	Steam distillation (yield: 0.3%, fresh rhizomes)/GC; GC/MS	Duve (1980) Smith & Robinson (1981)
Tahiti	Steam distillation/GC/MS	Vahirua-Lechat et al. (1996)
Australia	Steam distillation/GC	Connell (1970) Connell and Jordan (1971)
Australia/Africa	Steam distillation/GC	Connell (1970)
Argentina	Review	Rosella et al. (1996)
Brazil (Rio de Janeiro) Gigante and Calpira	Steam distillation/GC Steam distillation (yield: 2.2%) /GC; GC/MS	Taveira Magalhaes et al. (1997a,b) Taveira Magalhaes et al. (1977a)
Jamaica	Steam distillation/GC;	Gopalam and Ratnambal (1989)
Mauritius Island	Hydrodistillation/GC; GC/MS	Gurib-Fakim et al. (2002)
Poland	Solvent extract/GC; GC/MS	Kostrzeva and Karwowska (1976)
Nigeria	Steam distillation (dried rhizomes)/GC/MS	Ekundayo et al. (1998)
	Steam distillation/GC; GC/MS	Dambatta et al. (1998)
	Hydrodistillation (yield: 2.4%)/GC; GC/MS	Onyenekwe and Hashimoto (1999)

*CC: column chromatography; TLC: thin layer chromatography; GC: gas chromatography; GC/MS: gas chromatography/mass spectrometry coupling; EO: essential oil; RI: retention index (Kovats indices).

Pungent principles of ginger can also be analyzed as such or as trimethylsilyl (TMS) derivatives. In the first case, after extraction using 0.85 $g.L^{-1}$ supercritical CO_2, the extract was directly submitted to electron-spray mass spectrometric identification. Gingerols and shogaols have been identified and their concentrations determined. A low concentration of shogaols is characteristic to this extraction procedure (Bartley, 1995). In the second case, Harvey (1981) reported GC/MS data for the TMS derivatives of gingerols, methyl gingerols, shogaols, methyl shogaols, paradol, gingerdiols, hydroxycurcumins, and demethylated hexahydrocurcumin. GC/MS identification of ginger components was made by comparison of the unknown mass spectrum with a great number of mass spectra of known molecules stored on computer disks equipped with a data acquisition system that is an integral part of the instrument. Several papers, reviews, books and data banks are available (Vernin et al., 1998) (see Table 3.9).

Retention Indices as Filters (or Relative Retention Times, (α_R)

Retention times (R_t) and mass spectra of unknown compounds have been compared with those of authentic standards in the earlier studies of ginger oils (Connell, 1970; Kami et al., 1972; Chen and Ho, 1987, Kim et al., 1992). However, these retention values are not reproducible and vary greatly with the temperature on a given chromatographic

Table 3.9 Compilation of selected mass spectra: reviews, books, and data banks

Books and reviews	*Author(s) or origin (year)*
Registry of mass spectral data	Stenhagen et al. (1974)
Qualitative analysis of flavor and fragrance volatiles by GC-MS	Jennings and Shibamoto (1980)
Eight peak index of MS	Mass Spectrometry Data Centre (1983, 1986)
Identification of essential oil components by GC-MS	Adams (1995, 2001)
Monoterpene hydrocarbons	Ryage and Von Sydow (1963), Thomas and Willhalm (1964)
Monoterpene aldehydes and ketones	Von Sydow (1964)
Monoterpene alcohol	Von Sydow (1963)
Monoterpene esters	Von Sydow (1965)
Monoterpene derivatives	Von Sydow (1970) Yukawa and Ito (1973)
Monoterpenes	Swigar and Silverstein (1981)
Sesquiterpene hydrocarbons	Hirose and Buseki (1967)
Sesquiterpene hydrocarbons	Hayashi et al. (1967)
Sesquiterpene hydrocarbons	Moshonas and Lund (1970)
The atlas of spectral data: Sesquiterpene hydrocarbons	Joulain and König (1998)
Isoprenoids from tobacco	Enzell et al. (1984)
Essential oils	Chien (1988)
Natural and synthetic flavors and fragrances	Tucker and Maciarello (1994)
Diterpenes, terpenes, and terpenoids	Enzell et al. (1965, 1966, 1967, 1969, 1972, 1980)
Flavor and fragrance materials	Colon and Vernin (1998)

Databases	*Author(s) or origin (year)*
EPA-NIH mass spectral database	Heller and Milne (1978, 1980, 1983, 1987)
NBS library compilation	Finnigan Mat (1984)
PBM database	Hewlett Packard (1988)
CD-ROM and DC-ROM systems for mass spectral data	Wiley and Sons (1988)
Database on essential oils	Chien (1988)
Compilation of mass spectra of volatile compounds in foods	De Brauw et al. (1981, 1988)
Wiley/NBS registry of mass spectral data	McLafferty (1988, 1989)
Bench-top/PBM version 3.0	McLafferty (1988)
MPI library of mass spectral data	Henneberg et al. (1989)
NIST/EPA/NIH mass spectra database	National Institute of Standards and Technology (1992)

column. Kovats indices (KI) do not suffer from this disadvantage (Kovats, 1958, 1965). At isothermic temperature, Kovats uses the following logarithmic equation with linear alkanes as reference compounds:

$$KI = 100\,n + 100 \times \frac{\left(\log t'R_{(x)} - \log t'R_{(n)}\right)}{\left(\log t'R_{(n+1)} - \log t'R_{(n)}\right)} \qquad (1)$$

where $t'_{R(x)}$, $t'_{R(n)}$, $t'_{R(n+1)}$ are the reduced retention times ($t_R - t_m$) of the unknown compound and the linear alkanes with n and n + 1 carbon atoms, respectively, which are eluted just before and after compound x. (t_m) is the retention time of the air or that of the more volatile solvent such as pentane. Their reproducibility on polar (Carbowax 20 M, DB-Wax, FFAP, BP 20, HP 20) and nonpolar columns (SE 30, SF 96, OV 1, OV 101, OV 117, DB 1, DB 5) is good under similar GC conditions on a given column.

In linear programmed temperature, which is the usual case, Van den Dool and Kratz (1963) used the following formula :

$$KI = 100\,n + 100\,i \times \frac{(X - M)_{(n)}}{(M_{(n+1)} - M)_{(n)}} \quad (2)$$

where X, $M_{(n)}$, and $M_{(n+1)}$ are either the retention temperatures (or the adjusted retention times) of the unknown and straight-chain aliphatic esters.

The calculation of KI values starts with the injection of either a standard alkane mixture (C_6 to C_{22}) for Carbowax 20 M or DB Wax and (C_6 to C_{30}) for OV 101 or DB 5 (or linear ethyl esters) under the same linear programming temperature (2 to 4° C/min).

The software of the integrator can detect each peak and calculates each KI value automatically and prints it out with other GC data. All GC and GC/MS data are stored on a disk and visualized on a screen with the possibility to make a zoom on a wanted part of the chromatogram.

Kovats indices (or retention indices) have been compiled in various reviews, books, and many other publications (Jennings and Shibamoto, 1980; Swigar and Silverstein, 1981; Sadtler, 1985; Shibamoto, 1987; Davies, 1990; Adams, 1995, 2001). Another method for the calculation of Kovats indices has been suggested by Boniface et al. (1987) using scans (S) instead of retention times. A simple program called MBASIC.SCAN1 using the linear relationship:

$$KI = a \times S + b \quad (3)$$

has been used to calculate all KI of a listing. However, a prerequisite for this is to find at least 10 compounds for which the KI are known and which are uniformly distributed in the reconstructed chromatogram. The interest in KI is evident since on polar and nonpolar columns different compounds can give the same mass spectra (Vernin and Petitjean, 1982; Vernin et al., 1986). KI of sesquiterpene hydrocarbons have also been reported by Andersen et al. (1969, 1970, 1973, 1977) and Joulain and Koenig (1998). KI as a preselection routine in mass spectra library searches of flavor and fragrance volatiles have been used by many workers (Alencar et al., 1984; Yamada et al., 1987; Vernin et al., 1986, 1998). Furthermore, these indices possess a number of properties that can be suitable as a route of identification. Differences between KI (DKI) on polar and nonpolar columns are characteristic of a particular family of compounds. They have been summarized by Vernin et al. (1998). Modern GC/MS techniques can also be used to obtain more information about either a series of compounds or on molecular weights of unknown compounds.

Selected Ion Monitoring Technique (SIM)

A complement to the use of KI is the selection of a certain number of characteristic fragments of a particular compound or a homologous series.This technique is called selected ion monitoring (SIM) and can be used both with electron impact (EI) and chemical ionization (CI).

Some of these ions for different groups of products have been reported by Vernin et al. (1998). For example, sesquiterpene hydrocarbons in an essential oil can be vizualized qualitatively and quantitatively by selection of ions at m/z = 93, 121,161, 204, and monoterpene hydrocarbons (with the exception of limonene, which gives upon EI a base peak at m/z = 68) by selection of ions at m/z = 93, 136, and so on. Thus, it is of particular importance to compare these two fractions obtained from different extraction methods and countries. This method was applied to the study of a "kintoki" Japanese ginger extract (Tanabe et al., 1991). Selected ions or base peaks (BP) of some compounds are reported in Table 3.10. Each compound has been quantified using naphthalene as the internal standard.

Chemical Ionization Techniques

Since some molecular masses at EI at 70 eV are not always visible, various workers used either recording mass spectra at 20 eV or gentler ionization methods. The theory and application of these latter techniques were developed in Harrison's book (1983) and in several papers (e.g., Bruins, 1987).

In a chemical ionization chamber, the pressure is higher (0.07 to 1.5 torr) than in a source under EI. In many cases, it is possible to obtain quasimolecular ions both in positive chemical ionization (PCI) using isobutane or ammonia as gaseous reagents $(M + H)^+$, and in negative mode (NCI) using the hydroxyl OH^- or NH_2^- ion as a reagent giving $(M - H)^-$. Numerous other reagents are used for this purpose, and their applications in analysis of essential oils and aromas have been summarized by Vernin et al. (1998). PCI (NH_3) gives better results with carbonyl compounds (terpenes, aliphatics, alicyclics, and aromatics) than in the NCI mode. Another important fragment at m/z $= (M + NH_4)^+$ is observed. Upon PCI/i-C_4H_{10} sesquiterpene hydrocarbons give an intense quasimolecular ion $(M + 1)^+$. Under the same conditions, mass spectra of sesquiterpene alcohols show intense fragment ions $(M + H - H_2O)^+$ at m/z = 205. Upon $PCI(NH_3)^+$, a typical set of ions is formed: $(M + H - H_2O)^+$, $(M + NH_4 -$

Table 3.10 Example of separated compounds obtained by the Selected Ion Monitoring (SIM) technique*

Base Peak (m/z)	*Separated compounds*[a]
69	Neral, geranial, geranyl acetate, β-bisabolene, β-sesquiphellandrene
81	1,8-Cineole
93	α-Pinene, camphene, myrcene, β-phellandrene
95	Borneol and isoborneol
119	ar-Curcumene, α-zingiberene

[a]Each compound has been quantified using naphthalene as an internal standard.
*Tanabe et al., (1991)

$H_2O)^+$, $(M + NH_4)^+$, and $(M + NH_3 + NH_4)^+$, respectively. NCI (OH^-) is particularly suitable for the identification of aliphatic and terpenic esters of essential oils that give rise to the formation of $RCOO^-$ ions. In the case of alcohols, the RO^- ions is the base peak. In the NCI technique, correct analysis of unsaturated monoterpenes is complicated because of the secondary reactions between $(M - H)^-$ ions and nitrous oxide. On the other hand, molecular ions have low intensity because protons are difficult to abstract. Saturated terpenes cannot be ionized by this technique.

Miscellaneous Methods

More and more sophisticated spectroscopic methods such as UV, high resolution infrared (HRIR), ^1H-NMR, and ^{13}C-NMR are usually employed for the identification of unknown compounds previously extracted from a complex mixture. But these methods are very time consuming and expensive.

IR spectra as a film on a KBr disk of some naturally occurring sesquiterpene hydrocarbons (β-sesquiphellandrene, and zingiberene) have been reported by Wenninger et al. (1967). IR spectra of zingiberene have also been published by Herout et al. (1953) and Pliva et al. (1960). But the assigned structure was that of β-zingiberene instead of the α-isomer. Before 1970, a summary of these works was reported by Connell (1970). Van Beek (1991) claimed that IR spectroscopy can distinguish between various types of ginger oils by comparing the intensity of peaks at 3470 cm^{-1} (alcohols), 1743 cm^{-1} (esters), and 1680 cm^{-1} for conjugated aldehydes. Addition of large quantities of extraneous materials can also be detected. Coupling GC/HPIR (high performance infrared) constitutes another interesting method of identification, but it has limited use in the case of complex mixtures.

UV spectroscopy at 375 nm has been used as a method for determination of (6)-gingerol in ginger oil consignments from China (Li, 1995).

^{13}C-NMR of ginger oils is very complex and the spectra are difficult to interpret because of the great number of peaks. On the other hand, compounds occurring below 0.2% are not measurable. The method can be used in addition to the usual technique based on retention indices and mass spectra. ^1H-NMR and ^{13}C-NMR are extremely valuable techniques for elucidation of the structure of an unknown isolated compound.

Atomic emission spectroscopy methods have also been shown to be effective and accurate in determining the components of food spices and essential oils from Zingiberaceae and other families (Zaidi et al., 1992). A new fluorimetric assay at 481 to 486 nm for the determination of the pungency of fresh ginger from China (gingerols) was found to be better than the standard TLC/densitometric method (Variyar et al., 2000).

Oleoresins: Gingerols, Shogaols, and Related Compounds

Oleoresins contain the nonvolatile pungent principles of ginger in addition to some essential oils and other nonvolatile compounds such as carbohydrates and fatty acids (Connell, 1970). Several reviews have been devoted to the chemistry and properties of gingerols and shogaols as pungent compounds of ginger rhizomes that are considered responsible for its medicinal properties (Nakatani, 1995; Kikuzaki, 2000) (see Table 3.11). Oleoresins are obtained by solvent extraction (acetone, ethanol, dichloromethane, dichloroethane, and trichloroethane). Yields range from 3 to 11% and sometimes can

Table 3.11 Summary of several works on ginger oleoresins

Origin	Methods/compounds	Author(s)
Australia	Solvent extraction (acetone) (6)-, (8)-, (10)-gingerols are in the ratio 56/13/31	Connell and Sutherland (1969)
India	Solvent extraction	Natarajan et al. (1972)
Japan	Solvent extraction Gingerols (3, 4, 5, 6, 8, 10, 12)	Masada et al. (1973, 1974a,b)
	Gingerdiols, methylgingerdiols, ginger diacetates and methylginger diacetates	Kami et al. (1972)
Poland	Solvent extraction Gingerols (31.1%), shogaols (20%)	Kostrezeva and Karwaswska (1976)
Jamaica	Solvent extraction (AcOEt) GC/MS of TMS derivatives	Harvey (1981)
Review	Gingerols	Nakatani (1995)
Brazil (Gigante and Calpira)	Solvent extraction Yields: 6.91–10.9% (ethanol) 2.53–5.62% (acetone), 3.35–3.91% (CH_2Cl_2)	Taveira Magalhaes et al. (1997b)
India	Solvent extraction/HPLC Gingerols and ginger oil, variation according to geographical areas. Stability of gingerols	Sane et al. (1998)
West India	Solvent extraction/LC shogaols (47.74%) and gingerols (27.13%)	Balladin and Headley (1999)
Ginger (powder, skin, baked)	HPLC	Huang et al. (1999)
India	1-Dehydrogingerdione	Charles et al. (2000)
	Gingerols' stability in aqueous solution	Battarai et al. (2001)
	Gingerols and shogaols	Okwu (2001)
	Solvent extraction 5-cyclic diaryl heptanoids	Kikuzaki and Nakatani (1995)
India (from Z. *zerumbet* or wild ginger)	Zerumbone oxide 3, 7, 11, 11-tetramethyl-8-hydroxy 2, 3-epoxycyclo undeca-6, 9-diene	Chabra et al. (1975), Bhatti et al. (1969)

reach 20%. However, they are greatly dependent on the solvent extraction conditions, the state of rhizomes (fresh or dried), the country of origin, the various areas within the same country, and harvest season.

The major pungent component of ginger oleoresin is (6)-gingerol, **1b** (1-[4-hydroxy-3-methoxyphenyl]-5-hydroxydecane-3-ol), first identified by Lapworth (1917) and by Connell and Sutherland (1969). These workers established the S-configuration for the hydroxyl group. The name (6)-gingerol was derived from the fact that alkaline hydrolysis of gingerol afforded n-hexanal—a six carbon aldehyde. Besides the presence of the well-known (6)-, (8)-, and (10)-gingerols, Masada et al. (1973, 1974a,b) pointed out the presence of lower homologues, that is, (3)-, (4)-, (5)-gingerols, and possibly also (12)-gingerol. Gingerdiol acetates and methyl ginger diacetates also occur in Japanese extracts.

The oleoresin and gingerol content in nine popular cultivars of ginger from India, Brazil, and Jamaica were evaluated by Gopalam and Ratnambal (1989). The gingerol content was determined according to the Indian Standards Institute (ISI) method. The

minimum gingerol content in the oleoresin is 18% by weight as per ISI (1975) requirements.

Cultivars can be divided into three groups: (1) those that contain a minimum amount of gingerol (i.e., 17.7 to 19.25%, corresponding to cultivars Wynad local, Narasapattam, and Maran), (2) those that contain medium gingerol levels (i.e., 20.09 to 21.32%, including Nadia, Karakkal, and No. 646 cultivars), and (3) those containing the highest gingerol content (i.e., 24.66 to 26.67%, corresponding to Ernad, Chernad, Rio de Janeiro, and Jamaica).

The mean of oleoresin content is 6.74%, the minimum and maximum being 5.30% for Wynad local (Kerala) and 8.59 for No. 646 (Himachal Pradesh), respectively. The amount of (6)-gingerols in fresh rhizomes of ginger cultivated in China and Japan was approximately 0.3 to 0.5%. The two other homologues, (8)- and (10)-gingerols (**1c** and **1d**), were 5 to 20%, relative to (6)-gingerol, respectively (Yoshikawa et al., 1994). Dehydration of (6)-gingerol leads to (6)-shogaol, and its oxido-reduction to (6)-gingerdione **1e** and (6)-gingerdiol **1f**, which upon acetylation affords (6)-gingerdiacetate **1g**. (6)-Methyl gingerols **2b** with a methoxy group instead of a hydroxy group at C-4 and (6)-dimethoxy gingerol **2a** lacking a methoxyl group at C-3 of the benzene ring were also reported in ginger rhizomes (Harvey, 1981; Kikuzaki and Nakatani, 1996). Their structures have been established by the usual spectroscopic methods.

During prolonged storage and according to the extraction process, large amounts of shogaols and to a lesser extent of zingerone were formed (Connell, 1971; Govindarajan, 1982). They affect the quality of the pungent flavor of ginger causing volatile off-flavors.

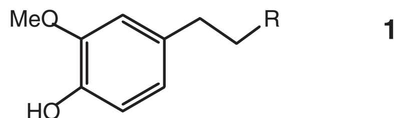
Besides zingerone (**1a**) pungent compounds of extracts are gingerols (**1**, **2**,), shogaols (**3** and **4**), which arise from dehydration of the corresponding gingerols, and related compounds such as paradol (**1i**), gingerdiones (**1e**), gingerdiols (**1f**), and gingerdiol acetates (**1g**). Their structures are given in Figure 3.1 (adapted from Akhila and Tewari 1984, and Kikuzaki 2000).

Zingerone, (6)-gingerol, and (6)-shogaol displayed moderate antioxidant activity (Nakatani and Kikuzaki, 2002). Activity diminished with the increasing chain length.

Diarylheptanoids (or curcuminoids), another related category of products, have been reported in Figure 3.2.

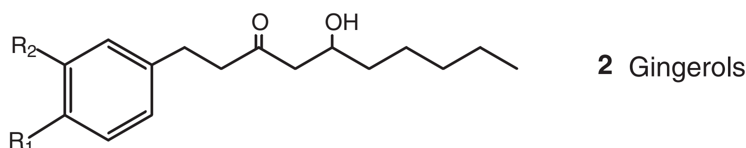
They are characterized by a heptane chain with two terminal 1,7-diphenyl rings substituted by a hydroxyl and a methoxyl substituents in the *para* and *meta* positions, respectively. The 3,5-positions of the alkyl chain contain either a β-ketohydroxy (**5**), a dihydroxy (**6**) and the corresponding diacetate (**7**) groups, or dehydroxylated compounds from hexahydrocurcumin (**5a**) giving rise to 4-one-3-ol called gingerenone (**8a**) and its derivatives (**8b**) and (**8c**). The level of hexahydrocurcumin is less than 0.005%. These compounds were isolated from ginger rhizome between 1969 and 1996 (Kikuzaki, 2000). Gingerenone A (**8a**) exhibits a moderate anti-coccidial activity and a strong antifungal effect against *Pyricularia orysae*, a plant pathogen (Endo et al., 1990).

Related diarylheptanoids isolated from turmeric (*Curcuma domestica* L., Synonym: *C. longa* L.), which also belongs to the Zingiberaceae family, exhibit antioxidant activity as well. Connell and Sutherland (1969), using a acetone extract of ginger rhizome from Australia, found the following ratio for (6)-, (8)-, and (10)-gingerols: 56:13:31, respectively. This accounts for 1:3 of the extract. Analysis of the natural pungent compounds of ginger from oleoresin was also carried out by Lewis et al. (1972), Connell and McLachlan (1972) and Haq et al. (1986). Gingerol and shogaol levels in a Polish extract



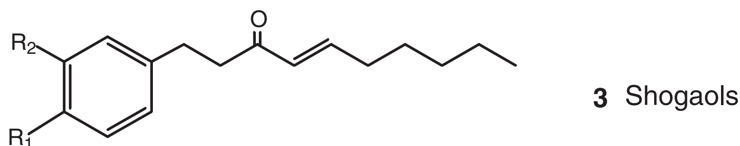
1

1a; R = (C=O)CH3	Zingerone
1b; R =-C(=O)CH2CHOH(CH2)4CH3	(6)-Gingerol
1c; R =-C(=O)CH2CHOH(CH2)6CH3	(8)-Gingerol
1d; R =-C(=O)CH2CHOH(CH2)8CH3	(10)-Gingerol
1e; R =-C(=O)CH2C(=O)(CH2)4CH3	(6)-Gingerdione
1f; R =-CHOHCH2CHOH(CH2)4CH3	(6)-Gingerdiol
1g; R =-CH(OAc)CH2CH(OAc)(CH2)4CH3	(6)-Gingerdiol diacetate
1h; R =-C(=O)CH2CH(OSO3H)(CH2)4CH3	(6)-Ginger sulphonic acid
1i; R =-C(=O)(CH2)6CH3	(6)-Paradol



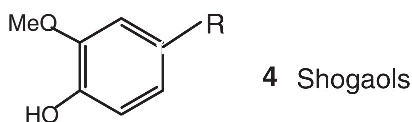
2 Gingerols

2a; R1 = OH, R2 = H	(6)-Demethoxygingerol
2b; R1 = R2 = OCH3	(6)-Methylgingerol



3 Shogaols

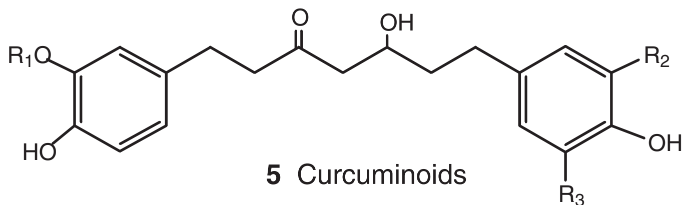
3a; R1 = OH, R2 = H	(6)-Demethoxyshogaol
3b; R1 = OH, R2 = OCH3	(6)-Shogaol
3c; R1 = R2 = OCH3	(6)-Methylshogaol



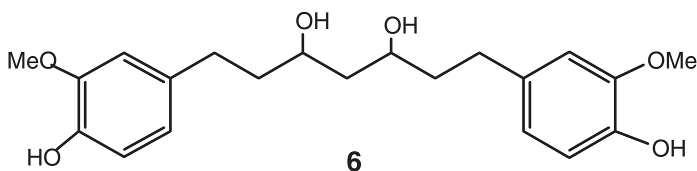
4 Shogaols

4a; R = CH2CH2C(=O)CH=CHCHOH(CH2)3CH3	(6)-Hydroxyshogaol
4b; R =-CH=CH-C(=O)CH2C(=O)CH=CH(CH2)2CH3	(6)-Dehydroshogaol
4c; R = CH_2CH_2 O $(CH_2)_3CH_3$	2-Propyl-5(β-(3-methoxy-4-hydroxyphenyl)ethyl)-furan

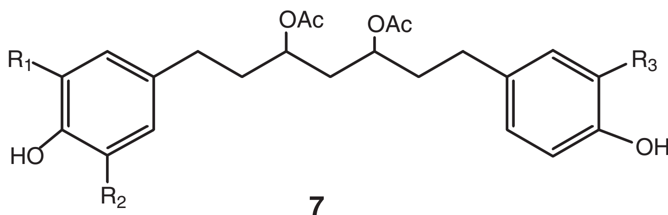
Figure 3.1 Gingerols, shogaols, and related compounds isolated from ginger (adapted from Akhila and Tewari, 1984 and from Kikuzaki, 2000).



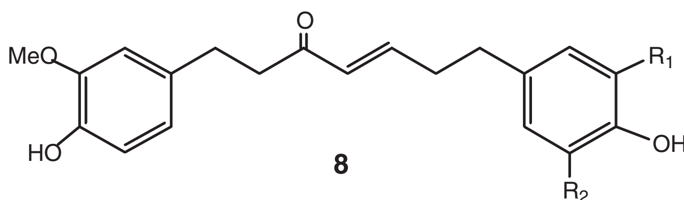
5a; R1 = CH3; R2 = OCH3; R3 = H — Hexahydrocurcumin
5b; R1 = CH3; R2 = OH; R3 = H — Demethylated hexahydrocurcumin
5c; R1 = R3 = H; R3 = OCH3 — Demethylated hexahydrocurcumin
5d; R1 = CH3; R2 = R3 = H — Demethoxylated hexahydrocurcumin
5e; R1 = CH3; R2 = R3 = OCH3 — Methoxylated hexahydrocurcumin



6a (3*R*) ; **6b** (3 *S*)



7a; R1 = R3 = OCH3; R2 = H (3*R*, 5*S*)
7b; R1 = R2 = R3 = OCH3 (rel. *RS*)
7c; R1 = R2 = R3 = OCH3 (3*S*, 5*S*)
7d; R1 = OCH3; R2 = H; R3 = OH (rel. *RS*)
7e; R1 = R3 = OH; R2 = H (3*S*, 5*S*)



8a; R1 = OCH3; R2 = H — Gingerenone A
8b; R1 = R2 = OCH3 — Methoxylated gingerenone A
8c; R1 = R2 = H — Demethoxylated gingerenone A

Figure 3.2 Curcuminoids (diarylheptanoids) isolated from ginger (adapted from Akhila and Tewari, 1984, and from Kikuzaki, 2000).

were 31.1 and 20% against 14.8 and 11.2%, respectively, when compared with foreign extracts (Kostrzewa and Karwaswska, 1976).

Pungent constituents of ginger, separated as TMS derivatives, were reported by Harvey (1981). Five gingerols (n = 2, 4, 6, 8, 10), three methylgingerols (n = 4, 6, 8), four shogaols (n = 2, 4, 6, 8), two methylshogaols (n = 4, 8), paradol (**1i**), and three gingerdiones were identified. Also found in the low-temperature region of the chromatogram were: ar-curcumene, several sesquiterpene hydrocarbons and their hydroxylated derivatives, zingerone and fatty acids (palmitic, oleic, and stearic).

Odoragram and aromagram of gingerol have been reported by Ney (1990a,b) using the sniffing method. As pepper, chilies, or mustard, they are characterized by a pungent taste. The content of oleoresins extracted with three different solvents has been studied by Taveira Magalhaes et al. (1997a,b) from various areas of Brazil. Results for the oleoresins and the essential oils are given in Table 3.12. The highest percentage of oleoresins was observed with ethanol as the solvent, whereas essential oils are better extracted with methylene chloride

Geographical variation of the content of gingerols was studied for different areas of India: Gujarat, Madhya Pradesh, Maharashtra, Kerala, and West Bengal (Sane et al., 1998). Analyses were carried out by HPLC using a Camag Limonat IV apparatus, benzene/methanol (10: 1 v/v) as the eluent, 310 nm scanning wavelength, and analysis of variance (ANOVA) calculations in order to determine whether the variation was significant or not. From these results, it can be concluded that there is no significant variation in the gingerol content in different states.

Comparison between the pungent compounds in ginger powder, ginger skin, and baked ginger was carried out by Huang et al. (1999). The content of gingerol in the three samples was 1.02, 0.28, and 0.25 g/100 g, respectively. Baked ginger contained 0.45 g/kg shogaols, but there were only traces in the other two samples. The stability of gingerols and shogaols in aqueous solution was studied by Bhattarai et al. (2001). Because gingerols are biologically active compounds, they may make a significant contribution toward medicinal applications of ginger and other products derived from ginger. They are thermally labile due to the presence of a β-hydroxyl-keto group in the structure and undergo dehydration readily to form the corresponding shogaols, as previously shown. Their stability was studied in the temperature range of 33 to 100° C in aqueous solutions at pH 1.4 to 7.

A study of the degradation product (6)-shogaol, or (1-(4-hydroxy-3-methoxyphenyl)decan-4-ene-3-one), was carried out by HPLC. Kinetics of (6)-gingerol degradation was characterized by least-square fitting of a rate equation. Degradation rates were found to be pH dependent with greatest stability being observed at pH 4. The reversible degradation of (6)-gingerol at 100° C and pH 1 was relatively fast and reached equilib-

Table 3.12 Percentages of oleoresins and Brazilian essential oils with different solvents*

Solvents	*Oleoresins (%)*	*Essential oils (%)*
Ethanol	6.91–10.9	3.92–12.64
Acetone	2.53–5.62	8.05–18.89
Methylene chloride	3.35–3.91	13.67–27.72

*Taveira Magalhaes, (1997a)

rium within 2 hours. Activation energies were calculated using the Arrhenius equation at temperatures ranging from 37 to 100° C. Owing to their pungent and biological properties, gingerols that constitute the major part of ginger oleoresins have been widely studied since 1970.

Modern techniques of extraction and qualitative and quantitative analyses (HPLC, GC/MS as TMS derivatives) provide a powerful identification tool. Their stability according to the medium is an important problem, not only for flavor quality but also for medicinal uses.

Synthesis and Biosynthesis of Pungent Compounds of Ginger Rhizomes

Several syntheses of zingerone, shogaols, and gingerols have been described in the literature (Connell, 1970; Afzal et al. 2001). As an example, synthesis of zingerone and (6)-shogaol from 3-(4-hydroxy-3-methoxy)-2-propenoic acid is reported in Scheme 3.2. The name *shogaol* comes from "shoga," the Japanese word for ginger.

Zingerone is obtained as colorless needles (mp = 40 to 41° C) with a salicylaldehyde odor (Molyneux, 1971). The first report on the synthesis of (6)-shogaol found in Japanese ginger was by Nomura and Tsurami (1926) by condensation of zingerone and hexanal. The structure of (6)-shogaol was determined using UV, IR, NMR, and MS data (Connell, 1970). The same worker reported the structure of (6)-gingeryl methyl ether using the same spectroscopic methods. The S-*trans* conformation in the liquid state at room temperature was established. The physical properties of the compound were as follows: crystalline solid, m.p. = 65.5 to 66° C, optical rotation at 23° C = + 28.4° C (chloroform), λ_{max} = 282 nm, ϵ = 2,650 (ethanol).

By a solvent extraction procedure, Connell (1970) isolated (6)-paradol (**1i**) in ginger oleoresin as a pale yellow, optically inactive pungent solid (m.p. = 27 to 29° C), λ_{max} = 282 nm, ϵ = 14,500 (ethanol). It was structurally characterized by ^{1}H-NMR, IR, UV, and MS data. It was synthesized from (6)-gingerol (**1b**) by hydrogenation of the shogaol produced upon dehydration (Scheme 3.3).

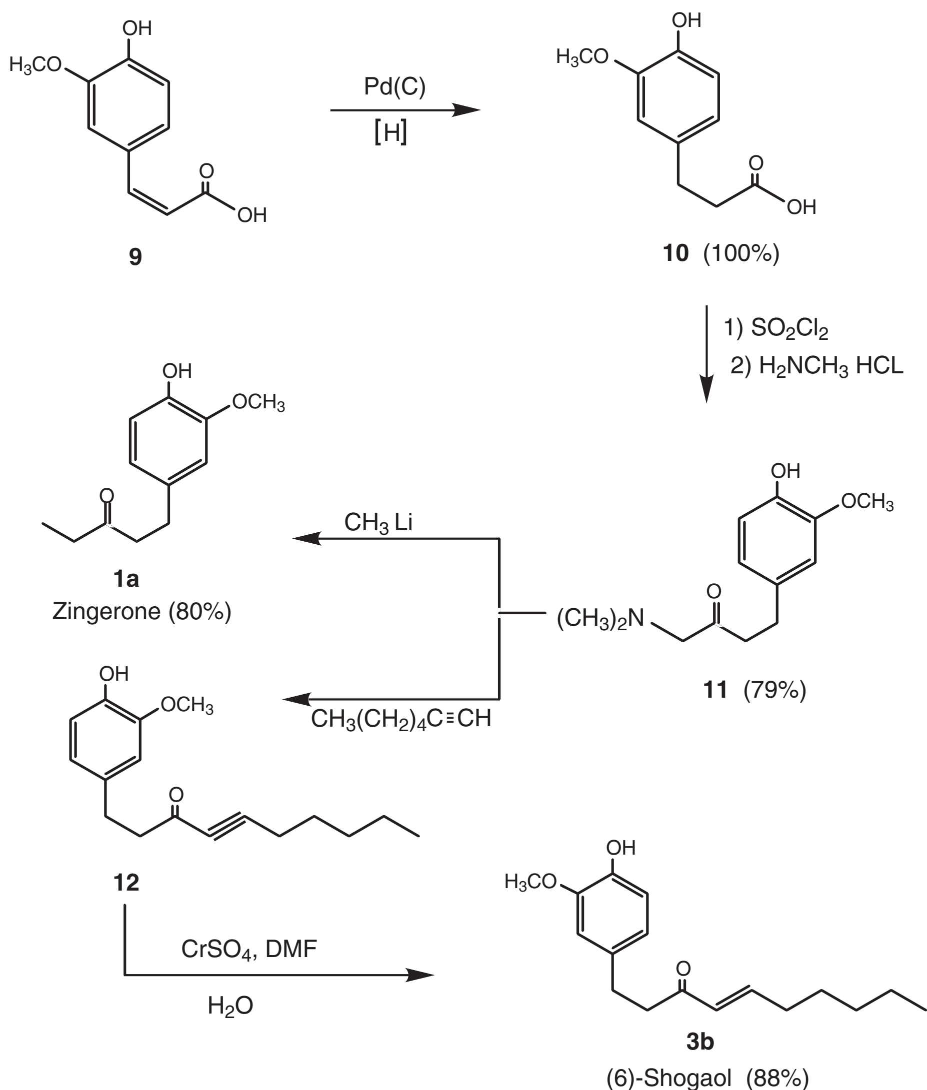
Biosynthesis of gingerols (**18**) from dihydroferulic acid (**13**) has been reported by Harvey (1981) (Scheme 3.4).

It involves the condensation of dehydroferulic acid (**14**) first with mevalonic acid and then with a short-chain carboxylic acid such as hexanoic acid to give the intermediate gingerdiones (**19**). All the compounds have been identified in ginger oleoresin by Connell and Sutherland (1969), Connell (1971), Connell and McLachlan (1972), Masada et al. (1973, 1974a,b), and Raghuveer and Govindarajan (1979).

1-Dehydrogingerdione (**21**) (Figure 3.3) was isolated and identified as well (Charles et al., 2000). The structures of five-membered ring diaryl heptanoids (**22**, **23**) isolated from purified dichloromethane extracts of ginger were elucidated by spectroscopic (^{1}H-NMR, ^{13}C-NMR, IR, MS) and chemical methods (Kikuzaki and Nakatani, 1996).

Ginger Essential Oils

Ginger oils are obtained by hydrodistillation or steam distillation, by extraction with supercritical carbon dioxide, or by solvent extraction of dried rhizomes. Yields and chemical composition vary greatly according to the cultivation, areas, countries, experimental, and analytical conditions. Ginger oil is a light yellow to yellow liquid with a

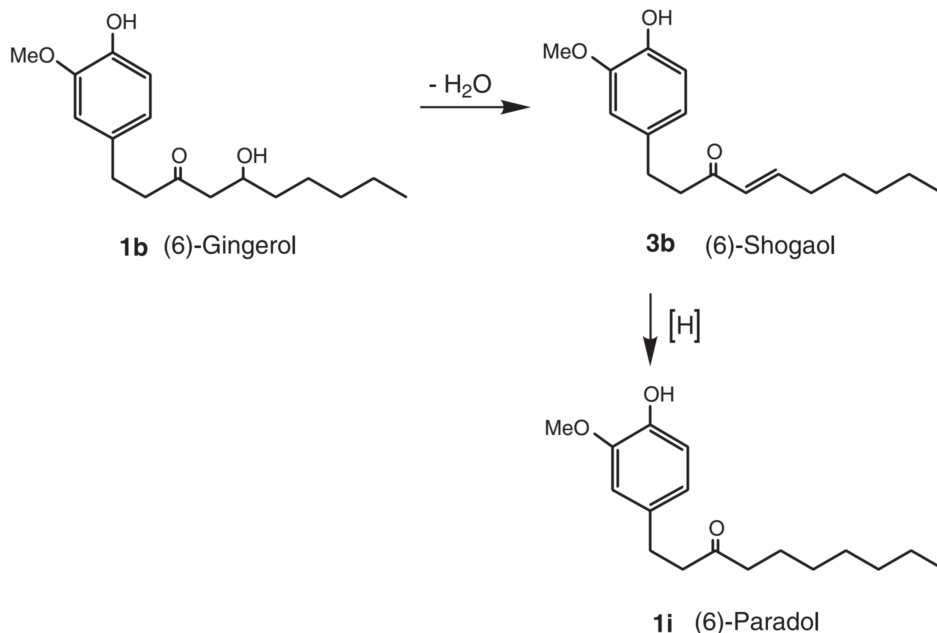


Scheme 3.2 Synthesis of zingerone **1a** and (6)-shogaol **3b**. Yields are given in parentheses (adapted from Saunders and Seidel [1992]).

characteristic lemon odor. India is the major producer of ginger oil followed by China, Japan, Jamaica, Australia, and Africa.

Physicochemical Properties

The physicochemical properties of ginger are given in Table 3.13 and Table 3.14. Badalyan et al. (1998) studied the effect of a solvent feed ratio (SF) on the refractive index (n_D) of an extract of Australian-grown air-dried ginger at 10 MP_a from 9 to 35° C. The n_D value increases with the SF ratio, with most of the essential oil components



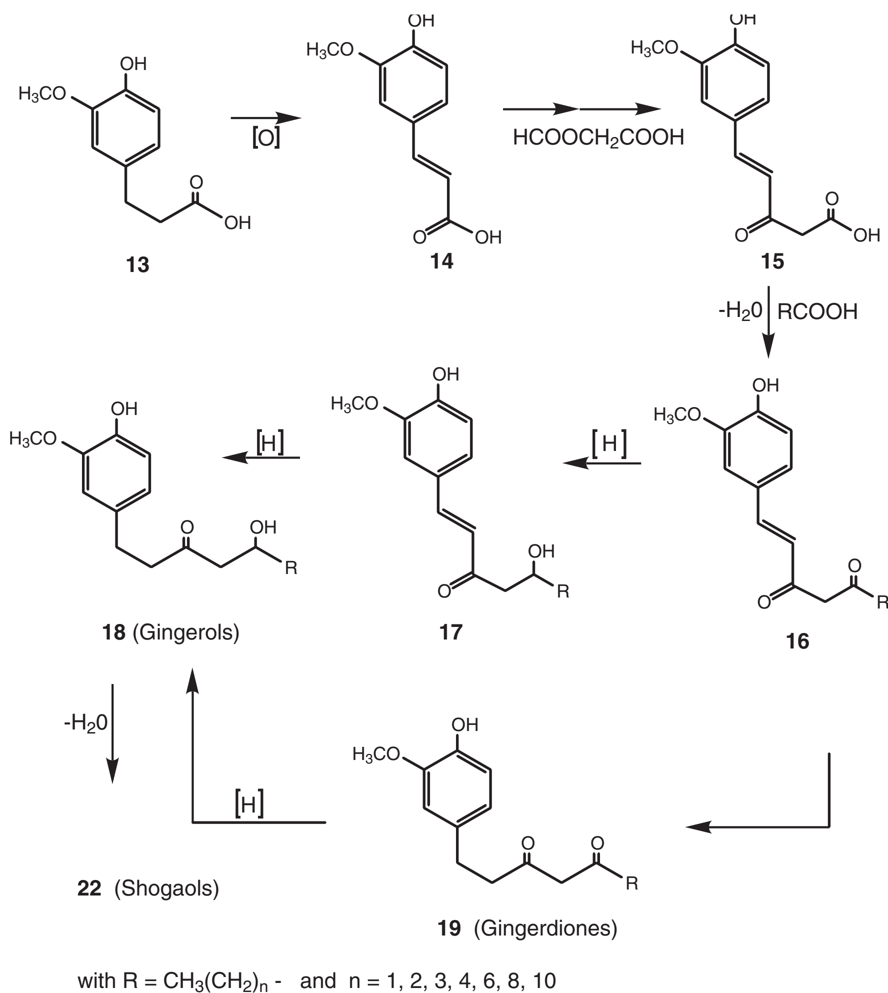
Scheme 3.3 Synthesis of (6)-shogaol **3b** and (6)-paradol **1i** from (6)-gingerol **1b** (from Connell [1970]).

being recovered when the SF ratio was less than 2. The SF ratio was found to be the major factor affecting the composition of ginger extract. The temperature had little effect on the composition within the range 9 to 35° C. Extraction of the sample with supercritical CO_2 revealed that solubility was the dominant limiting factor in the extraction procedure. Introducing small amounts of ethanol as a cosolvent increased the overall yield from liquid CO_2 and the recovery of ginger oleoresin.

Chemical Composition

Used in perfumery and cosmetics, the essential oils of ginger have been widely studied in producer countries. These studies have been reviewed by several workers (Guenther, 1952; Gildemeister and Hoffman, 1956; Connell, 1970; Masada, 1976; Lawrence, 1983, 1984, 1988, 1995, 1997; Afzal et al., 2001).

Before 1970 (Connell, 1970) and the use of packed columns, the number of identified compounds remained low. The main components were the sesquiterpene hydrocarbons, (−)-α-zingiberene, (+)-ar-curcumene, β-bisabolene, β-sesquiphellandrene, farnesene, γ-selinene, β-elemene, and β-zingiberene. Other compounds identified at this time were monoterpene hydrocarbons: α-pinene, β-pinene, myrcene, β-phellandrene, limonene, *p*-cymene, cumene and oxygenated compounds: 1,8-cineole, d-borneol, linalool, neral, and geranial, bornyl acetate, in addition to some aliphatic aldehydes (nonanal, decanal), ketones (methylheptenone), alcohols (2-heptanol, 2-nonanol), esters of acetic and caprylic acid, and chavicol. After 1967, the development of capillary GC and its coupling with MS and data banks has provided a suitable technique for a good separation and identification of a greater number of compounds.

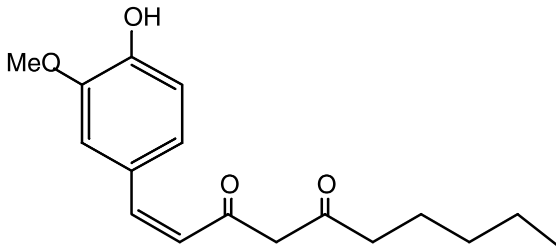


Scheme 3.4 Biosynthesis of gingerols from dihydroferulic acid 13 and mevalonic acid (adapted from Harvey [1981]).

Essential Oils from India

In a ginger oil from India, Nigam and Levi (1963) found: α-pinene, myrcene, *p*-cymene, 2-heptanol, 2-nonanol, bornyl acetate, and other compounds. According to them, these data are important for establishing the authenticity of the essential oil. One year later, Nigam et al. (1964) identified several sesquiterpene hydrocarbons (68.5%), (−)-α-zingiberene (38.6%), β-zingiberene, (+)-ar-curcumene (17.7%), α-farnesene (9.8%), γ-selinene (1.4%), β-elemene (1.0%), β-bisabolene in mixture with α-zingiberene, β-sesquiphellandrene, and sesquiterpene alcohols (e.g., zingiberenol, elemol), accounting for 16.7% of the oil.

Twenty-six varieties of essential oils from Kerala were studied by Natarajan et al. (1972). The cultivation of ginger roots, the physical characteristics, and the physical



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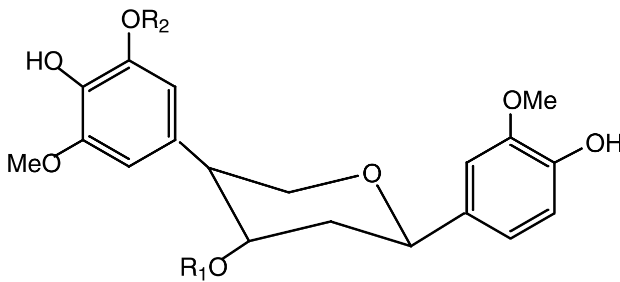
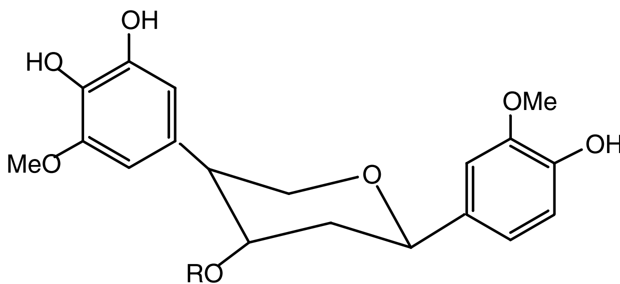


22a; (R1 = R2 =H)
22b; (R1 = H, R2 = CH3)
22c; (R1 = Ac, R2 = H)



23a; R = H
23b; R = Ac

Figure 3.3 1-Dehydrogingerdione 21 and diarylheptanoids 22, 23 identified in ginger rhizomes (adapted from Kikuzaki and Nakatani [1996]).

Table 3.13 Physiochemical properties of ginger essential oils from India[a], ISI[b,c], and EOA[c]

Characteristics	*India (Kerala)*[a]	*Cochin*[a]	*ISI*[b,c]	*EOA*[c]
Specific gravity* d^{20}_{X}	0.8690	0.8718	0.868–0.880	0.87–0.882
X = (° C)	(27°)	(28°)	(30°)	(25°)
Optical rotation* α^{X}_{D}	−54°	−40.1°	−28 to −45°	−28 to −45°
X = (° C)	(30°)	(28°)	(20°)	(at 20°)
Refractive index n^{X}_{D}	1.4891	1.4872	1.4840–1.4894	1.4880–1.4940
X = (° C)	(28°)	(18°)	(30°)	(20°)
Saponification value	7.4	—	20 max.	20 max.

[a]Reported by Akhila and Tewari (1984).
[b]Indian Standard Institute, New Delhi, India (1975).
[c]Essential Oil Association (USA); also reported by Masada (1976).
*Mathew (1973) gave the following values at 30° C: 0.8718, 1.4803, and −40.4° , respectively.

Table 3.14 Characteristic constants of two ginger varieties from Brazil

Characteristics	*Gigante*	*Calpira*
d^{20}_{20}	0.8815–0.8873	0.8826–0.8860
α^{25}_{D}	−15.3° to −6.8°	−22.0° to −32.0°
n^{20}_{D}	1.4874–1.4897	1.4895–1.4908
Yields[a]	1.2–2.5	2.5–2.8

[a]From dried rhizomes (according to Taveira Magalhaes et al., 1997a)

and chemical properties of the essential oils have been described by Mitra (1975). The major components of the essential oil of ginger root are α-zingiberene and β-bisabolene, and those of the oily resin are zingerone, gingerols, and shogaols. The same year, Terhune et al. (1975) reported the presence of epizonarene, zonarene, and sesquithujene. In 1983, Lawrence reviewed the studies devoted to ginger oils and reported his own results on an essential oil from India (Table 3.15). Of the 115 constituents isolated and identified, 43 of them were previously identified, whereas 72 had been identified for the first time as components of the ginger oil.

In a review on the chemistry of ginger, Akhila and Tewari (1984) reported about 30 volatile constituents. Among sesquiterpene hydrocarbons, the most important are: α-zingiberene, ar-curcumene, and β-farnesene, previously reported by Nigam et al. (1964). The percentages of neral, geranial, linalool, and borneol were 0.8, 1.4, 1.3, and 2.2%, respectively.

Fifteen cultivated varieties of ginger were investigated by Narayanan and Mathew (1985). They contain 1.4 to 2.6% of oil. Major constituents were: α-zingiberene (16.6 to 28.7%), neral (6.6 to 15.1%), and geraniol (5.8 to 11.5%). Zerumbone (t. to 5.6%),

Table 3.15 GC analyses of ginger oils from India, Brazil, and Jamaica*

Compounds/Countries	*Percentages (%)* India[a]	Brazil (Rio de Janeiro)	Jamaica
α-Pinene	2.9	2.7	2.4
Camphene	2.0	1.5	1.4
β-Pinene	1.1	0.07	1.3
Aldehyde C9	1.9	4.4	0.1
1,8-Cineole	3.9	5.1	1.0
ρ-Cymene	4.0	6.9	10.8
Linalool	3.4	3.1	4.8
1-Nonanol	5.2	2.1	2.8
α-Zingiberene	31.4	21.8	27.7
ar-Curcumene	8.1	0.26	10.9
β-Sesquiphellandrene	4.6	2.8	2.2
Nerolidol	4.7	tr	6.8
Zerumbone	5.1	8.8	3.4

*Adapted from Gopalam and Ratnambal (1989).
[a]Mean of values (rounded to the first decimal) of seven areas of India. Six compounds remain unidentified.

and limonene (0.3 to 1.7%) were also found in most varieties but were absent in three others. Alcohols and aldehydes account for 7.5 to 12.9% and 12.9 to 26.6%, respectively.

Erler et al.(1988) compared the composition of oils from India and Australia. They found noticeable differences in their terpenoid components. The main constituents were the usual sesquiterpene hydrocarbons. However, the essential oils from the Australian ginger consisted mainly of monoterpene hydrocarbons (camphene, β-phellandrene) and of the oxygenated derivatives such as neral, geranial, and 1,8-cineole. The following year, Gopalam and Ratnambal (1989) analyzed by GC on packed columns (10% Carbowax 20 M) essential oils obtained by hydrodistillation and steam distillation of seven popular cultivars of ginger. The selection of these cultivars was based on the yield of essential oils (1.4 to 2.6%) and gingerol content in the oleoresin. The levels of 13 identified and 6 unidentified compounds were reported and compared with the oils from Brazil and Jamaica (see Table 3.15).

There is a great difference in the percentages of the thirteen identified compounds in the samples grown in the seven areas of India. The amounts of α- and β-pinenes were higher in cultivars Karakkal and Ernard Chernad (4.2 and 4.5%, respectively). Typically, the lower the contents, the better the quality of the oil. The 1,8-cineole content was higher in cultivars Nadia (13.3%) followed by cvs. Wynad local (8.6%). α-Zingiberene and β-sesquiphellandrene are the most important compounds of freshly distilled oil. They can be converted into ar-curcumene during a long storage. Its percentage varied from 0.1% (Wynad local) to 32.9% (Narasapattam). The ratio of β-sesquiphellandrene and α-zingiberene is considered as indicative of the age of the oil. The percentage of

zerumbone, a well-known compound of wild ginger, is the highest in cv. Wynad local (Kerala) (19.8%), followed by Brazil (8.8%), Ernad Chernad (8%), and No. 656 (Himachal Pradesh) (7.4%). Only traces were observed in cv. Narasapatham. Indian ginger oils obtained by hydrodistillation of coarsely ground rhizomes are valued for their flavor and perfume.

Vernin and Parkanyi (1994) compared the chemical composition of commercial oils from India and China (see Table 3.16).

Table 3.16 Chemical composition of ginger essential oils of various origins*,**

	India		*China*		*Australia*
Compounds	*a*	*b*	*b*	*c*	*d*
HYDROCARBONS					
Monoterpenes					
α-Thujene	—	tr***	tr	—	0.93
α-Pinene	2.5	1.4	1.3	1.0	0.93
Camphene	8.0	4.5	4.7	3.9	3.7
β-Pinene	0.4	0.1	0.2	0.1	0.1
Sabinene	0.1	0.04	0.06	—	—
Myrcene	0.9	0.4	0.6	0.1	0.5
α-Phellandrene	0.3	0.2	0.15	—	—
Limonene	3.1	0.9	0.95	—	0.4
β-Phellandrene	4.2	3.4	2.5	—	1.6
α-Terpinene	—	0.1	0.2	—	—
γ-Terpinene	0.1	—	—	—	—
Aromatics (Miscellaneous)					
Toluene	tr	tr	tr	—	—
α-Cymene	0.1	—	0.06	—	—
α,*p*-Dimethylstyrene	tr	—	—	—	—
Cuminyl alcohol	tr	—	—	—	—
Isopropyl anisole	—	tr	tr	—	—
Sesquiterpenes					
δ-Elemene	—	tr	tr	0.1	0.23
γ-Elemene	tr	tr	tr	0.1	—
β-Elemene	0.2	tr	tr	—	0.2
(*Z* or *E*)-β-Farnesene	—	tr	tr	—	0.18
β-Bisabolene	6.0	(Mixture)+		—	2.7
α-Copaene	0.1	0.46	tr	—	—
α-Bisabolene	—	—	—	—	10.8
cis-γ-Bisabolene	7.0	—	—	—	—
β-Gurjunene	—	—	—	0.6	—
β-Caryophyllene	0.1	0.3	0.5	0.4	—
γ-Muurolene	—	—	—	tr	tr
δ-Cadinene	tr	tr	tr	—	—
δ-Selinene	—	—	—	tr	tr

ar-Curcumene	8.0	17.1	17.1	26.3	3.25
α-Zingiberene	30.0	46.2^{+}	38.1^{+}	0.28	25.9
β-Sesquiphellandrene	9.0	7.3	7.2	—	8.2
γ-Cadinene	—	—	—	—	0.14
(*E*)-β-Bergamotene	—	tr	tr	—	—
Germacrene B	0.6	tr	tr	—	—
Germacrene D	0.4	tr	tr	—	—
(*Z* and *E*)-Calamenenes	—	tr	tr	tr	tr
Pentenyl curcumene	—	tr	—	—	0.2
ALDEHYDES					
Monoterpenes					
Myrtenal	tr	—	—	—	—
Phellandral	tr	—	—	—	—
Neral	0.5	tr	tr	1.34	2.9
Geranial	0.9	tr	tr	2.93	2.5
Citronellal	0.4	—	—	—	—
Aliphatics					
Butanal	tr	—	—	—	—
2- and 3-Methylbutanals	tr	—	—	—	—
Hexanal	tr	tr	—	—	0.52
trans-2-Hexenal	tr	—	—	—	—
Octanal	tr	—	—	—	—
Decanal	tr	—	—	—	0.11
Undecanal	tr	—	—	—	—
KETONES					
Monoterpenes					
Cryptone	tr	—	—	—	—
Camphor	tr	tr	tr	0.1	—
Carvotanacetone	0.1	—	—	—	—
Aliphatics					
2-Hexanone	0.1	—	—	—	—
6-Mehtyl-5-hepten-2-one	0.2	0.2	0.35	0.4	—
2-Heptanone	0.1	tr	tr	—	—
2-Nonanone	0.1	0.4	tr	—	—
2-Undecanone	0.21	—	0.1	—	—
2-Tridecanone	—	tr	tr	—	—
ESTERS					
Monoterpenes					
α-Fenchyl acetate	0.1	—	—	—	—
α-Terpenyl acetate	1.4	—	—	—	—
Isobornyl acetate	—	—	—	—	0.1
Bornyl acetate	tr	tr	—	0.23	—
Geranyl acetate	—	—	—	2.92	0.12
Citronellyl acetate	0.4	—	—	0.29	—
Aliphatics					
2-Heptyl acetate	tr	—	—	0.1	—
2-Nonyl acetate	tr	—	—	—	—

Table 3.16 (continued)

ALCOHOLS					
Monoterpenes					
Linalool	0.6	tr	tr	0.46	0.46
cis-Sabinene hydrate	0.1	—	—	—	—
Borneol	0.1	—	—	—	—
Menth-2-en-1-ols	tr	—	—	—	—
Terpinen-4-ol	—	—	—	0.1	—
α-Terpineol	0.1	0.3	0.8	0.37	—
Isopulegol	0.1	—	—	—	—
Geraniol	tr	0.5	0.7	0.30	0.66
Citronellol	2.0	—	—	0.21	—
Sesquiterpenes					
Elemol	0.2	tr	tr	—	0.25
α-Bisabolol	—	—	—	—	0.14
β-Bisabolol	tr	—	—	—	—
Zingiberenol (I)	0.4	0.3	0.3	—	0.15
Zingiberenol (II)	—	tr	tr	—	—
Aromadendrenol	—	—	—	—	0.2
Cubebol	0.1	—	—	—	—
10-α-Cadinol	tr	—	—	—	—
cis-Sesquisabinene hydrate	0.3	0.2	0.2	—	0.22
α-Eudesmol	0.1	tr	tr	—	—
β-Eudesmol	0.6	tr	tr	—	—
trans-α-Sesquiphellandrol	0.4	0.2	0.1	—	—
Nerolidol	0.8	0.41	0.4	—	0.92
10-epi-γ-Eudesmol	—	tr	tr	—	—
Aliphatics					
2-Butanol	tr	—	—	—	—
2-Methyl-3-buten-2-ol	tr	—	—	—	—
3-Methylhexanol	tr	—	—	—	—
6-Methyl-2-hexanol	—	—	—	0.1	—
2-Heptanol	tr	0.36	tr	—	—
2-Nonanol	tr	tr	tr	—	—
Dodecatrienol	tr	—	—	—	0.2
MISCELLANEOUS					
Perillene	0.1	—	—	—	—
1,4-Cineole	tr	—	—	—	—
1,8-Cineole	1.0	1.7	2.1	4.0	3.0
Limonene epoxide	—	—	—	tr	tr
Terpinolene oxide	tr	tr	tr	—	—
Caryophyllene oxide	tr	—	—	—	—
α-Naginatene	0.2	—	—	—	—
Zingerone	—	—	—	—	0.6
(6)-Paradol	—	—	—	—	0.1
(6)-Shogaol	—	—	—	—	0.3

*a) Lawrence (1983) also reported alkanes C_{11} to C_{23} and the following sesquiterpene hydrocarbons: cyclosativene, cyclocopacamphene, sesquithujene, β-ylangene, selina-4,11-diene, selina-3,11-diene, selina-3(7),11-diene, α-amorphene, zonarene, 10-epizonarene, α-cadinene, and β-curcumene in trace amounts.
[b] Vernin and Parkanyi (1994), commercial samples.
[c] Zhu et al. (1995).
[d] Bartley and Foley (1994).
**Besides the usual compounds, Nishimura (1995), using the MDGC-MS technique, identified the following compounds in a fresh ginger extract: 2-octanol, 2,6-dimethyl-5-heptenal, 2-nonanone, 2-(3-methyl-2-butenyl)-3-methylfuran, nonanal, 2-pinen-5-ol, *cis*- and *trans*-rose oxides, 2-octylacetate, camphene hydrate, isoborneol, 3,7-dimethyloctadienols (3*Z*, 6*Z* and 3*E*, 6*E*), and (2,3-epoxy-3-methylbutyl)-3-methylfuran
$^{+}$ =α-Zingiberene + β-bisabolene.
***tr: traces

Table 3.17 Geographical variations of ginger oil yields from various areas of India

Samples/areas	*Gujarat*	*Madhya Pradesh*	*Maharashtra*	*Kerala*	*West Bengal*
1	0.23	0.11	0.09	0.1	0.12
2	0.23	0.12	0.09	0.1	0.12
3	0.24	0.13	0.09	0.1	0.11
4	0.24	0.13	0.09	0.1	0.12
Mean	0.3	0.12	0.09	0.1	0.11
COV%	3.07	7.21	0.8	0.72	7.87

Adapted from Sane et al. (1998).

Minor differences were noted. In particular, higher amounts of ketones (2-nonanone and 2-undecanone) and 2-heptanol were observed in the oil from India. On the other hand, the absence of bornyl acetate and calamenene isomers in the Indian ginger oil should be noted as well as the presence of two zingiberol isomers in both oils. If we compare the composition of the Indian oil with that studied by Lawrence (1983), Lawrence found higher amounts of monoterpenes and a lower amount of α-zingiberene.

Tomi et al. (1995), using a computer-assisted ^{13}C-NMR analysis in combination with HPGC, determined the major components of ginger oil: camphene (7.9%), β-bisabolene (5.9%), limonene (6.0%), (E,E)-α-farnesene (5.4%), and α-zingiberene (27.2%). Sane et al. (1998) studied geographical variations of ginger oils from the various areas of India (Table 3.17).

Their results show a greater yield for Gujarat (0.24%) than for the other three areas (0.12%). Rani (1999) studied the formation of sesquiterpene hydrocarbons in Indian ginger oil. The oil contained α-zingiberene (22%), β-zingiberenene (7%), β-bisabolene (14%), ar-curcumene (20%), and the remaining fraction contained α-selinene, β-elemene, β-farnesene, sesquithujene, and sesquisabinene. It also contained some oxygenated mono- and sesquiterpenes. The biosynthesis of the three main sesquiterpene hydrocarbons was established using the isotopic method.

Essential Oils from China

A review of the raw and dry ginger produced in Szechuan shows that the essential oil contains α-zingiberene, ar-curcumene, α-farnesene, β-farnesene, linalool, gingerol, β-sesquiphellandrene, zingerone, dehydrogingerol, hexahydrocurcumin, and other

compounds (Chen and Guo, 1980). Dry ginger produced in Szechuan contained 1 to 2% essential oil as compared with 0.2 to 0.4% of raw ginger found in Peikin. TLC indicated that most of the constituents were identical. The citral content for a Chinese oil was very low (0.22%) (Lin and Hua, 1987) compared to that found in Japanese oils or in a Fijian oil (64%) (Smith and Robinson, 1981). Chen and Ho (1988) compared the chemical composition of ginger oils from Taiwan obtained by steam distillation and supercritical CO_2 extraction. These results are reported in Table 3.18.

Ginger oils from Taiwan obtained both from steam distillation and liquid CO_2 extraction were fractionated into hydrocarbons and oxygenated hydrocarbons using silica gel CC. The two fractions were analyzed by HRGC and HRGC/MS. Monoterpenes, sesquiterpenes, aliphatic aldehydes and ketones, and neral and geranial as well as monoterpene and sesquiterpene alcohols were the major categories of ginger components. They were partially affected or generated by thermal-induced degradation during steam distillation. From the results reported in Table 3.18, it appears that the amount of monoterpene hydrocarbons greatly increased with CO_2 extraction with the exception of terpinolene. To a smaller extent, the same is true for sesquiterpene hydrocarbons. However, the percentage of ar-curcumene decreased in the fraction obtained with liquid CO_2 extraction.

The constituents of ginger oils prepared by different processes (cold dried, hot dried, or baked at 220° C) were compared by column chromatography and mass spectra (Ye et al., 1989). Odor assessments for volatile compounds of ginger essential oils from Taiwan by sniffing GC were carried out by Sheen et al. (1992a). Geranial, β-sesquiphellandrene

Table 3.18 Comparison of the hydrocarbon fraction of ginger oils from Taiwan obtained by steam distillation and supercritical CO_2 extraction

Compound	*Steam distillation*	*Liquid CO_2 extraction*
Monoterpene hydrocarbons		
α-Pinene	0.16	0.98
Camphene	0.4	3.08
β-Pinene	0.02	0.16
Myrcene	0.08	0.9
β-Phellandrene	0.09	0.89
Limonene	0.31	2.75
γ-Terpinolene	0.11	0.11
Total	1.17	8.87
Sesquiterpene hydrocarbons		
β-Elemene	0.29	0.31
α-Zingiberene	14.19	24.15
β-Bisabolene	6.37	5.6
γ-Bisabolene	3.47	8.4
ar-Curcumene	16.3	7.96
Total	51.24	56.56

Adapted from Chen and Ho (1988).

+ ar-curcumene + geranyl acetate were found to be important aroma contributors. Other contributors were α-pinene, myrcene, β-phellandrene, 1,8-cineole, citronellol, camphene, β-pinene, limonene, α-terpineol, 2-heptenal + 6-methyl-5-hepten-2-one, citronellal + α-copaene, linalool, and α-zingiberene.

Vernin and Parkanyi (1994) studied a commercial sample of ginger oil from China. The results were compared with those obtained from India (see Table 3.16). Three ginger essential oils (Yu et al., 1998) obtained by different extraction methods (steam distillation, cold-pressed extraction, and CO_2 supercritical fluid extraction) were analyzed qualitatively and quantitatively by HRGC/MS. By steam distillation, 46 constituents were identified, whereas by cold-pressed oil and by the supercritical CO_2 extraction, 50 and 61compounds were identified, respectively. The main components and content of each oil were different. The principal components of the steam-distilled oil were monoterpenes and sesquiterpenes. The pungency components of ginger were not found. Besides sesquiterpenes, the other two oils contained gingerols and shogaols. The total content was 18.61% in the cold-pressed oil and 23.1% in the CO_2 extraction. These two oils preserved the typical spicy odor and pungency of ginger. Similar results were also reported by Yu et al. (1998). Sixty-six chemical components were identified by HRGC/MS in the volatile oil from ginger rhizomes. The major components were camphene, β-phellandrene, and 1,8-cineole. Li et al. (2001b) compared the chemical composition between dry and fresh ginger using HRGC/MS spectrophotometry and TLC. They analyzed the essential oils, total gingerols, and amino acids. Quantitative and qualitative differences were observed between dry and fresh ginger.

Essential Oils from Other Countries in Asia (Vietnam, Korea, Japan, Indonesia, Fiji, Philippines, and Malaysia)

Vietnamese ginger oil obtained by steam distillation of dried rhizomes (2.7% yield) was studied by GC, GC/MS, and ^{13}C-NMR (Van Beek et al. 1987). The oil included 28% monoterpene hydrocarbons, 37% oxygenated monoterpenes, 25% sesquiterpene hydrocarbons, 8% oxygenated sesquiterpenes, and 2% nonterpenoid compounds. Geranial (16%) and neral (8%) gave a lemon-like character to the oil. Among other identified compounds were: furfural, 2,5-dimethylhept-5-enal, dihydroperillene, *p*-cymen-8-ol, allo-aromadendrene, γ-muurolene, lauric acid, methyl isoeugenol, γ-eudesmol, farnesol, and xanthorrhizol. Decontamination of the dried ginger by gamma irradiation did not affect the yield and the composition of the oil, which was similar to that of fresh Sri Lankan ginger.

Ginger from Korea was extracted with liquid carbon dioxide by Kim et al. (1991, 1992). The extract (6.96% yield) was fractionated into two fractions using a silica gel column. The major compounds in ginger oil were: α-zingiberene, citronellol + β-sesquiphellandrene, geraniol, γ-bisabolene, and ar-curcumene + geranyl acetate. Ginger oil contained 68.1% of sesquiterpene hydrocarbons, 31.9% of oxygenated hydrocarbons (1,8-cineole, neral, geranial, geranyl acetate, citronellol, geraniol, α-terpineol + borneol). The volatile oil content was 0.33%.

In volatile oils of two fresh cultivars, the same workers characterized 101 compounds, of which 54 were identified by comparing GC retention times and mass spectra, and 47 only tentatively.

Comparison with ginger oils of different origins shows a good yield of the oil and the highest amount of sesquiterpene hydrocarbons.

The low-boiling compounds obtained by steam distillation from Japanese ginger rhizome were reported by Kami et al. (1972). Besides the usual monoterpenes and 1,8-cineole, they found alkanes (C_7 to C_9), aliphatic aldehydes (C_2, $C_3 - C_4$, iso-C_5), glyoxal, methylglyoxal, aliphatic ketones (acetone, isobutyl methyl ketone), aliphatic alcohols (n-propyl alcohol, sec-butyl alcohol, tert-butyl alcohol, n-nonyl alcohol), aliphatic esters (methyl acetate, ethyl acetate, ethyl propionate), and three sulfides (diethyl sulfide, ethyl isopropyl sulfide, allyl methyl sulfide). The major compounds in the headspace were camphene (41%), α-pinene (25%), myrcene (7%), 1,8-cineole (7%), β-phellandrene (6%), β-pinene (4%), tricyclene (or thujene) (3%), sabinene (1.5%) and δ-3-carene (0.5%). Percentages of other compounds account for 2%.

Using a capillary column (Carbowax 20 M, 34 m × 0.25 mm i.d.), Masada (1976) identified the following compounds: α-pinene, camphene, β-pinene, α-phellandrene, limonene, 1,8-cineole, C_8 to C_{10} aldehydes, linalool, linalyl acetate, β-caryophyllene, borneol, geranial, geraniol, and eugenol. The usual sesquiterpene hydrocarbons from ginger visible on the chromatogram have not been described and quantified.

Seven varieties of ginger (small type—Kintoki and Yanaka; medium type—Sansyu; large type—Otafuku, Tosaichi, Cambo, and Jumbo) were studied by Tanabe et al. (1991). The varieties were cultivated under the same conditions in Japan. Analyses were carried out by HRGC/MS and SIM. The results showed that there were considerable differences in the composition of the volatile components of fresh ginger among the tested varieties.

The comparison of three extraction methods (solvent extraction with acetone, steam distillation, and freeze-dried under vacuum) showed the first method to be the best for the Kintoki sample. Prolonged exposure to heat may cause decomposition of some components. Percentages of α-pinene, camphene, myrcene, β-phellandrene, 1,8-cineole, borneol, neral, geranial, geranyl acetate, ar-curcumene, α-zingiberene, β-bisabolene, and β-sesquiphellandrene are reported in Table 3.19 for the various tested areas.

In the original paper, the values were given in parts per million (ppm). For clarification and comparison with other countries, percentages have been calculated and the values (in ppm) for α-zingiberene are given. For example, the percentage of this sesquiterpene in Kintoki and Yanaka is 50.4%, corresponding to 5.227 ppm.

Van Beek (1991) reported gas chromatograms of an Indonesian ginger oil with a high citral content on DB-1 and DB Wax capillary columns. The major compounds were: the usual sesquitepene hydrocarbons, geranial, camphene, neral, α-pinene, myrcene, limonene, β-phellandrene, geraniol, and 1,8-cineole. On the nonpolar DB-1 column, there is a good separation of monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, and their oxygenated derivatives eluted at the end of the chromatogram. A good separation of the five main sesquiterpene hydrocarbons has been obtained, but the separation between limonene, β-phellandrene, and 1,8-cineole is poor. These latter compounds give a better separation on the DB-Wax column.

Essential oil of ginger from Fiji was studied by Smith and Robinson (1981) and compared with essential oils from other countries (India, China, Japan, Australia). The yield of the oil from Fiji obtained by steam distillation ranged from 0.1 to 0.2%. Analyses were carried out on packed columns. Among the 25 identified compounds, they show a higher content of neral (15 ± 5%), geranial (27 ± 9%), and 1,8-cineole (8 ± 2%) when compared with the oils from other countries.

In the hydrocarbon fraction, δ-elemene, α-copaene, β-bourbonene, α-bergamotene, β-elemene, β-caryophyllene, *trans*-β-farnesene, α-salinene, γ-amorphene, α-zingiberene

Table 3.19 Percentages of volatile components in dried ginger originating from various areas of Japan*

Compounds	*Percentages***			
			Type iii	
	Type i	*Type ii*	*a*	*b*
α-Pinene	1.85 ± 0.05	2.0	2.0	1.7
Camphene	7.45 ± 0.25	6.6	6.0 ± 0.6	4.4
Myrcene	1.05 ± 0.05	1.3	1.9 ±0	14.0
β-Phellandrene	2.5 ± 0.3	3.6	4.1 ±0.2	4.2
1,8-Cineole	3.2 ± 0.1	3.5	4.5 ± 0.3	3.3
Borneol	0.87 ± 0.03	1.0	0.54 ± 0.2	0.4
Neral	0.5 ± 0	1.3	2.35 ± 0.35	2.1
Geranial	3.0 ± 0.1	9.65	17.9 ± 0.5	15.3
Geranyl acetate	0.7 ± 0.1	1.2	3.2 ± 0.9	3.1
ar-Curcumene	1.5 ± 0.1	1.9	1.5 ± 0.2	1.5
α-Zingiberene	50.4 ± 1.3	42.6	32.5 ± 0.6	30
β-Bisabolene	10.4 ± 0.1	10.6	12.8 ± 0.8	10.9
β-Sesquiphellandrene	16.75 ± 0.05	14.5	10.9 ± 0.9	8.9
Dryness factor***	24.13/29.62	17.85	11.1 ± 1.4	9.62

*Adapted from Tanabe et al. (1991).
**The amounts (in ppm) of α-zingiberene in each sample were 5227.6, 3734.3, 5968.1, 7253.5, 4350.7, 5880.6, and 7262.0, respectively.
[i]Kinto and Yanaka; [ii]Sansyu; [iii]a, Otafuku, Tosaichi and Jumbo; b, Cambo samples, respectively.
***Freeze-dried weight/fresh weight × 100.

+ β-bisabolene, ar-curcumene, calamenene, caryophyllene oxide, and cuparene were identified. The two major compounds β-bisabolene and ar-curcumene, most likely arise during storage by rearrangement of α-zingiberene and β-sesquiphellandrene. Sesquiterpene, epizonarene, and zonarene also found in the oil have been previously identified in Indian essential oils by Andersen et al. (1973) and Terhune et al. (1975).

On the other hand, the oil from Fiji was found to be similar to those of the Japanese samples from Taneshoga and Oyashoga, which had a low geraniol-geranyl acetate content, and 17 to 20% neral, and 23 to 35% geranial, respectively. Nevertheless, other Japanese oils differed significantly depending on the location (Tanabe et al., 1991). A low citral (neral + geranial) content has been found in oils from India (<3%), and Africa, is higher in Australia and Japan, and the highest in Fiji.

By hydrodistillation of the fresh rhizomes of ginger from the Philippines, Anzaldo et al. (1986) obtained 0.2 to 1.0% oil yield. By using TLC, GC, and IR spectroscopic data, 10 components were identified, with citral being the major component. Geraniol and linalool were also present. Physicochemical constants of the oil were also reported.

Some important metabolites from Malaysian ginger have been reported by Hasnah and Ahmad (1993). Among several categories of identified compounds were: sequiterpenes (germacrene, humulene, zerumbone, zerumbodienone, and humulene epoxide), diterpenes including coronarin C, coronarin E, isocoronarin D, the isomer of isocoronarin D and labd-8(17),12-dien-15,16-dial, phenolics, and piperine. Some of these compounds seemed to be potent for certain biological activities.

Essential Oils from Africa (Nigeria)

Nigerian ginger essential oils were analyzed by Ekundayo et al. (1988). Samples of fresh rhizomes were purchased from a local market. Fresh and dried rhizomes after homogenization were hydrodistilled (yields were 1.02% and 1.84%, respectively). The two oils have been separated into oxygenated and hydrocarbon fractions and analyzed by GC/MS. The results are given in Table 3.20.

Table 3.20 GC-MS analyses of Nigerian ginger oils obtained from fresh and dried rhizomes**

	(%)	
Compounds	*Fresh*	*Dried*
HYDROCARBONS		
Monoterpenes[a]		
Tricyclene (or α-thujene)	0.1	tr*
α-Pinene	1.5	0.4
Camphene	5.6	1.7
Sabinene	0.1	tr
β-Pinene	0.3	0.1
Myrcene	1.1	0.5
α-Phellandrene	0.2	0.2
δ-3-Carene	tr	tr
p-Cymene	0.1	tr
1,8-Cineole (4.5 %) + limonene + β-phellandrene	10.5	4.5
γ-Terpinene	tr	tr
Terpinolene (+ linalool)	1.4	0.7
Sesquiterpenes[b]		
δ-Elemene (+ neryl acetate)	0.05	tr
α-Copaene	0.3	0.35
β-Elemene	0.1	0.2
β-Caryophyllene	tr	0.1
α-Bergamotene	0.3	0.35
(E)-β-Farnesene	0.3	0.3
allo-Aromadendrene	0.2	0.3
ar-Curcumene	4.2	3.1
Germacrene D	1.05	1.6
α-Zingiberene	12.2	28.1
β-Bisabolene	5.6	8.4
γ-Cadinene	0.4	0.7
β-Sesquiphellandrene	6.45	10.6
ALCOHOL[c]		
Monoterpenes		
Linalool	tr	tr
(Z)-Sabinene hydrate	0.2	0.1
(E)-Sabinene hydrate	0.1	tr
Isoborneol	0.1	tr

Borneol	2.2	1.6
Terpinen-4-ol	0.2	0.1
α-Terpineol	1.1	0.8
Citronellol	0.7	0.45
Geraniol	0.8	0.5
Sesquiterpenes		
Elemol	0.2	0.3
Nerolidol	0.1	0.7
Viridiflorol	0.3	0.4
β-Eudesmol	tr	tr
(*E*)-β-Sesquiphellandrol	0.6	0.6
(*E,E*)-Farnesol	0.3	0.4
CARBONYL COMPOUNDS AND ESTERS[d]		
6-Methyl-5-heptenone	0.2	0.1
Camphor	0.2	0.1
Citronellal	0.3	0.15
Neral	8.9	5.3
Geranial	15.0	9
Bornyl acetate	0.4	0.3
Citronellyl acetate	0.1	0.1
Neryl acetate	tr	tr
Geranyl acetate	0.4	0.5
(*E,E*)-Farnesal	0.4	0.5
[a]Total monoterpene hydrocarbons	16.4	3.7
[b]Total sesquiterpene hydrocarbons	30.15	51.6
[c]Alcohol	6.9	5.95
[d]Carbonyl compounds and esters	25.9	16.05
Total	79.35	77.3

*tr: traces
**Ekundayo et al., (1988)

These results showed a usual percentage of α-zingiberene for the essential oil obtained from dried rhizomes (28%) and a high content in neral and geranial as in Australian and Japanese oils. These percentages are higher in oils obtained from fresh rhizomes. The rhizomes of ginger were also examined for their oil and moisture contents by Dambatta et al. (1988). Some characteristics of the oil, such as acid value, the saponification index, and the iodine value, showed slight variations from the values reported for ginger oils obtained in other countries. GC/MS analysis of the oil revealed the presence of many components including camphene, myrcene, α-phellandrene, α-copaene, α-farnesene, β-caryophyllene, α-zingiberene, and germacrene, all being well-known components in ginger oils. The next year, Onyenekwe and Hashimoto (1999) studied the composition of the Nigerian essential oil obtained from dried rhizomes. The hydrodistilled oil (2.4%) consisted of 64.4% carbonyl compounds, 5.6% alcohols, 2.4% monoterpene hydrocarbons, and 1.6% esters. The main components were: α-zingiberene (29.5%), and sesquiphellandrene (18.4%). Besides the usual compounds, they also identified: 2,6-dimethyl hepten-1-ol, α-gurjunene, linalool oxide, isovaleraldehyde, 2-pentanone, α-cadinol, α-and

γ-calacorenes, eremophyllene, γ-muurolol, α-himachalene, α-cubebene, acetic acid, pinanol, α-santalene, geranyl propionate, geranic acid, *(E,E)*-α-farnesene, and N-methylpyrrole. The identification of this latter heterocyclic compound is of interest.

Afzal et al. (2001) reported retention indices both on polar and nonpolar columns, as well as the percentages of 29 volatile compounds identified in a Nigerian ginger oil. These results are given in Table 3.21 and compared with those reported by Akhila and Tewari (1984).

Table 3.21 Gas chromatography analysis of ginger oils from Nigeria*

	(%)	
Compounds	*a*	*b*
HYDROCARBONS		
Monoterpenes		
δ-3-Carene	—	tr**
α-Thujene	0.2	—
α-Pinene	3.1	0.4
Cumene	—	tr
Camphene	8.5	1.1
β-Pinene	0.6	0.2
Myrcene	1.5	0.1
Sabinene	0.8	tr
α-Phellandrene	0.5	tr
β-Phellandrene	8.9	1.3
Limonene	1.7	1.2
γ-Terpinene	0.1	—
ρ-Cymene	0.1	0.1
Terpinolene	0.3	—
Sesquiterpenes		
α-Copaene	0.55	—
α-Zingiberene	29	35.6
β-Bisabolene	10 ± 4	0.2
(*E,E*)-α-Farnesene	7.3	9.8
ar-Curcumene	—	17.5
β-Sesquiphellandrene	12 ± 2	—
β-Elemene	0.7	1.0
α-Selinene	—	1.4
OXYGENATED COMPOUNDS		
Monoterpenes		
Aldehydes		
Neral	1.35	0.8
Geranial	1.4	1.4
Nonanal	—	0.1
Decanal	—	0.2
Alcohol		
Linalool	0.6 ± 0.2	1.3
α-Terpineol	0.3	tr

Nerol	1.35	tr
d-Borneol	0.95	2.2
Geraniol	0.45	0.1
2-Heptanol	—	tr
2-Nonanol	—	0.2
Ketone		
Methylheptenone	0.4	0.1
Esters		
Bornyl acetate	0.8	0.1
Geranyl acetate	0.9	—
MISCELLANEOUS		
1,8-Cineole	—	1.3

*The first column, a, gives the mean of the values reported by Afzal et al. (2001) on polar and nonpolar columns. The second column, b, gives the values reported by Akhila and Tewari (1984) for comparison.
**tr: traces

The high percentage found by Afzal et al. (2001) for ar-curcumene (17.7%) seems to indicate a rearrangement of β-bisabolene. A very low content of neral and geranial in the two oils was observed in contrast to the results of Ekundayo et al. (1988) (see Table 3.20). The chemical composition of the sesquiterpene hydrocarbons reported by Afzal et al. (2001) corresponds to that for oils from other countries.

Essential Oils from Other Countries (Australia, Brazil, Poland, Mauritius Island, and Tahiti)

GC analysis of ginger oil from Australia obtained by hydrodistillation or steam distillation of dried rhizomes indicated that it was similar to that from other areas (Connell, 1970; Connell and Jordan, 1971). The major constituents are usual sesquiterpene hydrocarbons with a bisabolane skeleton: α-zingiberene (20 to 30%), ar-curcumene (6 to 19%), β-sesquiphellandrene (7 to 12%). These compounds are accompanied by usual monoterpene hydrocarbons and oxygenated derivatives. Of particular interest is the presence of a relatively high proportion of neral and geranial responsible for the distinctive citrus-like aroma of the oil. GC chromatograms on a column coated with Apiezon M at 130 and 147° C were reported as well as the chromatogram of an African oil. Zingiberone and zingiberenol were also identified.

Taveira Magalhaes et al. (1997a,b) studied essential oils and oleoresins of ginger from Brazil. Two kinds of ginger are characterized by the size of their rhizomes: Gigante commercial crop for export and Calpira for household consumption and of Japanese origin. Steam distillation of dried rhizomes gave essential oils that where characterized by their physicochemical constants and GC analysis. Comparative analysis showed differences between Calpira and Gigante gingers depending on the distillation method and the type of rhizomes (fresh or dried). The strong lemony scent due to its neral and geranial contents is more pronounced for Gigante oil than for Calpira oil. Agronomical and market aspects of ginger cultivation of the two varieties were also reported. The same workers reported the chemical composition of the essential oils of these two kinds of ginger. Most important components are given in Table 3.22. Yields of essential oils obtained from dried rhizomes were 1.2 to 2.5% for Gigante and 2.5 to 2.8% for Calpira.

Table 3.22 Gas chromatography analyses of Gigante and Calpira ginger oils from Brazil[a]

Compounds	*% (Fresh ginger)*	
	Gigante	*Calpira*
α-Pinene (+ camphene)	5.3–9.3	7.4–9.2
β-Phellandrene (+ 1,8-cineole)	6.4–11.2	6.2–9.3
Neral + geranial	14.3–20.7	6.2–7.0
(+) ar-Curcumene	4.0–6.0	7.0–8.4
(−) α-Zingiberene	18.4–27.8	25.3–32.6
β-Bisabolene (+ *E,E* − α-farnesene)	8.4–13.6	8.4–12.4
β-Sesquiphellandrene	7.0–9.7	9.2–12.2
Total SQHC	40.4–57.1	51.3–64.2

[a]According to Taveira Magalhaes et al. (1997a). GC analyses were carried out on packed columns (3 m × 1/8" id) coated with 5 percent SE 30 on Chromosorb W − AW DMCS 80–100 mesh.

In another paper, the same authors studied the effect of drying on essential oil and oleoresin compositions for Gigante ginger from various areas in Brazil. The essential oil content was determined on oleoresins obtained with different solvents. The Brazilian ginger provided an essential oil in a 2.2% yield. GC/MS analysis on a nonpolar capillary column (SE 30) of the oil is given in Table 3.23.

Table 3.23 GC-MS analysis of the Gigante essential oil from Brazil[a]

Compounds	*%*	*Compounds*	*%*
2-Heptanol	0.4	Borneol	0.7
α-Pinene	2.3	Neral	5.4
Camphene	5.7	Citronellol	1.0
β-Pinene	0.4	Geraniol (+ geranial)	9.6
6-Methyl-5-hepten-2-one	0.5	α-Copaene	0.5
Myrcene	1.3	Geranyl acetate	0.5
α-Phellandrene	0.6	β-Elemene	0.9
Limonene	1.6	Aromadendrene	0.5
β-Phellandrene	8.4	ar-Curcumene	7.9
(+ 1,8-cineole)		α-Zingiberene	19.0
ρ-Cymene	0.2	β-Bisabolene	4.7
Terpinolene	0.5	*(E,E)*-α-Farnesene	7.4
Linalool	0.7	β-Sesquiphellandrene	7.0
2-Nonanol	0.3		
Citronellal	0.3		
Total: Monoterpene hydrocarbons 18% Sesquiterpene hydrocarbons 47.4% Neral + geranial 13%			

[a]Adapted from Taveira Magalhaes *et al.* (1997b).

Table 3.24 Organoleptic properties of ginger oils of various origin*

Origin	*Color*	*Odor/Flavor*[a]
Cochin (India)	Bold, light brown pale yellow to light amber, partly peeled	Citrus, lemon-like, fresh woody and spicy odor
Sierra Leone (Africa)	Plump, dark, partly peeled from sides	Pungent, slightly camphoraceous flavor
Nigeria (Africa)	Bold, light color, partly peeled, fibrous	Very pungent, camphoraceous flavor
Jamaica	Bold, very light buff color, clearly peeled	Delicate, freshness with rubber-like note
Australia	—	More pronounced than in Indian oil

*Akhila and Tewari, (1984)
[a]The aroma character impacts are α-zingiberene, β-zingiberene, geranial, geraniol, and gingerone, while contributors are gingerols, borneol, linalool, 1,8-cineole, isoborneol, camphene, and 4-terpineol.

The composition and organoleptic properties of a ginger extract from the Polish Institute of Fermentation Industry were compared with those of two foreign extracts (see Table 3.24) (Kostrzewa and Karwowska, 1976). The Polish extract contained 26.0% essential oil compared to 25.3% and 20.6% for the other extracts. Levels of α-zingiberene and zingiberol in the oil and the total gingerols and shogaols were 52.0%, 16.0%, 31.1%, and 20.0%, respectively, in the Polish extract against 47.2 to 45.3%, 13.6 to 11.6%, 24.8 to 20.8%, and 14.8 to 11.2%, respectively, for the two foreign extracts. The organoleptic characteristics of the Polish extract were found to be similar to one of the foreign oils, and they were different from the other foreign extract.

Ginger oil obtained by hydrodistillation of the rhizomes of the common ginger grown in Mauritius was investigated by GC and GC/MS (Gurib-Fakim et al. 2002). The oil was characterized by the presence of geranial (16.3%), neral (10%), α-zingiberene (9.5%), β-sesquiphellandrene (6.3%), and ar-curcumene (5.1%). The oil from Mauritius is similar to those containing high amounts of neral and geranial and a low content of α-zingiberene.

Van Beek (1990) analyzed by GC, on two columns at different polarity, 48 ginger oils from nine countries. The sesquiterpe fractions of these oils were qualitatively fingerprint identical in spite of the differences in the growing, storage, drying, and extraction conditions. There were only quantitative differences in composition.Vahira-Lechat et al. (1996) studied a steam-distilled essential oil from Tahiti. They found: α-zingiberene + (E,E)-α-farnesene (3.3 to 7.8%), β-bisabolene (7.9 to 8.8%), β-sesquiphellandrene (7.1 to 8%), ar-curcumene (0.4 to 3.6%), neral (5.4 to 6.7%), and geranial (8.9 to 18.1%) as the major compounds. These results showed a low percentage of α-zingiberene and a high content of neral and geranial. A low content of ar-curcumene seems to indicate no rearrangement of β-bisabolene. The oil is rather similar to that of Mauritius island.

Wild Ginger (*Z. zerumbet* Smith) Essential Oils

Wild ginger is a perennial root herb that grows in subtropical climates such as India, Southeast countries, South Pacific islands, and Okinawa. It has been used locally for

gardening and folk medicines. Since the first report on the essential oil of Indian wild ginger by Nigam and Levi (1963), essential oils have been widely studied for their medicinal properties due to their high content of zerumbone. The oil originating from Fiji, said to have medicinal properties, differs from the cultivated variety in India in its zerumbone content, which is much higher (57.7%) as compared to 37.5% (Duve, 1980). Steam distillation of the local variety yielded 0.3% of clear oil, which compared favorably with that of the cultivated variety overseas.

Chemical investigation of the aerial parts (stems, leaves, and flowers) of wild ginger (Z. *zerumbet*) of Vietnamese origin was subjected to GC and GC/MS analyses (Dung et al., 1995). About 40 compounds have been identified in the stem and leaf oils, accounting for more than 83 ± 1% of the oils. The major compounds appeared to be (Z)-nerolidol (16.8 and 22.3%), β-caryophyllene (10.4 and 11.2%), zerumbone (21.3 and 2.4%), and *trans*-phytol (7.0 and 12.6%), respectively. Predominant minor constituents included β-pinene (5.4 and 5.2%), α-humulene (2.5 and 2.9%), caryophyllene oxide (1.1 and 5.5%), and linalool (1.1 and 2.4%). The volatile flower oil was found to contain more than 60 compounds with 45 compounds making up to 85% of the oil. (Z)-nerolidol (36.3%) and β-caryophyllene (13.2%) were the major constituents.

GC/MS analysis of the essential oil obtained from dried rhizomes of wild ginger from India resulted in the identification of 36 compounds. Curzerenone (14.4%), zerumbone (12.6%), camphor (12.8%), isoborneol (8.9%), and1,8-cineole (7.1%) were found as the major components. GC, GC/MS, IR, and ^{1}H-NMR analyses showed that the main constituents found in the hydrodistilled oil from Z. *spectabile* Valet, were terpinen-4-ol (23.7 percent), labda-8(17),12-diene-15,16-dial (24.3%), α-terpineol (13.1%), and β-pinene (10.3%) (Sirat and Leh, 2001).

Zerumbone isolated from wild ginger has been claimed to be a potent inhibitor of 12-D-O-tetradecanoylphorbol-13 acetate, which induced Epstein-Barr virus activation (Murakami et al., 1999). Its IC_{50} value (inhibitory concentration of 50 percent) (0.14 μM) is noticeably lower than those of the antitumor promoters these workers have hitherto obtained. 8-Hydroxy-α-humulene was markedly active (IC_{50} = 0.95 μM). Zerumbone is easily obtained from Japanese wild ginger and is a useful and reproducible natural product. It possess a strong suppression of an antiproliferative activity in vitro against cultured tumor cells of mouse *t*-lymphoma cells, EL_4 at a concentration of 100 $mg.L^{-1}$ (Sawada and Hosokawa, 2002). They also described the synthesis of a woody fragrance by simple hydrogenation of zerumbone, which has a great potential for the preparation of useful compounds (Sawada et al., 2002). Zerumbone derivatives arising from a fragmentation process of zerumbone dibromide were found to be selective inhibitors of the growth of gram-positive bacteria (Kitayama et al., 2001).

Diterpenoids

Besides the usual mono- and sesquiterpene derivatives several diterpenoids, (24 to 26), have been identified in ginger rhizomes (Lee et al., 1982; Kano et al., 1990; Kikuzaki and Nakatani, 1996). The galanolactone (27), a furan diterpene, has been isolated from the Japanese ginger "Kinoki" by Kano et al. (1990), but was not found in ginger from China and India. The 8β-17-epoxy-12-ene-15,16-dicarboxaldehyde isolated from ginger reduces plasma cholesterol concentrations in hypocholesterolemia induced in mice (Tanabe et al., 1993). Labdane-type diterpenes from ginger oleoresin are reported in Figure 3.4, according to Kikuzaki and Nakatani (1996).

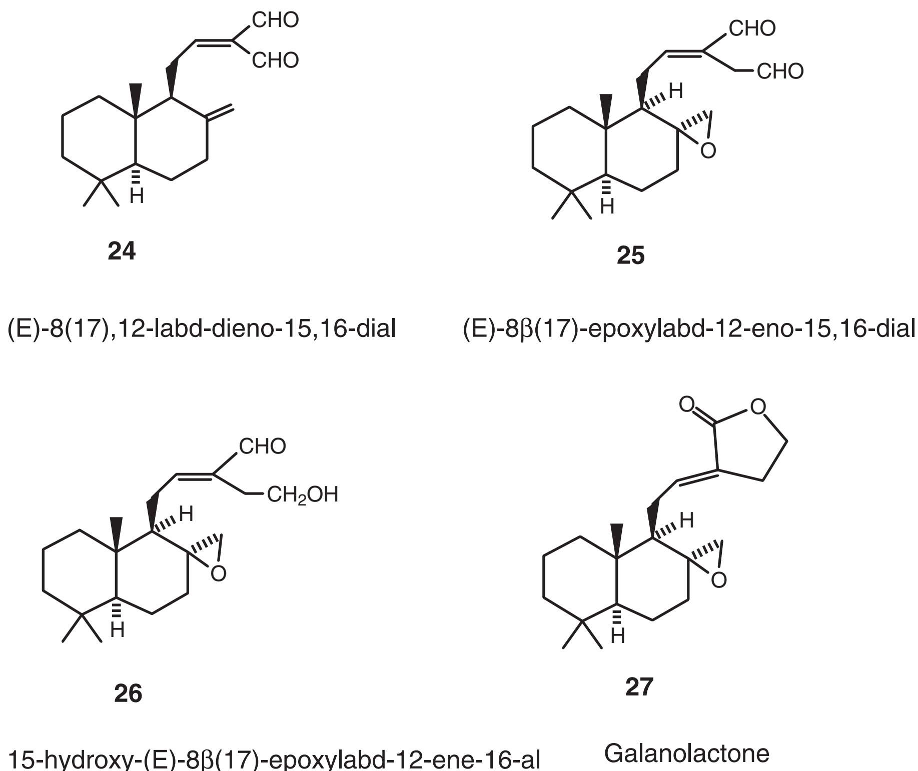
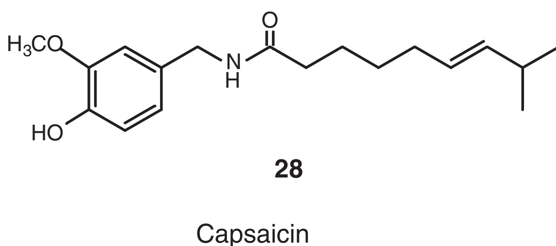


Figure 3.4 Diterpenoids of labdane type identified in ginger (adapted from Kikuzaki [2000]).



Capsaicin (**28**) is an artifact in ginger essential oil (Rosella et al., 1996).

Characteristic Flavor and Odor in Ginger

Odor quality of the oils for several imported and Australian commercial varieties of ginger have been compared by Mathew et al. (1973). Hot-air drying was the best method for the raw ginger products. The identification and evaluation of the flavor-significant components of ginger essential oil was made by Bednarczyk (1974) and Bednarczyk and Kramer (1975). They used stepwise multiple regression analysis, taking into account individual peak intensities and taste panel scores for ginger flavor intensity as a dependent

variable. Taste panel evaluation of the isolated components indicated that β-sesquiphellandrene and ar-curcumene are the prime contributors to the characteristic ginger attribute. α-Terpineol, neral, and geranial contribute to the lemony aroma of ginger oil, and may therefore be desirable additives to whole ginger oil to intensify its lemony or citrus character. Nerolidol contributes to the woody or soapy flavor and does not appear to be a good potential additive to ginger oil. A trained sensory panel judged a mixture of α-terpineol, neral, geranial, β-sesquiphellandrene, ar-curcumene, and nerolidol to be characteristic of ginger oil.

Kostrezewa and Karwawska (1976) investigated the characteristic flavor and odor of a Polish extract of ginger by comparing the yield of the essential oil and its levels of α-zingiberene and zingiberol as well as total gingerols and shogaols with two foreign extracts.

Pusrseglove et al. (1981) and Heath and Reineccius (1988) reported the impact compounds of ginger. Organoleptic properties of ginger oils from various origins have been described by Akhila and Tewari (1984).

Aromagrams and key compounds of various spices including ginger have been outlined and relation between their chemical structure and flavor have been described by Ney (1990a, b). Chemically speaking, ginger contains 2-methoxyphenols (or 4-substituted guaiacols). From the study of Nishimura (2001), it can be concluded that flavor dilution factors (FD), according to Grosh (1994), of compounds identified in fresh ginger are the highest for 1,8-cineole (15), linalool (20), citronellyl acetate (16), borneol (16), geranial (17), and geraniol (20), which are the most important contributors to the odor of ginger. Enantiomer separation of the characteristic odor compounds in Japanese fresh rhizomes of ginger was described in an excellent work of Nishimura (2001). Using multidimensional gas chromatography (MDGC) and chiral analytical HRGC/olfactometry (or sniffing), the odor character of each enantiomer was confirmed.

The fresh rhizomes of ginger were fractionated into a hydrocarbon fraction (hexane extract) and an oxygenated hydrocarbon fraction (methylene chloride extract). This latter fraction was subjected to chiral GC/olfactometry (GC/O) and GC/MS analyses. It was considered that monoterpenoids such as linalool, 4-terpineol, isoborneol, and borneol as well as geranial and neral might contribute to the characteristic odor of the fresh ginger. Each enantiomer was easily separated using the off-line MDGC system. The odor character of each enantiomer was confirmed by GC/O. The values are reported in Table 3.25.

Unfortunately, odor units which are the ratio between the concentration of each product in the oil and the corresponding threshold olfactive values, have not been measured.

Chemometrics

Fingerprint analysis of ginger oils by chemometrics methods using individual peak quantities as independent variables and their flavor intensities as dependent variables was performed by Bednarczyk and Kramer (1975). α-Terpineol, neral, and geranial, β-sesquiphellandrene, ar-curcumene, nerolidol, and *cis*-β-sesquiphellandrol accounted for 85% of the panel's flavor response. Identification of each isolated peak was carried out by IR, ^{1}H-NMR, and MS data and comparison with authentic samples. Unfortunately, α-zingiberene was not included in this study. Organoleptic evaluation included:

1. Tasting the mixture of compounds in each peak, individually
2. Tasting combinations of the mixtures

Table 3.25 Composition and odor description of enantiomers of four potent odor components of Japanese fresh ginger[a]

Compounds	*Configuration*	*(%)*	*Odor*
Linalool	R-(−)	66	Floral
	S-(+)	34	Black tea-like Weaker floral note
4-Terpineol	R-(+)	71	Musty
	S-(−)	29	Musty, dusty
Isoborneol	(1R, 2R, 4R)-(−) (1S, 2S, 4S)-(+)	100	Camphoraceous, India ink-like
Borneol	(1S, 2R, 4S)-(−)	8	Camphoraceous, India ink-like
	(1R, 2S, 4R)-(+)	92	Camphoraceous, India ink-like, fatty, putrid

[a]According to Nishimura (2001).

3. Tasting the compounds in each selected peak in combination with ginger oil
4. Tasting combination of compounds in selected peaks with ginger heat chemicals added

The results can be summarized as follows:

1. Neral, geranial, and α-terpineol are responsible for the characteristic lemony flavor and odor of ginger. β-sesquiphellandrene and ar-curcumene partly contribute to the characteristic ginger flavor intrinsic to the spice. Owing to their high threshold values, they have more of a tendency to dilute the flavor intensity of the oil rather than to increase it when they are added to the oil.
2. Nerolidol possesses woody, soapy, or green notes, not very reminiscent of ginger. *Cis* and *trans*-β-sesquiphellandrol presumably contribute to the significant flavor of ginger as well as other contributors selected by the regression analysis. Bednarczyk and Kramer (1975) concluded that this stepwise regression analysis makes it possible to preselect flavorfully significant compounds in a flavor essence.

More recently, Chau et al. (2001) described a fingerprint analysis by GC/MS of dried and fresh ginger rhizomes from China using chemometrics techniques. Unfortunately, essential oil classification by chemometrics according to its origin and flavoring properties seems to be missing. For such studies, the percentages of the following compounds have to be taken into account: limonene, camphene, 1,8-cineole, neral, geranial, nerol, geraniol, α-terpineol, geranyl acetate, α-zingiberene, β-sesquiphellandrene, β-bisabolene, (*E,E*)-α-farnesene, ar-curcumene, nerolidol, zingiberenols, and sesquiphellandrols.

Synthesis of Some Authentic Samples

Synthesis of terpenoids and sesquiterpenoids in flavors and fragrances has been widely studied since the end of the nineteenth century. Synthetic procedures have been reviewed in several books, particularly in Teisseire's (1991) excellent work.

In this section, only zingiberene isomers and its derivatives as well as other important constituents of ginger oils will be briefly described. Spectral data (MS, ^{1}H-NMR, ^{13}C-NMR) and KI on a nonpolar column of sesquiterpene hydrocarbons have been reported by Joulain and König (1998).

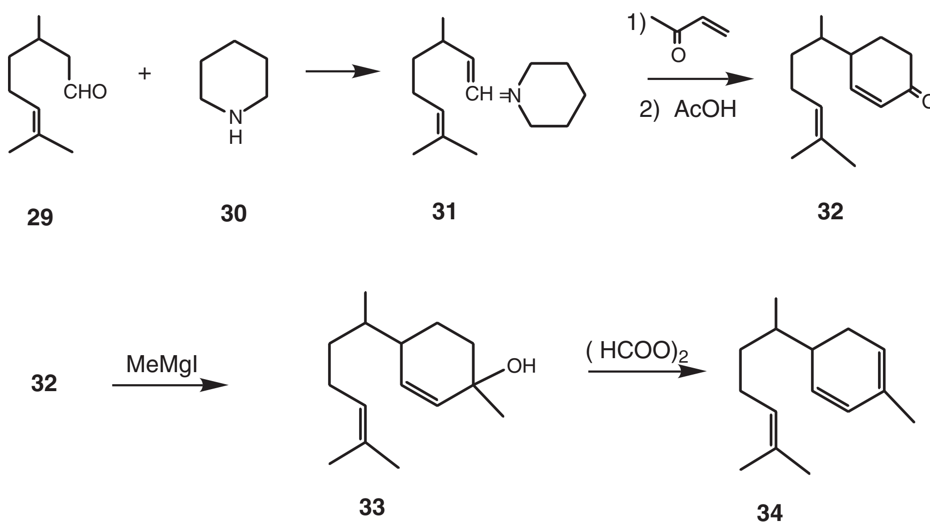
(−)-α-Zingiberene was first isolated in a concentrated form by Von Sodem and Rojahn (1900) by a distillation procedure. Its structure was studied by Eschenmoser and Shing (1950), Mills (1952), Arigoni and Jeger (1954), Banerjee (1962), and Joshi and Kulkarni (1965). The latter workers obtained the enamine (**31**) by condensation of (+)-citronellal (**29**) with piperidine (**30**) in the presence of anhydrous K_2CO_3. Treatment of enamine (**31**) with methyl vinyl ketone followed by acetic acid yielded a product that by careful chromatography gave the α,β-unsaturated ketone (**32**), a key intermediate that upon treatment with MeMgI gave a tertiary alcohol (**33**). Then (**33**) in the presence of oxalic acid gave zingiberene (**34**) containing 60% of a homoannular diene (Scheme 3.5).

Physical properties of (−)α-zingiberene (**35a**) were reported by Pliva et al. (1960):

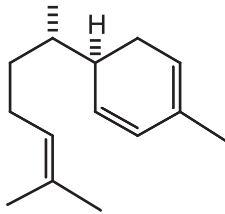
$$\text{b.p.} = 134\text{–}135^{\circ}\ \text{C/15 mm Hg};\ d^{20} = 0.8713;\ n^{20} = 1.4937;\ (\alpha)^{20} = -119.6^{\circ}\ \text{C}$$

It was identified in other essential oils such as Santal Amgris and in *Zizyphus spina-christi* from Egypt by El-Hamouly and Mohamad (2001). (+)α-Zingiberene (**35b**), an enantiomer of the above, has been synthesized for the first time from (−) menthol (**36**) in nine steps *via* the crucial intermediate 7(*R,S*)-isopropyl-10(*R*)-methyl-1(*S*)-4-oxobicyclo (4.4.0) dec-5-ene (Bhonsle et al. 1994) (Scheme 3.6).

The intermediate ketone (**37**) is converted to its ketal (**38**) with migration of the double bond by reacting it with ethanediol in refluxing benzene in the presence of a catalytic amount of *p*-toluene sulfonic acid. The ketal was then subjected to ozonolysis in heptane, and the subsequent reduction of the ozonide *in situ* gave the diol ketal (**39**). Deprotection and dehydration were achieved in a single step by stirring the diol ketal



Scheme 3.5 Synthesis of α-zingiberene 34 from (+) citronellal (adapted from Joshi and Kulkarni, 1965).



35a

(-)- α-Zingiberene

36 → → **37**

($HOCH_2)_2$, ϕ H,Δ → **38**

1) O_3 2) $AiLiH_4$ → **39**

10% H_2SO_4, EtOH → **40**

MeMgI, ether → **41**

$POCl_3$, Pyridine → **35b**

Scheme 3.6 Synthesis of (+) α-zingiberene **35b** (adapted from Bhonsle et al. [1994]).

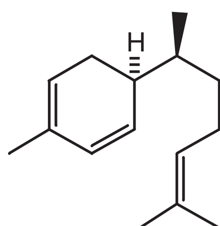
(**39**) at room temperature with 10% sulfuric acid in ethanol to yield the keto alcohol (**40**), which reacts with methylmagnesium iodide to afford the diol (**41**). This latter was subjected to dehydration with phosphorus oxychloride in pyridine yielding (+) α-zingiberene (**35b**) in a poor yield.

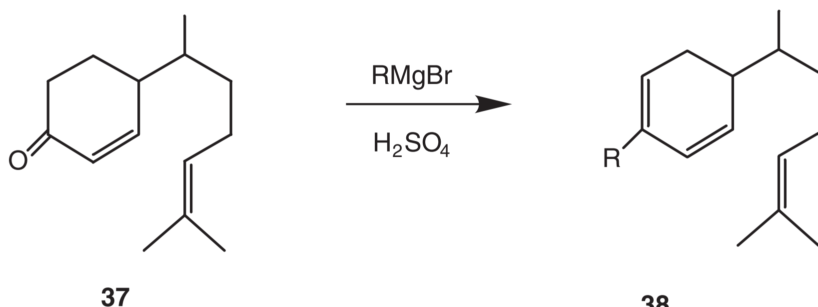
An alternative approach was proposed by dehydration of the ketoalcohol with phosphorus oxychloride in pyridine to yield ketoalkene which on treatment with MeMgI gave the alkene alcohol and by dehydration the expected compound in 59% yield. Several syntheses of (+) α-zingiberene have been reported by Chen and Ho (1989) Joshi and Kulkarni (1965).

7-epi-Zingiberene (**35c**), a diastereoisomer of the natural product, was isolated from wild tomato leaves (Breeden and Coates, 1994, 1995).

Structure elucidation was based upon its ^{1}H-NMR, ^{13}C-NMR, IR, UV, and MS. All data for the two diastereoisomers are identical except for C-9 and C-15 ^{13}C-NMR resonance. The (4*S*, 7*S*) stereochemistry of 7-epi-zingiberene was proven by dehydrogenation of (7*R*)-ar-curcumene.

Substituted α-zingiberenes (**38**) have been synthesized from α-zingiberene *via* the intermediate unsaturated ketone (**37**) by Wang et al. (1990). Reacting the ketone with BuMgBr followed by treatment with 20% H_2SO_4 gave 85% of the butyl derivative (**38**; R = Bu) (Scheme 3.7).

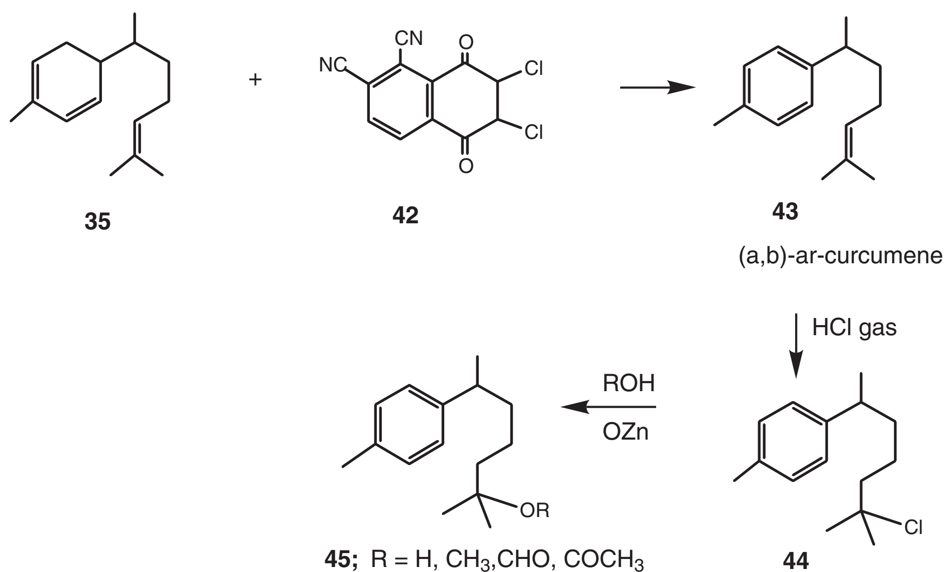




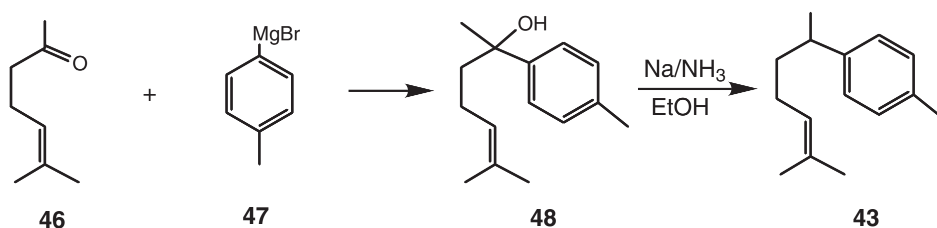
Scheme 3.7 Synthesis of substituted α-zingiberene **38** from the unsaturated ketone **37**.

Another process for the preparation of 1-(1,5-dimethyl-5-substituted hexyl)-4-methylbenzenes (45) has been patented by Menon and Rao (1993). By reacting α-zingiberene with 2,3-dihydro-5,6-dicyano-1,4-benzoquinone (42) in dry benzene at reflux with α-zingiberene affords (a,b)-ar-curcumene (43), subsequently converted into 1-(1,5-dimethyl-5-chlorohexyl)-4-methylbenzene (tertiary chloride) (44) by bubbling anhydrous HCl gas through the mixture. Its reaction with alcohols in the presence of zinc oxide affords the corresponding ar-curcuminyl alcohol derivatives (45; R = H, CH_3, CHO, $COCH_3$) in moderate yields (Scheme 3.8). Odors of the respective compounds were described.

An easy synthesis of ar- (or α-)-curcumene (43) was carried out by Birch (1965). By reacting the 6-methyl-5-hepten-2-one (46) with the 4-methylphenylmagnesium bromide (47), the intermediate alcohol (48) was obtained. Upon treatment with sodium-ammonia in ethanol, it gave the .expected compound (43).



Scheme 3.8 Synthesis of some 1-(1,5-dimethyl-5-substituted hexyl)-4-methyl benzenes 45 (adapted from Menon et al. 1993).



Scheme 3.9 Synthesis of ar-curcumene 43 from methylheptenone 46 (according to Birch 1965).

Synthesis of Zingiberenol and β-Sesquiphellandrols

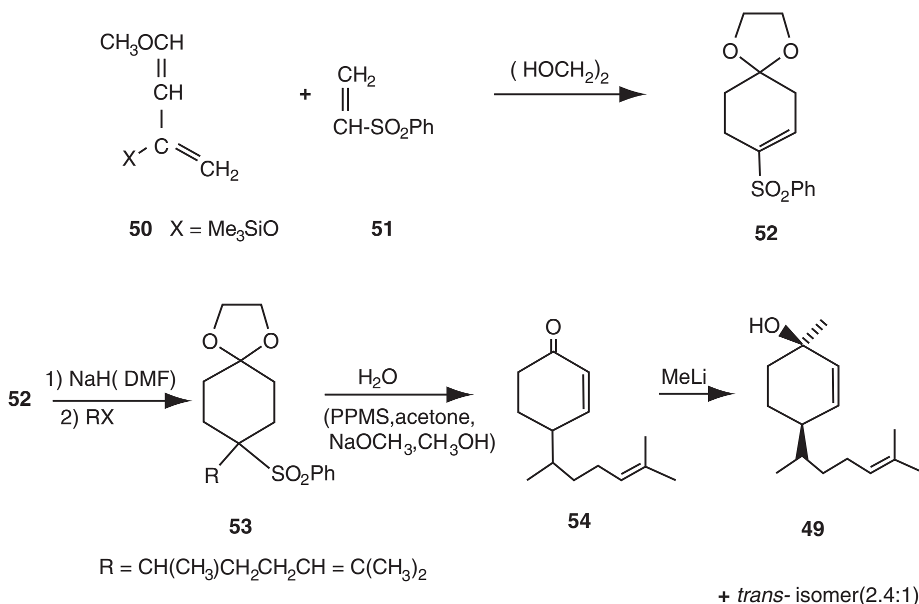
The structure of zingiberenol (49) extracted from higher boiling fraction of ginger oil and isolated by chromatography was tentatively established by Varma et al. (1962). NMR studies show a close similarity with β-eudesmol. In reality, the extracted compound was a mixture of β-eudesmol with 70% *trans* ring and 30% *cis* ring juncture. Some years later, the structure of zingiberenol (49) was determined by its chemical analysis and spectroscopic data (IR, NMR, MS) by Terhune et al. (1975).

Zingiberenol (49) and oxygenated bicyclo (3.3.1) nonanes were synthesized by Paquette and Kinney (1982) and Kinney et al. (1983) using the regiospecific γ-alkylation of the sulfonylcyclohexanone ketal (52). The latter was prepared in 85% yield by Diels-Alder reaction of sulfonylphenylethylene (51) with trimethylsilyl derivative of the 1-methoxy-1,3-butanediene-3-ol (50) followed by ketalization with ethylene glycol. This ketal was alkylated by RBr (R = $H_2C = CH - CH_2$-, $PhCH_2$) in the presence of sodium hydride in dimethyl formamide to give the corresponding alkyl cyclohexanone. Ketals (53) were obtained in 77% and 81%, respectively.

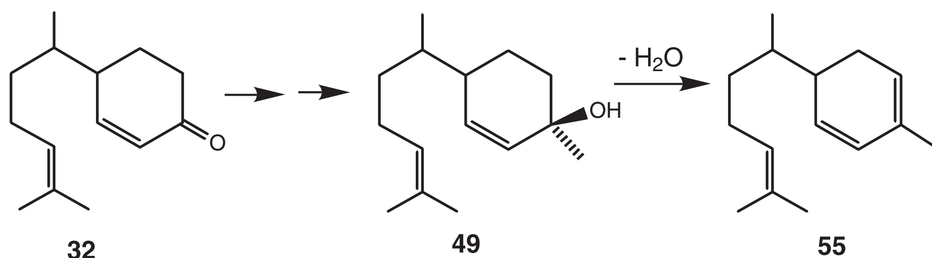
Desulfonation and hydrolysis of the γ-alkylated derivatives (53, R = $PhCH_2$) gave mixture of α, β- and β,γ-cyclohexenones (54) in 83% of a 68/32 mixture of 4-benzyl-α,β- and β,γ-cyclohexenones, respectively (Scheme 3.10).

α-Zingiberenol (49) and β-sesquiphellandrene (55) were synthesized from 4-(6-methyl-5-hepten-2-yl)-2-cyclohexen-1-one by Flisak and Hall (1986) according to Scheme 3.11.

The unsaturated ketone (32) was prepared using an one-pot tandem arylation multi-steps reaction-hydrolysis sequence. *Cis*- and *trans*-β-Sesquiphellandrols have been isolated from ginger oil and their structures determined by IR, UV, NMR, and MS data by Bednarczyk et al. (1975). They are stereoisomers of 5-(1,5-dimethyl-4-hexenyl)-2-methylene-3-cyclo-hexanol.



Scheme 3.10 Synthesis of zingiberenol 49 (adapted from Paquette, 1982 and Kinney et al. 1983).



Scheme 3.11 Synthesis of α-zingiberenol 49 and β-sesquiphellandrene 55 from the unsaturated ketone 32.

Precursors of Aroma and Flavoring Compounds

Biosynthesis of terpenoids and sesquiterpenoids in essential oils has been widely studied (Teisseire, 1991, and references cited therein). Biosynthesis of the main sesquiterpene hydrocarbons with a bisabolane skeleton has been reported by Rani (1999) in an Indian ginger oil. Cyclization of farnesyl pyrophosphate isomers (57) to (59) affords ar-curcumene, α-zingiberene and β-bisabolyl cation (60) (Scheme 3.12).

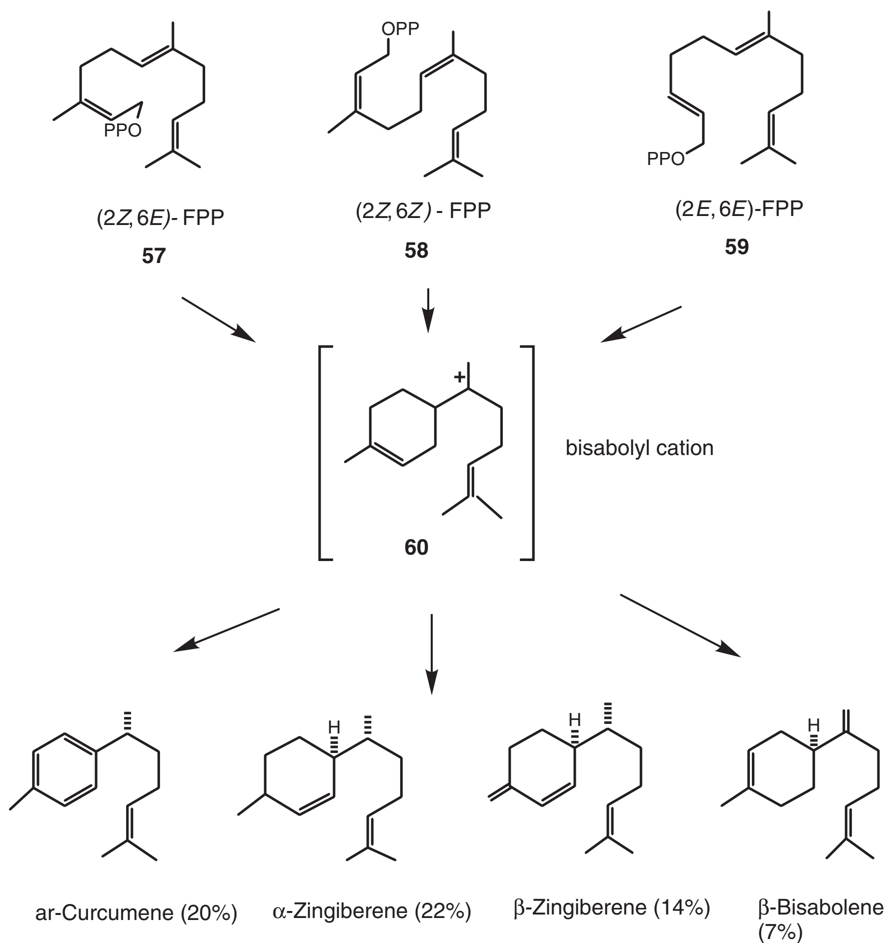
The atomic ratios (14C/3H) in ar-curcumene, α-zingiberene and β-bisabolene, which were fed with (2-14C, 2-3H_2), (2-14C, 4 R − 3H_1) and (2-14C, 5-3H_2) mevalonic acid and (1 − 3H_2) farnesyl pyrophosphate (FPP) revealed:

1. (2*E*, 6*E)*-isomer of FPP (59) is isomerized to (2*E*, 6*E)*—isomer (57) without loss of epimeric hydrogen, that is, without a redox process.
2. (2*Z*, 6*E*) FPP (57) is cyclized to a bisabolyl cation (60) that is the penultimate precursor of α-zingiberene, ar-curcumene, and β-bisabolene.
3. Two 1,2-hydrogen shifts take place during the formation of α-zingiberene, whereas one 1,2-hydrogen shift was observed during the formation of ar-curcumene.

Another interesting work is the first isolation of geranyl disaccharides (61) from ginger and their relation to aroma formation (Sekiwa et al. [2001b,c]) (Figure 3.5).

The precursors and enzyme activities involved in the formation of geraniol and related compounds in ginger were investigated. Repeated chromatography afforded the isolation of a glucoside and three kinds of disaccharides of geraniol from fresh rhizomes of ginger. Their structures were determined by spectroscopic analyses. After incubating, each glycoside with a crude enzyme solution prepared from ginger powder released significant quantities of geraniol. These data suggest that the glycosides exist as precursors or intermediates of geraniol-related compounds in ginger aroma. The nomenclature of these glycosides and amounts of geraniol liberated are given below:

61a: geranyl 6-O-α-L-arabino pyranosyl-β-D-glucopyranoside: 76.6% geraniol
61b: geranyl 6-O-β-D-xylopyranosyl-β-D-glucopyranoside: 19.3% geraniol
61c: geranyl 6-O-β-D-apiopyranosyl-β-D-glucopyranoside: 76.2% geraniol (relative to β-D-pyranoside = 100)



Scheme 3.12 Biosynthesis of sesquiterpene hydrocarbons from farnesyl pyrophosphates via a bisabolyl cation (adapted from Rani 1999). β-Zingiberene has been added.

To clarify the generation of geranial in ginger, the alcohol dehydrogenase activity was measured in a crude enzymatic system of ginger. The enzyme solution contained geraniol dehydrogenase (GeDH) specifically acting on geraniol as a substrate with NADP as a coenzyme, which belongs to the pyridine nucleotide dehydrogenase involved in redox reactions (Sekiwa et al., 2001a). Geranial generation and GeDH activity were investigated for different maturity stages and storage periods of ginger. Both were at maximum levels from just after harvesting to initial storage. The GeDH activity subsequently dropped and the generation of geranial also stopped. The substrate specificity is confirmed by adding NADP. These results suggest that the GeDH activity in ginger is related to the generation of geranial.

The higher content of monoterpene and sesquiterpene alcohols in a steam distillate of ginger arises probably from thermal degradation of the nonvolatile glycosides of the corresponding alcohols (Chen and Ho, 1989). Dissacharide glycosides of monoterpenols as aroma precursors from rose flowers have been reported by Oka et al. (1997).

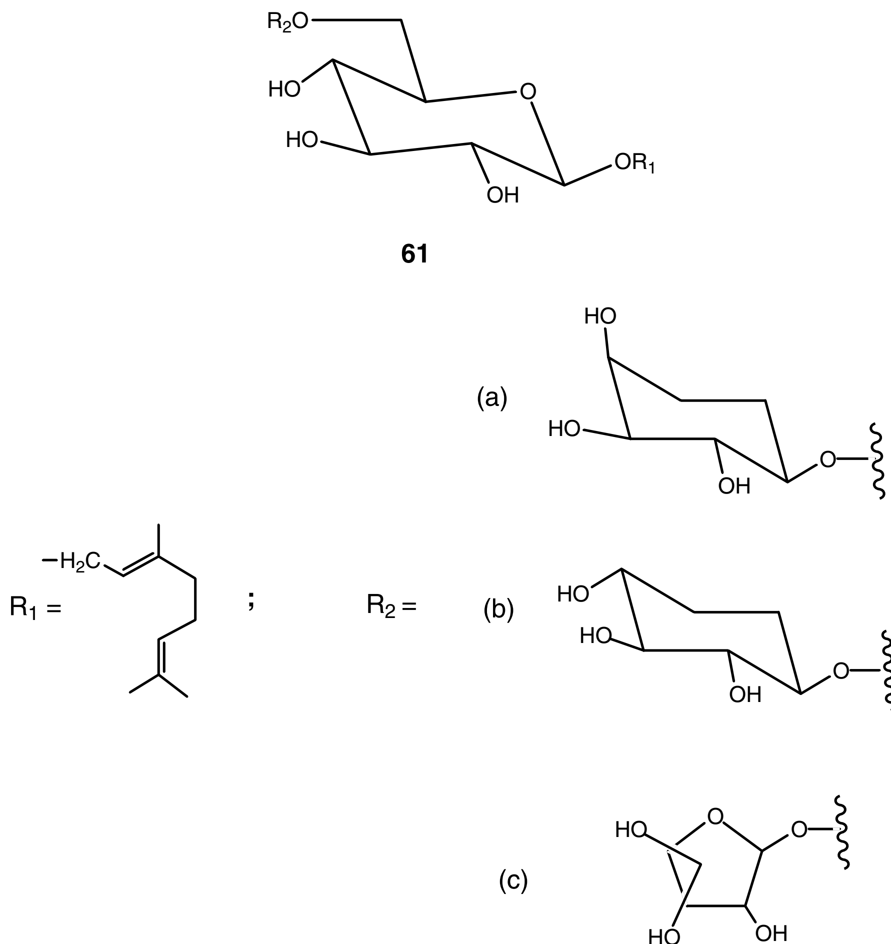


Figure 3.5 Structures of geraniol glycosides **61** from ginger (adapted from Sekiwa et al. 2001a).

Properties of Ginger

Ginger was in use as a folk medicine in China and India 3,000 years ago. Ginger has been proven to have a large range of properties, not only biological and physiological activities but also antidepressant, antinarcotic, antihistaminic, hypoglycemic, and, in agriculture, insecticidal and bactericidal properties. Many papers have been devoted to these properties and have been reviewed by various workers: Peng (1992), Mustafa et al. (1993), Duke (1994), Rosella et al. (1996), Ruedi and Juch (1999), Kikuzaki (2000), Afzal (2001), and Nakatani and Kikuzaki (2002).

The compounds responsible for the biological activity of ginger extracts are: gingerols, shogaols, (6)-paradol, (6)-gingerdiol, gingerenone A, zingerone, diarylheptanoids, hexahydrocurcumin and its derivatives (curcuminoids), and other compounds. It is interesting to note that the action of these compounds is quite different according to the state of rhizome. The fresh rhizome called “Shoukyo” in China is considered to be an antiemetic, a cough and cold remedy, an antitoxic, and a digestive stimulant. The

dried rhizome or "Kankyo" in China is considered to be a good remedy for stomach ache. Roasted ginger led to a marked decrease in blood coagulation in mice. Ginger essential oils have also interesting properties not only in perfumery, but also in cosmetology as an antiaging agent. In this section, a summary of these papers is given in Tables 3.26 and 3.27.

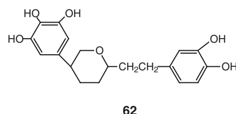
Table 3.26 Biological and physiological activity of ginger[a]

Properties	Responsible compounds	Author(s)(year)
Antioxidant Effects		
Inhibition of lipid peroxidation	Ginger extracts (zingerone)	Krishnakantha et al. (1993)
Inhibition of fulvic-acid-induced hydrogen peroxide production in chardocyte	Ginger oil	Guo et al. (1997)
Antioxidant effect in ground pork patties	Ginger extracts	Takaesova et al. (2001)
Protective effect against oxygen-free radical damage	A new cyclic diarylheptanoid[b]	He et al. (2001)
Antioxidant properties	Gingerols, shogaols	Wang et al. (2001), Nakatani and Kikuzaki (2002)
Antitumor Activitites		
Antitumour activity	Ginger extracts Malaysian ginger metabolites Vanillyl ketones (6)-gingerol, (6)-shogaol	Masada et al. (1973), Harvey (1981) Hasnah et al. (1993) Surch et al. (1999)
Antitumour activity (antiulcer)	(6)-Ginger sulphonic acid Ginger extracts *Amitra Bindu*[c]	Yashikawa et al. (1992, 1994) Ahn et al. (1993), Shanmugasumdaram et al. (1994)
Chemoprevention of cancer (colonic mucosa)	Zerumbone (from wild ginger)	Duve (1980)
Chemoprevention of cancer	Curcumin and curcuminoids	Masuda et al. (1998)
Chemoprevention of skin cancer	Ginger components + antioxidants	Ahmad et al. (2001)
Anti-Inflammatory Activities		
Anti-inflammatory activity	Proteolytic enzymes in ginger	Thompson et al. (1974)
Anti-inflammatory activity	Gingerols, shogaols, gingerenone A, (6)-gingerdiol, hexahydrocurcumin, zingerone	Schuhbaum et al. (2000)
Antiulcer effects	Gingerols, shogaols	Yamara et al. (1988), Beekstrom-Sternberg (1994)
Against arthritis and related desorders	Ginger extracts	Srivastava and Mustafa (1989, 1992), Sharma and Srivastava (1994)
Anti-inflammatory and antirheumatic activity	Ginger oil (+ eugenol)	Sharma et al. (1997)

Inhibition of arachidonic acid, prostaglandins, and leukotrienes	(6)-Shogaol, (6)-gingerol, (6) and (8)-gingerdiols	Kiuchi et al. (1982, 1992)
Inhibition effect on the leukotriene biosynthesis	Ginger oil	Ma et al. (1990)
Effects on Blood and Heart		
Decreasing blood pressure	(6)-Shogaol and (6)-gingerol in large concentration	Suekawa et al. (1984, 1986)
Cardiovascular effect	Gingerols, shogaols	Shoji et al. (1982)
Ca^{++}-spike suppression in portal veins of mice	(±)-(6)-Gingerols and (±)-yakuchinone	Kimura (1988, 1989)
Ca^{++}-pumping activity in rabbit skeletal and dog cardiac muscles	Gingerols	Kobayashi et al. (1987)
Inhibition of platelet aggregation	Gingerols or powdered ginger in large dose	Verma et al. (1993), Kawakishi et al. (1994), Bordia et al. (1997).
Cholesterolemic and Epatic Effects		
Cholesterolemic activity	Pungent principles of ginger	Gujral et al. (1978)
Reduction of hypercholesterolemia in mice	(*E*)-8β,17-epoxylabd-12-ene, 15,16-dial	Tanabe et al. (1993)
Antispasmodic effect (easier gastric mobility) and neuromuscular effect in mice	(6)-Shogaol and (6)-gingerol	Suekawa et al. (1984, 1986)
Antiepatotoxic activity	Gingerols and diarylheptanoids	Hikino et al. (1985)
Miscellaneous		
Cough suppressant	(6)-Shogaol (identical effect to that of dihydrocodein phosphate)	Kiuchi et al. (1982)
Serotonin-antagonistic effect (hypothermia and diarrhea inhibition)	Galanolactone	Huang et al. (1990, 1991)
Antileukemic	Ginger extracts	Hasnah et al. (1993)
Antiallergenic	Gingerols and shogaols	Yamahara et al. (1995)
Bactericidal against *Salmonella* and *Staphylococcus*	Ginger extracts	Duke (1994)
Reduction of rhinoviral activity	Sesquiterpenes of ginger	Denyer et al. (1994)
Increasing production of ceramide in the epidermis of mice	Ginger extracts	Okubo et al. (1999)
Antimicrobial activity	Ginger oleoresins	Chen et al. (2001)
Strong antibacterial effect	Ginger essential oil	Singh et al. (2001)
Prevention and treatment of induced disease β-amyloid protein	Gingerols and shogaols	Kim (2001)
Reducing symptoms of osteoarthritis (knee pain)	Highly purified ginger extracts	Altman et al. (2001)

Increasing activity of peroxidase and β-1,3-glucanase enzymes in the *callus* cultures	*Callus* cultures of ginger (+ salicylic acid)	Prachi et al. (2002)
Metabolism of (6)-gingerol in rats	—	Nakazawa and Ohsawa (2002)

[a]Besides these properties, ginger also possesses antimigraine effects, antinausea effects, antimotion sickness, and anti-postoperative nausea, as well as antiemetic, antipyretic, and analgesic effects (Afzal et al., 2001).
[b]New cyclic diarylheptanoid 62.



[c]Used as health food in India.

Table 3.27 Agricultural properties of ginger

Properties	*Responsible compounds*	*Author(s) (year)*
Antifertility	(−)-α-Zingiberene (superior to (−)-zingiberol and β-sesquiphellandrene)	Ni et al. (1988)
Ground regulators (effect of NAA and BAP)	Ginger extracts	Arimura et al. (2000)
Insecticidal activities against the shoot borer D *punctiferalis* in ginger (Melathion)		Koya et al. (1988)
Insecticidal synergistic effect	Ginger oil + garlic oils	Hus et al. (1999)
Insecticidal against cockroach (*Blattela germanica)*	Ginger oil + insecticidal products	Kawata (1998)
Antifungal	—	Hasnah and Ahmad (1993)
Insecticidal, antifeedant, and antifungal activities against *Rhizoctoria solani*	(6)-Dehydroshogaol (insecticidal) dehydrogingerone (antifungal)	Agarwal et al. (2001)
Reduction of *Dirofilaria immitus* by microfilaral in dogs	—	Datta and Sukul (1987)
Destruction of *Anisakis* larvae	(6)-Gingerol and (6)-shogaol	Goto et al. (1990)

For more details, the reader is refered to Chapters 13 and 14.

On account of the progress of biochemistry and pharmacology since the last 30 years, the noteworthy bioactivity of ginger has been recognized.

Processing of Ginger

Deterpenation

Ginger deterpenation by liquid chromatography using silica gel column was achieved by Shankaracharya and Shankaranarayana (1987). They claimed that the terpeneless or deterpenated essential oils are valued for their stability and enhanced flavor strength.

Therefore, distilled ginger and pepper oils were deterpenated by column chromatography. They were slurried with petroleum ether (60 to 80° C) and eluted with acetone and ethyl acetate. The yield of terpeneless ginger was 16.6%. The physicochemical properties and the gas chromatogram of the distilled oil, their terpenes, and terpeneless oils have been reported. The procedure can be used to obtain good-quality terpeneless ginger oil. In another study by column chromatography, Omanakutty et al. (1987) used the following parameters for the adsorbent: adsorbent-oil ratio, mode of packing, L/D ratio, activity of the adsorbent, and quantity of the eluents. Analyses have been carried out by GC and GC/MS. The parameters optimized for 75 g of ginger oil have been found to be satisfactory up to 1 kg level in the laboratory. Change of raw material has little effect on the composition and quality of the oxygenated fraction. Odor characteristics are kept.

Preservation and Encapsulation

Preservation of grated ginger was done in the presence of 0.1, 1.0 weight % ginger spicy oil at pH 3.4 to 4.5; ethanol and organic acids have been added (Yamamoto et al., 1990). The preserved grated ginger has its freshness, flavor, and taste well kept. Grated ginger (80 g), ginger oil (0.6 g), NaCl (2.8 g), and sugar (16 g) were mixed, adjusted to pH 3.5 with citric acid, and preserved for 12 months without losing the original flavor and taste.

Four ginger preparations were compared by Ding and Ding (1988):

1. Fresh ginger
2. Dried ginger under sunlight
3. Dried by heating at 220° C in a sand bath
4. Dried by heating at 300° C in a sand bath

The essential oil content decreased by approximately 57% after 300° C treatment. Heating also decreased the levels of gingerols and shogaols in ginger. The effect of the drying process on the composition of the essential oil from Australian ginger showed that the major effects are a reduction in gingerol content, an increase in terpene hydrocarbons, and the conversion of some monoterpene alcohols to their corresponding acetates, both for fresh and dried ginger samples (Bartley and Jacobs, 2000). Chemical peeling of fresh ginger by using strong acid, was optimized by Liu (1999).

Molecular encapsulation of fresh ginger flavor was studied by Sankarikutty and Narayanan (1990). Encapsulation of ginger flavor by inclusion in β-cyclodextrin was better by addition of steam-distilled ginger oil to a saturated aqueous solution of the cyclodextrin, followed by agitating, holding at 5° C for 2 to 3 hours, and drying at room temperature.

Trapping of the headspace of crushed ginger oil or collecting the steam distillate of the oil in aqueous cyclodextrin and then spray drying gave inferior products. Changes of microencapsulated ginger essential oil after storage were also observed (Lin et al. 1992). Spray-dried, microencapsulated ginger oils were prepared and stored at room temperature for 1 year. Significant changes of microencapsulated ginger oils were observed after storage (it is not the case with garlic). Many high boiling–point compounds are formed during storage. Sensory analyses also indicated a significant decrease of intensity and harshness of stored microencapsulated ginger oil. On the other hand,

the increase of woody note was significant for stored oil. However, the acceptance as a whole did not differ between stored and fresh microencapsulated ginger oil. The oil quality of the stored microcapsules was much better than that of absorbate. It was shown that stable and soft gelatin solution capsules contain more than one component selected from the group consisting of cinnamon, fennel oil, clove oil, peppermint oil, ginger oil, cardamon oil, lemon oil, orange-peel oil, and l-menthol in the capsule and a polypeptide-gelatin mixture (15 to 70:85—30% by weight) as the capsule film. The capsules stored at 40° C and 75% humidity for 1 month were stable and showed no changes in color and in the property of the capsule film (Komata et al., 1990).

The effect of pH, particle diameter, temperature, water activity, and the amount of gelatin of the microcapsule of ginger essential oil was studied by Sheen et al. (1992b). A novel pharmaceutical, dietary supplement and a cosmetic preparation containing fatty acids and ginger extract for the treatment or prevention of inflammation, hypersensitivity, or pain was patented by Weidner (2000). The homogeneous mixture thus obtained with eicosopentaenoic acid and docosahexanoic acid and ginger was suitable for encapsulation in a soft gelatin capsule. A mixture of boswellic acid, a curcuminoid, a gingerol, a capsaicinoid, a bioflavonoid, and a vitamin C source was found to be more suitable than a botanical source to prevent or treat inflammation and pain in mammals, particularly humans. The composition may be administered as a tablet, a liquid, or a powder as an oral dose (Krumhar and Heller, 2000). Yang et al. (2001) identified (R) − ginsenolide and 20(*S*) − ginsenoside in ginger capsule.

Irradiation Effects

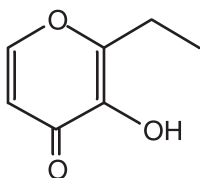
Effects of ethylene dioxide and gamma irradiation on the chemical sensory and microbial quality of ground spices and their essential oils (ginger, cinnamon, fennel, and fenegreek) were studied by Toofanian and Stegeman (1988). Irradiation of ground ginger with a dose of 5 KGy resulted in a slight decrease of 14%, whereas fumigated ginger showed no significant loss in volatile oil content. No major differences in sensory properties were found when comparing the untreated irradiated or fumigated species.

Andrews et al. (1995) studied the chemical and microbial activity of irradiated fresh ground ginger using a 10 KGy ionizing radiation dose from a cobalt 60 source. Gamma irradiation decreases the amounts of most of the extractable flavor components. Those known to contribute to the typical ginger flavor; that is, α-zingiberene, β-sesquiphellandrene, β-bisabolene, farnesene isomers, ar-curcumene, and α-cubebene, decreased 25 to 59% following irradiation. The radiation treatment reduced the aerobic microbial population from 108 to 101 colony-forming units (CFU)/g. Sensory qualities of flavor and odor of ginger powder were similar for treated and untreated ginger. Gamma irradiation of ginger rhizomes by 10 KGy and storage for 9 months reduced the decrease of the oleoresin content of ginger during the storage period by 14% in unground samples and 11% in ground samples (Onyenekwe, 2000). There was a dose-dependent decrease in the (6)-gingerol content of the ground ginger, which decreased by 65.6, 67.4, and 70.4% for the 0.5 and 10 KGy samples, respectively. The corresponding values for the unground ginger samples were 37.8, 40.0, and 44.3% at the end of the storage period. It can be concluded that the dose dependence is rather weak and that gamma irradiation has a higher effect on the decreasing the content of (6)-gingerol in the ground ginger than in the unground ginger. In the case of the essential oil, the decrease is lower (0 to 14%).

Formulations and Uses

Several reviews have been devoted to various ginger formulations as a spice for food in ready-cooked dishes and fish, not only in Asian and Indian countries, but also throughout the entire world (Ho et al., 1989, 1997; Kikuzaki, 2000; Metz and Cupp, 2000; Liu et al., 2000).

A formulation of tablets given by Goku (1983) includes a mixture of egg yolk lecithin (18 g), cognac (1 g), wine flavor (1 g), ginger flavor (0.1 g), and cheese flavor (0.1 g). It was combined with sugar (500 g), lactose (275 g), and starch (200 g) granulated by a conventional method and finally mixed with sucrose and fatty acid esters and made into tablets. The 2-ethyl-3-hydroxy-4-(4*H*)-pyranone (**63**) can also be added to the mixture.



63

In a study of the chemical and nutritional quality of fermented fish silage containing potato extracts, formalin, and ginger extracts, it was found that ginger extracts proved to be effective as an antioxidant in fermented *tilapia* silage (*Oreochromis niloticus)* (Fagbenro and Jauncey, 1994).

A preparation process for seasoning oil consists of:

1. Mixture of cysteine (0.1 to 5%), lysine (0.5 to 10%), serine (1 to 15%), arginine (2 to 20%), glucose (0.05 to 5%), fructose (0.1 to 5%), xylose (0.01 to 2%) at 10 to 50º C to obtain seasoning liquid mixture (I)
2. Soating seeds of sunflower or powders of peanuts or soybean in 1 to 5 volumes of (I) for 5 to 180 minutes
3. Drying to 5 to 20% water content
4. Roasting at 170 to 220º C for 10 to 40 minutes
5. Pressing to obtain oil
6. Adding vegetable extract

The preparation method for the vegetable extract consists of stirring one of dried vegetables (garlic, red pepper, ginger, cabbage, carrot, mustard, parsley, or pepper) in 20 to 30 volumes of the oil of sunflower or soy at 40 to 60º C for 6 to 120 minutes (Yun et al., 1996). The roasting step (4) can give rise to a Maillard reaction between α-amino acids and reducing sugars (Vernin, 1982; Vernin et al., 1992; Rogacheva et al., 1998). This reaction has not been studied in the case of ginger.

Ma et al. (2001) compared volatile compounds of dried ginger when decocted in different combinations with other ingredients of Banxiaxiexiintang (BXXT) decoction. The changes of the contents of 15 volatile compounds of dried ginger being one of the

ingredients of BXXT decoction when decocted with other different ingredients were studied by GC/MS. The ingredients other than dried ginger were divided into different groups according to the four natures and five tastes theory, and dried ginger was decocted in combination with the different groups in turn. All ingredient combinations showed influence on the output of the volatile components of dried ginger by decocting. This experiment was an attempt to study the formulation by a chemical method.

Okwu (2001) reported the chemical evaluation and nutritional and flavoring potentials of ginger and five other indigenous spices. Preserved ginger is prepared from the immature rhizome, whereas the more pungent and aromatic spice is prepared by harvesting and drying the mature rhizome. Dried ginger is used directly as a spice and also for the preparation of ginger oil and ginger oleoresin. The ginger oleoresin possesses the full organoleptic properties of the spice, that is, aroma, flavor and pungency, and finds similar applications as the ground spice in flavoring of processed foods (Ebewele and Jimoh, 1988).

Ginger extracts in mixture with other compounds can be used in products such as antiaging cosmetics and skin protectants. A lotion containing ginger extract, ethanol, guanidine compounds, trimethylglycine, methyl para-hydroxy benzoate, triethoxyethoxyethyl phosphate, hydrolyzed *Prunus amygdalus* extract, glycine, and purified water to 100 weight % was suggested by Sano et al. (2001).

In Asian and Indian countries ginger is widely used in processed foods, in meat and fish fatty sauces, in mixtures with other spices and flavorings, and in alcoholic beverages (punch, ale). All these applications will be described in more detail in Chapters 14 and 15.

Anecdote

In a tribe of the Mollucas Islands, also called the "Spices Islands," it is usual for girls (12 to 13 years old) to have their face and arms smeared with a yellow-colored cream containing dried ginger before wedding festivities.

Conclusion

The most important conclusions based on the above review can be summarized as follows.

- For comparison purposes, a greater uniformity and standardization of the methods of extraction and analysis of ginger essential oils are desirable.
- More information about diarylheptanoids **62** (curcuminoids) (see Table 3.26) and diterpene derivatives should become available, and a search for new compounds belonging to these groups should be done by using more selective extraction and analytical methods.
- It seems that, so far, no papers have been devoted to the statistical treatent (chemometrics) of the classification of ginger essential oils and their pungent constituents according to their origin and sensory properties.
- The positive experience concerning the biological activity of these compounds obtained with animals should be extended to humans.
- The different forms of ginger (e.g., gels, tablets, pills, preserved ginger) should be used not only for their beneficial health effects, but also the natural form of ginger should find more uses in cuisine (sauces for meats and fish) with or without coconut milk and other spices and flavorings, in crackers/biscuits (e.g.,

ginger biscuits, gingerbread), alcoholic beverages (ale, punch), and nonalcoholic beverages (as an additive to fruit juices).

Known for more than 3,000 years, ginger will undoubtedly find many new uses still to be discovered.

Acknowledgments

The authors are indebted to Dr. René Barone, Faculty of Sciences, St-Jérôme, Marseilles, for his interest in the manuscript. Thanks are also due to Mrs. Rose-Marie Zamkostian and Geneviève M.F. Vernin for their assistance as well as the INIST/CNRS (Institut National de l'Information Scientifique et Technique/Centre National de la Recherche Scientifique) for providing us numerous documents.

Appendix: Mass Spectra and Kovats Indices of Some Characteristic Aroma and Flavoring Compounds of Ginger

About the SPECMA 2000 Data Bank

A data bank applied to flavor and fragrance materials began 20 years ago in the laboratory of one of us (G.V.) with the collaboration of three informaticians (Vernin and Petitjean, 1982; Vernin et al., 1986; Boniface et al., 1987).

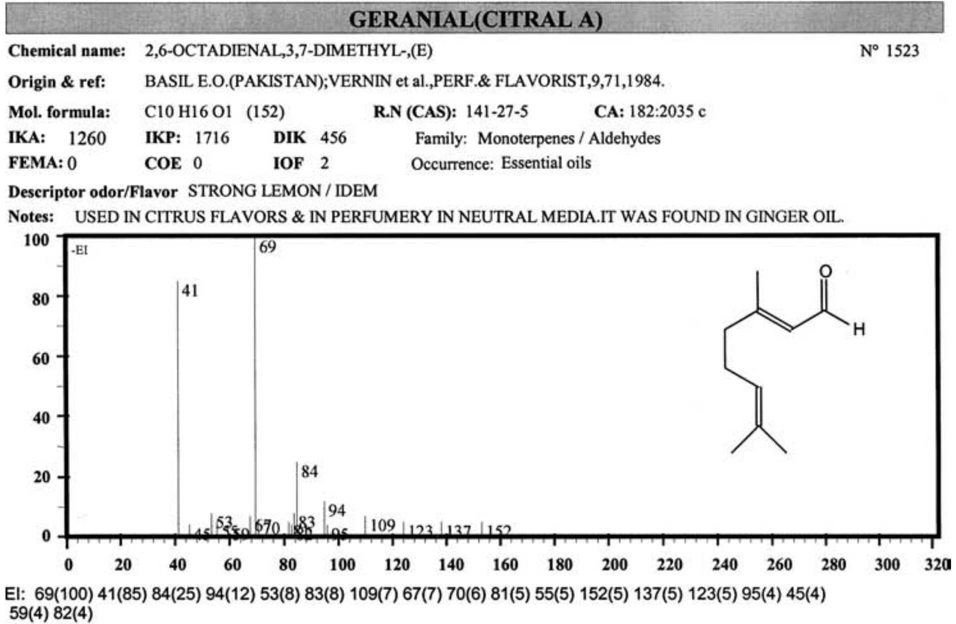
Several versions of the bank have been realized according to the progresses of software and hardware and ideas. The last version of the bank functions with ACCESS 2000 software via Windows 98, Millenium, and XP. A program of molecule design, Chem-Windows DB, has been incorporated into the previous system (Colon and Vernin, 1998).

For each compound, the following data are given:

- Usual name, chemical name and synonym(s)
- Origin and reference of the mass spectrum
- Molecular formula ($C_xH_yO_zN_uS_v$), registry number (or CAS)
- Reference to *Chemical Abstracts*
- KI on nonpolar and polar columns and KI difference on the two columns
- Descriptor (odor/flavor): a short note including occurrence in other products, configuration, and other data
- Mass spectrum both under graphical and numerical forms
- Mass spectra upon negative and positive chemical ionization (NCI and PCI) when they are available as other data

Worded as follows, this bank is a powerful and remarkable tool for the identification of volatile and aromatic compounds in flavor and fragrances.

We hope that it will be published very soon, but there are always mass spectra to be added! As examples, mass spectra of some characteristic compounds of ginger are reported hereafter (Figure 3.6 to Figure 3.16).



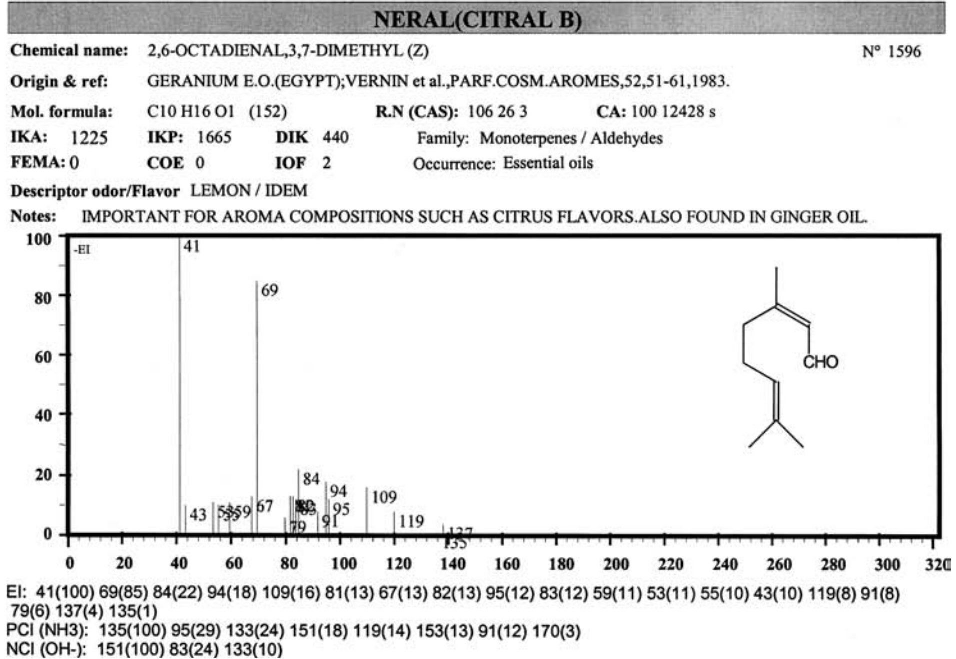


Figure 3.6 Mass spectra of geranial and neral.

ZINGERONE (VANILLYL ACETONE)

Chemical name: 2-BUTANONE,4-(4-HYDROXY-3-METHOXYPHENYL) N° 2630

Origin & ref: GRAPE JUICE;GINGER ROOT OLEORESIN.STRAUSS et al, J.AGRIC.FOOD CHEM.,35,519-522,1987.

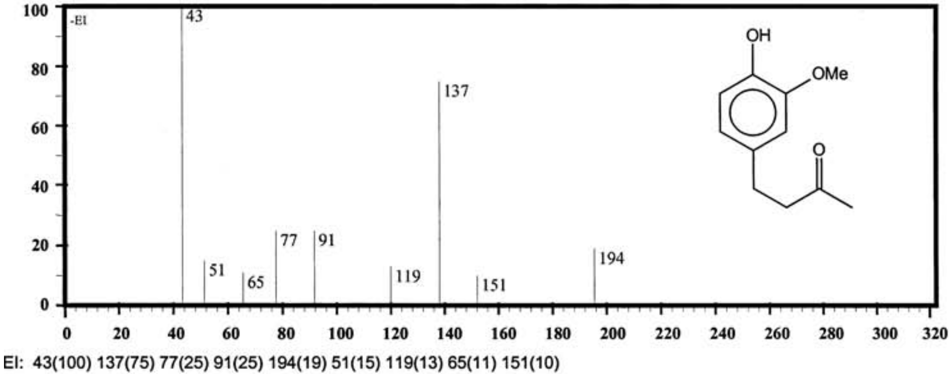
Mol. formula: C11 H14 O3 (194) **R.N (CAS):** 122-48-5 **CA:** 107 37977 c

IKA: 1625 **IKP:** 2620 **DIK** 995 Family: Aromatics / Phenol & derivatives

FEMA: 3124 **COE** 139 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor BALSAMIC & VANILLA ODOR / SPICY, PHENOLIC, AT 80 ppm (TASTE)

Notes: FLAVOR PROPERTIES HAVE BEEN DESCRIBED BY OHLOFF et al, FOOD REV.INT.,1,99-105,1985.



EI: 43(100) 137(75) 77(25) 91(25) 194(19) 51(15) 119(13) 65(11) 151(10)

ZINGERONE (VANILLYLACETONE)

Chemical name: 2-BUTANONE,4-(4-HYDROXY-3-METHOXYPHENYL) N° 2631

Origin & ref: GINGER OIL (PRIVATE FILE)

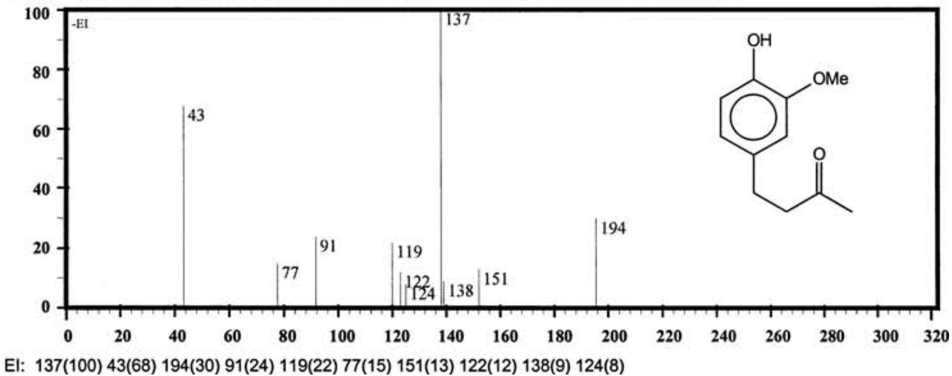
Mol. formula: C11 H14 O3 (194) **R.N (CAS):** 122-48-5 **CA:** 0:0

IKA: 1640 **IKP:** 2625 **DIK** 985 Family: Aromatics / Phenol & derivatives

FEMA: 3124 **COE** 139 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor SPICY, PHENOLIC & BALSAMIC , CREAMY VANILLA-LIKE / SPICY. BITING TASTE AT 80 ppm.

Notes: SOURCE:BRITANIA NATURAL PRODUCTS;USED FOR VANILLA & GINGER NUANCES.



EI: 137(100) 43(68) 194(30) 91(24) 119(22) 77(15) 151(13) 122(12) 138(9) 124(8)

Figure 3.7 Mass spectra of zingerone.

BETA-BISABOLENE

Chemical name: CYCLOHEXENE,1-METHYL-4-(5-METHYL-1-METHYLENE-4-HEXENYL   N° 2862

Origin & ref: BASIL E.O. (YOUGOSLAVIA);VERNIN et al, PERF.& FLAVORIST,9,71-86,1984.

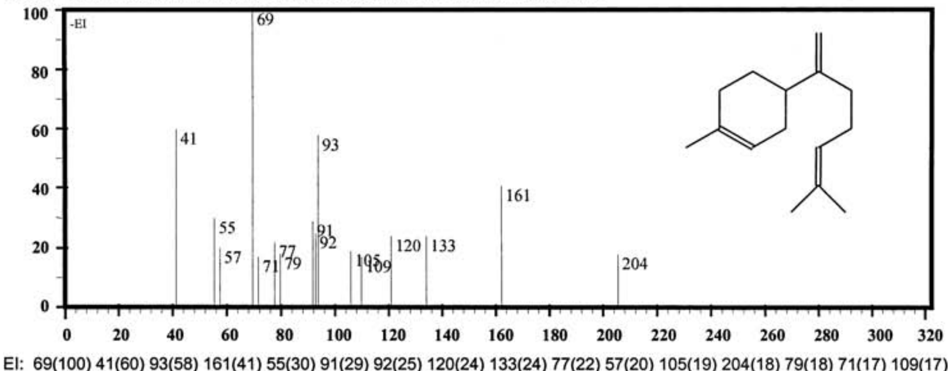
Mol. formula: C15 H24 (204)   **R.N (CAS):** 495 61 4   **CA:** 102 119397 z

IKA: 1505   **IKP:** 1749   **DIK** 244   Family: Sesquiterpenes / Hydrocarbons (200 <MW< 206)

FEMA: 0   **COE** 0   **IOF** 2   Occurrence: Essential oils

Descriptor odor/Flavor

Notes: ALSO FOUD IN LEMON,WILD CARROT, BERGAMOT & GINGER OIL.



EI: 69(100) 41(60) 93(58) 161(41) 55(30) 91(29) 92(25) 120(24) 133(24) 77(22) 57(20) 105(19) 204(18) 79(18) 71(17) 109(17)

BETA-SESQUIPHELLANDRENE

Chemical name: CYCLOHEXENE,3-(1,5-DIMETHYL-4-HEXENYL)-6-METHYLENE-,[S-(R*,S*)]   N° 5945

Origin & ref: COMPILATION MS VOL. COMPONDS IN FOOD;DE BRAUW et al,TNO,THE NETHERLANDS,Vol.10,1981.

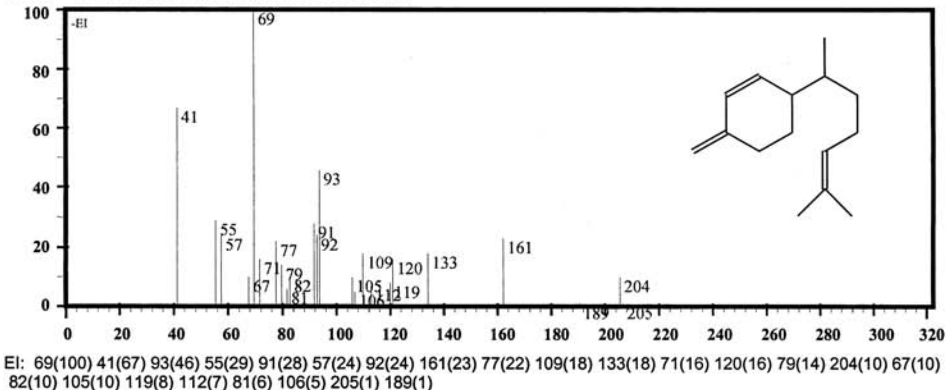
Mol. formula: C15 H24 (204)   **R.N (CAS):** 20307 83 9   **CA:**

IKA: 1520   **IKP:** 1740   **DIK** 220   Family: Sesquiterpenes / Hydrocarbons (200 <MW< 206)

FEMA: 0   **COE** 0   **IOF** 2   Occurrence: Essential oils

Descriptor odor/Flavor FRESH GINGER /

Notes: CONSTITUENT OF ZINGIBER OFFICINALIS.



EI: 69(100) 41(67) 93(46) 55(29) 91(28) 57(24) 92(24) 161(23) 77(22) 109(18) 133(18) 71(16) 120(16) 79(14) 204(10) 67(10) 82(10) 105(10) 119(8) 112(7) 81(6) 106(5) 205(1) 189(1)

Figure 3.8 Mass spectra of β-bisabolene and β-sesquiphellandrene.

ALPHA-ZINGIBERENE

Chemical name: 1,3-CYCLOHEXADIENE,5-(1,5-DIMETHYL-4-HEXENYL)-2-METHYL-,[S-(R*,S*)] N° 3162

Origin & ref: GINGER E.O.; VERNIN & PARKANYI, SPICES, HERBS, FUNGI..(CHARALAMBOUS Ed.),ELSEVIER,1994,579.

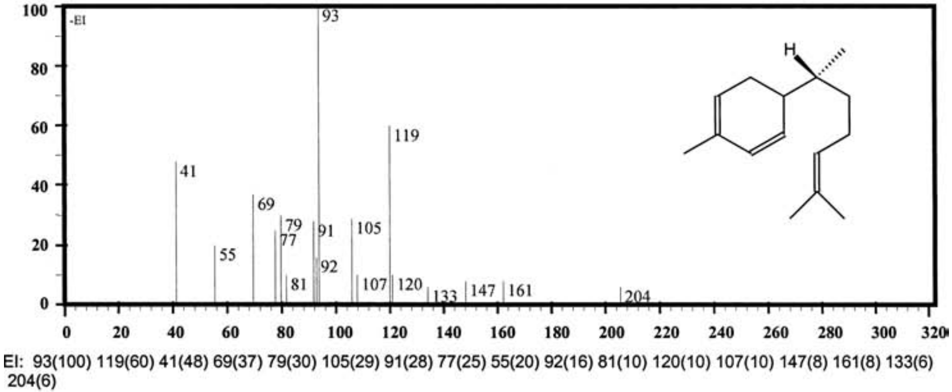
Mol. formula: C15 H24 (204) **R.N (CAS):** 495 60 3 **CA:** 121 178142 c

IKA: 1500 **IKP:** 1720 **DIK** 220 Family: Sesquiterpenes / Hydrocarbons (200 <MW< 206)

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor FRESH GINGER / IDEM

Notes: CONSTITUENT OF ZINGIBER ZERUMBET.OIL.IT CAN OCCURS IN WINES.



EI: 93(100) 119(60) 41(48) 69(37) 79(30) 105(29) 91(28) 77(25) 55(20) 92(16) 81(10) 120(10) 107(10) 147(8) 161(8) 133(6) 204(6)

ALPHA- BERGAMOTENE-, (TRANS)

Chemical name: BICYCLO[3.1.1.] HEPT-2-ENE,2,6-DIMETHYL-6-(4-METHYL-3-PENTENYL)[1S(1,5,6-ALPHA) N° 3163

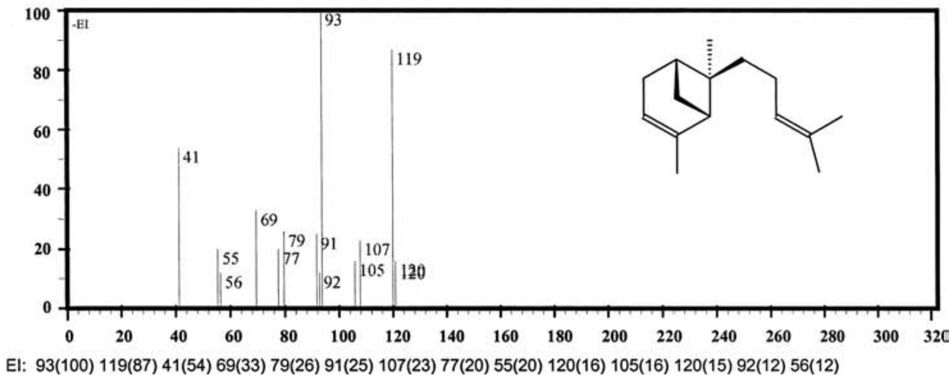
Origin & ref: GINGER E.O.; VERNIN & PARKANYI., SPICES, HERBS, FUNGI..(CHARALAMBOUS Ed.),ELSEVIER,1994,579

Mol. formula: C15 H24 (204) **R.N (CAS):** 13474 59 4 **CA:** 121 178142 c

IKA: 1440 **IKP:** 1570 **DIK** 130 Family: Sesquiterpenes / Hydrocarbons (200 <MW< 206)

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor



EI: 93(100) 119(87) 41(54) 69(33) 79(26) 91(25) 107(23) 77(20) 55(20) 120(16) 105(16) 120(15) 92(12) 56(12)

Figure 3.9 Mass spectra of α-zingiberene and α-bergamotene.

AR- CURCUMENE

Chemical name: BENZENE,1-(1,5-DIMETHYL-4-HEXENYL)-4-METHYL — N° 2807

Origin & ref: CINNAMON (CHINA);VERNIN et al. IN: SPICES, HERBS, FUNGI, ELSEVIER,34,411-425,1994.

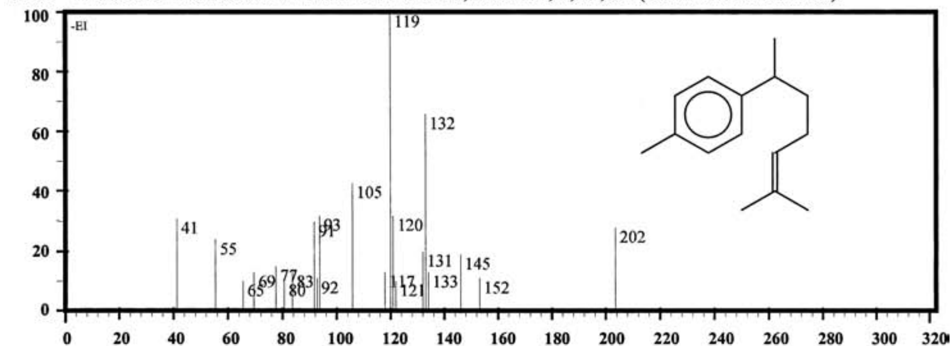
Mol. formula: C15 H22 (202) **R.N (CAS):** 644 30 4 **CA:** 121 81384 v

IKA: 1495 **IKP:** 1745 **DIK** 250 Family: Sesquiterpenes / Hydrocarbons (200 <MW< 206)

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor

Notes: IT OCCURS IN GINGER OIL. VERNIN & PARKANYI, ELSEVIER,34,579,1994(G.CHARALAMBOUS Ed.).



EI: 119(100) 132(66) 105(43) 93(32) 120(32) 41(31) 91(30) 202(28) 55(24) 131(20) 145(19) 77(15) 69(13) 83(13) 117(13) 133 92(11) 152(11) 121(10) 65(10) 80(10)

PENTENYL CURCUMENE

Chemical name: 2,6-DIMETHYL-10-(p-TOLYL) UNDECA-2,6-DIENE — N° 5034

Origin & ref: SALVIA DORISIANA (STANDLEY); HALIM & COLLINS, J.AGRIC.FOOD CHEM.,23(3),506-510,1975.

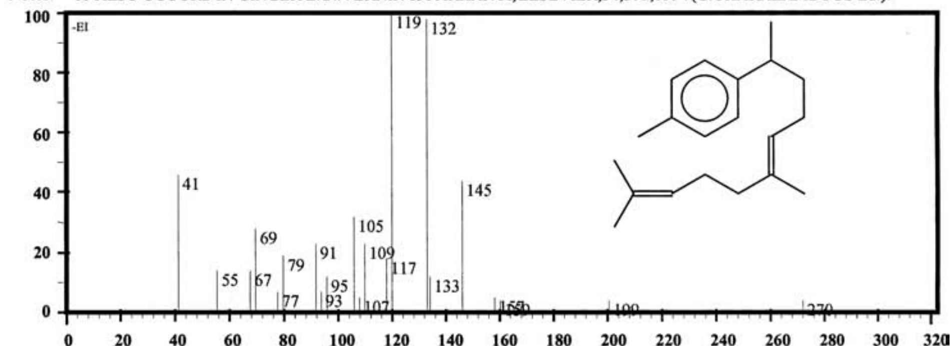
Mol. formula: C20 H30 (270) **R.N (CAS):** 55968 43 9 **CA:**

IKA: 0 **IKP:** 0 **DIK** 0 Family: Aromatics / Hydrocarbons

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor

Notes: IT ALSO OCCURS IN GINGER E.O.. VERNIN & PARKANYI, ELSEVIER,34,579,1994 (G.CHARALAMBOUS Ed.).



EI: 119(100) 132(98) 41(46) 145(44) 105(32) 69(28) 109(23) 91(23) 79(19) 117(18) 55(14) 67(14) 95(12) 133(12) 93(7) 77(7) 157(5) 107(5) 159(4) 199(4) 270(4)

Figure 3.10 Mass spectra of ar-curcumene and pentenyl curcumene.

ZINGIBERENOL

Chemical name: 2-CYCLOHEXEN-1-OL,4-(1,5-DIMETHYL-4-HEXENYL)-1-METHYL N° 3694

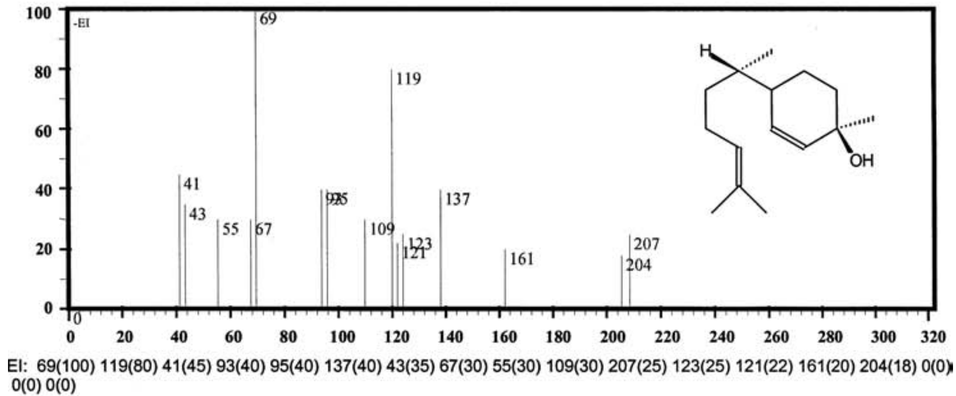
Origin & ref: GINGER OIL;CHEN & HO,J.AGRIC.FOOD CHEM.,36,322-328,1988.

Mol. formula: C15 H26 O1 (222) **R.N (CAS):** 58334 55 7 **CA:** 108 130203 c

IKA: 0 **IKP:** 2110 **DIK** 0 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor



EI: 69(100) 119(80) 41(45) 93(40) 95(40) 137(40) 43(35) 67(30) 55(30) 109(30) 207(25) 123(25) 121(22) 161(20) 204(18) 0(0) 0(0) 0(0)

ZINGIBERENOL

Chemical name: 2-CYCLOHEXEN-1-OL,4-(1,5-DIMETHYL-4-HEXENYL)-1-METHYL N° 3715

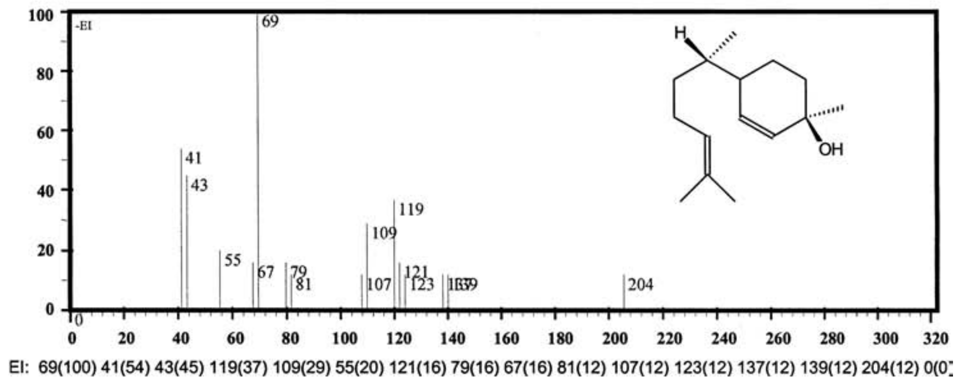
Origin & ref: GINGER OIL;VERNIN et al.,IN:SPICES,HERBS..(G.CHARALAMBOUS Ed.),ELSEVIER,34,579,1994.

Mol. formula: C15 H26 O1 (222) **R.N (CAS):** 58334 54 7 **CA:** 121 178142 c

IKA: 0 **IKP:** 2070 **DIK** 0 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor



EI: 69(100) 41(54) 43(45) 119(37) 109(29) 55(20) 121(16) 79(16) 67(16) 81(12) 107(12) 123(12) 137(12) 139(12) 204(12) 0(0)

Figure 3.11 Mass spectra of zingiberenol.

10-EPI- GAMMA -EUDESMOL

Chemical name: 2-NAPHTHALENEMETHANOL,1,2,3,4,4a,5,6,7-OCTAHYDRO-ALPHA,ALPHA,4a,8-TETRAMe N° 3712

Origin & ref: GINGER OIL;VERNIN et al; IN:SPICES., HERBS, FUNGI (G.CHARALAMBOUS Ed.), ELSEVIER,34,579,1994.

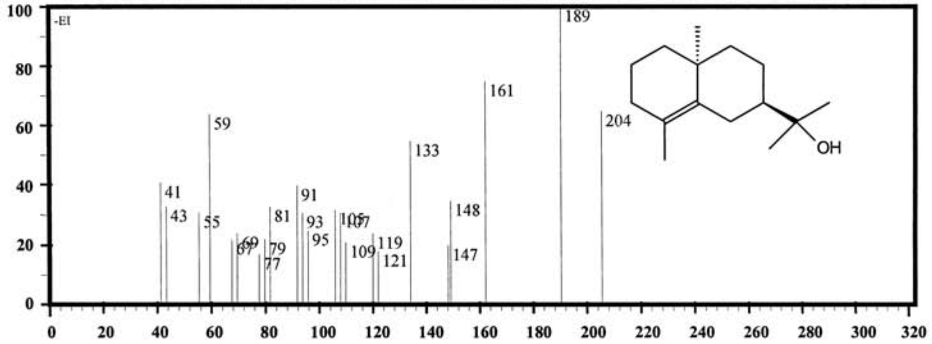
Mol. formula: C15 H26 O1 (222) **R.N (CAS):** 15051 81 7 **CA:** 0:0

IKA: 1605 **IKP:** 2060 **DIK** 455 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor

Notes: ALSO FOUND IN VETIVER OIL BY KAISER & NAEGELI,TETRAHEDRON LETT.,(20),2009,1972) & IN GERANIUM.



EI: 189(100) 161(75) 204(65) 59(64) 133(55) 41(41) 91(40) 148(35) 43(33) 81(33) 105(32) 93(31) 107(31) 55(31) 95(25) 69(2
119(24) 67(22) 79(22) 109(21) 147(20) 121(18) 77(17)

SESQUISABINENE HYDRATE(IN MIXTURE)

Chemical name: BICYCLO[3.1.0.]HEXAN-2-OL,5-(1,5-DIMETHYL-4-HEXENYL)-2-METHYL(TRANS) N° 3726

Origin & ref: GINGER OIL; CHEN & HO,J.AGRIC. FOOD CHEM.,36,322-328,1988.

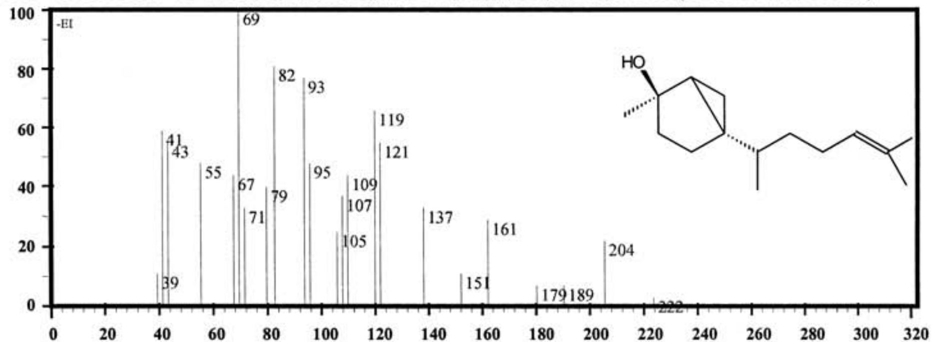
Mol. formula: C15 H26 O1 (222) **R.N (CAS):** 58319 05 4 (CIS **CA:** 108 130203 c

IKA: 1560 **IKP:** 2100 **DIK** 540 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor

Notes: ALSO FOUND BY VERNIN & PARKANYI,ELSEVIER,34,579,1994,SPICES,HERBS ..(G.CHARALAMBOUS Ed.)



EI: 69(100) 82(81) 93(77) 119(66) 41(59) 43(55) 121(55) 55(48) 95(48) 109(44) 67(44) 79(40) 107(37) 71(33) 137(33) 161(29)
105(25) 204(22) 39(11) 151(11) 179(7) 189(7) 222(3)

Figure 3.12 Mass spectra of 10-epi-γ-eudesmol and sesquisabinene hydrate.

TRANS- BETA-SESQUIPHELLANDROL

Chemical name: CYCLOHEX-1-EN-4-OL,3-METHYLENE-4-METHYL-6-(1,5-DIMETHYL HEX-4-EN-1-YL) N° 3595

Origin & ref: GINGER OIL.,VERNIN et al., IN: SPICES, HERBS.. (G.CHARALAMBOUS Ed.), ELSEVIER,34,579-594,1994.

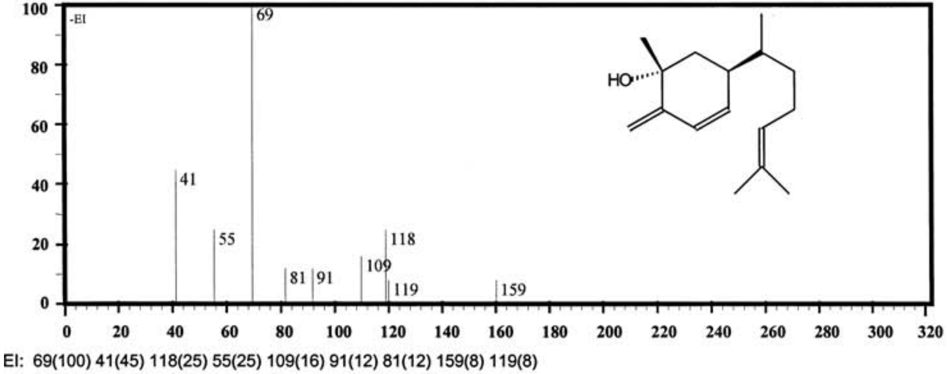
Mol. formula: C15 H24 O1 (220) **R.N (CAS):** 56144 27 5 **CA:** 121 178142 c

IKA: 0 **IKP:** 2046 **DIK** 0 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor

Notes: CIS & TRANS ISOMERS WERE FOUND IN GINGER EXTRACTS(J.AGRIC.FOOD CHEM.,36(2),325-327,1988).



EI: 69(100) 41(45) 118(25) 55(25) 109(16) 91(12) 81(12) 159(8) 119(8)

CIS-BETA-SESQUIPHELLANDROL

Chemical name: 1-CYCLOHEXEN-4-OL,3-METHYLENE-4-METHYL-6-(1,5-DIMETHYL-4-HEXEN-1-YL)-,(CIS) N° 10205

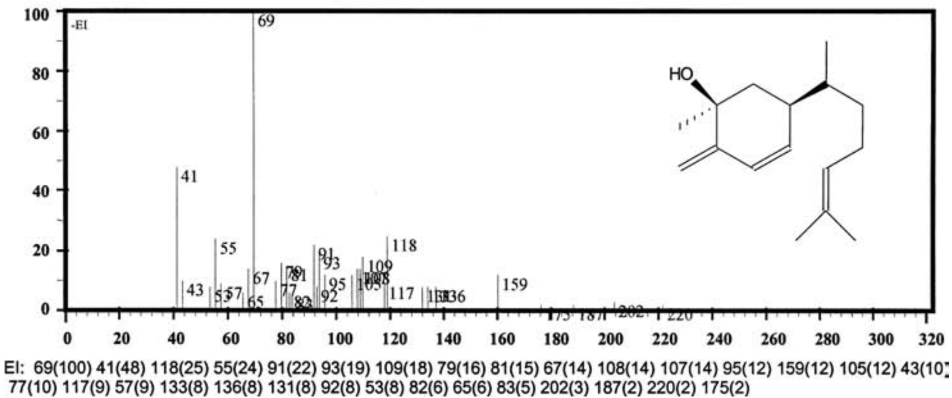
Origin & ref: GINGER E.O.; BEDNERCZYK & KRAMER, CHEMICAL SENSES & FLAVORS,1,377-386,1975.

Mol. formula: C15 H24 O1 (220) **R.N (CAS):** **CA:**

IKA: 0 **IKP:** 0 **DIK** 0 Family: Sesquiterpenes / Alcohols

FEMA: 0 **COE** 0 **IOF** 0 Occurrence: Essential oils

Descriptor odor/Flavor



EI: 69(100) 41(48) 118(25) 55(24) 91(22) 93(19) 109(18) 79(16) 81(15) 67(14) 108(14) 107(14) 95(12) 159(12) 105(12) 43(10) 77(10) 117(9) 57(9) 133(8) 136(8) 131(8) 92(8) 53(8) 82(6) 65(6) 83(5) 202(3) 187(2) 220(2) 175(2)

Figure 3.13 Mass spectra of *trans-* and *cis-*β-sesquiphellandrols.

(6)-GINGEROL AS TMS

Chemical name: 3-DECANONE,5-OTMS-1-(4-OTMS-3-METHOXYPHENYL) N° 10170

Origin & ref: GINGER OLEORESIN; HARVEY, J. OF CHROMATOGRAPHY,212,75-84,1981.

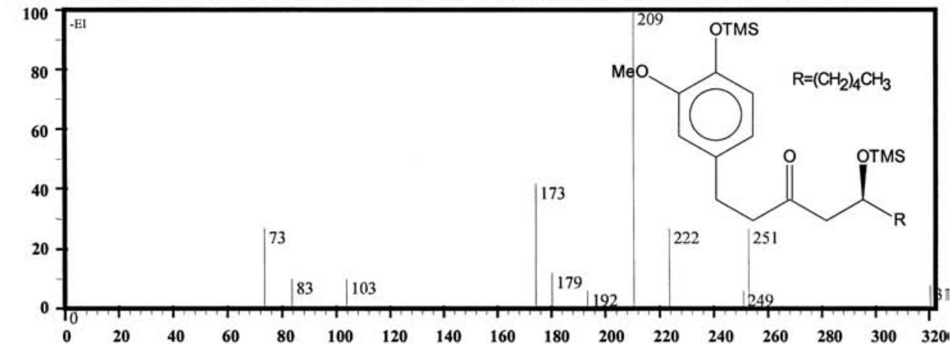
Mol. formula: (438) **R.N (CAS):** **CA:**

IKA: 0 **IKP:** 0 **DIK** 0 Family: Araliphatics / Ketones

FEMA: 0 **COE** 0 **IOF** 0 Occurrence: Oleoresins

Descriptor odor/Flavor

Notes: GC/MS AT 25 EV OF TRIMETHYLSILYL DERIVATIVES OF PUNGENT PRINCIPLES OF GINGER OLEORESIN.



EI: 209(100) 173(42) 438(42) 73(27) 222(27) 348(27) 251(27) 348(27) 179(12) 83(10) 333(10) 103(10) 318(8) 192(6) 249(6) C

HEXAHYDROCURCUMIN AS TMS

Chemical name: HEXAHYDROCURCUMIN AS TMS N° 10171

Origin & ref: GINGER OLEORESIN; HARVEY; J. OF CHROMATOGRAPHY,212,75-84,1981.

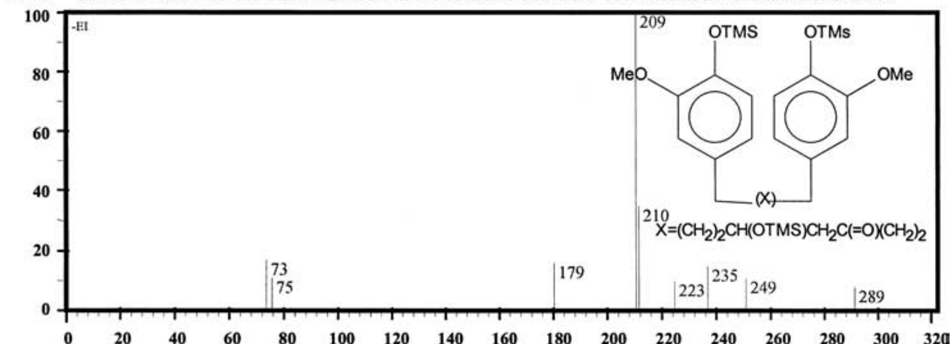
Mol. formula: **R.N (CAS):** **CA:**

IKA: 0 **IKP:** 0 **DIK** 0 Family: Araliphatics / Ketones

FEMA: 0 **COE** 0 **IOF** 0 Occurrence: Oleoresins

Descriptor odor/Flavor

Notes: GC/MS AT 25 EV OF TRIMETHYLSILYL DERIVATIVES OF PUNGENT PRINCIPLES OF GINGER OLEORESIN.



EI: 209(100) 210(35) 500(26) 73(17) 179(16) 235(15) 590(14) 75(11) 249(11) 223(10) 289(8) 501(5)

Figure 3.14 Mass spectra of (6)- and (10)-gingerols.

(6)-GINGEROL(GUAIACOL DERIVATIVE)

Chemical name: 3-DECANONE,5-HYDROXY-1-(4-HYDROXY-3-METHOXYPHENYL) N° 4612

Origin & ref: OLEORESIN OF GINGER & E.O.; CONNELL, THE FLAVOUR INDUSTRY, 1970, 677-693.

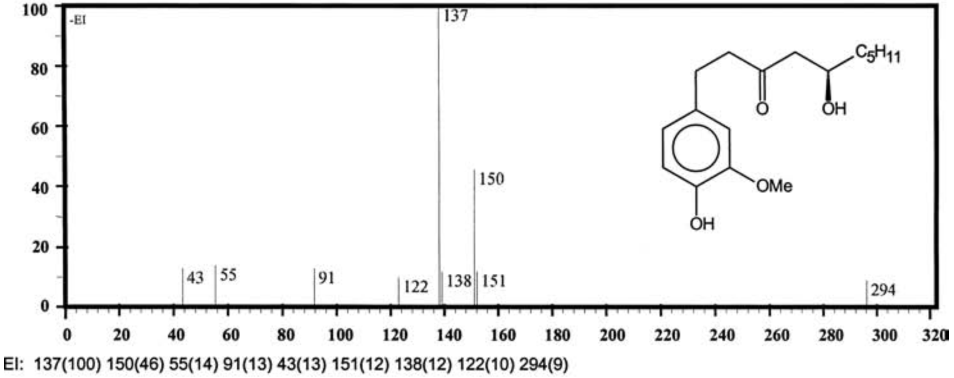
Mol. formula: C17 H26 O4 (294) **R.N (CAS):** 23513 14 6 **CA:** 74 34534 v

IKA: 0 **IKP:** 0 **DIK** 0 Family: Aromatics / Phenols

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor PUNGENT / IDEM

Notes: CARDIOTONIC AGENT IN FOOD FLAVORS.



(10)-GINGEROL(GUAIACOL DERIVATIVE)

Chemical name: 3-TETRADECANONE,5-HYDROXY-1-(4-HYDROXY-3-METHOXYPHENYL)-,(S) N° 5870

Origin & ref: OLEORESIN OF GINGER; CONNELL, THE FLAVOUR INDUSTRY, 1970, 677-693.

Mol. formula: C21 H34 O4 (350) **R.N (CAS):** 23513 15 7 **CA:** 74 34534 v

IKA: 0 **IKP:** 0 **DIK** 0 Family: Aromatics / Phenol & derivatives

FEMA: 0 **COE** 0 **IOF** 2 Occurrence: Essential oils

Descriptor odor/Flavor / PUNGENT

Notes: SEE ALSO CA:96 109955 y & 104 205701 s.

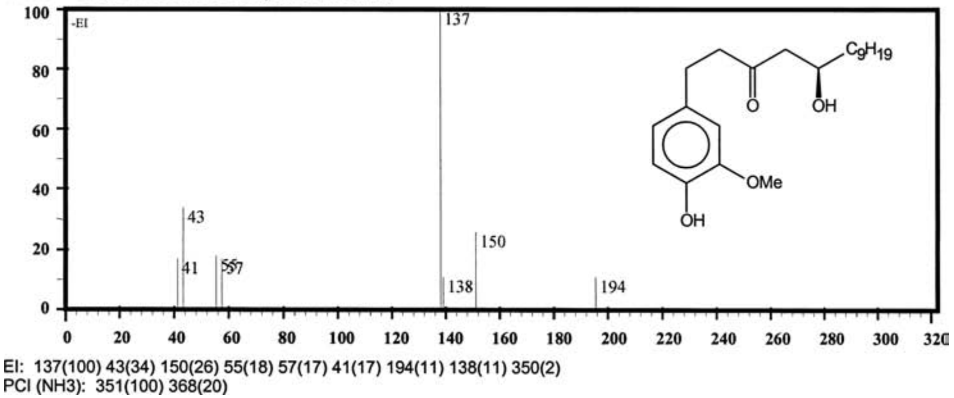
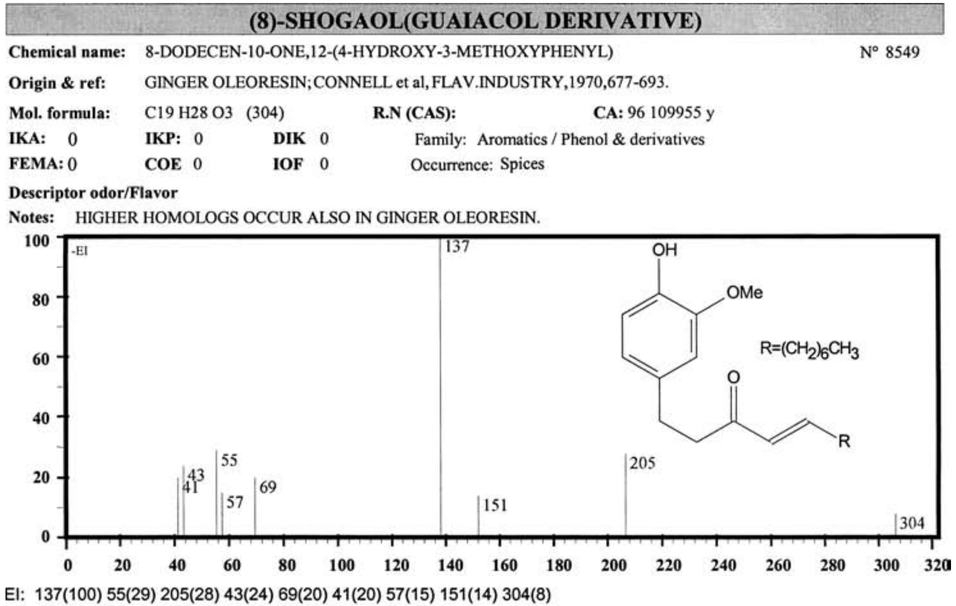


Figure 3.15 Mass spectra of (6)-gingerol (TMS) and hexahydrocurcumin (TMS).



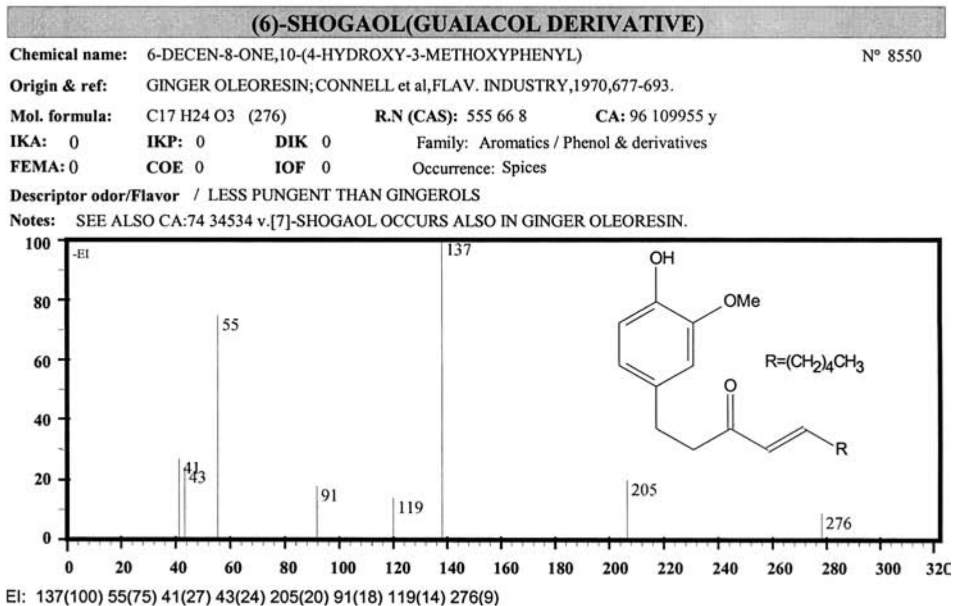


Figure 3.16 Mass spectra of zingerone.

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4 Tissue Culture and Biotechnology of Ginger

K. Nirmal Babu, K. Samsudeen, D. Minoo, S. P. Geetha, and P. N. Ravindran

Recent advances in plant tissue, cell, and protoplast culture combined with genetic engineering have opened up new and exciting possibilities in propagation, gene manipulation, crop improvement, and germplasm conservation in many plant species. Micropropagation has been established as a sound commercial proposition, especially in ornamentals and plantation crops to produce nuclear stock free from pathogens and viruses. Technologies like anther, pollen, and protoplast culture will speed up the process of producing better varieties. All these developments have contributed to the acceptance of in vitro culture techniques as viable and valuable tools. In addition, the potential of in vitro conservation and cryopreservation to conserve genetic resources, plant varieties, cell lines, and pollen through the establishment of in vitro gene banks is becoming a reality. It is now possible to manipulate genetically cultured cells and tissues to produce improved plants and high-value substances.

The cell- and tissue-culture techniques have a tremendous advantage in horticultural crops, especially those that are propagated vegetatively. Ginger is no exception, more so because the conventional breeding programs are hampered due to lack of fertility and natural seed set. Rhizome rot caused by *Pythium* spp. and bacterial wilt caused by *Ralstonia solanacearum* are major diseases affecting ginger that are spread primarily through infected rhizomes. Tissue-culture techniques would help in the production of pathogen-free planting material of high-yielding varieties. Since no source of resistance is available in the germplasm, somaclonal variation could be an important source of variability to evolve high-yielding, high-quality disease-resistant lines. Tissue-culture techniques could also be used for in vitro pollination and embryo rescue in ginger. However, the applicability of such techniques depends upon the ability to regenerate plants effectively within in vitro cultures. Protocols for micropropagation, plant regeneration, in vitro pollination, protoplast culture, the development of synseeds, and cryopreservation are available. These can be effectively used in ginger crop–improvement programs. All these aspects are discussed, reviewed, and updated in this chapter.

Micropropagation

Many workers reported micropropagation of ginger using shoot meristems (Hosoki and Sagawa, 1977; Nadgauda et al., 1980; Pillai and Kumar, 1982; Ilahi and Jabeen, 1987; Bhagyalakshmi and Singh, 1988; Saradha and Padmanabhan, 1989; Balachandran et al., 1990; Choi, 1991a; Choi and Kim, 1991; Samsudeen, 1996; Nirmal Babu, 1997), base of the pseudostem (Ikeda and Tanabe, 1989; Choi, 1991b; Nirmal Babu, 1997; Nirmal Babu et al., 1998), and roots (Nel, 1985). The most commonly used medium was the MS basal medium (Murashige and Skoog, 1962) supplemented with IAA, IBA, NAA,

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Table 4.1 In vitro responses of ginger

Explant used	*Media composition*	*In vitro response*	*Reference*
Vegetative buds and rhizome bits with axillary buds	MS + 2 mgl^{-1} NAA (liquid medium)	Multiple shoots and in vitro rooting	Nirmal Babu et al. (1996e)
Vegetative buds	MS major elements +Ringe-Nitsch minor elements, vitamins, 1 ppm BA, 2% sucrose	Multiple shoots with roots	Hosoki and Sagawa, 1977
Vegetative buds, ovary, rhizome, and leaf sheath	MS + 0.5 ppm NAA MS + 2 mgl^{-1} 2,4-D	Callus	Choi (1991), Nirmal Babu et al. (1997)
Rhizome	MS + 0.5 mgl^{-1} 2,4-D + 0.5 mgl^{-1}BA	Plantlets	Ilahi and Jabeen (1987)
Flower, inflorescence	MS + 10 mgl^{-1} BA + 0.2 mgl^{-1} 2,4-D	Conversion of flowers to plants	Nirmal Babu et al. (1992b)
Anther	MS + 1.5 mgl^{-1} 2,4-D + 200 ml/l coconut milk	Callus, roots	Ramachandran and Nair (1992)
Callus derived from bud, ovary, leaf	MS + 10 mgl^{-1} BA, 0.2 mgl^{-1} 2,4-D	Callus induction and plant regeneration	Nirmal Babu (1997)
		Organogenesis and plantlet formation	Nirmal Babu et al. (1992a, 1996b)
Callus derived from vegetative buds	MS + 0.1 mgl^{-1} Kin, 0.2 mgl^{-1} BA, 10% coconut milk	Shoot regeneration	Nadgauda et al. (1980)
In vitro plantlets	MS +9–12% sucrose		
	MS +75 g/l of sucrose MS + 2 g/l sucrose and 1g/l of mannitol	In vitro rhizomes	Bhat et al. (1994) Sharma and Singh (1995) Peter et al. 2002

[a]IISR, Unpublished information from author's laboratory.
MS, Murashige and Skoog (1962) medium;
SH, Schenk and Hildebrandt (1972) medium;
WPM, Woody Plant Medium (McCown et al., 1979) medium.
IAA: Indole-3-acetic acid
IBA: Indole-3-butyric acid
NAA: α-naphlhalene acetic acid
2, 4-D: 2,4-Dichloropenoxy acetic acid
BAP: 6-Benzylaminopurine

2,4-D, kinetin, and BAP in different concentrations and combinations (Table 4.1). Only Pillai and Kumar (1982) used SH (Schenk and Hildebrandt, 1972) medium.

Nirmal Babu (1997) tested various explants—vegetative bud, immature inflorescence, leaf (pseudostem), ovary, and anther—for their morphogenetic responses (see Figure 4.1A–L) on MS basal medium supplemented with cytokinins (BAP and kinetin) and auxins (NAA and 2,4-D). MS basal medium supplemented with auxin (NAA 0–4 mgl^{-1}) and cytokinin (BAP 0–4 mgl^{-1}) gave positive response in inducing multiple shoots and roots. The presence of NAA at low concentrations (1 mgl^{-1}) resulted in good growth of culture, root induction, and shoot multiplication and addition of BAP at 4 mgl^{-1} increased the multiple shoot induction, but reduced root induction. NAA alone at high concentration (2–4 mgl^{-1}) inhibits shoot growth as well as root induction, whereas BAP alone at higher concentration (4 mgl^{-1}) induced only multiple shoots and rarely roots. Earlier workers also reported that BAP and NAA combinations were best for shoot

Figure 4.1 Stages in ginger tissue culture: (a) ginger plant; (b) vegetative bud explant and culture initiation; (c) multiple shoots; (d) regenerating callus; (e) organogenesis and embryogenesis from ovary derived callus; (f) conversion of floral buds into vegetative buds; (g) in vitro fruit formation; (h, i) plant regeneration from anther culture; (j) in vitro *rhizome* formation; (k, l) stages in hardening.

multiplication in ginger (Sakamura et al., 1986; Charlwood et al., 1988; Sakamura and Suga, 1989).

The induction of both roots and shoots in the same medium reduces the time taken for cloning considerably, and in ginger it takes about 60 days for an explant to develop

into a well-developed plantlet in the first cycle using a primary explant from the greenhouse-grown plant. When the subcultures are initiated from the in vitro developed axillary shoots, the rate of proliferation was further increased and the time taken for plantlet development was reduced to 45 days per cycle (Nirmal Babu, 1997).

Vegetative Bud Culture

Vegetative bud explants containing both shoot tip and axillary buds were used for clonal multiplication. Growth regulators, NAA (1 to 4 mgl^{-1}) and BAP (1 to 4 mgl^{-1}) were tested in various combinations. Only 50 percent of the explants could be established, whereas the rest were lost due to contamination. The explants took nearly 20 days for exhibiting first signs of growth and bud break and subsequently produced both multiple shoots as well as roots in all the growth-regulator concentrations tried. The number of shoots ranged from 1 to 9 and the number of roots ranged from 1 to 10 after 60 days of culture (see Figure 4.1a–c). Both NAA and BAP induced multiple shoots and roots in ginger vegetative bud explants. However, the cultures responded differently in different treatments. MS medium supplemented with 4 mgl^{-1} NAA and 4 mgl^{-1} BAP gave the lowest response (40 percent) for production of multiple shoots or roots, whereas that supplemented with 1 mgl^{-1} NAA and 4 mgl^{-1} BAP or NAA alone (1 mgl^{-1}) gave highest culture response (90 percent). The mean number of multiple shoots ranged from 1.2 to 5.2 in different treatments. MS medium supplemented with 3 mgl^{-1} each of NAA and BAP gave the lowest number (1.2) of multiple shoots, whereas while that supplemented with 1 mgl^{-1} NAA and 4 mgl^{-1} BAP gave the highest number (5.2).

The mean number of roots ranged from 0.7 to 5.4 in different treatments. MS media supplemented with 1 mgl^{-1} NAA gave the highest number (5.4) of roots and MS media supplemented with 4 mgl^{-1} BAP gave the least number (0.7) of roots.

Considering that both induction of multiple shoots and roots are equally important, development of both in a single medium reduces the time taken for plant development. In such cases, MS medium with 1 mgl^{-1} NAA alone or 1 mgl^{-1} NAA and 4 mgl^{-1} BAP was ideal for multiplication of ginger from vegetative bud explants (see Table 4.1). These treatments were significantly superior to the rest with respect to multiple shoot production and root induction. The plantlets from the vegetative bud cultures are healthy, robust, and 8 to 12 cm tall with three to four roots. These plantlets were hardened in a humid chamber for 20 to 25 days with 85 percent establishment.

Inflorescence Culture and Development of Shoots from Floral Meristem

Floral meristems from young inflorescences, when the determination of an individual floral meristem was not canalized, can be induced to grow vegetative shoots in vitro. In rhizomatous crops like ginger, the use of floral meristems reduces the problem of culture contamination that is so common when rhizome explants are used.

In ginger, vegetative shoots were produced in 70 percent of the explants when 1-week-old inflorescences were cultured on MS medium supplemented with 10 mgl^{-1} BAP and 0.2 mgl^{-1} 2,4-D. One or rarely two plantlets developed per axil of the bract in the majority of the cases (see Figure 4.1f). In about 26 percent of the cultures multiple shoots ranging from 5 to 25 were induced. These shoots grew into complete plantlets in 7 to 8 weeks' time. However, in 20 percent of the cultures the older flower buds

Table 4.2 Morphogenetic response of immature inflorescence explants on MS basal medium

Sl. No.	*Explant*	*Culture medium*	*Cultures responded (%)*[a]	*Morphogenetic response*
1.	One-week-old whole inflorescence	MS + 10 mgl^{-1} BAP + 0.2 mgl^{-1} 2,4-D	20	Opening of flower buds and development of normal flowers
			44	Conversion of floral buds to vegetative buds with 1–2 shoots
			26	Conversion of floral buds to vegetative buds and multiple (5–25) shoots
			2	Flower bracts developed into leaf-like structures
2.	Single flower culture	MS + 10 mgl^{-1} BAP + 0.2 mgl^{-1} 2,4-D	40	Development of fruit but ovary splits open and no further growth
			20	Development of fruit and subsequent development of plantlets from fruits

[a]Mean of 20 replications

developed into flowers and opened while in culture (Table 4.2). These are the meristems that were already differentiated into flower primordia (Nirmal Babu et al., 1992b).

The development and maturity of flower in the aseptic cultures of ginger inflorescence will also result in the exciting possibility of aseptic pollen, which can directly be used for conservation in a cryopollen gene bank and for in vitro pollination.

Single Flower Cultures and Development of Fruit

Sexual reproduction is an important mechanism for the introduction of variability through recombination in a population. In nature, ginger produces many flowers but fails to set fruit. New biotechnological methods like in vitro pollination and embryo rescue are employed in many plant species for obtaining viable seeds and subsequently the plants when normal mechanisms fail to develop seeds due to incompatibility and failure in embryo development. By culturing young 1-week-old immature inflorescences on MS medium supplemented with 10 mgl^{-1} BAP and 0.2 mgl^{-1} 2,4-D, it was possible to effect in vitro pollination and the ovary developed into trilocular fruits by 60 to 90 days in 20 percent of the cultures (see Figure 4.1g), and subsequently plants could be recovered from the fruits. In 20 percent of the cultures single plantlets were seen emerging directly from the ovaries by the seventh week (Nirmal Babu et al., 1992b). These plantlets developed roots simultaneously and later produced tillers. Development of seeds by in vitro pollination in ginger was also reported by Valsala et al. (1997). In nature also, rare fruit set was reported (Purseglove et al., 1981). The possibility of in vitro–induced seed development will open up new possibilities of sexual reproduction and development of seed-derived progenies of ginger by selfing and hybridization hitherto ineffective in ginger, thus bringing entirely new directions to ginger crop–improvement programs.

Plant Regeneration from Callus

Successful development of a plant regeneration protocol is essential in that it has a cascading effect. The success of many other advanced in vitro techniques such as in vitro mutant selection, protoplast fusion, and genetic transformation depends directly upon the ability to regenerate plants from the derived tissue. In addition, polyploidy, aneuploidy, and chromosome structural changes, which commonly occur in fast-dividing cells, along with many other factors, result in accumulating heritable variation in the regenerating plants, giving rise to new variability in the gene pool (somaclonal variation) that can be used for crop improvement.

Callus can be initiated in vitro by culturing small explants on growth-supporting medium supplemented with exogenous growth-regulating factors. During this process, cell differentiation and specialization, which might be occurring in the intact plant tissue, are reversed and the explant gives rise to new tissue that is composed of meristematic and unspecialized cells. During dedifferentiation, storage products typically found in resting cells tend to disappear. New meristems are formed in the tissue and these give rise to undifferentiated parenchymal cells without any of the structural order that was characteristic of the organ or tissue from which they were derived. Although callus remains unorganized, as growth proceeds, some kind of specialized cells may be again formed. Such differentiation can take place at random, but may be associated with centers of morphogenesis, which can give rise to organs. Thus, callus culture is usually made up of two types of tissues, differentiated and nondifferentiated.

Callus Induction

Many parts of the whole plant may have an ultimate potential to produce callus in vitro, but it is frequently found that callus cultures are more easily established from some organs than others. Young meristematic tissues are most suitable and meristematic areas in older parts of a plant can also give rise to callus. Monocotyledons react differently and are less likely to form callus than dicotyledons (Pierik, 1987). A difference in the capacity of tissue to give rise to callus is particularly apparent in monocotyledons. For example, in most cereals, callus growth can be obtained only from organs such as zygotic embryos, germinating seeds, seed endosperm, seedling mesocotyl, and very young leaves but so far never from mature leaf tissue (Green and Philips, 1975; Dunstan et al., 1978).

Nirmal Babu (1997) reports that in ginger, callus was successfully induced in vegetative bud, young leaf, ovary, and anther tissues on MS medium supplemented with various levels (0.5 to 5.0 mgl^{-1}) of NAA and 2,4-D for induction and proliferation of callus. Although auxins, in general, induce callus formation, this worker reported that only 2,4-D at concentrations ranging from 0.5 to 5.0 mgl^{-1} was effective in inducing callus in all explants tried, with the best concentration being 3 mgl^{-1}. NAA induced a slight amount of callus at higher concentrations of 3 to 5 mgl^{-1} only. The explants differed in their ability to form callus. The best is vegetative bud followed by anther explant. Leaf explant gave the least amount of callus. The amount of callus produced was 2.7 g per tube in leaf and 3.4 g per tube in vegetative bud. Callus tissue was not of one kind. Strains of callus differing in appearance, color, degree of compaction, and morphogenetic potential commonly arise from a single experiment. In ginger, the callus was loose, friable, and pale yellow in color. In the subsequent cultures, the callus contained some hard organized embryogenic "lumps" (meristemoids) within the mass

of loose cells (Nirmal Babu, 1997). The callus could be maintained and multiplied by monthly subcultures on the same media.

The earlier reports on callus induction in ginger were those of Pillai and Kumar (1982), Kulkarni et al. (1987), Sakamura and Suga (1989), Choi (1991b), Malamug et al. (1991), Kacker et al. (1993), Ilahi and Jabeen (1992), and Samsudeen (1996).

Plant Regeneration

Two-month-old calli derived from various explants—vegetative bud, young leaf, ovary and anther tissues—were cultured on a series of MS basal media supplemented with varying levels of auxin (2,4-D) and cytokinins (Kinetin and BAP) for morphogenesis and plant regeneration (Table 4.3)

When fresh calli, immediately after its induction, was cultured on MS medium without growth regulators, it resulted in rhizogenesis. The cytokinins, kinetin, and BAP when used individually did not result in organogenesis even after four to five cycles of subculture. But addition of cytokinins (kinetin and BAP) at concentrations of 5 to 10 mgl^{-1} in the presence of 0.2 mgl^{-1} 2,4-D resulted in induction of morphogenesis—both organogenesis and embryogenesis—and subsequent development of plantlets. MS medium supplemented with 10 mgl^{-1} BAP and 0.2 mgl^{-1} 2,4-D gave the best morphogenic response. Once the morphogenic pathway of the cultures was determined, they continued to show their morphogenic potential in subsequent subcultures even after 2 to 3 years.

In vegetative bud-derived callus, the number of plantlets developed per culture were higher in BAP (28 to 60) than in kinetin (8 to 26). The rate of shoot production and plantlet formation increased considerably to 36 to 62 shoots per culture when growth regulators were completely excluded from the medium in later subcultures after the induction of morphogenesis (see Figure 4.1c).

MS medium supplemented with 10 mgl^{-1} BAP and 0.2 mgl^{-1} 2,4-D was also the best for leaf-derived callus. The number of shoots per culture was higher in BAP (15 to 35). Transfer to growth regulator-free culture medium after initial morphogenesis resulted in enhancement of plant regeneration to 30 to 60 shoots. The time taken for the leaf-derived callus to differentiate and develop into a complete plantlet ranges from

Table 4.3 Effect of explant on plant regeneration through callus phase on MS basal medium[a]

Sl. No.	*Explant*	*Callus production (g)*[b]	*Days taken for morphogenesis*[c]	*Morphogenetic pathway*[b]	*No. of plantlets ±SD*[b]
1.	Vegetative bud	3.40	146	Organogenesis (shoot) and embryogenesis	26.2 (±6.2)
2.	Leaf	2.70	162	Organogenesis (shoot)	24.4 (±6.2)
3.	Ovary	3.10	131	Embryogenesis and organogenesis (shoot)	47.6 (±9.3)
4.	Anther	3.20	120	Organogenesis (shoot)	12.6 (±3.1)

[a]Mean of 10 replications
[b]Supplemented with 3 mgl^{-1} 2,4-D.
[c]Supplemented with 0.2 mgl^{-1} 2,4-D and 10 mgl^{-1} BAP.

6 to 8 months, whereas while it takes about 5 to 7 months for the vegetative bud-derived callus.

In callus derived from ovary tissues morphogenesis was observed on MS media supplemented with 5 to 10 mgl^{-1} BAP or kinetin and 0.1 to 0.2 mgl^{-1} 2,4-D and also with 5 mgl^{-1} BAP or kinetin and 0.2 mgl^{-1} 2,4-D after four to five subcultures. In both the media white globular heart-shaped embryo-like structures were observed in 67 to 80 percent of the cultures. In about 22 percent of the cultures both organogenesis and embryogenesis were observed in the same culture. This process continued in the subsequent cultures on the same medium. The embryogenic calli were separated and used for subsequent cultures. When growth regulators were removed from the culture medium at this stage, the callus turned green and the rate of morphogenesis increased considerably, resulting in many embryo-like structures that could be separated easily with a gentle tap. On subsequent transfer to fresh medium without growth regulators, the embryoids developed into complete plants. The somatic embryos produced secondary embryoids by adventitious embryogenesis resulting in a large number (100 to 300) of tiny embryoids (see Figure 4.1e). This type of multiplication continued on growth regulator-free medium even after 2 years of continuous culture, indicating that once the callus turns embryogenic, growth regulators are not needed for further multiplication. The embryoids produced were either compactly arranged or loosely arranged. The development of these embryoids into complete plantlets was higher when NAA (1 mgl^{-1}) was added to the culture medium, which also enhanced rooting. This protocol with a production potential of a large number of tiny propagules is ideally suited for in vitro manipulations such as in vitro mutagenesis, in vitro polyploidization, and in vitro selection against biotic and abiotic stresses. The somatic embryos are ideally suited for direct DNA transfer using a particle-delivery system and development of transgenics.

The explants differed in their morphogenetic response with regard to the morphogenetic pathway as well as the plantlets regenerated. The plant regeneration was by organogenesis in leaf- and anther-derived callus, whereas it was by both organogenesis and embryogenesis in vegetative bud-derived and ovary-derived callus. Histological studies have proved the origin of both organogenesis and embryogenesis. Embryo development followed typical monocotyledonous stages of development from globular, heart-shaped to torpedo-shaped embryos with clear-cut scutellum and coleoptile development. The embryo showed clear shoot and root poles with no vascular connection between the host tissue and the embryo. The explants differed with respect to days taken for morphogenesis and their plant regeneration potential. Anther-derived callus was quickest to respond (120 days) compared to leaf-derived callus, which is slowest (162 days). The mean number of plantlets recovered ranged from 12.6 from anther-derived calli to 47.6 in ovary-derived calli (see Table 4.2). The embryogenic calli derived from ovary were canalized and produced an increasing number of somatic embryos in the subsequent cultures. These somatic embryos also resulted in repetitive embryogenesis and budding resulting in a large number (over 100) of somatic embryos in a given culture tube. Thus, the ovary was the best among the explants tried for plant regeneration and recovery. This efficient plant-regeneration system is ideally suited for in vitro selection, in vitro mutagenesis, and genetic manipulation experiments (Nirmal Babu et al., 1996b).

Shoots developed from the callus were placed on the modified MS medium with 1 mgl^{-1} of NAA for rooting that was earlier identified as ideal for root induction. An extensive root system developed within 5 weeks in this medium. Rooting was better when liquid medium was used instead of solid medium.

Successful plant regeneration in ginger was earlier reported (Nadgauda et al., 1980; Ilahi and Jabeen, 1987; Kulkarni et al., 1984; Malamug et al., 1991; Kackar et al., 1993). The explants used were young sprouts and young leaf segments and the plant regeneration was via organogenesis and embryogenesis. Earlier studies indicate BAP at high concentration resulted in morphogenesis and plant regeneration from these explants.

Anther Culture

Since the first report of induction of androgenesis in *Datura* (Guha and Maheshwari, 1964), anther culture has gained considerable importance in our efforts to produce haploids and dihaploids. Haploid plantlets are formed in two distinct ways: by embryos originating directly from microspores without callusing (direct androgenesis) or by organogenesis from haploid callus tissue. Haploid cells, in general, are unstable in culture and have a tendency to undergo endomitosis to form diploid cells. This property of cell culture can be exploited for obtaining homozygous lines of ginger.

Callus formation and the development of roots and rhizome-like structures were reported from excised ginger anthers cultured on MS medium containing 2,4-D and coconut milk (Ramachandran and Nair, 1992).

Samsudeen et al. (2000) reported regeneration of plantlets from excised anthers. They cultured excised anthers with uninucleate pollen mother cells and pollen were inoculated on modified MS medium supplemented with 0.2 to 3.0 mgl^{-1} 2,4-D after cold treatment. Cold treatment was given for 1, 2, and 7 days at 0°C. Of the three different cold treatments tried, callus was induced only from anthers, which had 7 days of cold treatment. These anthers developed friable callus in solid as well as in liquid medium in about 6 weeks. Occasional development of roots was observed in liquid cultures. Their study has shown that solid medium is better than liquid medium for ginger anther culture. 2,4-D at 3 mgl^{-1} was good for both callus induction and callus proliferation, giving about 3 g of callus in about 30 days of culture when incubated in light. Calli obtained from ginger anthers were cultured on MS basal medium supplemented with 2,4-D (0 to 0.2 mgl^{-1}) and BAP (0 to 10 mgl^{-1}). MS medium with 2,4-D at 0.2 mgl^{-1} and BAP at 10 mgl^{-1} was the best for organogenesis and plant regeneration. The plant regeneration was by organogenesis and shoot development (see Figure 4.1h). Seventy percent of the cultures gave a morphogenetic response with a range of 1 to 20 shoots and an average of 12.6 shoots per culture tube (see Figure 4.1i). These shoots were multiplied and rooted on MS basal medium with 1 mgl^{-1} NAA before hardening and field establishment. The regenerated plants are being indexed for the selection of haploids or dihaploids.

Effect of Explant on Plant Regeneration

The various explants tried (i.e., vegetative bud, leaf, ovary, and anther) differed in callus induction, morphogenetic ability of callus, and pattern of morphogenesis through the callus phase (see Table 4.3). Anther-derived callus was quicker to turn morphogenetic followed by ovary-, vegetative bud-, and leaf-derived calli. The origin of callus determined the morphogenetic pathway it follows for development of plantlets.

Histological studies confirmed that plant regeneration in ginger callus was by organogenesis as well as embryogenesis, depending upon the origin of the explant. Calli derived from vegetative bud as well as ovary showed both organogenesis and embryogenesis, whereas those from leaf and anther followed only the organogenetic path of development. In addition, among the different explants tried, ovary was the most effective for plant regeneration through the callus phase, which gave 47.6 plantlets per tube, followed by vegetative bud (26.2), leaf (24.4), and anther (12.6). The morphogenetic calli obtained from all the explants showed their morphogenetic ability even after repeated subcultures both on the same medium or on growth-regulator–free medium, indicating that growth regulators are needed only for induction of morphogenesis. Once the callus turns morphogenetic, it retains the morphogenic ability for a long time if cultured on the same medium. These cultures remained morphogenetic and produced plantlets even after 2 years of repeated subcultures (Nirmal Babu, 1997).

Hardening and Field Establishment

A substantial number of micropropagated plants do not survive transfer from in vitro conditions to greenhouse or field environments due to the "delicate" nature of plants raised in vitro. Compared to in vitro conditions, the outside atmosphere, which has substantially lower relative humidity, higher light, and septic environment, causes stress to the micropropagated plants. Shoots and plants in culture are grown in conditions that provide little physiological stress since a carbon source is provided, reducing the need for photosynthesis. Due to the high relative humidity and low light within in vitro conditions, the anatomy and physiology of tissues are different from those of plants grown in greenhouse conditions. In addition, the aseptic environment in vitro reduces the stress of pathogens. Various factors such as development of epicuticular wax, functional stomata, root system, and increased photosynthetic ability influence the acclimatization. Most plant species grown in vitro require a gradual acclimatization and hardening for survival and growth in a natural environment (Preece and Sutter, 1991; George, 1996). As the plantlets are progressively acclimatized, the rate of water loss from their leaves decreases and the photosynthetic ability of the plant increases, especially in the leaves newly produced after transfer, resulting in a higher rate of establishment.

Nirmal Babu (1997) reported that ginger plantlets micropropagated as well as callus-regenerated plants were hardened and transplanted in a porous soil mixture of vermiculite, sand, and garden soil in equal proportions with 57 to 85 percent success depending upon the origin of explant. High humidity was maintained for the initial 20 to 30 days by keeping them in a humid chamber. The humidity was reduced gradually for hardening and establishment. The survival rate of transplanted plantlets ranged from 57 to 85 percent and the time taken for hardening ranged from 22 days in direct regenerated plants to 30 days in callus-regenerated plants. Plants regenerated from ovary-derived callus have the lowest establishment rate of 57 percent, whereas those multiplied directly from vegetative buds have the highest rate of 85 percent field establishment. The tissue-cultured plantlets obtained by direct multiplication and plantlets regenerated from vegetative bud-, leaf-, ovary-, and anther-derived calli differed in their size at the time of hardening. There is a direct correlation between plant size and survival rates; the bigger plantlets are easier to establish after hardening than the smaller plantlets. In general, plantlets multiplied directly from vegetative buds were bigger and hence have

Table 4.4 Morphological features of plantlets derived from various explants at the time of hardening[a]

	Direct regeneration		*Callus regeneration*			
Explant	*Vegetative bud*	*Inflorescence*	*Vegetative bud*	*Leaf*	*Ovary*	*Anther*
No. of plantlets/culture	5.2	2.8	26.2	24.4	47.6	12.6
Plant height (cm)	11.9	11.2	8.7	2.7	6.2	6.8
No. of roots/plant	3.2	3.2	2.3	3.1	1.3	2.0
No. of leaves/plant	7.8	7.2	5.4	4.2	6.0	8.0
Leaf length (mm)	52.0	48.0	51.0	45.0	39.0	30.0
Leaf breadth (mm)	6.0	5.0	6.0	4.0	3.0	4.0
Days taken for hardening	22.0	25.0	30.0	30.0	30.0	30.0
Establishment (%)	85.0	80.0	70.0	74.0	57.0	68.0
Rhizome wt. in 1st season (g)	3.3	2.8	1.6	1.2	0.8	0.7

[a]Mean of 10 replications

Table 4.5 Morphological characters of micropropagated plants developed through direct regeneration (MP) and callus regeneration (CR)

Sl. No.	*Plant type*	*Plant ht. (cm)*	*No. of tillers/plant*	*No. of leaves/ plant*	*Width of rhizome (cm)*	*No. of nodes/finger*	*Internode distance (mm)*	*Yield/plant (g)*
1.	MP	91.0±23.8	11.4±4.4	8.8±4.6	2.8±0.5	9.2±1.1	5.1±0.8	382.0±225
2.	CR	91.5± 6.1	10.2±2.2	8.8±1.2	2.7±0.2	8.1±0.7	4.9±1.0	447.4±243
3.	C	76.4±16.6	8.4±1.1	9.2±0.7	2.7±0.5	8.0±0.7	4.9±1.7	352.0±114

± Standard deviation; C: Control

a higher rate of establishment compared to plantlets regenerated through callus, which gave lower rate of establishment (see Tables 4.4 and 4.5). At the nursery stage, most of the plants were morphologically similar (see Figure 4.1k and l) except a few having leaves with white chlorotic patches and wavy margins.

Tissue-cultured plants of ginger could be hardened and acclimatized to the field conditions with relative ease due to the genetic nature of the zingiberaceous crops that are conventionally propagated through vegetative means. Earlier studies in ginger and other zingiberaceous crops like turmeric, cardamom, and *Kaempferia* support this view (Hosoki and Sagawa, 1977; Nadgauda et al., 1980; Bhagyalakshmi and Singh, 1988; Vincent et al., 1992).

Tissue-cultured plants were maintained in polythene bags for the first season and then transferred to earthern pots. Rhizomes of tissue-cultured plantlets were too small (0.7 to 3.3 g) to harvest after the first season (see Figure 4.2b) and if harvested, the rhizomes may dry up if care is not taken. The micropropagated plantlets behaved like seedlings of similar zingiberaceous crops. The size of the rhizome increased over the years and developed into normal size comparable to that of mother plants only in third year. This indicates that tissue-cultured plantlets cannot be directly used for commercial cultivation

and need to be maintained for at least two to three crop seasons in the nursery before commercial planting (Nirmal Babu, 1997; Nirmal Babu et al., 1997, 1998, 2000).

Evaluation of Somaclones

The success of any in vitro culture technique depends either on the ability to clone the genotypes for production of uniform planting material or the ability to bring about variations that can be exploited in crop-improvement programs (see Figure 4.2a–h). The genetic uniformity of plants multiplied by tissue culture depends on a number of factors, with the two most important being the method of multiplication and the genotype.

Accumulated information now shows that plants propagated by precocious shoots show no more spontaneous mutation than those propagated by conventional means. Plants regenerated from callus or cell suspension cultures may show a varying proportion of structural or physiological abnormalities depending upon the species, origin, and the age of culture (Yeoman, 1986). Other factors such as growth regulators (D'Amato, 1978; Zakhlenyuk and Kunakh, 1987), composition of the culture medium (Bayliss, 1977; Feng and Quyang, 1988), culture conditions (Cerutti, 1985; Jackson and Dale, 1988), and culture method (Wilson et al., 1976) influence somaclonal variation. The reasons for variations in micropropagated plants can also be due to the variation that existed in the source plant (preexisting variation), epigenetic or physiological effects, and genetic changes (Swartz, 1991; George, 1996). Extensive studies conducted during the last decade have shown that the cell and callus cultures, especially on periodical subculture, undergo various morphological and genetic changes: polyploidy, aneuploidy, chromosome breakage, deletions, translocations, gene amplifications, inversions, and mutations (Nagl, 1972; Meins, 1983; D'Amato, 1985). In addition, there are changes at the molecular and biochemical levels, including changes in the DNA, rearrangement of genes, somatic crossing over, altered nucleotide methylation, perturbation of DNA replication by altered nucleotide pools, and slicing or activation of genes by mutations in associated noncoding regions and transposons (Scowcroft, 1984) and enzymes (Cullis, 1983; Day and Ellis, 1984; Ball and Seilleur, 1986; Brettel et al., 1986). Thus, in vitro technology is a powerful tool for the induction of much-needed genetic variability in ginger.

Morphological and Biochemical Characterization

Morphological and biochemical characterization of 4-year-old micropropagated as well as callus-regenerated plants was reported by Nirmal Babu (1997) in comparison with conventionally propagated plants (see Table 4.6). Direct regenerated plants and callus-regenerated plants as separate groups when compared with conventionally propagated plants revealed a good amount of variation with regard to plant height, number of tillers and of leaves per plant, girth of rhizome, number of nodes per finger, internodal distance, yield per plant (see Figure 4.2a–d), dry recovery percentage, and oleoresin and fiber contents. Micropropagated and callus-regenerated plants have higher mean values with regard to plant height, number of tillers, number of nodes per finger, and yield per plant compared to controls, whereas they have lesser mean values with regard to number of leaves per plant and oleoresin and fiber contents. With regard to the width of rhizomes,

Figure 4.2 Somaclonal variation and microrhizomes in ginger: (a) bold rhizomes harvested from ginger somaclone (CR 1222); (b) comparison of rhizomes from TC plants with that of conventionally propagated plants; (c) tissue-cultured plants after second year of nursery in comparison with conventionally propagated plants; (d) variations in rhizome size, shape, and internodal length in micropropagated plants; (e) growth recovery of microrhizome-derived plants in comparison with conventionally propagated plants; (f) initial growth of microrhizome-derived plants in comparison with conventionally propagated plants; (g) microrhizomes from ginger tissue cultures; (h) rhizomes harvested from microrhizomes as planting material.

Table 4.6 Morphological characters, yield, and quality attributes of promising somaclones in ginger

Sl No.	*Somaclone*	*Plant ht. (cm)*	*No of tillers/ plant*	*Rhizome size*	*Yield (g)*	*Dry recovery (%)*	*Oleoresin (%)*	*Fiber (%)*
1.	MP 61-9	81	13	Medium	870	26.0	2.5	4.4
2.	MP 74-15	78	7	Bold	780	23.5	3.8	4.3
3.	MP 76-1	96	10	Medium	474	27.5	4.5	4.2
4.	MP 76-3	93	9	Medium	398	25.7	2.8	3.8
5.	CR 10-1	79	9	Medium	367	23.5	4.2	3.8
6.	CR 816	79	10	Medium	390	24.0	3.0	5.0
7.	CR 818	83	9	Bold	300	22.0	1.6	3.6
8.	CR 822	76	11	Medium	398	24.7	3.8	3.9
9.	CR 855	69	8	Medium	472	25.0	2.0	4.3
10.	CR 1222	87	8	Bold	600	21.0	3.9	3.9
11.	Control	101	12	Medium	513	28.0	3.8	4.9

MP, micropropagated plants; CR, callus-regenerated plants

internodal distance, and dry recovery percentage, all the three groups are on par. When we consider the range observed within the group, micropropagated plants showed the highest range with regard to plant height, number of tillers and leaves per plant, width of rhizome, and number of nodes per finger, whereas callus-regenerated plants showed the highest range with regard to internodal distance and yield.

Variations were also observed among tissue-cultured and callus-regenerated plants in their oleoresin content, fiber content, and dry recovery. The oleoresin content ranged from 1.6 to 7.6 percent, crude fiber percentage ranged from 3.6 to 6.7, and dry recovery from 21.2 to 31.8 percent among the tissue-cultured plants, whereas the control had 5.2 percent oleoresin, 5.9 percent fiber, and 28 percent dry recovery.

Nirmal Babu (1997) and Nirmal Babu et al. (1996b) observed variations in both micropropagated and callus-regenerated plants with respect to their tolerance to *Pythium aphanidermatum* and *Ralstonia solanacearum (Pseudomonas solanacearum)* when the plants were inoculated twice with the organism. Eight somaclones showed a relatively low percentage of disease incidence (*P. aphanidermatum* infection). However, these lines succumbed to infection in field trials and pot culture experiments (Kumar et al., unpublished data), indicating insufficient levels of disease resistance. Isolation of *Pythium*-tolerant lines was earlier reported in ginger (Kulkarni et al., 1987). Intraclonal variations are known in ginger and turmeric, and many promising lines and varieties were identified after clonal selection (Rajeevan and Mohanakumaran, 1993; Khader et al., 1994; Rattan et al., 1994). This accounts for variations observed in conventionally propagated plants. These preexisting variations are also reflected at higher level in micropropagated and callus-regenerated plants. Thus, somaclonal variation is an important source of variability and can be exploited for crop-improvement programs in ginger.

A few promising lines having important yield attributes and other useful characters could be selected from both micropropagated and callus-regenerated lines (Nirmal Babu, 1997).

In Vitro Selection

Kulkarni et al. (1984) reported isolation of *Pythium*-tolerant ginger by using culture filtrate as the selecting agent. In vitro selection for resistant types to *Pythium* and *Pseudomonas* is in progress at IISR using culture filtrates of the pathogen (see Figure 4.3), or pathotoxin as the selecting agent (Nirmal Babu et al., 1996b, Dake et al., 1997).

Identification of Promising Lines

A few promising lines with regard to yield, disease resistance, and other quality attributes could be identified from the tissue-cultured plantlets (see Table 4.4). Somaclones MP 61-9, CR 10-1, CR 816, and CR 822 showed comparatively lower disease incidence (*Pythium* infection) and also high per plant fresh rhizome yield of 870, 367, 373, and 358 g, respectively. Somaclone 855 with a fresh rhizome yield of 472 g per plant showed comparatively lower disease incidence against both *P. aphanidermatum* and *R. solanacearum*. Somaclones MP 74-15 and CR 1222 were also high yielders with 780 and 600 g of fresh rhizomes per plant, respectively. Somaclone, MP 74-15 with a fresh rhizome yield of 780 g and CR 818 with a fresh rhizome yield of 398 g also have bold rhizomes. In addition, the rhizomes of CR 1222 were attractive with extrabold fingers (Figure 4.2D), which was latter found to be a polyploid. Based on biochemical assays, somaclones CR 818 (3.6 percent) and MP 49-7, MP 70-4, MP 97, and CR 10-1 (all with 3.8 percent) were identified as low-fiber types, which is a preferred character.

In Vitro Micro Rhizome Induction

Species that normally produce such organs as bulbs, tubers, and corms can be induced to form these miniature propagules within in vitro cultures under appropriate environmental conditions. Plants that naturally produce tubers can be induced to produce miniature versions of the storage organs in a medium containing high cytokinin levels (George, 1993). Miniature storage organs have a great advantage as they can be readily removed from a culture flask in a dormant condition and stored ex vitro without precautions against sepsis. If they are produced in vitro from disease-free stocks, microtubers provide an ideal method for propagating and distributing disease-free planting material. When planted in soil, they behave as normal tubers.

In vitro induction of rhizomes and their germination in ginger has been reported by various workers (Sakamura et al., 1986; Sakamura and Suga, 1989; Bhat et al., 1994; Sharma and Singh, 1995; Nirmal Babu, 1997; Nirmal Babu et al., 2003). Bhat et al. (1994) reported in vitro induction of rhizomes in ginger at higher sucrose concentrations (9 to 12 percent). Quality analysis of in vitro–developed rhizomes indicated that they contain the same constituents as the original rhizome but with quantitative differences. The composition of basal medium seems to affect the composition of oil (Sakamura et al., 1986; Sakamura and Suga, 1989; Charlwood et al., 1988). Sharma and Singh (1995) reported microrhizomes with four to five buds weighing 73 to 459 mg that were induced on MS medium with 75 g/l sucrose. After storage in moist sand at room temperature for 2 months, 80 percent of the microrhizomes sprouted into plants.

Geetha (2002) and Peter et al. (2002) tried various combinations of sucrose and mannitol in different concentrations to induce microrhizomes in ginger (see Table 4.7).

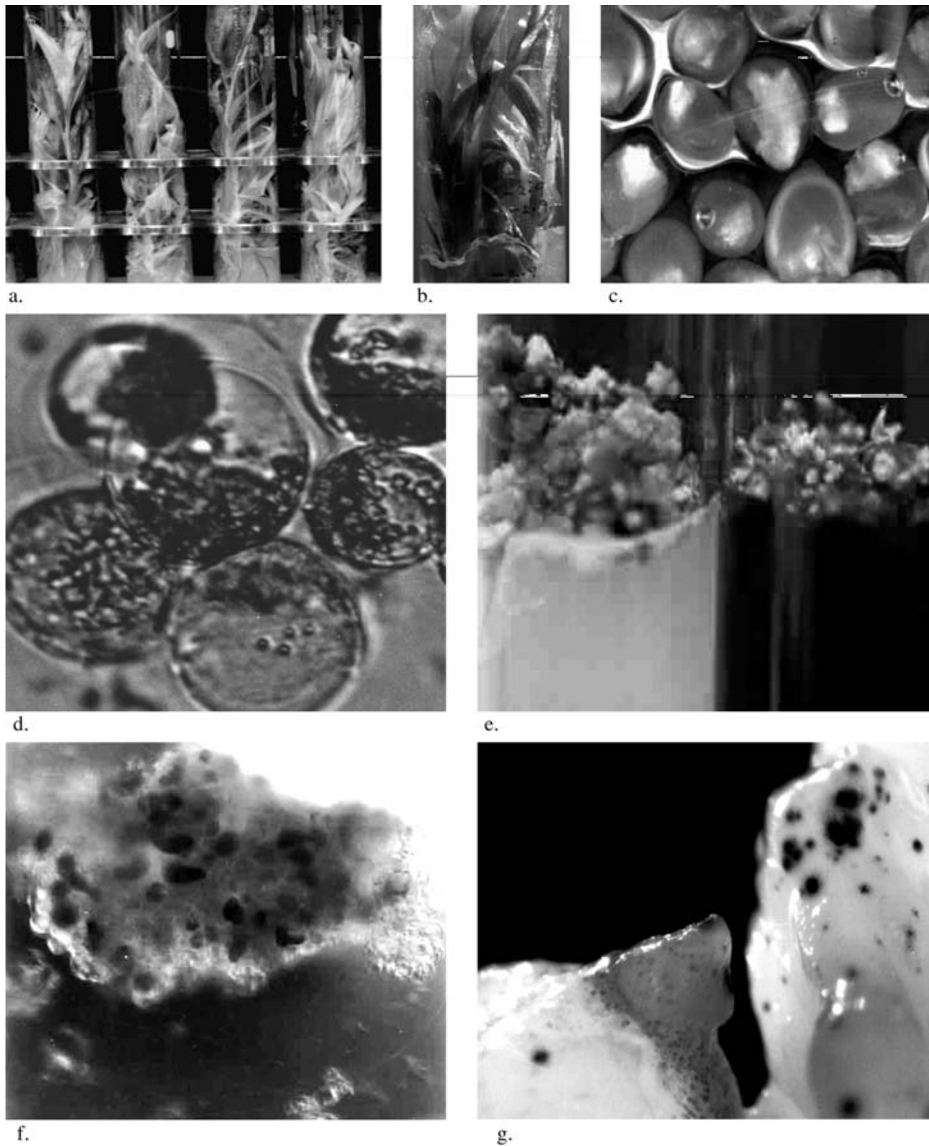

Figure 4.3 In vitro conservation and other biotechnological approaches in ginger: (a) cultures under medium-term conservation in minimal growth medium; (b) one-year-old culture under minimal growth; (c) synthetic seeds; (d) isolated protoplasts; (e) in vitro selection of embryoids against disease-causing organisms; (f) oil cells in cell suspension cultures; (g) transient expression of GUS in embryogenic calli.

Microrhizomes of 0.05 to 15 g fresh weight per explant were induced in ginger tissue cultures in 1 to 12 months on MS basal medium supplemented with higher levels of carbon source. In 3 percent sucrose, microrhizome formation was observed in 30 to 40 percent cultures only after 12 months in culture. In the medium with 1 or 1.5 percent

Table 4.7 Effect of sucrose and mannitol on induction of microrhizomes in ginger on ms basal medium

Sucrose (%)	*Mannitol (%)*	*Time period for induction of microrhizome (months)*	*Percentage response*[a]	*Fresh weight (g)*[a]
3.0	—	12	30–40	0.05–1.0
9.0	—	1	80–100	5–15
10.0	—	1	80–100	5–10
12.0	—	1	80–100	3–6
1.0	1.0	8	50–60	0.06–1.2
1.5	1.5	8	50–60	0.1–1.2
2.0	1.0	8	30–40	0.02–0.5
3.0	3.0	No induction	—	—
3.0	6.0	No induction	—	—
5.0	5.0	No induction	—	—
6.0	6.0	No induction	—	—

MS, Murashige and Skoog (1962) medium.
[a]Mean of 20 replicates

each of sucrose and mannitol, time taken for microrhizome formation was reduced to 8 months with 50 to 60 percent of the cultures responding. In this combination comparatively smaller microrhizomes, weighing up to 0.05 to 1.2 g, were produced. Microrhizomes were produced in 80 to 100 percent of cultures when sucrose concentrations were increased to 9, 10, and 12 percent. The microrhizomes from these cultures were larger with a fresh weight of 3 to 15 g in 1 to 6 months. The other combinations of sucrose and mannitol did not induce microrhizomes (see Table 4.7). Microrhizomes resembled the normal rhizomes in all respects, except for their smaller size. They consisted of two to four nodes and one to six buds. They also have the aromatic flavor of ginger and resembled the normal rhizome in anatomical features. The presence of well-developed oil cells, fibers, starch grains, and curcumin cells was also observed. These microrhizomes were directly planted in the field without any hardening with 80 percent success. Care has to be taken to ensure soil moisture in the first 20 days after planting. The plants derived from the microrhizomes although shorter in size (see Table 4.8), have more tillers per plant. The microrhizomes weighing 2–15g, gave a fresh rhizome yield of 100 to 800 g per plant, and an average yield of 10.5 kg per 3 m^2 bed, whereas the control gave a per bed yield of 15 kg (Figure 4.2e–h). The fresh rhizome yield of conventionally propagated plants when 20 to 30 g of seed rhizome was used, was 400 to 1,100 g per plant. In comparison with conventional propagation, the per bed yield was lower in microrhizome-derived plants, but the seed material used was also lesser in the latter. Microrhizomes gave lesser yield per unit area, but very high recovery vis-à-vis the weight of seed material used, and coupled with freedom from disease will make microrhizomes an ideal source of planting material. Microrhizome-derived plants, although slow in initial field establishment, were able to pick up later and grew on par with the control within 4 to 5 months. Microrhizome-derived plants produced more tillers per plant than the micropropagated and the control plants. Field data analysis also indicated that microrhizomes are more stable than micropropagated plants (Nirmal Babu et al., 2003).

Table 4.8 Morphological data of microrhizhome-derived plants compared with control (var: Jamaica)

Days after	*Plant Height*	*Tiller/ plant*	*Leaf/ tiller*	*Leaf Length*	*Leaf Breadth*	*No. of nodes*	*Petiole Length*	*Inter-nodal Dist.*
30 mr	24.92	4.60	9.30	21.03	2.80	8.07	0.30	5.77
c	31.88	4.04	8.08	20.31	2.82	7.41	0.39	3.33
60 mr	29.72	14.2	16.0	25.76	3.10	13.01	0.20	3.74
c	32.02	5.01	9.03	22.1	2.81	8.20	0.30	2.29
90 mr	53.12	16.6	19.6	23.24	2.20	18.2	0.30	1.60
c	53.90	5.70	9.50	23.20	2.90	9.10	0.30	2.82

mr, microrhizomes; c, control mother plant

In Vitro Conservation and Other Biotechnological Approaches

Synthetic Seeds

Synthetic seeds or artificial seeds in ginger were made by encapsulating in vitro–regenerated shoot buds, somatic embryos, and calli in 5 percent sodium alginate gel. The beads were round, uniform in size, and also sufficiently strong for easy handling (see Figure 4.3c). The encapsulated synthetic seeds were stored up to 9 months when maintained aseptically in MS basal medium at 22±2°C. Such synthetic seeds germinated on MS medium supplemented with 1.0 mgl^{-1} BAP and 0.5 mgl^{-1} IBA into normal plants with 80 percent success (Sajina et al., 1997; Geetha, 2002; Swapna, 2002; and Peter et al., 2002).

Synthetic seeds form ideal source material for germplasm conservation and exchange. In addition, disease-free planting material can be moved from one place to another by using encapsulated propagules, especially in ginger, where major diseases are transmitted through infected rhizomes (see Figure 4.3c). Disease-free encapsulated shoot buds were produced in ginger by Sharma et al. (1994).

In Vitro Conservation and Cryopreservation of Germplasm

As in vitro techniques are becoming more important in crop improvement through somatic cell genetics, genetic stocks are assuming more variable forms from in vitro plantlets to protoplasts and DNA (Withers, 1985). With due precautions, the genotypes of plants propagated by node or shoot culture can be preserved without change. This type of in vitro culture can therefore be used to maintain genotypes over long periods. Fortunately, several ways have been found to reduce the rate of growth of cultured material so that it can be kept unattended for moderate lengths of time.

In Vitro Conservation

Modifying the constituents of culture medium by decreasing the carbohydrate/nutrient supply, changing the osmotic potential using the combinations of sucrose and mannitol and withdrawal of growth regulators from the culture medium, storage in reduced light, desiccation combined with cold treatment, reduced oxygen tension, and the use of growth regulators such as absisic acid induces slow growth in many crop species.

At the IISR, ginger plantlets could be successfully conserved for extended periods of over 12 months on half-strength MS basal medium supplemented with 15 gl^{-1} each of sucrose and mannitol. The cultures were sealed with aluminum foil and maintained at a temperature of 22±2°C. Thus, in ginger, minimal growth was induced by minimizing the evaporation loss using aluminum foil to seal the culture vessel, reduction of both the carbon source and the nutrients to half strength, and addition of mannitol. Ginger cultures grew well at 22±2°C but deteriorated when kept under lower temperatures of 5°C and 10°C. The rate of growth was higher when full-strength MS medium was used. High concentration of sucrose (30 gl^{-1}) increased culture growth substantially, resulting in exhaustion of culture medium. When the concentration of sucrose was reduced to 20 gl^{-1} and nutrient concentration to half, the cultures could be maintained for a much longer period of 200 to 240 days with a survival percentage of 75 to 81 depending upon the closure used. Addition of mannitol (10 to 15 gl^{-1}) and reduction of sucrose to lower levels (15 to 10 gl^{-1}) induced slow growth, and subsequently 73 to 80 percent of the cultures could be maintained for a period of 360 days when the culture vessels were closed with aluminum foil (see Figure 4.3a and 4.3b). Full- or half-strength MS medium supplemented with 10 or 15 gl^{-1} each of sucrose and mannitol and 1/2 MS with 20 gl^{-1} sucrose and 10 gl^{-1} mannitol allowed the cultures to be maintained for 360 days (see Table 4.9) (Nirmal Babu, 1997; Nirmal Babu et al., 1999, 2000; Geetha, 2002; and Peter et al., 2002).

According to Balachandran et al. (1990), ginger cultures could be maintained up to 7 months without subculture by using polypropylene caps as culture vessel enclosures. Dekkers et al. (1991) reported that ginger shoots could be maintained for over 1 year at ambient temperatures (24 to 29°C) in a medium containing mannitol (25 gL^{-1}) with an overlay of mineral oil.

At present, over 100 core collections of ginger are maintained at the IISR in vitro gene bank with yearly subculture. The small-sized plantlets kept in the conservation medium for over 5 years with yearly subculture when transferred to the multiplication medium (MS + 30 gl^{-1} sucrose and 1 mgl^{-1} NAA) gave normal growth with good multiplication rate. These plantlets were established easily with $>$80 percent success and developed into normal plants similar to the mother plants. Thus, the in vitro conservation technique is a safe alternative for a vegetativley propagated crop such as ginger for conservation and exchange of disease-free planting material.

Cryopreservation

Cryopreservation offers a better alternative when the base germplasm of any crop can be preserved for long durations with minimum effort. However, protocols for viable cryopreservation and post-thaw recovery of cryopreserved material are not available for ginger.

Geetha (2002) and Peter et al. (2002) reported that ginger in vitro-derived shoot tips could be successfully cryopreserved with limited success by pretreating the shoot tips with 0.75 M sucrose, desiccating for 1 hour, and plunging into liquid nitrogen (−185°C). Only 20 percent of the cultures developed into plantlets after cryopreservation. They also reported that encapsulated shoot buds of ginger (Synseeds) could be successfully cryopreserved after preculture on 0.75 M sucrose for 3 days and desiccated for 4 hours on laminar airflow. Plantlets could be regenerated from 20 percent of the cultures after cryopreservation.

Table 4.9 Effect of media components and culture vessel closures on induction of minimal growth in ginger cultures

Treatments			*Growth rate*				Duration of storage with 80% survival (months)
Basal medium Concentration (MS)	*Sucrose (S) + Mannitol (M) (gm/l)*	*Closure types*	*Increase in height (cm)*[a]		*Average no. of shoots/culture*		
			Mean	*SD*	*Mean*	*SD*	
Full strength	30 S + 0 M	CP	7.2	0.56	4.6	0.70	3–4
Full strength	30 S + 0 M	SC	10.4	0.88	4.9	0.88	4–5
Full strength	20 S + 0 M	CP	5.6	0.98	2.6	0.84	3–4
Full strength	20 S + 0 M	SC	8.6	0.52	3.3	1.06	4–5
Full strength	20 S + 10 M	CP	4.7	0.73	2.8	0.92	4–5
Full strength	20 S + 10 M	SC	6.8	0.63	2.6	0.97	6–7
Full strength	15 S + 15 M	CP	6.3	0.60	2.7	0.95	4–5
Full strength	15 S + 15 M	SC	6.6	0.41	3	0.82	7–8
Full strength	10 S + 10 M	CP	3.7	0.60	1.5	0.71	5–6
Full strength	10 S + 10 M	SC	4.8	0.72	2	0.82	7–8
Half strength	30 S + 0 M	CP	6.4	0.81	3.4	0.97	3–4
Half strength	30 S + 0 M	SC	6.9	0.57	4	0.82	5–6
Half strength	20 S + 0 M	CP	5.4	0.40	1.9	0.88	4–5
Half strength	20 S + 0 M	SC	6.9	0.37	1.7	0.82	5–6
Half strength	20 S + 10 M	CP	5.1	0.42	1.7	0.67	4–5
Half strength	20 S + 10 M	SC	6.3	0.37	1.9	0.74	6–7
Half strength	15 S + 15 M	CP	4.8	0.49	2.3	0.82	5–6
Half strength	15 S + 15 M	SC	5.7	0.54	3.4	0.84	10–12
Half strength	10 S + 10 M	CP	5.4	0.77	2.2	0.63	5–6
Half strength	10 S + 10 M	SC	5.9	0.32	2.8	0.79	10–12

MS, Murashige and Skoog medium; S, sucrose; M, mannitol; SC, screw cap; CP, cotton plug.
[a]Mean of 10 replications.

Cell Suspension Culture

Plant cells accumulate secondary metabolites at specific cell sites at specific developmental stages under specific conditions of cell culture; hence, plant tissue culture can be used as an alternative to whole plants as a biological source of potentially useful metabolites and biologically active compounds (Yeoman, 1987). The genetic makeup, the regulation of gene expression, the cellular physiology, and the regulation of metabolism must be considered in order to develop highly productive and practical plant cell lines.

Production of volatile constituents in ginger cell cultures were reported earlier by Sakamura and Suga (1989). Ilahi and Jabeen (1992) also reported preliminary studies on alkaloid biosynthesis in callus cultures of ginger, and Charlwood et al. (1988) have reported the accumulation of flavor compounds by cultures of ginger. Nirmal Babu (1997) reported successful establishment of cell suspension cultures in ginger. These cultures are maintained by weekly transfers to the fresh nutrient medium containing MS basal salts and 1 mgl^{-1} of 2,4-D for over 2 years and are in continuous growth and multiplication. The cells were heterogeneous, and during the process of subcultures,

some of the cells differentiated into oil-producing cells (see Figure 4.3f), although the number of oil-producing cells were less for commercial exploitation. These reports are very preliminary and much more work needs to be done before ginger cell cultures can be used for commercial production of flavor components in vitro.

Protoplast Isolation and Culture

Successful isolation, culture, and fusion of protoplasts are important because of their role in studies of plant improvement by cell modification and somatic hybridization. Another aspect of considerable interest is the storage of protoplast through immobilization and cryopreservation, which are of great importance, especially in the pharmaceutical industry (Bajaj, 1989a, 1989b).

Protoplasts were successfully isolated from young in vitro–derived leaves (see Figure 4.3f) using an enzyme mixture containing 0.5 percent macerozyme R10, 3 percent hemicellulase, and 5 percent cellulase Onozuka R10 and mechanically macerating the plamolysed leaf tissue after incubating at 15°C for 10 hours and at 30°C for 6 hours. The protoplast yield was 2.5×10^5 per gram of leaf tissue with 55 percent viability. The isolated protoplasts were round and were filled with chloroplasts. Cell suspension cultures required a slightly different concentration of enzyme mixture with 1 percent macerozyme R10, 3 percent hemicellulase and 6 percent Onozuka cellulase R10. The incubation conditions were 15°C for 10 hours and 30°C for 8 hours. The yield of protoplasts was lesser from a callus/cell suspension with 1×10^5 protoplasts per gram weight of callus in an isolation solution containing cell protoplast washing (CPW) salts, 7 percent mannitol, 1 percent macerozyme, 3 percent hemicellulase, and 6 percent cellulase Onozuka R10. The protoplasts isolated from cell suspension cultures were round, with little or no chloroplasts inside, with 72 percent viability (see Table 4.10). The protoplasts derived from leaf tissue were heterogeneous and comprised of protoplasts of different sizes (0.15 to 0.21 mm). The protoplasts derived from cell suspension cultures were mostly of uniform size (0.39 mm). They were cultured up to 20 days as droplet cultures in MS liquid medium with 0.5 mgl^{-1} BAP, 0.5 mgl^{-1} NAA, and 0.5 mgl^{-1} 2,4-D supplemented with 3 percent sucrose and 7 percent mannitol. The cell contents became dense by 1 week and fresh medium needed to be added at 7-day intervals. The protoplasts started regenerating the cell wall within 2 to 3 days. Within 3 to 4 weeks of culture, cells started dividing. Protoplasts plated on liquid as well as solidified medium

Table 4.10 Effect of source tissue, enzyme concentration, and incubation conditions on yield of protoplasts

Source	*Enzyme solution*	*Incubation conditions*		*Protoplast yield*	*Viability (%)*	*Size (mm)*
Leaf	0.5% Macerozyme R 10 +3% Hemicellulase +5% Onozuka cellulase R10	16 h	15°C for 10 h, 30°C for 6 h, 53 rpm in dark	2.5×10^5/g of leaf	55 with chloroplasts	0.21
Callus	1% Macerozyme R10 + 3% Hemicellulase + 6% Onozuka cellulase R10	18 h	15°C for 10 h, 30°C for 8 h, 53 rpm in dark	1×10^5/g of callus	72 no chloroplasts	0.39

after 20 days gave similar results. The dividing cells developed into microcalli in 50 to 70 days in MS medium with 1 mgl^{-1} NAA and 1 mgl^{-1} BAP. The protoplasts started cell division within 2 to 3 days and developed into microcalli in 50 to 70 days. So far, no reports are available on plant regeneration from protoplast-derived microcalli (Geetha et al., 2000).

Genetic Transformation

The tremendous progress made during the last decade has demonstrated that refinement of routine in vitro techniques coupled with recombinant DNA technology and genetic engineering have opened up new vistas for plant improvement (Potrykus et al., 1985; Potrykus and Spangenberg, 1995). The *Agrobacterium*-mediated gene transfer is most successful in plants, but has limited applications in monocots due to host range limitations. Bombardment of intact plant cells with high-velocity, DNA-coated microprojectiles is another very effective method for production of transgenic plants (Sanford et al., 1987; Franks and Birch, 1991).

Nirmal Babu (1997) reported transient expression of GUS in ginger embryogenic calli (see Figure 4.3g) when it was bombarded with microprojectiles (1.6 μm gold particles) using a BioRad PDS-1000/He gene gun at 900 and 1,100 psi helium pressure with the target distance of either 6 or 9 cm. The vector used was pAHC 25 containing GUS (β-glucuronidase) and BAR (phosphinothricin–acetyl transferase) as reporter and selectable marker genes respectively and carrying Ubi-1 (ubiquitin) promoter (Christensen and Quail, 1996). The best GUS score was obtained when the target distance was 9 cm with 900 psi helium pressure. The GUS score of 133 blue spots per square centimeter indicates not only the optimization and efficiency of the biolistic process, but also the ability of the ubiquitin promoter to drive the expression of the reporter gene (see Figure 4.3g).

Molecular Characterization

With the advent of molecular biology techniques, DNA-based markers very efficiently augment morphological, cytological, and biochemical characters in germplasm characterization, varietal identification, clonal fidelity testing, assessment of genetic diversity, validation of genetic relationship, phylogenetic and evolutionary studies, marker-assisted selection, and gene tagging. Owing to plasticity, ubiquity, and stability, DNA markers are easier, efficient, and less time consuming, especially in perennials where morphological markers are few. The relatively easy to use, low-cost, and highly accurate nature of the polymerase chain reaction (PCR)–based technologies such as RAPD, AFLP, and microsatellites are widely appreciated.

RAPD Profiling of Ginger Cultivars

Genomic DNA was successfully isolated in the authors' laboratory from young and fresh leaves of ginger plants using the modified cetyl amino butane (CTAB) method of Ausubel et al. (1995). Development of RAPD profiles for various ginger cultivars (see Figure 4.4a) and related species is in progress at the Indian Institute of Spices Research to study the interrelationships and to identify the core collections in the germplasm.

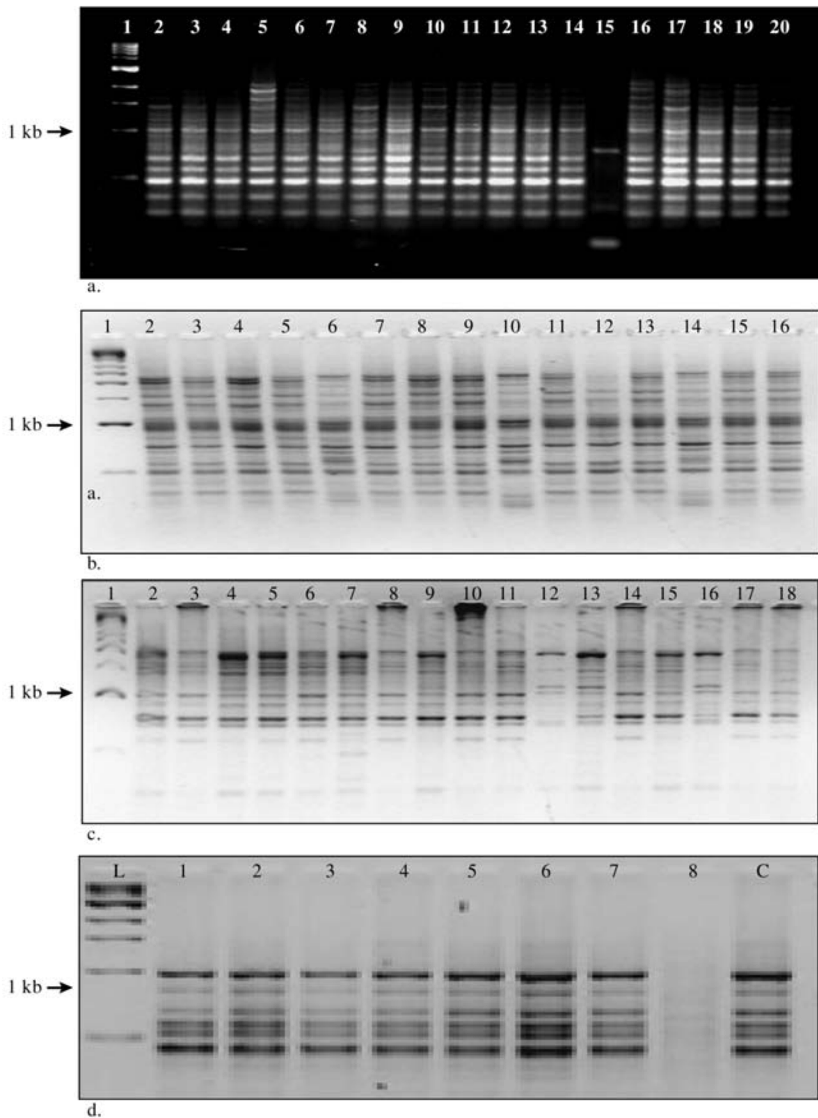

Figure 4.4 Molecular characterization of ginger: (a) RAPD profiles as expressed by OPERON primer OPD 11 among different cultivars of ginger collected from different geographical regions. lanes: 1 1 kb ladder, 2 Maran, 3 Australia, 4 Jamaica, 5 Gurubathani, 6 Bhainse, 7 RRE, 8 Hawaiian, 9 Sabarimala, 10 Mananthody, 11 Anamica, 12 Bisonvally, 13 China, 14 Jugijan, 15 IISR Rajitha, 16 IISR Varada, 17 Wyanad local, 18 Nadan, 19 PGS 43, 20 V2-E5-3. (b) RAPD profiles as expressed by OPERON primer OPE 01 in micropropagated plants of ginger: lanes: 1. 1 Kb Ladder, 2 RRE 1, 3 M Control, 4 MP 49-7, 5 MP 50-3, 6 MP 54-2, 7 MP 54-4, 8 MP 61-4, 9 MP 61-9, 10 MP 61-10, 11 MP 64-3, 12 MP 68-4, 13 MP 70-3, 14 MP 70-5, 15 MP 74-4, 16 MP 76-3. (c) RAPD profiles as expressed by OPERON primer OPD 10 in callus regenerated plants of ginger: lanes: 1 1 Kb Ladder, 2 RRE 1, 3 M Control, 4 CR 3, 5 CR 4, 6 CR 7, 7 CR 9, 8 CR 10-1, 9 CR 13, 10 CR 20, 11 CR 42, 12 CR 64, 13 CR 67, 14 CR 816, 15 CR 817, 16 CR 1222, 17 CR 1441, 18 AC-1. (d) RAPD profiles of microrhizome derived plants of ginger, as expressed by OPERON primer OPB 10: L—1kb ladder, lanes 1, 2, 3, 4, 5, 6, 7, 8: microrhizome derived plants, C—control.

RAPD Profiling of Ginger Somaclones and Microrhizome-Derived Plants

Suja (2002) and Nirmal Babu et al. (2003) used RAPD profiles amplified by 11 operon primers as an index for estimating genetic fidelity of selected "variants" among micropropagated and callus-regenerated plants. They observed differences in RAPD profiles observed in some of the micropropagated plants that indicated micropropagation even without the callus phase induced variations in 9 of the 13 plants tested. Similar differences were noticed among 12 out of 15 callus-regenerated plants. In general, this indicates a high amount of variability among the selected micropropagated and callus-regenerated plants of ginger, and the majority of the morphological variants selected from earlier studies did show variations in RAPD profiles (see Figure 4.4b and c). Earlier studies by Rout et al. (1998) indicate that RAPD profiles did not indicate any polymorphism among the micropropagated plants. The observations of Suja (2002) and Nirmal Babu et al. (2003) differ with the earlier finding. The variability observed may be due to bigger population size used by the latter workers to detect the morphological variants first and confirmation of their genetic nature of variation using RAPD profiles subsequently. Other workers also reported somaclonal variation in ginger (Kulkarni et al., 1987; Samsudeen, 1996; Nirmal Babu, 1997), probably because of the genetic nature of ginger that has resulted in many varieties and cultivars even without sexual reproduction. However, the microrhizome-derived plants did show a high degree of genetic uniformity as expressed by RAPD profiles (see Figure 4.4d). Thus, the present study indicated that direct micropropagation of ginger results in somclonal variation; hence, propagation of ginger through microrhizome pathway significantly reduces this variation.

RAPD Profiles of Ginger In Vitro Conserved Lines

Studies on RAPD profiling within the replicates of ginger in vitro-conserved lines using 10 operon random primers did not detect any polymorphism between the conserved lines in any of the primers tested, indicating the genetic stability of the in vitro-conserved lines (Geetha, 2002).

Conclusion

This marvelous spice and medicinal plant, ginger, is constrained severely by the absence of seed set, and the breeder is left with the alternative of clonal selection or induced mutations with all its uncertainty and limitations. Biotechnology opened up many potential avenues such as tissue culture, somaclonal variation, in vitro mutagenesis and selection, molecular fingerprinting, recombinant DNA technology, and genetic modification through transgenics for creating disease-resistant lines. Concerted efforts are needed to solve the serious problems besetting this "great medicine" and "universal cure" as described in the Indian systems of medicine, which is a great spice unparalleled in the range of applications and uses.

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5 Ginger Production in India and Other South Asian Countries

E.V. Nybe and N. Mini Raj

Ginger requires a warm and humid climate. The plant thrives well from sea level to an altitude of 1,500 m in the Himalayas, the optimum elevation being between 300 and 900 m (Pruthy, 1993). A well-distributed rainfall (150 to 300 cm) during the growing season and dry spells during land preparation as well as before harvest are required for large-scale cultivation of the crop. In areas receiving less rainfall, the crop needs regular irrigation.

Ginger can be grown in a wide range of well-drained soils of at least 30 cm depth, ranging from heavy laterite loams to clayey loam. Laterite loams containing not more than 30 percent sand or 20 percent clay and free from gravel have given higher yields (Pruthy, 1993). Panigrahi and Patro (1985) studied the performance of five ginger cultivars in three soil types in Orissa, India, and reported that in a sandy loam red soil, the cultivar Thingpuri gave the highest yield of 22 t/ha. Cho et al. (1987) recorded higher ginger yield in an alluvial plain area than in hilly or mountain foothill areas. Yield was high in soils having more than 1 m depth and with good drainage, and was negatively correlated with ploughing depth and soil moisture content. Liu and Gao (1987) studied the arsenic content in red soils and its effects on growth and yield of ginger. The total arsenic content varied between 76 and 1970 ppm. When arsenic was supplied to soils, the dry matter yield of ginger was decreased by 3.5 to 32 percent. Lee et al. (1990) reported that soils that were suppressive to rhizome rot had a higher clay content and lower pH than those conducive to the disease. The most favorable soil pH is 6.0 to 6.5 (Cho et al. 1987). Hackett and Carolane (1982) reported that soil with uniform loamy texture is more suitable than other soil types. Sahu and Mitra (1992) got the highest yield in sandy loam soil having the minimum bulk density (1.20 g/cc), moderate acidic reaction (pH 5.7), and high organic matter (organic carbon 1.1 percent) and available potassium (351 kg/ha). The yield decreased with increase in soil clay content and decrease in pH.

Time of Planting

In south India, the crop is grown mainly as a monsoon crop from April–May to December but as an irrigated crop in north and central India. As a rain-fed crop, the first week of April is the best time of planting to get a higher yield under Kerala (India) conditions, registering a 200 percent increase in yield compared to planting in the first week of June. Considering the erratic behavior of southwestern monsoons, it is better to plant the crop as early as possible after the receipt of soaking rains. When June and July plantings were compared, planting in June recorded a higher yield and low incidence of soft rot. For irrigated ginger, the best time for planting is the middle of February. Sreekumar et al.

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(1981) at Ambalavayal (India) observed that the highest germination percentage was obtained with planting at the end of January or mid-February (average 80 percent).

Phogat and Pandey (1988) at Nainital (UP), India, noted that the highest values for all indices studied (plant height, number of leaves, number of tillers, rhizome length, rhizome width, number of rhizomes/plant, and yield of fresh rhizomes) were obtained by planting on March 15. The yields for 2 years were 253.4 and 226.3 quintals/ha with planting on March 15; planting on May 29 gave the lowest yields (119 and 101.6 quintals/ha).

From Orissa (India), Mohanty et al. (1990) reported that in trials on the effect of planting date on yield, planting on April 1 gave 29.67 t/ha, which declined to 4.2 t/ha when planting was on July 1. In Sri Lanka, where ginger is a homestead crop, planting starts immediately after the first rains in April or May.

Seeds and Seed Rate

In ginger, rhizomes are used for planting. The rate of seed rhizome varies from 900 to 1,500 kg/ha. For selection and preservation of seeds, the following method is recommended in Kerala, India (KAU, 1993). Mark healthy and disease-free plants in the field when the crop is 6 to 8 months old and still green. Select the best rhizomes free from pests and diseases from the marked plants. Harvest them separately and handle seed rhizomes carefully to avoid damage to buds. Soak the selected rhizomes for 30 minutes in a solution of Mancozeb and Malathion to give a final concentration of 0.3 percent for the former and 0.1 percent for the latter. Dry the treated rhizomes in shade by spreading on a floor and then store in pits lined with sand or sawdust. It is advisable to spread layers of leaves of *Glycosmis pentaphylla*. Pits are covered with coconut fronds. Examine the stored rhizomes at monthly intervals and remove the rhizomes that show signs of rotting. This will help to keep the inoculum level low. Also treat the seed rhizomes in the same manner before planting.

Randhawa and Nadpuri (1970) suggested the seed rate of 1,250 kg/ha. For plains and lower altitudes, 1,500 to 1,800 kg, and at higher altitudes, (>1000 m) 2,000 to 2,500 kg is recommended (Aiyadurai, 1966; NRCS, 1989). Kingra and Gupta (1977) used 2.3 to 3.5 t/ha at Himachal Pradesh. Lee et al. (1981) used 6 t/ha, which gave about 140,000 plants/ha. The yield increased with the seed rate (Mohanty et al., 1988), but the seed rate is also the most costly input, accounting for 40 to 46 percent of the total cost of production (Jayachandran et al., 1980).

Under Indian conditions, the optimum size of the seed bit is m15 g with one or two viable buds, and seed rate recommended is 1,500 kg/ha (see Figure 5.1). Soaking seed rhizomes for 24 hours, 10 days prior to planting results in good sprouting. The ginger sprouts of 4 to 6 cm can be detached from the mother rhizomes and can be utilized as planting material without adversely affecting further growth of the plant (Nair, 1977). The separated rhizomes can be used for vegetable purpose. The effect of storing seed rhizomes after cutting them into pieces was studied. Early and fairly uniform germination was observed in plots planted with seed rhizomes cut and stored for 45 and 30 days before planting (KAU, 1993). In China and other adjoining ginger-growing countries the recommended ginger seed size is 75 g bits having one healthy bud.

Sengupta et al. (1986) reported an increase of 33, 51, and 80 percent in yield by increasing the weight of ginger rhizomes from 10 to 20, 30, and 40 g, respectively. The

Figure 5.1 Ginger seed rhizome bits (15 g) used for planting.

average 2-year yield (50.18 t/ha) was highest using a 40 g rhizome bit. Ahmed et al. (1988), at Gazipur, Bangladesh, observed that the highest yield of 13.42 t/ha was obtained with the largest rhizomes (21 to 30 g) planted at the closest spacing of 15 cm. The smallest rhizomes (10 g) planted at 25 cm gave only 5.41 t/ha. Korla et al. (1989), at Himachal Pradesh, reported that rhizome bits weighing 20 to 25 g gave the best results with regard to plant height, number of tillers, rhizome length and breadth, and yield. Roy and Wamanan (1989), at Gauhati, India, also reported that the yield of fresh ginger increased from 4 to 26 t/ha by increasing the weight of seed bits from 5 to 35 g.

The possibility of reducing the size of ginger planting material using miniseed rhizomes (minisetts) was investigated. The treatments included three sizes of rhizome bits—5, 10, and 15 g. Increasing the size of rhizome bits resulted in increased sprouting percentage, higher yield, and larger rhizome size (Whiley, 1974). Under open and intercropping conditions, rhizome bits weighing 15 g recorded the highest sprouting. Green ginger yield increased with increasing rhizome size both under open and intercropped condition. Plants raised from rhizome bits weighing 5 g gave the lowest yield, which was inferior to other treatments. Plants from rhizomes weighing 15 g recorded the highest green ginger yield (Table 5.1). Under open conditions plants raised from rhizome bits weighing 10 and 15 g gave higher dry ginger compared to plants from 5 g. Rhizome bits of cv. Kuruppampady performed better, however, when intercropped in a coconut garden. Cv. Maran gave higher yield in all the three sizes of seed material used (see Table 5.2). The size of rhizomes did not cause differences in quality components like volatile oil and starch in any variety, but it induced small variations in nonvolatile ether extract (NVEE) and crude fiber. The cost-benefit analysis indicated that the use of minisetts, weighing 10 g, is more profitable (Nizam and Jayachandran, 2001).

Table 5.1 Effect of size of seed rhizome and variety on green ginger yield (kg/ha) under open condition

	Rhizome size (g)			
Variety	*5*	*10*	*15*	*Mean*
Kuruppampady	20,400	21,488	25,200	22,360
Maran	11,584	13,128	19,488	14,736
Nedumangad	11,360	16,000	13,328	13,560
Rio de Janeiro	11,416	15,896	15,912	14,408
Mean	13,688	16,632	18,480	

CD (0.05) S - 2800* V × S - NS V - 3422*

Table 5.2 Effect of size of seed rhizome and variety on green ginger yield (kg/ha) as intercrop in coconut garden

	Rhizome size (g)			
Variety	*5*	*10*	*15*	*Mean*
Kuruppampady	11,476	16,317	17,354	15,049
Maran	19,024	22,999	22,875	21,633
Nedumangad	15,745	27,546	26,448	23,246
Rio-de-Janeiro	7,656	13,812	15,405	12,291
Mean	13,475	20,169	20,520	

CD (0.05) S - 2563* V × S - 5127* V- 6716*

In some places, farmers plant whole rhizomes and unearth them when the crop reaches about 30 to 35 cm in height (Singh, 1982). The recovery is about 94 percent at three months after planting. This practice helps the farmers to recover 60 to 70 percent of the seed cost.

Spacing and Method of Planting

Spacing varies with soil fertility, cultivar, climate, and management practices. Earlier reports indicated that closer spacing gave better yield (Loknath and Das, 1964; Aiyadurai, 1966; Randhawa et al., 1972; Nair, 1982). Based on trials, planting of ginger is recommended on raised beds (in order to facilitate drainage) at a spacing of 20 × 20 cm or 25 × 25 cm and a depth of 4 to 5 cm with the viable bud facing upward. Pandey (1999) reported that among different spacings (40 × 20, 30 × 20, 40 × 30 and 50 × 20 cm) the highest yield was observed under closest spacing. Planting of irrigated ginger in raised beds (see Figure 5.2) gave the highest yield when compared to planting in ridges, furrows, and flat ground (KAU, 1993). The seed rhizome is placed 3.5 to 5.0 cm deep in a pit and soil is pressed over it (see Figure 5.3) followed by light irrigation. Mulching the beds twice with green leaves is important (see Figure 5.4). In general, the planting depth varies with the size of the planting unit, soil type, and soil moisture content (Kandiannan, 1996). Bolder seed rhizomes are planted deeper and smaller rhizome bits at shallow depths. The commonly adopted practice is to place the rhizome

Figure 5.2 Raised beds (3 m × 1 m × 0.25 m) ready for planting ginger.

piece at 4 to 10 cm depth (Kannan and Nair, 1965; Aiyadurai, 1966; Paulose, 1973; Lee et al., 1981; Mohanthy et al., 1990; Wilson and Ovid, 1993).

Mohanty and Sarma (1978) reported that best growth and the highest rhizome yield (23.4 t/ha) was obtained with Ceresan wet-treated rhizomes, planted in raised beds, with farmyard manure (FYM) at 25 t/ha + N, P_2O_5, and K_2O at 75, 50, and 50 kg/ha, respectively, and mulched with green leaves at 15 t/ha at planting followed by two mulches using 7.5 t/ha at 45 and 90 days after planting (Figure 5.4). A good crop of ginger raised in this way is shown in Figure 5.5.

Kin et al. (1998) reported that narrow ridge cultivation reduced the ginger rot disease effectively by 78.1 percent compared with unridged plots.

Shade

The crop prefers light shade for good growth, but shade is not absolutely necessary. Jayachandran et al. (1991) investigated the effect of shade on the yield of ginger cv. Rio de Janeiro by growing plants under no shade (open) and 25, 50, and 75 percent shade. Shade was provided by coconut leaves spread on a pandal (shelter). At harvest (8 months after planting), the fresh rhizome yield was highest under 25 percent shade and lowest under 75 percent shade (20,093 and 10,778 kg/ha, respectively). The yield under open conditions was similar to that under 50 percent shade. Dry ginger recovery was highest under 25 percent shade (2,733 kg/ha).

Screening of ginger for shade tolerance was done with six cultivars (Maran, Kuruppampadi, Himachal, Rio de Janeiro, Nedumangad, and Amballore local) under four shade levels (0, 25, 50, and 75 percent) (George, 1992). This study confirmed the shade-loving nature of ginger, registering a significantly higher yield under different shade

Figure 5.3 Planting ginger-sprouted seed rhizome bits placed in the pits.

levels than under open, with 25 percent shade recording the highest value. The quality of ginger rhizomes improved when grown under shade. Based on the rhizome yield, the cultivars adapted to each of the shade levels were identified as Kuruppampadi and Himachal (0 percent shade), Nedumangad, Himachal, and Kuruppampadi (75 percent shade). Himachal was found to be adapted to all situations. Under natural shade of coconut, Amballore local showed better performance.

The response of ginger to different shade levels (0, 25, 50, and 75 percent) and mulching levels (7.5, 15, 22.5, and 30 t/ha) was studied by Babu (1993). The highest yield (22.8 t/ha) and dry matter production were recorded in a low-shade condition of 25 percent and at the mulch level of 30 t/ha (Table 5.3). As the performance of the crop

Figure 5.4 Beds mulched with green leaves immediately after planting.

Figure 5.5 General view of ginger plot nearing maturity.

Table 5.3 Effect of shade and mulch on mean green ginger yield (kg/ha)

Shade (%)	*Mulch (green leaves* (t/ha^{-1})*)* 7.5	15	22.5	30.0	Mean
0	13,164	1,4145	17,398	19,517	16,056
25	18,029	21,439	26,030	26,036	22,883
50	15,535	20,492	21,123	22,007	19,789
75	16,292	17,303	20,839	21,786	19,055
Mean	15,755	18,345	21,347	23,337	

CD (0.05) M - 291* S × M - 569* S - 476*

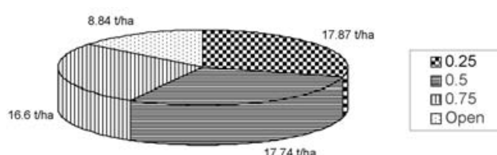

Figure 5.6 Effect of shade on rhizome yield of ginger.

was better under shade than in an open situation, the crop was considered to be shade loving and suitable as an intercrop in coconut gardens (see Figure 5.6). The uptake studies showed that the fertilizer requirement for intercropped ginger in low shade levels will be 10 to 50 percent higher than that of a pure crop.

Ancy et al. (1993) studied Rio de Janeiro plants, grown under 0, 25, 50, or 75 percent shade (provided by dry coconut fronds) and supplied with fertilizers at 75, 100, 125, or 150 percent of the recommended rate of 75, 50, and 50 kg of N, P_2O_5, and K_2O/ha. The volatile oil content was highest (2.19 percent on a dry weight basis) under 25 percent shade, and the NVEE content was significantly higher under 25 or 50 percent shade than under 0 or 75 percent shade. The rhizome fiber content was not affected by shade and fertilizer treatments.

Nath (1993) at Assam, India evaluated the effect of shade (provided by a pigeon pea crop) and rhizome treatment (1 percent formaldehyde) on rhizome rot caused by *Pythium myriotylum* using the cv. Tura. The highest yield was recorded in rhizome-treated plants grown in the shade for 150 days. The increased yield was mainly due to reduction of disease, as disease incidence was 45.8 and 41.3 percent respectively, in the control and rhizome-treated plants grown without shade and 19.4 percent in rhizome-treated plants grown in the shade. It is suggested that the temperature around the crop may have been reduced by shading and this could have ultimately suppressed the growth of fungus. Wilson and Ovid (1993) studied the effect of shade on growth and yield of ginger and observed that the average yield of ginger was highest (68.4 t/ha) under okra shade.

Ancy et al. (1998) noted that nutrient uptake increased with increasing fertilizer rate under all shade intensities but the response in terms of rhizome yield per unit increase in fertilizer rate was highest under 25 percent shade followed by 50, 0, and 75 percent shade. Dry rhizome yield was highest (3,415.25 kg/ha) under 25 percent shade with nitrogen, phosphorus, and potassium (NPK) at 150 percent of the recommended rate.

Table 5.4 Effect of shade on volatile oil content of ginger (v/w%)

	Period (DAP)				
Shade (%)	*120*	*150*	*180*	*210*	*240*
0	1.46	2.35	2.22	2.06	2.18
20	1.94	2.79	2.57	2.20	2.26
40	2.24	2.51	2.65	2.26	2.31
60	2.44	3.35	2.78	2.40	2.42
80	2.47	3.57	2.54	2.43	2.45
CD (0.05)	0.069*	0.097*	0.039*	0.089*	0.098*

Jayachandran et al. (1998) recorded that under artificial shade (25 percent), ginger yield was 11 to 27 percent higher than in open fields, and even under 50 percent artificial shade the yield was better than under open conditions. Under natural shade in coconut plantation, there was a 32 percent increase in rhizome yield.

Another experiment (Sreekala, 1999) to study the effect of shade on biomass production and partitioning of photosynthates in ginger cv. Rio de Janeiro confirmed the preference of the crop to low-shade levels registering better growth and yield. Different shade levels (0, 20, 40, 60, and 80 percent) influenced the quality of ginger rhizomes. Volatile oil was more under higher shade levels in general (60 and 80 percent) while nonvolatile ether extract was higher under 20 percent shade (see Table 5.4). Starch as well as crude fiber content was more in plants grown under open conditions.

The photosynthetic rate and related parameters of ginger measured at 6 months after planting using a leaf chamber analyzer indicated that photosynthetically active radiation on the leaf surface as well as stomatal conductance were high under open conditions. But the leaf internal carbon dioxide concentration as well as stomatal resistance was high under heavier shade levels (60 and 80 percent). The photosynthetic rate as well as the transpiration rate was higher in plants grown in the open. Although, at 20 percent shade, the photosynthetic rate was less, the yield was high. This might be because of the photo-oxidation that has taken place at high light intensities or due to the inefficient translocation of photosynthates in open conditions compared to 20 percent shade (Ancy and Jayachandran, 2000). Ajithkumar et al. (2002) studied the effect of shade regimens on the photosynthetic rate and stomatal characters using the cv. Rio de Janerio. They found that the highest photosynthetic rate was in plants grown in the open conditions, followed by plants grown under 20 and 40 percent shade. The photosynthetic rate, stomatal conductance, transpiration rate, stomatal index, and stomatal frequency were significantly reduced linearly with increasing levels of shade. The yield increase under 20 and 40 percent shade compared to the open condition is attributed to be due to the higher leaf area under these shade levels.

Sreekala and Jayachandran (2002) worked out the influence of shade on physiological parameters of ginger. They reported higher dry matter accumulation, leaf area index, net assimilation rate and crop growth rate under low (20 percent) shade levels. (See Chapter 2 on Botany for a more detailed treatment of this topic.)

Radiotracer analysis done using labeled ^{14}C has shown that under low-light intensity, the photosynthates translocated efficiently to the lower portion, whereas in an open condition efficient translocation did not take place. Studies have shown that a crop can

tolerate shade up to 40 to 50 percent. Thus, partially shaded coconut gardens can be exploited for increasing the area under ginger.

Another screening trial conducted in Kerala for shade tolerance with 13 cultivars of ginger and the same set of shade levels confirmed the shade-loving nature of ginger, producing the highest rhizome yield and quality rhizomes at 25 percent shade. Cultivar Valluvanad was selected as the best single variety for all situations. The cultivars selected as suitable for each of the shade levels were Jamaica, Valluvanadand, Kuruppampady (0 percent shade), PS-667 and Jamaica (50 percent shade), Valluvanad, Jamaica, and Jorhat (75 percent shade) (Sreekala and Jayachandran, 2001). The cv. Rio de Janeiro raised as a pure crop and as an intercrop recorded highest dry matter production as intercrop in 6-year-old coconut plantation when compared to 2-year-old plantation. It appears that relatively low temperature combined with low-light intensity contributes to the development of more chlorophyll in ginger plants grown in shade, leading to higher photosynthetic rates (Sreekala et al., 2001). It can also be due to better utilization of photosynthates, as its degradation due to photorespiration has slowed down, because of a decreased respiration rate at a lower temperature.

Nutrient Uptake and Removal

The growth of ginger can be classified into three distinct periods: a phase of active vegetative growth (90 to 120 days after planting), a phase of slow vegetative growth (120 to 180 days after planting), and a phase of senescence (180 days to harvest). The pattern of rhizome development also followed the same trend except that the development of rhizome continued up to harvest (Johnson, 1978). According to Johnson, the total uptake of N, P, and K progressively increased with advancing periods of crop growth, and the uptake by the leaf and pseudostem progressively increased up to 180 days after planting and decreased thereafter. However, the uptake by rhizome steadily increased till harvest. He also standardized the period between 90 and 120 days after planting as the ideal time for leaf analysis and recommended the 5th to 12th leaves for foliar diagnosis.

Organic Matter

In olden days, ginger was cultivated in freshly cleared forest soils and as such there was no need to apply fertilizers. But the situation has changed and now it has become impossible to realize a satisfactory yield without an adequate supply of fertilizers together with a heavy dose of organic matter. Sadanandan and Iyer (1986) observed that organic amendments such as neem cake and *Pongamia* cake reduced the incidence of rhizome rot and improved the yield in ginger. Cho et al. (1987) opined that the ginger yield was positively correlated with the soil organic matter content. In Kerala, the major ginger-producing state of India, the recommended dose of organic matter is 25 to 30 t/ha of FYM and 30 t/ha of green leaves as mulch applied in three splits, 15 t at the time of planting and 7.5 t each at 60 days and 120 days after planting (KAU, 1993).

In a field trial on alfisol, application of 45 t/ha of FYM and 600 kg KCl/ha resulted in the highest yield of rhizome with acceptable quality in terms of fiber content (Sugito and Maftuchah, 1995). Khandar and Nigam (1996) reported that the rhizome yield of ginger increased with an increased ratio of FYM application (33 t/ha) compared to

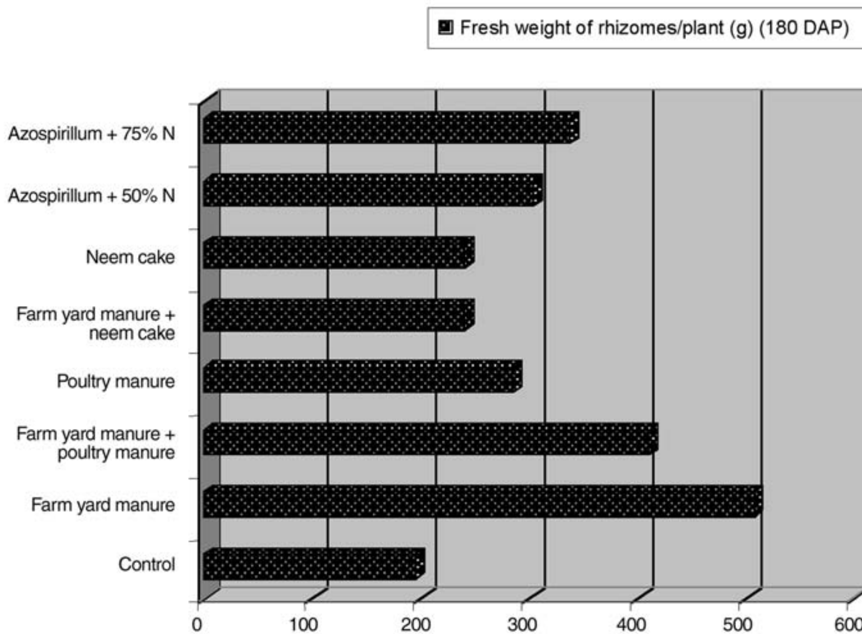

Figure 5.7 Effect of different sources of organic manure and Azospirillum on fresh weight of ginger rhizomes.

22 t/ha. Plant height was greater with FYM. Chengat (1997) studied the effect of organic manure and *Azospirillum* on the growth and yield of ginger in Kerala (Figure 5.7). Application of FYM at the rate of 48 t/ha resulted in the highest returns and benefit-cost ratio (2.32), giving an additional profit of 32.04 percent over control. Sadananandan et al. (1998) reported that among six organic fertilizers (FYM, neem cake, brasicca cake, groundnut cake, and gingelly cake), groundnutcake gave the highest soil organic matter. Neem cake gave the highest benefit-cost ratio followed by groundnut cake.

Nutrient Requirements

For ginger crop, the requirement of nitrogen (N) is the most critical among the major nutrients. Although the nutrient is directly available to the plant in nitrate form, it is easily lost by leaching. Under tropical conditions, the loss by leaching and denitrification is very high. At the same time, the nitrate N moves upward with the capillary rise of water during drought. Ammonium ions perform better than nitrates under heavy leaching situations. Unlike N, phosphorus, (P), is highly immobile in the soil because of its reaction with iron and aluminum hydroxides. Therefore, the amount of phosphatic fertilizer needed for the crop is relatively high. For a short-duration, quick-growing crop like ginger, fertilizer containing a high proportion of water-soluble P_2O_5 is needed for a better yield (Sushama and Jose, 1994). When ginger is grown as a homestead crop, potassium, (K), nutrition plays an important role. Only under high rates of K application can the crop be grown successfully under shade conditions (Jayaraj, 1990).

Secondary nutrients are also essential for the healthy growth of ginger. However, deficiency of secondary nutrients is less general. Since very large quantities of FYM and leaf mulch are applied to a ginger crop, the micronutrient requirements will be met from them and deficiencies of micronutrients are seldom reported.

The nutritional aspects of ginger have been subjected to detailed studies by various workers. Samad (1953) reported no significant response to fertilizer application. However, the fertilizer trials conducted by the Agricultural Department of Kerala, India, in collaboration with Indian Potash Limited during 1957 to 1960 revealed that application of 50 kg each of N and P_2O_5 and 100 kg of K_2O/ha produced the highest yield in ginger.

A significant increase in the yield was observed by Loknath and Dash (1964) with the application of 60 kg N, 40 kg P_2O_5, and 60 kg K_2O/ha in Orissa state, India. Trials conducted by Randhawa and Nandpuri (1965) indicated that combination of 100 kg N, 50 kg P_2O_5, and 50 kg K_2O/ha was the best for realizing the highest yield in ginger. Aiyadurai (1966) indicated that N at the rate of 50 to 100 kg/ha significantly increased the yield by 18 to 32 percent and improved the dry matter content of rhizome. Randhawa and Nandpuri (1969) further reported that application of 50 kg and 100 kg/ha of N, and 50 kg each of P_2O_5 and K_2O increased the plant height, tiller production, and yield of rhizome. Nair (1969) and Paulose (1970) recommended 60, 60, and 150 kg of N, P_2O_5 and K_2O/ha, respectively. Dasaradhi et al. (1971) emphasized the need for application of N at the active growth and tillering stages during which the foliar N content will go up to 3 percent. However, a poor response of ginger to K was reported by Muralidharan and Kamalam (1973). Muralidharan et al. (1973) indicated that application of N at the rate of 70 kg significantly increased the tiller production and yield of ginger.

With an application of P_2O_5 at 20 and 40 kg/ha, Saraswat (1974) obtained an increase of 21.5 and 11.5 percent yield respectively, whereas N and K were ineffective. The oil content was adversely affected by N application. Nair (1975) observed that foliar application of a combination of 2 percent urea and Planofix 400 ppm was beneficial for growth and yield of ginger.

According to Johnson (1978), high levels of N (80 kg/ha) had a significant effect on number, length, and breadth of leaves and number of tillers in ginger. However, there was a yield reduction when the N level was increased from 80 to 120 kg. A fertilizer dose of 80:30:40 kg/ha of N, P_2O_5, and K_2O (NPK) was found optimum for ginger. Phosphorous and K did not have any significant effect on morphological characters. The uptake of N, P, and K increased progressively with advancing period of growth. There was marked uptake of these nutrients by the plant during the active plant growth (90 to 120 days after planting). Sadanandan and Sasidharan (1979) recorded the highest yield with 50 kg N/ha. Pawar and Patil (1987) observed that the highest yield of green ginger (16.4 t/ha) during the first year of cultivation was obtained from plots that received 225 kg N, 90 kg P_2O_5, 180 kg K_2O, and 30 t FYM/ha. In the second year the highest yield was obtained from plots fertilized with same quantity of NPK and 20 t FYM/ha.

Maity et al. (1989) reported that the optimum fertilizer dose of ginger was N at 100 kg, P_2O_5 at 60 kg, and K_2O at 90 kg/ha. Studies on the response of manure and different sources of N, P, and K by Saha (1989) at Meghalaya, India, had shown that the highest yield (8.3 t/ha) of fresh rhizomes was obtained from plots that received NPK at the rate of 90, 60, and 90 kg/ha, respectively as urea, diammonium phosphate, and muriate of potash. Haag et al. (1990) recorded the accumulation of macronutrients in the decreasing order of N, K, calcium (Ca), magnesium (Mg), sulfur (S), and P, and that of micronutrients as iron (Fe), magnesium (Mn), zinc (Zn), boron (B), and copper (Cu).

Mohanty et al. (1993) at Orissa, India found that the yield of ginger rhizomes increased with the increasing rate of fertilizer application and highest yield (10.16 t/ha) was recorded in the treatment with the highest fertilizer dose of N at 125 kg, P_2O_5 at 70 kg, and K_2O at 150 kg/ha. Xu et al. (1993) observed that N fertilizer (ammonium sulfate) utilization by ginger plants increased with a delay in application, being greatest with application as a dressing during the middle of the vigorous plant growth stage (42.24 percent for 300 mg N/plant). Chatterjee et al. (1992) reported that plant height (84.6 cm), number of tillers/plant (7), number of leaves/plant (66.7), and rhizome yield per plant (268 g) increased with application of urea (2 percent) and 20 mg NAA/l.

Studies conducted at the All India Co-ordinated Spices Improvement Project, Vellanikkara, Kerala, India, showed that application of N, P_2O_5 and K_2O at 50, 40 and 40 kg/ha increased the yield as compared to no fertilizers. Kerala Agricultural University recommends 75 kg N, 50 kg P_2O_5, and 50 kg K_2O/ha. The full dose of P and half dose of K are to be given as basal and one-half N applied 60 days after planting. The remaining half dose of N and half dose of K_2O are to be applied 120 days after planting (KAU, 1993).

Govind et al. (1995) reported that 90 kg of P_2O_5/ha produced taller plants, more tillers and leaves per plant, more secondary rhizomes per plant, and higher fresh and dry yields of rhizome in cv. Nadia in Meghalaya region. Sixty kg P_2O_5/ha showed more primary rhizomes per plant. Different P_2O_5 rates (104.6, 83.7, and 90.8 kg/ha) gave an almost similar yield (147.3 to 149.0 q/ha). Joseph and Jayachandran (1996) emphasized the necessity of increasing the quantity of fertilizer to 150 percent of the recommended dose (75:50:50 kg NPK/ha) where ginger is grown under low to medium shade (25 and 50 percent). Under intense shade (75 percent), there was no response to fertilizer treatment.

Thakur and Sharma (1997) showed that N and P up to 100 and 60 kg/ha, respectively, increased the rhizome yield significantly. N, P, and K uptake by ginger increased with the increase in application of N and P rate up to 150 and 90 kg/ha. Chenghat (1997) studied the influence of organic manures and *Azospirillum* on uptake of N, P and K and found that the uptake was more in plots incorporated with FYM (48 t/ha) followed by *Azospirillum* + 75 percent N. The soil nutrient status in terms of available N and K was found to be high in plots inoculated with *Azospirillum* + 75 percent N, whereas available P was higher in plots receiving recommended NPK. Per plant yield was better under farmyard manure treatment.

Ai et al. (1998) reported that N application at 40 kg/ha resulted in the higher content of protein and amino acids and favored the formation of sugar, starch, ascorbic acid and volatile oil, but when too much N was applied, all the above constituents decreased. The sugar content increased with P application in the range of 0 to 15 kg/ha. Potassium promoted the formation of starch and fiber but was detrimental to ascorbic acid. Rhizome quality was the best at 40:75:40 kg NPK/ha. The quality of ginger was also superior under low shade and was unaffected by fertilizer treatments. The need for an increased fertilizer requirement under shade has been confirmed in another trial wherein application of 150 kg N, 100 kg P_2O_5, and 100 kg K_2O/ha gave higher yield, and net profit for ginger raised as an intercrop in coconut gardens (Kumar, 1999) (see Table 5.5). Gowda et al. (1999) reported that the yield of ginger cv. Rio de Janeiro could be increased by application of 150:75:50 kg NPK/ha under Bangalore conditions. The uptake of N, P, and K in the leaf and pseudostem progressively increased up to day 180 and then decreased while their uptake in rhizome steadily increased until harvest. The graded doses of N, P, and K failed to influence the oleoresin content of ginger.

Table 5.5 Economics of fertilizer application in ginger as intercrop in coconut garden

Sl. no.	*Treatments kg/ha* $N\text{-}P_2O_5\text{-}K_2O$	*Cost of cultivation (Rs/ha)*	*Dry ginger yield (kg/ha)*	*Value (Rs)*	*Profit/Loss (Rs/ha)*	*BC ratio*
1	No fertilizers	82,200	1,977	86,355	4,155	1.05
2	0-0-50	82,682	2,180	95,222	12,540	1.15
3	0-0-1000	83,163	2,248	98,049	14,885	1.19
4	0-50-0	82,623	1,947	84,901	2,278	1.03
5	0-50-50	83,105	2,413	1,053,400	22,295	1.27
6	0-50-100	83,586	2,246	98,118	14,532	1.17
7	0-100-0	83,047	2,143	93,606	10,559	1.13
8	0-100-50	83,529	1,781	77,794	5,735	0.93
9	0-100-100	84,010	2,265	9,8935	1,492	1.18
10	75-0-50	82,893	2,463	107,597	24,704	1.30
11	75-0-50	83,375	2,632	114,953	31,578	1.38
12	75-0-100	83,856	2,820	123,178	39,322	1.47
13	75-50-0	83,316	2,893	126,379	43,063	1.52
14	75-50-50	83,798	3,177	138,758	54,960	1.66
15	75-50-100	84,279	2,980	130,166	45,888	1.54
16	75-100-0	83,740	3,010	131,477	47,737	1.57
17	75-100-50	84,222	2,640	115,315	31,093	1.37
18	75-100-100	84,703	3,183	139,047	54,344	1.64
19	150-0-0	83,586	2,842	124,125	40,539	1.49
20	150-0-50	84,068	2,732	11,934	35,266	1.42
21	150-50-100	84,549	3,083	134,679	50,130	1.59
22	150-50-0	84,009	3,253	142,104	58,096	1.69
23	150-50-50	83,105	2,637	115,071	32,066	1.39
24	150-50-100	84,972	3,140	137,155	52,183	1.61
25	150-100-0	84,433	3,088	134,897	50,464	1.60
26	150-100-50	84,915	3,285	143,489	58,574	1.69
27	150-100-100	85,316	4,167	182,001	96,605	2.13

Rs: Indian Rupees, B.C.: Benefit: Cost ratio

An investigation to determine the fertilizer requirement of ginger under varying shade intensity using ginger cv. Rio de Janeiro was laid out in strip plot design with four shade levels (0, 25, 50, and 75 percent) and four fertilizer levels (75, 100, 125, and 150 percent of the recommended dose of 75:50:50 N, P_2O_5, and K_2O/ha) and was replicated five times. Under open conditions, a significant increase in the dry ginger yield was obtained, up to 125 percent, and the highest profit was also realized from this treatment. The growth and yield of ginger were highest under 25 percent shade. The response to fertilizer treatments in terms of growth characters and yield were highest under this shade level. A significant increase in green and dry ginger yield was obtained with each increment of fertilizer dose up to the highest level (Jayachandran et al., 1991).

Secondary and Micronutrients

Since ginger is cultivated with high doses of organic manure and green leaf mulch, an additional supply of secondary and micronutrients is not usually required. However, Roy

et al. (1992), West Bengal, India, had observed that in local cultivars of ginger, the highest yield of 48.8 t/ha was obtained with a combination of 0.3 percent zinc, 0.2 percent iron, and 0.2 percent boron. Wang et al. (1993) reported that zinc affects protein synthesis and RNA metabolism leading to amino acid accumulation under zinc deficiency. Srinivasan et al. (2003) carried out a study on zinc nutrition of ginger. They found that zinc deficiency exists in 49 percent of soil samples analyzed from various ginger-growing regions of India. Their study indicated that zinc application at 5 kg/ha increased the rhizome yield significantly. The culture model they developed indicated that 6 kg/ha zinc is the best for maximizing the yield.

Biofertilizers

Ginger responds well to the application of biofertilizers. Studies conducted by Vilasini (1996) indicated that soil solarized for 30 days and incorporated with *Trichoderma* (125 g/m^2) and amended with neem cake (500 g/m^2) could control the disease effectively and increase the yield considerably. Sharma et al. (1997) found that inoculation with *Glomus mosseae* at the spore stage (10×10^2)/g soil gave taller ginger plants, with higher yield (46.5 g per pot) and greater number of tillers per plant than other treatments under the subtropical conditions of Himachal Pradesh, India. Soil application of *Gigaspora margarita* (2.5 g per rhizome) at the time of planting increased plant height, number of leaves and tillers, root weight, and yield of ginger, which is similar to that of pine needle organic amendment and seed treatment with *Trichoderma harzianum*.

Treating rhizomes of cv. Mahi with *Azetobacter* and *Azospirillum* followed by application of N at 50 kg/ha produced a higher green ginger yield of 20.34 t/ha against an uninoculated field (receiving 75 kg N/ha), which yielded 17.44 t/ha (Konde et al., 1988).

Mulching

Mulching of beds with green leaves is an important and essential operation in ginger cultivation. The effect of mulching on growth and yield of ginger has already been established from various studies. Mulching is essential for weed control, for moisture conservation and to protect the beds from the beating action of rain. Heavy mulch can change the physical and chemical environment of the soil underneath, resulting in the increased availability of P and K. Mulching increased the germination and growth of plants in terms of height and number of tillers. Weed growth in the control plots was much higher than the plots mulched.

Applications of leaf mulch immediately after planting and 6 weeks after using a total of 20 t/ha of green leaves resulted in 200 percent increase in yield over the nonmulched crop, and this was found sufficient in the ginger-growing areas of the higher elevations of Western Ghats, South India. In the plains, mulching the crop with 30 t/ha of green leaves has been recommended. Immediately after planting, the beds should be mulched with 15 t/ha of green leaves, which is repeated with 7.5 t/ha each at 2 and 4 months after planting. Mulching is done coinciding with weeding, top dressing, and earthing up. Among the different mulch materials, leaves of *Glycosmis pentaphylla*, *Glyricidia maculata*, and *Artocarpus altilis* were found to produce good results.

In trials with the ginger cv. Maran, Mohanthy (1977), at Pottangi (Orissa), India, reported that when the plants were mulched with (1) banana leaves, (2) grass, or (3) soil, the best results with regard to sprouting, yield, suppression of weeds, and prevention

of soil erosion were obtained in mulching with banana leaves. Mishra and Mishra (1982) reported that mulching with dry leaves markedly suppressed the early weed growth and increased the crop emergence, growth, and yield. They also reported that application of weedicides, 2, 4, dichlorophenoxy acetic acid (2,4-D), or Atrazine together with mulching gave the highest yield and returns in ginger.

In Assam, India, the highest yield of fresh ginger (24 t/ha) was recorded with green leaf mulch (Roy and Wamanan, 1988). Mohanty et al. (1990), observed that of the various mulching treatments tested, leaf mulch gave the highest yield of 34.8 t/ha compared with 11.97 t/ha in the unmulched control.

Valsala et al. (1990) studied the possibility of growing daincha (*Sesbania aculeata*) in the interspaces of ginger beds and utilizing the green leaf material for mulching in Kerala, India. The cv. Maran was grown on raised beds (3 × 1 m with 50 cm interspaces). It was given a first mulch using locally available leaves. *S. aculeata* was sown in the bed interspaces immediately after planting of ginger rhizomes, it was uprooted 60 days later and used as a second mulch. It provided 4 kg green leaves per 1.5 m^2, which was 50 percent of the normal requirement of 8 kg/1.5 m^2. The daincha roots are also considered to be a good source of organic matter.

Pawar (1990) compared polyethylene (PE) film mulch or sugarcane trash mulch (5 t/ha), and without any mulch under Maharashtra conditions combined with different irrigation regimens (60, 80, 100, and 120 mm cumulative pan evaporimeter [CPE]). The highest yields of green ginger were obtained with the mulches and irrigation at 60 or 80 mm CPE. Under the semi-arid conditions of the trials, it was concluded that, with a PE mulch, only 50 percent less irrigation water was required to give the same yield as full irrigation.

Korla et al. (1990) conducted trials with local cv. Dharja and found that the mean yield was highest (205 to 206 g/plant) in plots mulched with grass clippings + FYM or pine needles + FYM. In Kerala, the recommended dose of mulch is 30 t/ha of green leaves applied in three splits, 15 t at the time of planting and 7.5 t each at 60 and 120 days after planting (KAU, 1993).

Kurian et al. (1997) at Vellanikkara, Kerala, India noted that green manure crops of *Sesbania rostrata*, *S. aculeata*, *S. speciosa*, *Crotalaria juncea*, or fodder cowpea (*Vigna unguiculata*), when grown amongst a ginger crop and used as the second mulch, or sown a second time 2 months after the ginger was planted and used as the third mulch, reduced weed problems in the ginger crop. The ginger rhizome yield was highest with *S. aculeata* used as the second mulch.

Babu and Jayachandran (1997) in Kerala, India, studied the effects of shade (0, 25, 50, or 75 percent) and mulching with leaves of *Swietenia mahagoni* on the yield of cv. Rio de Janeiro. Yield increased with increasing the rate of mulching. Interactions between the mulching rate and shade were observed. Under 25 percent shade, similar yields (5,256 and 5,246 kg/ha) were obtained from treatments with 100 percent (30 t/ha) and 75 percent (22.5 t/ha) of the recommended mulching rate, respectively. Gupta and Awasthi (1997) observed that in trials at Jagdalpur, India, in the kharif (monsoon) seasons of 1994 and 1995, ginger cv. Suprabha, grown with mulches of palas leaves (*Butea monosperma*), sal leaves (*Shorea robusta*), rice straw, dry grass, leaf mould, or soil, the best treatment was palas leaf mulch, which produced average fresh yield of 21.90 t/ha compared with 16.75 t/ha in the unmulched control.

Soil Solarization

Solarization had a profound promotive effect on ginger growth by suppressing the weed population, and the effect lasted until harvest. Even though solarization substantially reduced weed population, its effect was less on sledges. *Bulbostylis barbata*, *Cynadon dactylon*, and *Cyperus rotundus* survived the solarization. Vilasini (1996) observed that soil solarization for 30 days combined with *Trichoderma* application could control the rhizome rot disease and increase the yield.

An increased growth response of ginger plants was observed as a result of solarization. Growth parameters such as height, number of leaves/plant, number of tillers, number of roots, leaf length, leaf breadth, and fresh weight of shoots and rhizomes were influenced by solarization. A significant increase in yield was obtained through solarization. *Trichoderma* incorporated + neem cake amended + 30 days solarized treatment gave the highest yield/plant (623.23 g) and also per plot (10,159.57 g), which was 53.6 percent more than that of control. The availability of N, P, and K was improved by solarization. The initial cost of solarization is comparatively high. An amount of Rs. 52,500 is required for solarizing ore ha of a ginger field. An additional profit generated from this technique was Rs. 40,136/ha/yr for 30 days solarization (Anaith et al., 2000) (see Figure 5.8).

Water Management

Ginger is grown both as a rain-fed and irrigated crop. Korla and Tiwari (1999) at Solan, Himachal Pradesh, India, observed that significant effects of rain-fed and irrigated conditions were observed on pseudostem length, tillers per plant, leaf length, leaf breadth, and yield per plot. Significant genotypic differences were observed for pseudostem length, rhizome length, rhizome breadth, and yield per plant. In general, the commercial cultivar Himgiri performed well and was consistent under both environments for most of the characters. The performance of SC 646 was similar to Himgiri

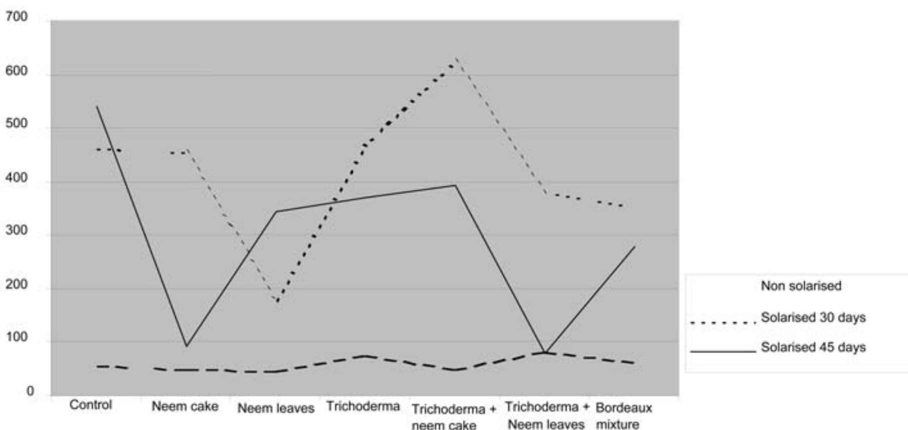

Figure 5.8 Influence of soil solarization on yield in ginger (g/plant).

for tillers/plant, leaves/plant, leaf length, leaf breadth, rhizome length, rhizome breadth, yield of individual plants, and total yield/plot. Plessis and Anderson (1986) found that overhead sprinkling of water raised the yield of ginger from 36.4 to 45.2 t/ha.

Intercropping and Rotation

Ginger is grown as a pure crop as well as an intercrop or in rotation with other crops. In Kerala it is grown as an undercrop in coconut and arecanut gardens, in coffee estates, and in rice fallows. In irrigated areas, ginger is grown in rotation with chilies, vegetables, groundnut, ragi, and maize. In Kerala as well as in Sri Lanka ginger forms a component of the homestead farming, and is grown mixed with a variety of crops. Ginger is a very successful crop component in intercropping and multicropping systems. It is intercropped with vegetables (such as cabbage, beans, cucumber, and lady's finger), pulses (such as pigeon pea and black gram), cereals (maize and finger millet), oil seeds (castor, soybean, and sunflower) and with crops such as tobacco, pineapple, tapioca, taro, *Discoria*, and *Amorphophallus*. It can also be grown as a mixed crop with castor, finger millet, maize, and red gram. Chilies-ginger–mixed cropping is prevalent in many areas.

Nizam and Jayachandran (1977) in Kerala, studied the effect of seed rhizome size and varieties on the quality of ginger under open conditions and as an intercrop. Three sizes of seed rhizomes (5, 10, and 15 g) of ginger cultivars Kuruppampady, Maran, Nedumangadu, and Rio de Janeiro were planted in the open or as an intercrop in a 30-year-old coconut plantation. Nonvolatile ether extract (NVEE) was significantly influenced by rhizome size in open conditions; plants raised from 15 g rhizomes had significantly higher NVEE than plants raised from 5 or 10 g rhizomes. However, this effect was not observed in the intercropping treatment. In open conditions, plants raised from 5 g rhizomes had the highest crude fiber content, but when grown as an intercrop, plants raised from 15 g rhizomes had the highest crude fiber content. The cv. Kuruppampady recorded the highest NVEE under open and intercropped conditions.

Sankar and Swamy (1988), at Coimbatore, India, studied the ginger cultivar Rio de Janeiro grown as (1) monoculture, (2) as an intercrop in 2-year-old and (3) 6-year-old arecanut plantations. Average day temperatures in (1), (2), and (3) were 30, 28.3, and 27.9°C, respectively. The average light intensities available to the ginger plants were 104.81, 33.09, and 15.61 klx, respectively. Leaf area was highest in (3) and lowest in (1). Chlorophyll-a and chlorophyll-b contents increased up to day 150 after planting in (2) and (3), and up to day 180 in (1); thereafter, it declined in all cases. Rhizome yields in (1), (2), and (3) were 2.7, 9.2, and 13.5 t/ha, respectively.

Jasural et al. (1993) investigated the performance of ginger under rain-fed conditions in pure stands and as intercrops with 5-year-old poplars planted at three spacings (5×5, 5×4 and 5×3 m) at Himachal Pradesh. The average illumination below the canopies was 53, 46, and 38 percent of incident radiation, respectively. The crop performed better as an intercrop than as a pure stand as measured by growth (height, tillers and leaves per plant, and leaf length and breadth), yield (rhizome length and breadth, yield per plant and hectare, and dry matter content) and survival. However, all parameters decreased as poplar spacing became closer than for the pure crop. For

quality parameters, only the oil content in ginger showed significant differences. Among the poplar spacings, 5 × 4 m was the best. Singh et al. (1991) showed that ginger is a very favorable crop component under agroforestry. However, crop rotation is essential, as ginger depletes soil nutrients and due to the buildup of inocolum of rhizome rot pathogens (Kandiannan et al., 1996). However, solanaceous plants should be excluded from such crop rotation.

Sujatha et al. (1994) noted that the highest sprouting percentage (100 percent) was recorded for cultivars Earanadan and Valluvanad when 26 ginger cultivars were grown in 3 × 1 m plots to be screened as intercrops for coconuts at the Regional Agricultural Research Station, Pilicode, Kasargod District, India. The highest fresh yields were recorded for cv. Kuruppampady (356.5 g/plant, 17.11 kg/3 m^2 plot, and 57.05 t/ha), followed by Wynad, Mananthody, and Earanadan. The highest dry yield was recorded for PGS-667 (4.53 kg/plot, 15.5 t/ha), followed by Kuruppampady and SG-551.

In Sikkim, India, ginger is intercropped with mandarin orange (*Citrus reticulata* Blanco) and mixed with maize. Many farmers believe that raising maize and ginger together gives more yield than sole crops (Patiram, 1995). Partial shade provided by the mandarin orange provides a congenial atmosphere for ginger. After harvesting of maize, ginger plants become exposed to more sunlight and that favors development of bolder rhizomes. Mixed cropping is more efficient and productive than sole cropping because of higher combined yields (of calories and proteins) and better energy use efficiency (Willey, 1979).

Manjunath et al. (1998) evaluated ginger as an intercrop in coconut gardens in the Goa region of India. In trials carried out between 1993 and 1996 cv. Sangli local was found to be the suitable annual intercrop for intensive management with May to June sowing, resulting in good yields and the highest net returns. Intercropping increased coconut yields from an average of 13 nuts/palm before intercropping to 39 nuts/palm after 3 years of intercropping.

Sharma and Bajaj (1998) undertook studies to improve ginger yield against infection with *Pratylenchus penetrans*, *Meloidogyne incognita*, *Helicotylenchus dihystera*, and *Tylenchorhynchus mashhoodi* in Himachal Pradesh, by intercropping with bell pepper, *Capsicum annum,* in eight different treatments. Intercropping of one rhizome of ginger × one plant of bell pepper gave the highest ginger yield (600 g/rhizome). This treatment was completely free from *P. penetrans* and *M. incognita*. All treatments with bell pepper plants equal to or higher in number to that of ginger rhizomes had higher ginger yields than treatments with ginger alone or with fewer bell pepper plants. In the former, populations of *P. penetrans* and *M. incognita* were lower than in the latter treatments. Pegg et al. (1969) recommended beans, cucurbits and strawberries as suitable crops for rotation to minimize nematode problems.

Kandiannan et al. (1999), investigated the effect of intercropping ginger with maize under rain-fed conditions. The crops were planted in June on raised beds (3 × 1 m): ginger at 25 × 30 cm and maize at each corner of the raised bed. Maize was harvested 90 to 100 days after planting and ginger 8 months after planting. There were no significant differences in the percentage of sprouting, total number of tillers/bed, and fresh rhizome yield between ginger grown alone and with maize, indicating that intercropping had no deleterious effect.

Growth Regulators

Das and Nair (1976) studied the effect of urea at 2 percent and/or planofix containing NAA at 200 or 400 ppm applied to five ginger cultivars in June. The crop was harvested in the following February. The production of dry ginger was highest in the cv. Maran, followed by Sierra Leone, China, Thinladium, and Rio de Janeiro. The best treatment was urea + planofix at 200 ppm.

Application of Ethrel (Ethephon: 2-chloroethane phosphonic acid) three times at 200 ppm as a foliar spray starting from day 70 after planting at an interval of 15 days increased vegetative growth in ginger, whereas Cycocel had no significant effect on vegetative growth. Foliar application of 2 percent urea + 400 ppm planofix reduced the fiber content in cultivars Maran, China, and Tinladium (Jayachandran and Sethumadhavan, 1979). Ravishankar and Muthuswamy (1984) reported that ginger plants treated with 2-chloroethyltrimethyl ammonium chloride (CCC) have only negligible endogenous gibberellins. CCC at 180 and 200 ppm improved auxin and cytokinin levels in the rhizomes. Furutani and Nagao (1986) were of the opinion that the rhizome yield in ginger increased with diaminozide and decreased with GA3 and Ethephon. Application of Ethrel at 50 to 400 ppm, 2 months after planting and twice at 20-day intervals recorded higher yield of rhizomes (25 t/ha) over untreated controls (Phogat and Singh, 1987). Futurani et al. (1985) noted a higher ginger rhizome yield with the application of ethephon 750 ppm combined with a preplant soaking in hot water at 51°C for 10 minutes. The treatment increased the shoot number by 122 percent and yield by 38 percent. Nair and Das (1982) reported a higher oleoresin content with the application of 2 percent urea and 400 ppm Planofix. Chatterjee et al. (1992) reported that a maximum plant height (84.6 cm), the number of tillers/plant (7), the number of leaves/plant (66.7), and rhizome yield/plant (268 g) were with the 2 percent urea + 20 mg NAA/l treatment combination. The highest leaf N content at 160 days after planting was obtained with the one percent urea + 20 mg NAA/l treatment combination. The highest leaf P and K content at 160 days after planting was obtained with one percent urea treatment.

Organic Farming of Ginger

Organic farming is an approach to sustainable agriculture aiming to create an integrated, ecofriendly and economically sustainable production system. This integrated system includes the protection of soil fertility through the application of organic matter and fostering the soil biological activity. Nutrients are applied through relatively insoluble nutrient sources (organics), maintenance of the nitrogen source through the raising of leguminous crops, recycling organic residues, and disease and insect pest control through crop rotation, use of natural predators, biopesticides, and resistant varieties as well as by maintaining diversity in crop plants.

The approaches to the organic cultivation of ginger involve the following aspects (Potty and Krishnakumar, 1999; Arya, 2001).

1. Nutritional management through:
    - The application of FYM, oil cakes, vermi-compost, and bio-fertilizers
    - Raising leguminous cover and intercrops
    - Use of permitted fertilizers such as powdered rock phosphate and sulfate of potash

2. Insect–pest management through:
   - Cultural practices
   - Mechanical (manual) collection and removal of root grubs, beetles, and others
   - Use of biopesticides such as neem products, extracts of *Lantana*, and incorporation of *Trichoderma* in the soil
   - Use of bioagents such as *Bacillus thuringiensis* strain kurusakthy, into the borehole of pseudostems to kill the larvae of the stem borer; *Trichoderma*, for control of other soilborne pathogens
3. Use of tolerant varieties
4. Disease management through practices such as crop rotation and adjusting planting time
5. Adoption of proper cultural practices such as providing drainage, shade, and timely removal of affected plants etc.

Maturity and Harvest

Harvest maturity varies according to the end use. If the rhizomes are for vegetable use or for the preparation of such products as ginger preserves and candy, harvesting should be done 4 to 5 months after planting. For dry ginger production and for distillation of oil or solvent extraction of oleoresin, harvesting is done 8 to 9 months after planting. Harvesting is delayed at higher elevations, in cooler climates, and under irrigation. Maturity studies were conducted in four cultivars at seven stages starting from 165 to 270 days after planting. Dry ginger recovery was highly correlated with crop duration. Dry ginger recovery was highest at 270 days after planting, and a dry recovery around 20 percent is essential to obtain an attractive marketable product. The percentage of oleoresin, oil, and fiber contents was highest at 165 days after planting, whereas the yield per hectare of oleoresin and oil varied with cultivars, and the highest was found at 270, 195, 225, and 225 days after planting in cultivars Rio de Janeiro, Maran, Kuruppampady, and Wynad local, respectively. For vegetable purposes, the crop could be harvested from 6 months onward (Nybe and Nair, 1978)

Jayachandran et al. (1980) noted highest yield of green ginger/plant at 7 months when the percentage of the contents of oleoresin and volatile oil was also highest. Dry ginger recovery, however, was highest at 8 months, when the starch content was maximal and the crude fiber content minimal. Nybe et al. (1982) evaluated 25 ginger cultivars at Vellanikkara, India, for their yields of fresh rhizome, drying percentage, oleoresin, oil, and crude fiber contents. Cv. Nadia gave the highest yield of fresh rhizomes (28,554 kg/ha) and dry ginger (6,453 kg/ha). Cv. Rio de Janeiro contained the highest oleoresin (10.5 percent), followed by Maran (see Figure 5.9). Ratnambal et al. (1987) reported that although the percentage contents of essential oil and oleoresin decreased with increasing maturity, the final yield per hectare of these two quality components was highest at full maturity. Cultivars Maran, Ernad, Chernad, and Nadia are recommended for fresh rhizome production, and Maran, Ernad, Chernad, Karakkal, and Nadia are recommended for dry ginger production.

Pawar and Patil (1990) observed that the dry weight of rhizomes per plant and green ginger yield were highest when the crop was harvested 8 months after planting. Mohanty et al. (1990) observed that of the seven cultivars tested, Suprabha and S-646 gave the

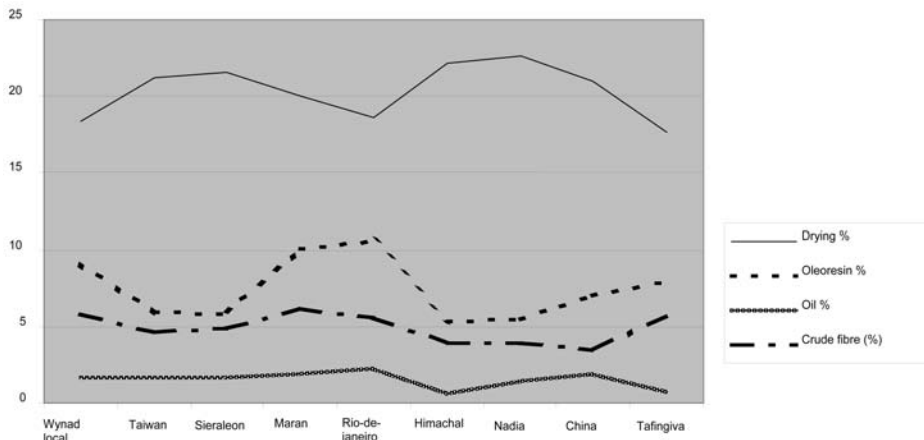

Figure 5.9 Quality parameters of ginger types.

highest yields (>28 t/ha) and Rio de Janeiro the lowest yield (10.62 t/ha). Roy and Wamanan (1990) observed that yield was correlated with shoot height, leaves/clump, and tillers/clump. Pandey and Dobhal (1993) reported that the plant height, number of fingers, and yield/plant were positively correlated with each other and with most of the other traits. Path coefficient analysis revealed that the weight of fingers, number of fingers, width of fingers, and leaf width had a direct effect on yield. The weight of fingers also had a positive indirect effect on yield.

Patiram et al. (1995) reported that ginger is harvested twice in Sikkim. In the first stage during May and June, the mother or seed rhizomes are harvested. This harvested product (*mau* in the local language) is of inferior quality. The main harvesting comes 7 to 8 months after planting and continues up to January. Rai and Anita (1997) also recorded the mother rhizome extraction practiced by local farmers for many years in the hills of Sikkim and Darjeeling, India. By extracting the mother rhizome, farmers get back their investment on seed rhizome even if there is a severe outbreak of rhizome rot disease. The mother rhizome has equal market value as freshly harvested ginger because of the large size of rhizomes (100 to 500 g) planted. The wound created while detaching the mother rhizome may serve as an entry point for pathogens. Airdrying, packing in 250-gauge low density polyethylene (LDPE) bags followed by irradiation at 60 Gy keep the rhizomes in good marketable condition for up to 2 months at ambient temperature without sprouting or significant loss of quality and less than 5 percent weight loss.

Singh et al. (1999) observed that the cvs. Thingladium, Nadia, and Khasi local had the highest rhizome yields (more than 30 t/ha) under the conditions of Nagaland, India. The lowest rhizome yield was recorded in Tura and HP 666 (less than 20 t/ha). Cvs. Thinglaidum, Nadia, and Rio de Janeiro had the highest fiber and oil contents.

Postharvest Handling

Bhuyan et al. (1990) conducted thin-layer drying experiments on the cv. Siliguri in order to study its drying characteristics. The quality of dried ginger was also evaluated

by determining its volatile oil and oleoresin contents. A small-capacity tray dryer was designed and built and its performance tested. The heat utilization factor, coefficient of performance, overall thermal efficiency, and uniformity of drying of sliced ginger on each of the trays were determined. The dryer performed satisfactorily. The air temperature of 60ºC was found suitable for drying ginger slices.

Ali et al. (1991) at Udaipur, India, developed an abrasive, brush-type, ginger-peeling machine. The machine consists of two continuous vertical abrasive belts with a 32-gauge steel wire brush. The brush wires are 2 cm high and spaced at 1.9 cm intervals and the peeling zone is 135 cm long and 30 cm wide. The machine was found to operate satisfactorily with a peeling efficiency of about 85 percent and a capacity of 200 kg/h.

The influence of various postharvest treatments like scraping, slicing, blanching, boiling, coating, and their combinations on the yield and quality of dry ginger and storage life was studied. Slicing the ginger rhizomes before drying is preferred over conventional drying since it reduces the time for drying and the product obtained has good color and comparable quality (Kumar, 1992).

Radha et al. (1993) in Rajasthan, India, developed a small, manually operated ginger-peeling machine for application at the level of the individual farmer. It operates on the principle of abrasive peeling. The performance of the machine was evaluated in terms of peeling efficiency and ginger meat loss. At full-capacity operation, the machine had a peeling efficiency of 71 percent with 1.3 percent losses.

Mukherjee et al. (1995) evaluated the feasibility of a combination process involving gamma irradiation, packing in closed PE bags, and biological control of fungi causing storage rot as a means of extending the shelf-life of fresh ginger rhizomes at ambient temperature (25 to 30°C). Storage in closed PE bags reduced weight loss but increased sprouting and rooting, which could be prevented by gamma irradiation at 60 Gy (unit of absorbed dose of radiation). Rotting caused by *Sclerotium* (*Corticium rolfsii*) was, however, a major cause of spoilage during extended storage. Four isolates of *Trichoderma* sp. isolated from sclerotia of *C. rolfsii* infecting ginger rhizomes, one of *Gliocladium virens*, and four isolates of fluorescent *Pseudomonas* were tested, of which one isolate of *Trichoderma* was found highly effective in suppressing the growth of *C. rolfsii.* The efficacy of the antagonist was demonstrated under simulated market conditions using artificially inoculated rhizomes. The recommended procedure consists of dipping washed, air-dried rhizomes in *Trichoderma* suspension (108 spores/mL), air-drying, and packing in 250-gauge LDPE bags followed by irradiation at 60 Gy. Rhizomes thus treated remained in good marketable condition for up to 2 months at ambient temperature without sprouting or significant loss of quality and <5 percent weight loss. An in vitro bioassay system was developed to demonstrate the efficacy of the antagonist to protect the cut surface of sliced rhizomes inoculated with the pathogen. The method could be used for rapid screening of antagonists.

Storage

Because ginger rhizomes are bulky and perishable, the storage of the seed rhizome for 3 to 4 months from harvesting to next planting season is faced with many problems, such as rotting, sprouting, rooting, and shriveling, which can result in huge losses. Therefore, adopting an efficient storage technique in ginger will go a long way in minimizing the storage loss of the valuable planting material.

Trials conducted in Kerala showed that storing ginger in 200-gauge thick polythene covers of size 35 × 25 cm with 125 punch holes (each hole with 4 mm diameter) was an effective method (Jayachandran et al., 1992). In Kerala, traditionally, ginger seed rhizome is stored with the leaves of *Glycosmis pentaphylla* in wooden pole racks or sleeves and kept under shade. The rhizomes are also stored in pits dug under shade, the floor of which is lined with sand or sawdust (KAU, 1993).

Rai and Hossain (1998), Orissa, India, reported that there are three traditional methods of seed rhizome storage: storage in soil pits, storage in a dry, shady place, and storage in the field involving delayed harvesting. The first method is the best for small-scale growers, but it is expensive and laborious for large-scale growers. Storage in a dry, shady place is economical for the larger growers, but there is a problem of rhizome drying. Storage in the field by delayed harvesting is not to be encouraged as it harbors rhizome rot–causing fungi and bacteria as well as insect pests such as scales and mealy bugs.

Research on agronomy, nutrition management, and various other aspects of production technology has not been carried out in other ginger-producing countries such as Sri Lanka, Nepal, Bhutan, and Bangladesh. The research information comes mainly from the studies carried out in India. Ginger is a minor crop in other countries, and most of the production aspects are applicable to other south Asian countries as well. The constraints faced by ginger growers in these countries are also the same. Solutions are not yet available for the most severe constraints such as the rhizome rot and bacterial wilt. In spite of the advancements in productivity, the gap between the average yield (15–20 t/ha) and potential yield (40–50 t/ha) is wide, and the potential yield of ginger in India and other producing countries such as China is still wider. A great deal of work has to go into the production physiology of ginger to narrow this gap, to increase the productivity, and to make ginger production more economical and remunerative.

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6 Ginger Production in Southeast Asia

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Southeast Asia (SEA) is an important ginger-producing and ginger-consuming region. China tops the list of ginger-producing SEA countries, with a production of 240,000 tons from an area of 80,000 ha. The main ginger-production centers in China are the provinces of Shandong, Guangdong, Zhejiang, Anhui, Jiangxi, and Hubai. China also has the richest genetic variability for ginger; many varieties and morphotypes have been identified. China also has perhaps the highest ginger productivity; the highest yield figure reported is 120 t/ha. Farmers grow many ginger types to suit the user agencies and processing industry. The ginger varieties and types grown in traditional growing areas show much variation in the yield, quality, and morphological characters. This chapter deals with ginger production in the SEA region with emphasis on China.

Types of Ginger

The SEA gingers can be classified based on growth and morphological characters into sparse seedling type and dense seedling type.

Sparse Seedling Type: Plants are tall, vigorous, generally 80 to 90 cm high; leaves are larger and thick; the color is deep green; and tillers are thick and strong. This group has fewer tillers (generally 8 to 12) than the dense seedling type, and they are plump and sparsely arranged. Rhizomes are bigger, have an appealing appearance, less but large and plumpy primary fingers (usually arranged in a single tier), and long internodes. This type has high yield and good commodity quality. The representative cultivars are Guanzhou (sparse-ringed big fleshy ginger) and Shandong Laiwu (big ginger).

Dense Seedling Type: This type has moderate height, generally 65 to 80 cm, less vigorous, smaller, lighter green leaves, more tillers (usually 10 to 15, sometimes over 20), more but smaller primary branches, more nodes, and shorter internodes. The primaries are arranged in two or more tiers. The representative varieties are, for example, Shandong Laiwu (sliced ginger), Guangzhou (dense-ringed fleshy ginger), and Zhejiang (red-claw ginger).

Ginger can also be classified based on end uses into edible medicinal type, edible processed type, and ornamental type.

Edible Medicinal Type: This type can be used both for eating and for medicinal purposes. Most varieties in China belong to this group. Most of them are used mainly for eating but also have been used medicinally, such as Shandong Lai Wu big ginger, and Fujian red-bud ginger. A few are used for both purposes, such as Hunan yellow-heart ginger (for medicine) and chicken-claw ginger (for eating).

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Edible Processed Type: This type is used as processing material and should have a lower fiber content and a higher water content in the rhizome. Such cultivars have a delicate texture, light color, dense fragrance, and light piquancy. This group includes Guangzhou (fleshy ginger), Zhejiang (red-claw ginger), Tongling (white ginger), Fujian bamboo ginger, Zunyi (big white ginger), and other varieties.

Ornamental Type: These types are appreciated for their beautiful striped leaves and flowers. They are mainly distributed in Taiwan and the east–south Asia areas. The typical varieties are Laishe ginger, flower ginger, stripe leafed tea ginger, strong ginger, Hengchun ginger, and Hekou ginger.

Important Cultivars

Ginger is propagated through rhizomes. Breeding work is difficult because of sterility. So only local cultivars are in vogue, and most major ginger-growing regions have cultivars specially suited to that region. These local cultivars are all selected, domesticated, and planted for a long time under local natural conditions; they generally have adaptability, higher yield, better quality, and unique use value. The local types are mainly named after place names, color of the rhizome or bud, or other morphological features. Some major fine ginger cultivars in China are given below.

Laiwu Slice Ginger

Laiwu slice ginger is a local cultivar in Laiwu, Shandong province. It is a vigorous type, reaching 70 to 80 cm in height. The leaves are emerald green, 18 to 22 cm long, and 2 to 2.5 cm wide. It has better spreading capacity, and belongs to the dense seedling type. It usually has 12 to 15 tillers per plant. The rhizome has yellow skin and flesh, and more primaries that are arranged closely. It also has delicate flesh, spicy and fragrant, good quality, durability for storage and transportation, and higher yield. The rhizome weighs 300 to 500 g on average; some may reach 750 g. The average yield is 30,000 to 37,500 kg/ha, and even can reach 45,000 to 60,000 kg under good management.

Laiwu Big Ginger

Laiwu big ginger is a local cultivar of Laiwu that belongs to the sparse seedling type. It usually has 10 to 12 tillers per plant; some may have more than 15 tillers. The plants are more vigorous than Laiwu slice ginger. In general, the plants are 75 to 90 cm tall; some plants reach up to 1.2 m, the leaves larger, 20 to 25 cm long, and 2.2 to 3 cm wide. Rhizomes have deeper colors than those of Laiwu slice ginger, and are thick and strong. The rhizome skin and flesh are all yellow. Its primaries are fewer and are arranged sparsely. It has an appealing appearance and good commercial qualities. It is fleshy and has a delicate texture like Laiwu slice ginger. The rhizome weight of each plant is 500 to 600 g. The average yield is 45,000 to 60,000 kg/ha, and can reach 60,000 to 67,500 kg/ha under good management. By adding film mulch, the yield could be enhanced to over 75,000 kg/ha.

Sparse-Ringed Big Fleshy Ginger

Sparse-ringed big fleshy ginger is a local cultivar of Guangdong province. The plant is 70 to 80 cm high, with deep green leaves, less branches, and a flat rhizome. The color

of the rhizome skin is light yellowish white, and the tender bud is pink. The rhizome branches are arranged in a single tier. The product has a light piquancy, less fiber, delicate flesh, good quality, but poor disease resistance. In local areas, it is planted in February to March and harvested in July to the next February. The rhizomes can live through the winter in the field. More often it is planted as intercrop. A single plant weighs 1 to 2 kg and the yield by intercropping is 22,500 to 30,000 kg/ha.

Dense-Ringed Delicate Fleshy Ginger

Dense-ringed delicate fleshy ginger is also a local cultivar of Guangdong province. The plants are 60 to 80 cm high, and leaves are dark green, 15 to 20 cm long, and 2 to 2.5 cm wide. It has a better capacity for branching, so each plant has more primaries and secondaries arranged in tiers. Both the skin and flesh of the rhizome are yellow and it has tender flesh, more fiber, strong piquancy, and better tolerance to drought and diseases. The yield is about 15,000 to 22,500 kg/ha when planted as an intercrop.

Red-Claw Ginger

Red-claw ginger is a cultivar in Zhejiang province. It is a vigorous plant with tillers 60 to 80 cm high and leaves that are deep green and 22 to 25 cm long and about 3 cm wide. The plant has 22 to 25 tillers. The primaries are more and plumpy. The skin and flesh are yellow, the bud is red in color, hence called "red claw." The rhizome has good piquancy, less fiber, fine and smooth texture, and good quality. The yield is usually about 30,000 to 37,500 kg/ha. This cultivar prefers a warm and moist environment, but cannot endure cold and drought, and it has poor disease tolerance.

Yellow-Claw Ginger

Yellow-claw ginger is also a cultivar of Zhejiang province. The plants are 60 to 65 cm high in general. Each plant has 13 to 17 tillers and leaves that are deep green and 22 to 24 cm long and 2.8 to 3 cm wide. Rhizomes are light yellow but without any red bud. So it is called "yellow-claw." The rhizome primaries are smaller and closely arranged. The rhizome has high piquancy. This cultivar has better disease tolerance but lower yield. In general, a single rhizome is 250 to 400 g in weight; the yield is 22,500 to 27,000 kg/ha.

Tongling White Ginger

Tongling white ginger is a local cultivar of Anhui province. The plant is 70 to 90 cm high. Its leaves are narrow and have deep green color. The rhizome is plumpy, and the color is from milk-white to light yellow; the tender bud is pink. Its appearance is very appealing. The rhizome has delicate texture, less fiber, heavy piquancy, and excellent quality. The yield is about 27,000 to 30,000 kg/ha.

Xingguo Ginger

Xingguo ginger is a cultivar of Xinggou county, Jiangxi province. The plant is vigorous, reaching 70 to 90 cm in height. It has many tillers, 1.1 to 1.2 cm thick, light-purple bases, and a special smell. The leaves are 22 to 25 cm long and 2.8 to 3 cm wide. The rhizome is plump and has double-layered fingers, light-yellow skin, white to yellow flesh, a light purple bud, a crisp texture, less fiber, moderate piquancy, and good quality

and storability. In local areas, it is usually planted in April and harvested in October to December. Generally, a single rhizome is 300 to 400 g in weight, and the yield is 22,500 to 30,000 kg/ha.

Fuzhou Ginger

Fuzhou ginger is a cultivar of Jiangxi province. It has more fiber and heavy piquancy. The plant is about 70 cm high, with dark green leaves, about 20 cm long and 2.5 cm wide, and tillers that are 0.7 to 1.2 cm thick. The rhizome has light-yellow skin, white-yellow flesh, and purplish shoots. The yield is about 30,000 to 37,500 kg/ha.

Laifeng Ginger

Laifeng ginger is a local cultivar of Laifeng country, Hubei province. It has shorter, green leaves; white to yellow rhizome; rhizome fingers are smooth; flesh has tender texture, less fiber, heavy piquancy, delicate fragrance, higher water content, and good quality. Besides being used as flavoring, it is also suitable for processing into sweetmeats. But its storability is poor. It is usually planted in April to May and harvested in late October to early November. The yield is 27,000 to 33,000 kg/ha.

Besides the above varieties, there are many others, such as Zaoyang ginger of Hubei province, Zunyi big white ginger of Guizhou, Chenggu yellow ginger of Shanxi, Yulin round fleshy ginger of Guangxi, Bamboo root ginger and Maniyang ginger of Sichuan, Red-claw ginger of Changsha, Red-bud ginger of Fujian, Xuancheng ginger of Anhui, Yellow-heart ginger of Hunan, Yuxi yellow ginger of Yunnan, and fleshy ginger of Taiwan.

In Japan the ginger types are classified into three groups: (1) small plants with many tillers and a small rhizome; (2) medium plants with an intermediate number of tillers and a medium-sized rhizome, and (3) larger plants with fewer tillers and larger rhizomes. The common cultivars included in these groups are Kintoki, Sanshu, and Oshoga respectively. A stabilized tetraploid line of Sanshu (4x Sanshu) is also being cultivated in Japan (Adaniya, 2001). In addition, *Z. mioga* (Japanese ginger) is also grown in Japan for spice purposes.

Morphological and Growing Characteristics

The ginger plant is erect and has fibrous roots, aerial shoots, leaves, flowers, and rhizomes. Its morphological characteristics are shown in Figure 6.1.

Root: Ginger root includes fibrous root and fleshy root. After planting, many roots having indefinite growth grow from the base of the sprouts. They are called fibrous roots. The number of the fibrous roots keep on increasing with the seedling growth, and each carries many tiny lateral roots. The fibrous roots are thin, have root hairs, and so they are also called absorption roots. Toward the rapid growing stage, several fleshy roots of indefinite growth come out from the lower node of the mother ginger and primary fingers. These fleshy roots are 0.5 cm thick and 10 to 25 cm long. They are milk-white, with few root hairs and no lateral roots. They have the functions of absorption and support, and they also can be eaten. Ginger roots are shallow, distributed within 30 cm deep in the soil, and only a few reach the lower soil layers. They are underdeveloped with low absorption ability. Therefore, ginger requires good conditions of soil, fertilizer, water, and so on.

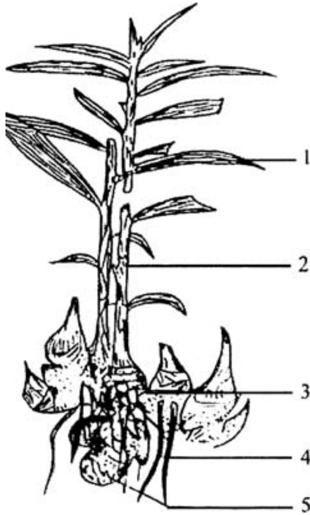

Figure 6.1 The morphological characteristics of ginger plant. 1. Leaves. 2. Overground stem. 3. Rhizome. 4. Root. 5. Seed rhizome.

Stem: The stem of ginger has two parts: the overground leafy shoot, or pseudostem, and the underground perennial stem (rhizome). The leafy shoot is erect, green, and formed by enveloping, overlapping leaf sheaths. It is 60 to 100 cm high. Under normal conditions, the aerial shoots increase in height by 1 to 1.2 cm a day; later by the middle of September, the plant height tends to become stable.

In the seedling stage, only vegetative growth takes place, usually one tiller grows out in every 20 days. When entering the root-growing stage, lateral branches of the rhizome grow out quickly; one branch usually grows out every 5 to 6 days. After the middle of October, with the decrease in temperature, the growth slows down. The number of lateral branches (fingers) of the rhizome depends on the cultivars and planting condition. Generally, dense seedling cultivars have 15 to 20 primary fingers under moderate fertility and normal water-supplying conditions, whereas sparse seedling ones have 10 to 15. Cultivars when planted in fertile soil, with adequate supply of water and fertilizers, will have more fingers. There are nodes on the rhizome; the number and the density of the nodes vary in the mother rhizome, and the primary and secondary fingers. Usually, the "mother ginger" is smaller, with short internodes, whereas the primaries are bigger with long internodes.

After planting, the apical bud comes out and becomes the main tiller or primary shoot. Along with the growth of the tiller, its base part inflates gradually into a rhizome. It is the first formed rhizome ball, and is called the mother ginger or the mother rhizome. The buds on both sides of the mother ginger develop and produce two to four tillers and they become the first branches. The bases of these tillers inflate into rhizomes, which become the primary fingers. The buds on these primaries shoot out again and form the second-order tillers, the bases of which develop into secondary fingers. The buds of these branches can shoot out and form the third- and fourth-order tillers and their bases also inflate into the third and fourth-order fingers. The later produced buds usually do not develop into branches due to the increasing cold. Thus, all the rhizome balls formed by

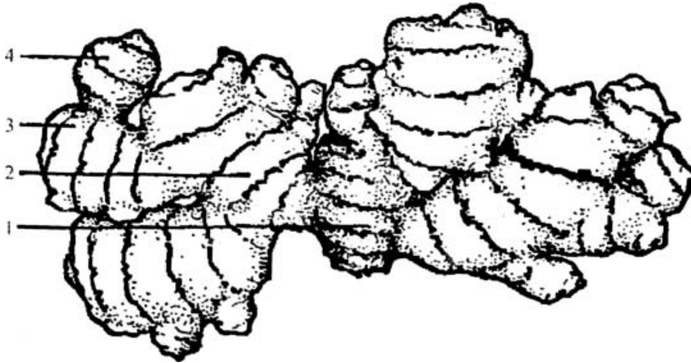

Figure 6.2 The rhizome of ginger. 1. Mother rhizome. 2. Primary finger (first-order branch). 3. Secondary finger (second-order branch). 4. Tertiary finger (third-order branch).

one rhizome are in regular order, which finally give rise to a complete rhizome (Figure 6.2). The newly harvested ginger rhizome is yellow; it is called popularly "tender ginger" or "fresh ginger." After storage, the residual stems and roots fall off. The skin of the rhizome turns to a khaki color and is called "yellow ginger." When the yellow ginger is planted as seed and dug out later in the harvest season, it is called "old ginger."

Leaf: Ginger has green, narrow leaves that are 18 to 24 cm long and 2 to 3 cm wide with short petioles. The leaf sheaths that form the pseudostem are long and narrow. They have the functions of supporting leaves and protecting overground stems. On the junction of leaves and sheathes are a pair of projecting appendages that are the ligules. The newly born leaves are small and rolled into a cylinder, which spread out while growing. The leaves are arranged in a biseriate manner (distichously).

In the seedling stage, the leaf grows slowly; usually 2 to 4 days are needed for a new leaf to come out. With the beginning of autumn the growth quickens, and the leaf area enlarges rapidly. In the rapid-growing stage leaves are produced in quick succession and two leaves are produced every day per plant. After October, with the temperature decreasing, the plant growth slows down, and so also does the leaf growing speed. The leaf area in the seedling stage makes up only 15 to 20 percent of the total leaf area, whereas the leaf area produced from August to October is about 75 percent of the total leaf area (Table 6.1)

Growing Period

Ginger is a vegetatively propagated plant, and in most years, the whole growing period is utilized for vegetative growth only; except in certain years, when some plants produce flowers. So there are no definite growing and flowering phases. Under proper growth conditions, ginger can germinate at any time because it has no natural dormancy. The duration of its growing period is influenced by moisture availability, temperature, and other environmental conditions. The entire growing period can be divided into germinating stage, seedling stage, flourishing growing stage, and dormant stage according to its growing tendency and season (Figure 6.3).

Table 6.1 Growth character of ginger leaves*

Date	*Leaves of primary shoot*	*Leaf no. of primary tiller*	*Leaf no. of secondary tiller*	*Leaf no. of tertiary tiller*	*Total no. of leaves/plant*	*Leaf area of one plant (cm²)*	*Increment of leaf area in different stages*	
June 18	0				0			
July 7	5.3				5.3	82.6	82.6	2.71
Aug. 8	14.8	8.6			23.4	522.7	440.1	14.47
Sept. 3	24.2	36	8		68.2	1888.9	1361.2	44.7
Oct. 3	25.4	55.4	47.42		129.0	2825.7	941.8	30.97
Oct. 24	26.0	58.4	67.6	3.2	155.2	3041	215.3	7.08

*Source: Zhao and Xu (1992)

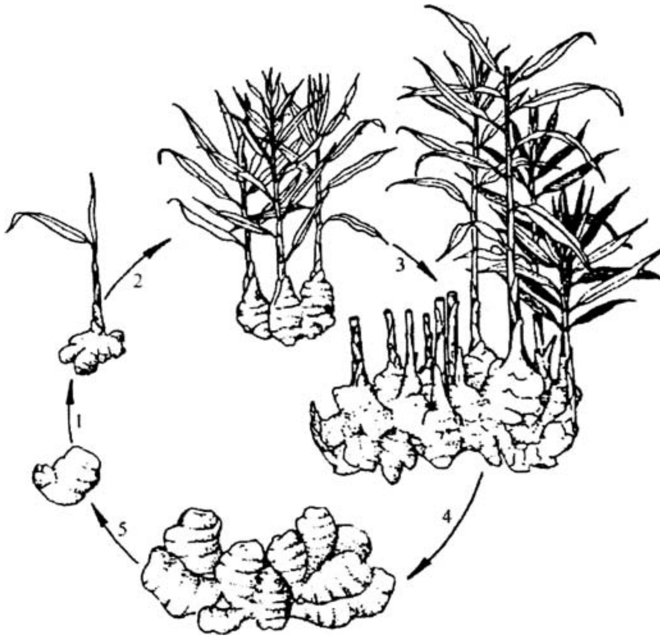

Figure 6.3 Sketch map of ginger-growing stages. 1. Germinating stage. 2. Seedling stage. 3, 4. Flourishing growing stage. 5. Rhizome dormant stage.

Germinating Stage

The germinating stage starts when the dormant bud begins to sprout to the opening of the first leaf (Figure 6.4). This takes about 50 days. The nutrition for germination and rooting comes from the stored nutrition in the rhizome bud. So the size and nutrition of seed set has great influence on the growth of seedlings in subsequent stages.

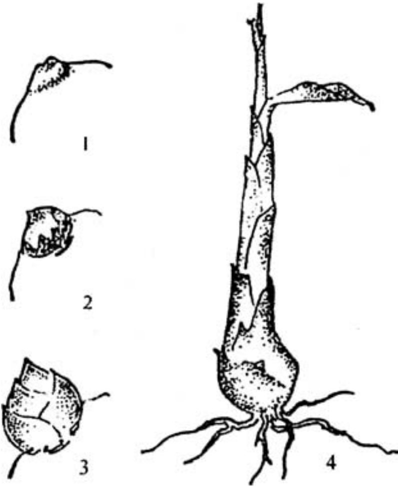

Figure 6.4 Germination process of ginger. 1. Sprouting stage. 2. Peel off stage. 3. Squama stage. 4. Seedling-forming stage.

The growing bud is very small in the germinating stage; only about 0.24 percent of the gross volume of the planting unit. But this period is the foundation of the henceforth growth. So it is necessary to select seed properly and create favorable conditions in order to produce good and strong seedlings (Zhao and Xu, 1992).

Seedling Stage: The seedling stage is from the first leaf opening to the stage at which the plant develops two tillers; a stage that is usually called "the three-ply forks" period, and it takes 60 to 70 days from planting. In this period, the nutrition is supplied by the seed rhizome at first, and is later absorbed and produced by the seedling itself. The growth consists of the primary shoot and root system. After seedlings come out of the soil, fibrous roots increase gradually and some small lateral roots are also produced, thus forming the main absorption root system. Under normal weather conditions, the primary shoots grow at the rate of 1 to 1.5 cm a day. At the end of the seedling stage, the dry matter of this shoot makes up about 66.8 percent of the whole plant. When the seedling period is over, most plants have two lateral tillers (primary tillers), therefore, it is called "three-ply forks" stage. The leaves grow slowly during the first 20 days of the seedling stage; one new leaf is produced every 3 to 4 days. A month later, the new leaves are produced quickly with the lateral tillers appearing and elongating, with about one to two leaves being produced every day. The leaves of primary shoot make up about 63.2 percent of the total at this stage, and the total leaves at the end of seedling stage make up 15.1 percent of the total leaves of the whole growing period.

The plant grows slowly in the seedling stage; the growing mass makes up 7.83 percent of the total. In this stage, in order to promote better growth, it is important to control weeds and give adequate care in order to make a sound foundation for the production of lateral tillers, rhizome formation, and enlargement.

Flourishing Growing Stage: The flourishing growing stage takes about 70 to 80 days from the "three-ply forks" to harvest. The plants in this period show quick growth. On the one hand, many tillers arise and leaf number and area increase sharply; on the other hand, the rhizome expands quickly. This period can be divided into two stages. From

"three-ply forks" to mid-September is the early flourishing stage, in which the plant still focuses on growth of the aerial shoot. Many tillers arise, the leaf area increases rapidly, roots grow continuously, and some fleshy roots are also produced. The rhizome has already formed, the rhizome branches producing fingers, but their growth is slow. After mid-September, the growth emphasis is shifted to the rhizome. At this time, the root quantity becomes stabilized, tillering speed decreases, and the leaf area reaches steady state. Photosynthates produced by leaves are mainly transported and deposited in rhizome. This stage is the rhizome-expanding stage. As to the growing conditions, the fertilizer and water availability should be maintained to promote plant development to form a strong assimilation system and ensure strong photosynthetic ability in the early flourishing stage. In the rhizome-inflating stage, maintaining the availability of nutrients and water are essential to prevent the premature senility of the stem and leaves that ensures a longer time for assimilation and development. Hence irrigation, fertilization, earthing up, and other measures to enhance the yield to the maximum should be practiced.

Rhizome Dormant Stage: Ginger cannot endure frost and is usually harvested before the first frost, which compels the rhizome into dormancy. When temperature rises again the next spring, it enters the next growing period.

Impact of Environmental Conditions

Temperature: Ginger originated in tropical Asia, and it prefers a warm, humid climate and cannot endure very low temperature. But by long-term cultivation, selection, and domestication, it has become adaptable to lower temperatures. Ginger can germinate below 20°C, but only slowly. The appropriate germinating temperature is 22 to 25°C. If the temperature goes above 30°C, germination is quick but the sprouts will be weak. In the seedling stage and the early growing stages, the suitable temperature is 22 to 28°C and that during the rhizome-enlarging stage is 25°C (Xizhen et al., 1998d). When the temperature drops below 15°C, ginger will stop growing and should be harvested.

Light: Ginger grows well under moderate light intensity. Studies have shown that the light compensation point of a single leaf is 20 to 30 μmol $m^{-2} \cdot s^{-1}$ and its light saturation point is 660 to 820 μmol $m^{-2} \cdot s^{-1}$. But the photosynthesis of the clump (whole plant) requires much higher light than that of a single leaf (Dewan et al. 1991, 1995, Xizhen et al., 1998c, 2000). It has been shown that the clump light saturation point has not been reached when the photon flux density reaches 1,180 μmol $m^{-2} \cdot s^{-1}$. So higher light is required for the ginger clump in the field (Dewan et al., 1995, Kun et al., 2002, Xianchang et al., 1996).

The light intensity requirement of ginger varies in different growing stages. It requires darkness in the germinating stage, moderate light in seedling stage, and higher light in the actively growing stage. Ginger is not influenced by day length. It can form rhizomes regardless of long, short, or natural light conditions, although a natural condition is the best (Zhenxian et al., 2000).

Water: The ginger root system is poorly developed and grows shallow, so its water-absorption ability is weak and the plant cannot endure drought. Under drought conditions, the plant becomes dwarfed, photosynthesis becomes weak and yield decreases. Moreover, more fiber may be formed in the rhizome and the quality becomes poor. Experiments have shown that the effect of soil humidity has a very significant effect on

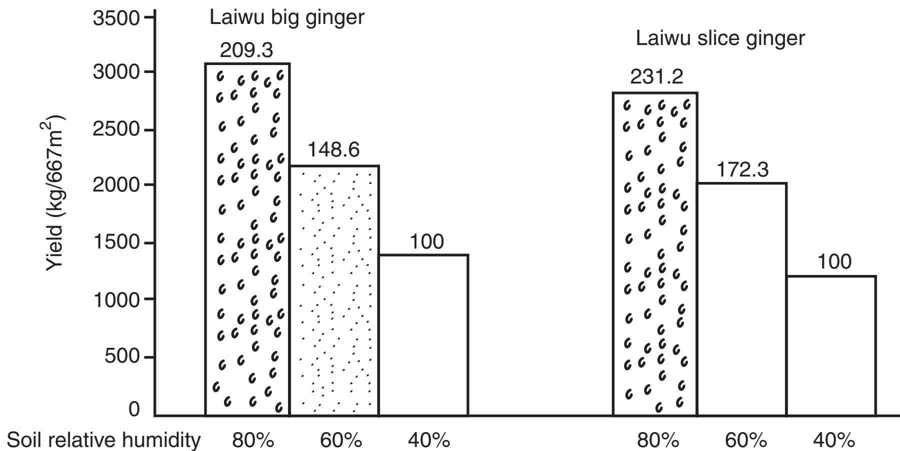

Figure 6.5 Effect of soil water content on ginger yield (Kun, 1999b).

the growth and yield of ginger. When the soil relative water content is in the range of 40 to 80 percent, the growth parameters such as plant height, tiller number, and leaf area increase with the increasing of soil humidity. If soil water is low and cannot meet the demands of the plant, the yield decreases drastically (Figure 6.5). But ginger cannot endure waterlogging either. Waterlogging affects the growth and development of ginger, and leads to ginger rot, which will lead to a severe yield reduction. So a supply of an optimum quantity of water in the growing season is important to guarantee better plant growth and higher yield

A ginger plant differs in its water requirements in different growth stages. In the seedling stage plants grow slowly and have little growth of biomass, so they need little water. But if the climate is hot and dry in this stage, the soil water evaporates quickly, the water metabolism of the plant is vigorous, and its transpiration rate will be high. So plants in the seedling stage are weak and unable to fight a drought. Thus, enough water should be ensured during this stage in order to avoid growth retardation. If water requirements are not met, the leaves often show the "roll up pigtail" symptom, plants grow slowly, photosynthesis is weak, and the yield will decrease drastically. During the active growing stage, the biomass is increased greatly; so the plants require more water. The soil should be moist and the relative water content should be kept to 70 to 80 percent.

Soil: Ginger is not very strict about soil texture and can grow well on arenaceous, loam, or clay soils; however, soil texture has a great influence on yield and quality. Loam soil is loose and with good aeration. It can hold water and nutrients. So it is beneficial for the growth of seedlings and the development of the root system. Therefore, the yield of the rhizome is higher and its quality is better when ginger is grown in loamy soil.

Ginger is sensitive to the pH of soil, especially in the active growing stage. The soil pH has a significant influence on the growth of aerial shoots as well as on the rhizomes (Table 6.2). Ginger is fond of slightly acid soil and can grow well in soils with a pH of 5 to 7. If the pH is more than 8, growth is retarded.

Mineral Nutrition: Because of the weak absorption ability of its roots, a ginger plant requires good soil nutritional levels. According to Kun (1994), the fertilizer requirement

Table 6.2 Effect of pH on growth and yield of ginger

Treatment	*Plant ht (cm)*	*Tillers/plant*	*Leaves/plant*	*Rhizome weight (g/plant)*
4	67.0	10.2	124.8	234
5	75.8	12.0	154.2	353
6	77.4	13.0	169.4	362
7	83.2	14.8	67.4	334
8	62.0	5.6	67.4	117
9	53.8	5.4	55.4	104

for producing 1,000 kg fresh ginger is N (nitrogen) – 6.34 kg, P_2O_5 (phosphorous) 0.75 kg, K_2O (potassium) 9.27 kg, Ca (calcium) – 1.30 kg, and Mg (magnesium) 1.36 kg.

The mineral absorption varies in different stages of growth. Generally, ginger plants absorb little fertilizer in the seedling stage as it grows slowly and the biomass production is small. During the active growing stage, the absorption rate and quantity increase greatly with the increasing growth rate and biomass (Xianming, 1961). It has been measured that the absorption quantity of N, P, and K in seedlings is 12.25 percent of the total absorption in the whole growing period and 87.75 percent during the active growing stage (see Figure 6.6). During the whole growing period, value of absorption of elements follow the order K > N > Mg > Ca > P (Xu et al., 1993).

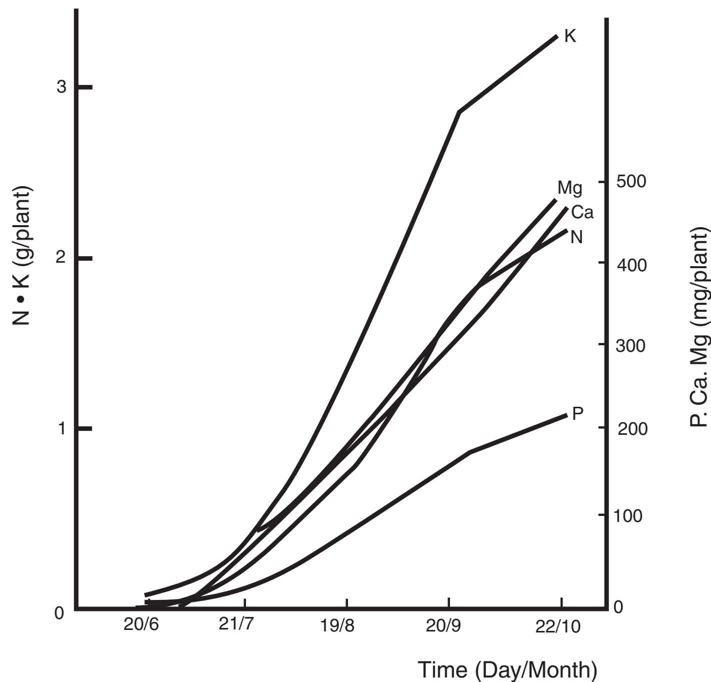

Figure 6.6 The absorption of some minerals by ginger.

Ginger is sensitive to N, P, and K nutrition. N is the important component of protein and the major element of chlorophyll. So it is closely related to photosynthesis and many other primary and secondary metabolic processes (Kun and Feng, 1999). K is vital to the functioning of many enzymes. It influences many metabolic functions and has a great effect on growth, transportation of photosynthates, and respiratory metabolism, besides being an ingredient of many organic compounds of plants. P also participates in many metabolic functions including nucleic acid metabolism and is closely related to growth, yield, and the quality of crops (Xizhen et al., 1998b). So the quantity of N, P, and K fertilizer has a great effect on the growth and yield of ginger (Table 6.3) (Xizhen et al., 1997a, b).

Ginger needs a balanced fertilizer application. If some nutrient element is absent, the growth and development of plants will be affected and the composition of the rhizome will be affected too, leading to a reduction in carbohydrates, protein, and volatile oil. If excessive fertilizers are used, the roots will find it difficult to absorb the minerals because of a too high ionic concentration and a too low water potential of soil. As a result, the growth of aerial shoots will be suffocated, photosynthesis will be weakened, and the yield will be reduced (see Tables 6.4–6.6).

In addition to N, P, K, Ca, and Mg, some microelements are also necessary for the growth of ginger. Kun had shown that 3.67 g B (boron) and 9.88 g Zn (zinc) are absorbed per 100 kg rhizomes. Xiaoyun (1993, 1994) concluded that the yield will be increased

Table 6.3 Effect of N, P, and K on growth and yield of ginger

Treatment	*Plant ht (cm)*	*Stem thickness (mm)*	*Tillers/plant*	*Leaf area (dm^2/plant)*	*Yield (kg/hm^2)*
Complete fertilization	84.8	13.2	18.0	50.47	48,700.5
Lack of N	76.1	11.5	12.7	30.78	29,982.0
Lack of P	75.3	11.7	14.3	31.10	32,142.0
Lack of K	76.9	11.0	13.7	29.13	28,350.0

Source: Xizhen et al. (1997a).

Table 6.4 Effect of N, P, K on quality of ginger rhizome

Treatment	*Dissolvable sugar (%)*	*Starch (%)*	*Fiber (%)*	*Protein (%)*	*Amino acid (%)*	*Vc (mg/kg FW)*	*Volatile oil (ml/kg FW)*
Complete fertilization	4.51	4.14	1.22	1.68	0.94	57.1	2.3
Lack of N	3.81	2.99	1.04	0.94	0.89	54.0	1.7
Lack of P	4.17	2.46	1.23	1.31	0.81	53.9	2.1
Lack of K	3.93	3.34	0.93	1.36	0.84	64.9	2.1

FW: Fresh weight
Source: Xizhen (1998a).

Table 6.5 Effect of excessive fertilization on quality of ginger rhizome

Treatment	*Plant ht (cm)*	*Stem thickness*	*Leaf area (cm^2/plant)*	*Branches/ plant*	*Yield (kg/hm^2)*
N excessive	80.0	11.8	33.18	14.7	36556.5
P excessive	75.3	11.9	30.45	11.8	36313.5
K excessive	82.5	12.2	37.14	14.3	40618.5
Control	84.8	13.2	50.47	18.0	48700.5

Source: Xizhen (1997a).

Table 6.6 Effect of excessive fertilization on quality of ginger

Treatment	*Dissolvable sugar (%)*	*Starch (%)*	*Fiber (%)*	*Protein (%)*	*Amino acid (%)*	*Vc (mg/kg FW)*	*Volatile oil (ml/kg FW)*
N excessive	3.40	3.36	1.46	2.01	1.06	24.0	2.0
P excessive	6.11	2.64	1.01	1.65	0.89	56.2	2.1
K excessive	3.08	5.56	1.34	1.34	0.97	25.0	1.9
Control	4.51	4.14	1.22	1.68	0.94	57.1	2.3

Source: Xizhen (1998a)
FW: Fresh weight

by 23.9 percent and 12.1 percent if 30 kg/ha $ZnSO_4$ or 15 kg borax are used, respectively; and that yield is increased by 38.9 percent if both of them are used together. The tendency and profile of absorption of Zn and B by ginger is similar to that of N, P, and K (Xiaoyun et al., 1993, 1994).

Agrotechnology of Ginger

Planting Season

Ginger needs a warm climate and cannot withstand cold, and hence its planting should be adjusted to avoid the winter cold. The following conditions should be considered before the planting time is confirmed:

1. Soil temperature should be above 15ºC;
2. Ginger growth period takes more than 135 to 150 days from sprouting to the first frost; the effective accumulated temperature in the growing period should amount to 1,200 to 1,300ºC;
3. Adjust the rhizome-forming stage to coincide with the months that have suitable temperatures that favor rhizome expansion.

In warmer areas ginger can be planted from January to April. In the Valley of the Yangtze River, it should be planted from the last 10 days of April to the first 10 days

of May. In the Hubei area, it is usually planted in the first 10 days of May. In the northeastern and northwestern areas and other high and frigid zones, ginger cannot be planted in the field condition because of the prevailing cold weather.

Planting time is crucial in ensuring high yield. Too early planting while the soil temperature is still low will affect germination. If planted too late, the growing period will be shorter and the rhizome yield will be affected. Studies have shown that delay in planting results in a lower yield of ginger (Table 6.7).

Cultivating Strong Buds

Cultivating strong buds is the chief technique of successful ginger production (Zhao et al., 1992). Because young buds are the foundation of the seedlings, only strong buds can grow into strong seedlings, and strong seedlings provide a good foundation for vigorous plants and for rhizome formation. Therefore, seeds should be treated as necessary to cultivate strong buds before planting.

Strong buds are usually shorter and thicker, their tops are obtuse and rounded, whereas weak buds are smaller, with pointed tips or somewhat curved (Figure 6.7). The following factors determine whether buds are strong or not.

Nutritional Condition of Seed: In general, if the rhizome is fat, has a bright color, and is provided abundant nutrition, the buds would be fat and strong. If the rhizome balls (fingers) are thin and small, the nutritional condition is poor, and the buds will usually be weak. So we should choose fat rhizomes as seed in order to cultivate strong buds.

Table 6.7 Effect of planting time on ginger growth and yield

Planting time (Day/Month)	*Caulis (shoot) ht (cm)*	*Branches/ plant*	*Leaves/plant*	*Leaf area (cm^2/hm^2)*	*Yield (kg/hm^2)*
8/5	65.3	11.4	147	68,475	44,670
12/5	62.0	9.3	133	62,175	38,895
18/5	55.5	10.0	132	61,620	36,885
24/5	60.6	8.3	103	48,060	27,675
3/6	57.0	7.7	103	48,060	27,870
8/6	58.0	7.7	95	44,670	20,010

Source: Xianming (1961).

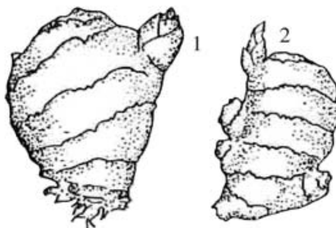

Figure 6.7 Configuration of ginger bud. 1. A healthy bud. 2. A weak bud.

Bud Position: The bud that grows in the upper part and toward the outer side is fat and strong, whereas those growing in the basal part and toward the inner side are usually small and weak.

Temperature and Humidity in the Course of Germination: Temperature and humidity are the important factors that affect bud quality. In the course of germination, a temperature at about 22 to 25°C can make buds fat and strong. If the temperature is higher than 28°C, in the longterm, buds are often thin and weak. At the same time, high humidity should be maintained. If the humidity is too low, the ginger epidermis may lose water and wrinkle, and the sprouting speed and bud quality may be affected seriously.

Method of Strong Bud Cultivation and Seed Selection

Sunning and Tiring of Seeds: Take seed-ginger from the storing cellar 20 to 30 days before planting, wash off mud, and spread on straw or clean ground and sun them for two to three days. This is called "sunned ginger." The seeds should be taken back into the house in the evening if the temperature becomes low. The action of sunning increases ginger temperature within, breaks up rhizome dormancy, speeds up sprouting, decreases the water content of seeds, prevents them from rotting, and is also convenient for seed selection. Then, pile up the seeds for two to three days inside the house and cover them with straw. This is called "tire ginger." Tiring promotes the breakdown of nutrition present in the seed rhizome and makes it available to the sprout well in time (Zhao and Xu, 1992).

In the course of sunning and tiring, seeds should be selected; strictly choose seed rhizomes that are big, fat, and fleshy; have a bright color and fresh flesh; are rigid, not shriveled, and not rotten or frozen; and have not been harmed by insects and disease. Eliminate the bad rhizomes that are thin and weak, shriveled, brown in flesh, or soft in quality.

Bud Enhancement or Bud Priming: This step induces young buds to sprout quickly, grow quickly and orderly, and prolong the growing time in order to increase yield. The ways of bud priming vary in different areas. But controlling temperature and humidity during germination is the key to strong bud cultivation. An experiment indicated that at 22 to 25°C, buds emerge in 25 to 30 days, and the young sprouts are strong. If the temperature is higher than 28°C, although germination is quicker, the sprouts are often thin and weak. If the temperature is lower than 20°C, propagules germinate slowly and affect the crop duration (Table 6.8).

During ginger s priming, humidity should be kept to 60 to 80 percent. If the seeds are covered too thinly with soil or mulch or the temperature is too high, they lose

Table 6.8 Effect of temperature on germinating time and bud size

Treatment (°C)	*Germinating time (days)*	*Bud length (cm)*	*Bud thickness (cm)*	*Bud type*
29–30	10–15	1.2–2.0	0.8–1.0	Thin and weak
24–25	20–25	1.5–2.0	1.0–1.8	Fat and strong
20–21	30–35	1.6–1.9	1.1–1.4	Fat and strong
16–17	50–60	0.9–1.0	0.8–1.0	Thin and weak

Table 6.9 Effect of bud size on growth (per plant basis) and yield of ginger (per ha)

	July 20			*Aug 20*			*Oct 20*			
Treatment	*Plant ht (cm)*	*Branches*	*Leaves*	*Plant ht*	*Branches*	*Leaves*	*Plant ht*	*Branches*	*Leaves*	*Yield (kg/ hm²)*
Big bud	67.1	2.4	23.8	69.2	5.8	55.2	80.8	13.0	145.8	38349.0
Medium bud	69.6	2.3	23.4	77.9	5.8	68.7	94.8	15.9	190.9	46791.0
Small bud	56.4	1.4	22.3	74.4	5.6	70.4	93.4	15.5	192.7	48253.5

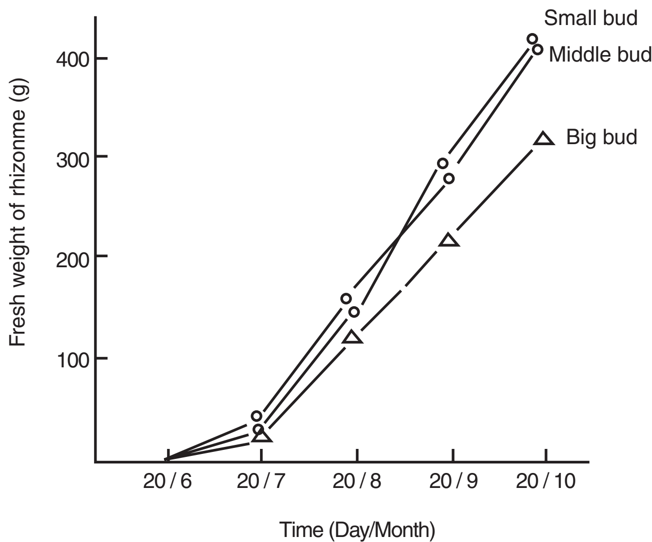

Figure 6.8 Effect of bud size on the fresh weight of ginger rhizomes.

water, which restricts sprouting of young buds and often causes the buds to shrivel. So thicker cover materials should be used to ensure good sprouting.

Standard of Bud Size: Ginger buds are of three types: (1) big buds, which are longer than 2 cm and 0.8 to 1.0 cm thick; (2) medium buds, which are 1 to 2 cm long and about 1 cm thick; and (3) small buds, which are shorter than 1 cm and are 0.5 to 0.7 cm thick. The effect of the bud size on growth and yield has been studied (Table 6.9). The result showed that big buds sprout earlier and grow quicker in the seedling stage. But the leaf area is smaller in the active growing stage, and grows slower in later stages, leaves show premature senility, and the yield is not high. While medium and small buds sprout later and grow slower than big buds in the seedling stage, but their growing speed quickens in the active growing stage, and their vigor exceeds that of big buds (Figure 6.8). Hence, it is generally felt that the bud size should be 0.5 to 2.0 cm long and 0.5 to 1.0 cm thick. Buds should be white and fresh and bright, and the bud's body should be fat and the top obtuse and rounded (Zhao and Xu, 1992).

Preparing the Field and Applying Base Fertilizers

The ginger root system is underdeveloped and its nutrient-absorbing ability is poor. So it cannot endure drought or waterlogging. The ginger field should be fertile, should have deep soil that is rich in organic substances, capable of retaining moisture and fertilizer, can be irrigated and drainedeasily, and isomewhat acidic. It is better to rotate crops for three to four years. It is not advisable to plant ginger continuously in the same plot; and the land becomes unfit for ginger planting at least for three to four years if the crop has been infected with blast.

Once the ginger field is selected, tillage should start in the autumn or winter after the previous crops have been harvested. Ploughing 25 to 30 cm deep promotes roots to extend to such a depth, and enlarges the absorption area. After the ground thaws out next year, harrow carefully once or twice, apply 75 to 120 t/ha high-grade manure and 750 to 1125 kg/ha calcium superphosphate, and then harrow the field flat carefully.

In the north of China, making ridge and planting in ditch is often being adopted. The ditch is in an east to west or south to north direction, and is about 25 to 30 cm deep. Farmers in the north often apply bean cake or cooked beans as fertilizer. In general, 1,125 to 1,500 kg/ha crushed cake or 750 to 1,125 kg/ha cooked and fermented bean is spread in the ditch (Figure 6.9). In addition, 225 kg $(NH_4)_2$ SO_4, 375 kg calcium superphosphate, and 150 kg K_2SO_4/ha are also used together as a basal application. Fertilizers are mixed with soil (Xizhen et al., 1997a).

There are more rains in the south of China, so high farmlands are usually used in ginger cultivation. The farmers always cover the seed rhizome with a layer of soil and 75 t/ha manure mixed together and then finally with 2 to 4 cm soil.

Planting

Preparation Before Planting: Ginger rhizomes are big, and there are several buds on each piece of rhizome. In order to select good seed and strong buds, we need to select buds and to break seed-rhizomes carefully into small pieces by hand. Usually, the bigger the seed, the earlier the seeds sprout, the more vigorous the seedlings grow, and the higher the yield. If seeds are too small, they will sprout later, the yield per plant will be decreased, the commercial quality will be poor, and the economic benefit will be

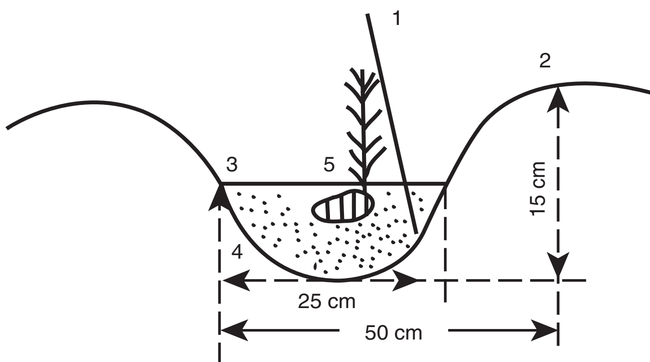

Figure 6.9 Sketch of a ditch and base for fertilizer application in the north of China. 1. Ginger straw. 2. Ridge. 3. Ginger ditch. 4. Base for fertilizer and soil. 5. Ginger plants.

Table 6.10 Effect of seed size on growth and yield of ginger

Seed size (g)	*Unearth time of sprouts (d)*	*Plant ht (cm)*	*Leaves/plant*	*Branches/plant*	*Yield (kg/hm²)*
120	14	85.2	112.4	7.6	46,821.0
100	17	90.0	177.6	13.0	48,010.5
75	20	85.2	155.6	11.9	53,359.5
50	22	88.2	137.6	9.8	42,904.5
30	26	74.4	120.6	9.0	36,712.5

lower. But it is not that bigger is better: if seeds are too big, more rhizomes are used, and the investment will be higher. So it is better to break rhizomes into about 75 g pieces (Table 6.10). One or two strong and short buds should be left on each piece and the rest removed, so as to pool the whole nutrition on the buds that are left.

Irrigation Before Planting: Ginger rhizomes sprout slowly, germinating time is long, and so sufficient water is required before planting. It is usually accomplished through irrigation after the basal fertilizers are applied, and about one hour before planting.

Planting Method: Immediately after irrigation, rhizome pieces are set in ditches at a certain spacing (Figure 6.10), paying attention that the buds are left upward. After that, the seeds need to be covered with soil immediately or else the buds may become damaged in open sun.

Seed Quantity: Ginger seed quantity is mainly decided by seed size and planting density. Generally, dense-seedling cultivars are planted 105,000 to 112,500 plants/ha; sparse seedlings cultivars are planted 82,500 to 90,000 plants/ha. Every piece of seed rhizome is 50 to 75 g in weight, thus the seed quantity is about 5,250 to 7,500 kg/ha.

Plant Density: Plant density has a decisive effect on the growth, clump, and canopy photosynthetic rates and yield of ginger (Table 6.11). With an increase of plant density, the indices such as plant height, branches, canopy photosynthetic rate, and yield are all increased to a different degree. But with a certain plant density, the indices mentioned above become stable, if the plant density is further increased, the photosynthetic rate and yield decrease.

The plant density of ginger is influenced by soil type, fertilizer and soil moisture condition, planting time, seed quantity, field management, and other factors. So the optimum plant density is not stable but changes. The quantity should be adjusted to local conditions and be determined according to types of cultivars and other conditions.

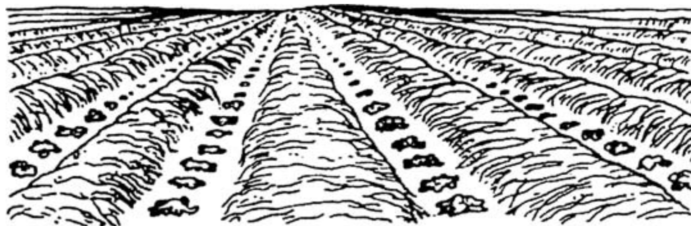

Figure 6.10 Sketch map of ginger planting method.

Table 6.11 Effect of plant density on growth, photosynthesis, and yield of ginger

(Plants/ha)	Plant ht (cm)	Branches/ plant	Leaf area index (m^2/m^2)	Photosynthetic rate μmol.m^{-2} (ground).s^{-1}	Yield (kg/hm^2)
75,000	62	103	3.21	8.16	26,001.3
90,000	64	122	4.25	10.07	29,223.8
105,000	67	138	5.31	12.23	33,168.3
120,000	73	152	6.15	14.56	39,557.6
135,000	74	159	6.63	14.78	39,224.3
150,000	74	163	7.02	14.66	39,392.0

Source: Xianchang et al. (1996).

According to the results of our study, it is better to plant 82,500 to 90,000 plants/ha in a middle fertile level field for cultivars such as the Lai Wu big ginger at a row space of 60 to 65 cm and an individual plant space of 19 to 20 cm. For Lai Wu slice ginger, it is better to plant 105,000 to 112,500 plants/ha at a row spacing of 50 to 55 cm and an individual plant spacing of 18 to 20 cm.

Shading

Ginger belongs to the medium-light plants and cannot endure high temperatures. But its seedling stage occurs in the hot summer, when sunlight is strong and air and soil temperatures are high. If shading or other measures to lower temperature and hold humidity are not implemented, ginger seedlings will be weak and short, resulting in yield decline. So in the seedling stage, ginger should be shaded or other measures adopted to lower the temperature and to keep humidity high (Table 6.12)

Studies have shown that there is obvious photoinhibition under high light stress at midday under field conditions. The extent of photoinhibition is serious during the seedling stage because of higher light intensity and temperature. After shading, the degree of photoinhibition declines markedly. So shading can make ginger leaves sustain a higher photosynthetic efficiency, and increase the dry matter accumulation, thereby increasing the unit area yield (Zhenxian et al., 1999, 2000).

Shading decreases not only light intensity, but also lowers the temperature and enhances the air relative humidity and soil water content. Shading increases more regular rhizome sprouting and uniform population size. Shade is beneficial in enlarging the root system

Table 6.12 Effect of shading on microclimate of ginger fields

Shading extent (%)	Soil temperature (°C)	Water content of soil (%)	Air relative humidity
0	32.9	15.44	49.5
20	29.7	15.63	51.9
60	29.4	15.73	52.9
80	26.6	16.25	55.3

Measured at 12:00 on June 15, 1996.

Table 6.13 Effect of shading on growth and yield of ginger

Shading degree (%)	*Plant ht (cm)*	*Shoot thickness (cm)*	*Branches/plant*	*Leaf area (cm^2/plant)*	*Yield (kg/ha)*
0	48.3	1.04	8.8	2,666.7	18,592.5
20	58.4	1.15	12.1	3,466.7	27,475.5
60	72.1	1.18	13.8	5,200.0	38,715.0
80	77.9	1.19	10.0	4,666.7	24,150.0

and increasing its vitality, and provides a good environment for vigorous growth of plants. Temperature decreases and humidity increases as a result of shading (Table 6.13).

Only proper shading can make soil humidity and soil water content harmonize and meet the growing requirements of ginger. Insufficient shading is ineffective. If the shading is excessive, the shoot growth becomes lanky with weak stems and thin leaves and leads to a yield decrease because of deficiency of light. Two years of experiments showed that 50 to 60 percent of shading is suitable for better growth of ginger (Shaohui and Zhenxian 1998, Xizhen et al., 2001) (Table 6.14).

Shading Methods: The traditional shading in the north of China is achieved by inserting straw (also called "inserting shadow straw"); that is, making a sparse fence with millet straw. Usually, three to four pieces of millet straw are made into a bundle on the south side (east to west line) or the west side (north to south line) of the ginger line. The fence height is around 60 to 70 cm, and it is slightly slanted to the north or east (Figure 6.10). About 6,000 kg/ha straw is required. Millet straw can be replaced by corn straw. Mountainous areas can use locally available materials. For example, tree branches are usually used in Laiwu City in Shandong province (Figure 6.11). Stilettoed black plastic film, sun-shading net, and other materials are gradually became common after 1995; they all have a good shading effect (Zhao and Ku, 1992, Xizhen et al., 2001).

In the south of China, shading sheds called "put up ginger shed" are usually used. These sheds are erected after buds sprout. Bamboo or sticks 2 to 3 cm thick are planted on both sides of the farmland, and then little bamboo staffs 1.7 to 2.0 m high are bound horizontally, covered with grass or wheat straw, and finally fixed with ropes (Figure 6.12).

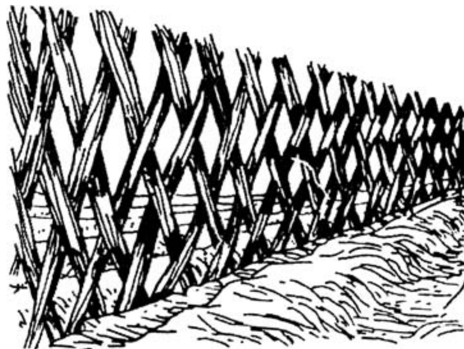

Figure 6.11 Shading mode of Laiwu ginger.

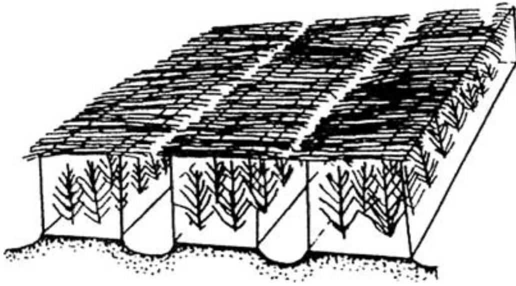

Figure 6.12 Sketch map of ginger shading shed.

For such shading, 6,000 pieces/ha of bamboo staffs and about 5,250 kg/hm^2 couch grass are needed.

Other Modes of Lowering Temperature and Holding Humidity: Traditional shading methods are labor intensive and costly. Detailed research on the photosynthetic characteristics of ginger in recent years indicated the existence of certain photoinhibition phenomena under high light stress, which is a photoprotective mechanism for growth and development. The photosynthetic rate and carboxylation efficiency have not increased with shading, but decreased as the shading intensity increased. The main effect of shading is not only reduction in light intensity, but obviously it also reduces the soil temperature and air temperature around ginger plants and increases the water content of soil by reducing evaporation. Shading is very important to ginger growth. Two effective methods were developed through many years' research that can replace the present shading methods.

Covering with Straw on the Ground: After the planting, a layer of 3 to 5 cm thick wheat straw or other straw is spread evenly on the surface of the ginger bed. About 300 to 4,500 kg wheat straw is required per hectare. This method can save manpower and cost, is easy to do and also has a better effect of decreasing temperature and holding soil water than shading above the ground. It has improved the field microclimate better and promoted plant growth and development and, therefore, the yield was higher. But straws are very light-weight and can easily be blown away by wind (Kun, 1999b).

Black Plastic Film Mulching: This method of shading is achieved by stretching a double layer of black plastic film tightly over the ridge to cover it after planting. If the ridge was covered with transparent film after planting in the beginning of April, then one layer of black plastic film covering should be layered over the transparent film in the beginning of May. The film must be inserted into soil with the back of a sickle, keeping about 15 cm between the trench bottom and the film. One width of film can be used to cover two rows (the width of film is 1.1 to 1.2 m) or four rows (the width of film is 2.4 m). The results of the experiment showed that the film mulch was better for reducing temperature and holding soil moisture than shading aboveground with straw or other materials (see Table 6.14). Plants grew stronger obviously (Table 6.15), and the yield increased by 8 to 30.2 percent, the cost reduced by 1,230 to 4,725 Yuan/ha (Table 6.16), the economic benefit markedly enhanced, and there were no problems of being blown away. Because of these benefits, plastic film mulching is being popularized among ginger growers (Xianchang et al., 1995, Zhifeng et al., 2001).

Table 6.14 Effect of black film mulching on the ground on soil temperature, soil water content, and germination rate of ginger

Treatment	*May 18*		*June 15*		*Germination rate (%)*	
	Soil temperature (°C)	*Water content (%)*	*Soil temperature (°C)*	*Water content (%)*	*May 18*	*June 15*
Black film	26.0	23.66	28.0	19.92	80.2	96.2
Cover with straw	25.8	20.20	28.0	16.96	20.8	91.3
Insert branches (CK_1)	28.4	18.64	30.1	15.73	23.6	76.6
Insert stilettoed black film (CK_2)	25.8	19.21	27.6	16.35	35.8	83.5
Insert shading (CK_3)	26.4	18.99	28.2	16.01	33.2	81.0

Measurement time 14:00
Souce: Xizhen et al. (2001)

Table 6.15 Effects of black film mulching on growth and yield of ginger

Treatment	*Plant ht (cm)*	*Shoot thickness (cm)*	*Tiller nos./plant*	*Leaf area (dm^2/plant)*	*Yield (kg/ha)*	*% increase over control*
Black film	79.6	1.35	13.0	100.41	70,704.0	116.4
Cover with straw	74.1	1.32	13.1	81.31	61,852.5	101.7
Insert branches (CK_1)	78.7	1.31	12.5	97.14	56,487.0	107.7
Insert stilettoed black film (CK_2)	78.5	1.31	11.1	72.26	63,217.5	104.0
Insert shading net (CK_3)	77.9	1.28	11.4	76.79	53,667.0	88.3
($CK_1 + CK_2 + CK_3$)/3					60,790.5	100
*$CK_1 + CK_2 + CK_3 \div 3 = 100\%$						

Source: Xizhen et al. (2001)

Table 6.16 Cost calculation of black film mulching and overground shading

Material	*Quantity (kg/ha)*	*Price (yuan/ha)*	*Manpower (man-day/ha)*	*Manpower cost(yuan/ha)*	*Total (yuan/ha)*
Black film	52.5	450	7.5	90	540
Straw	3,000		7.5	90	375
Branches (CK_1)	7,500	4,500	60	720	5,220
Stilettoed black film (CK_2)	450	1,500	22.5	270	1,770
Shading net (CK_3)	300	1,500	22.5	270	1,770

Source: Xizhen et al. (2001)

No matter which mode of shading or covering is used, it should be done in the first 10 days of May, and it should be removed during the last days of July or during the first 10 days of August, because at that time, the weather becomes cooler, the light intensity gradually reduces, and the plants enter into the vigorous growing stage in which the tillers expand rapidly and begin to shade each other. If mulch is not removed in time, it may cause sunlight deficiency and have an adverse effect on leaf area expansion, growth, and yield.

The frost-free period is shorter in the north of China. It is one of the important factors that limit ginger production. Film mulch used in ginger not only helps plants prolong the growing stage, and makes the assimilation organs grow in strength early, gain a bigger assimilation system, and increase yield, but also enhances soil temperature and conserves moisture, controls weed growth, and decreases tillage times, thereby saving labor and cost. The planting time when film mulch is used should be earlier—in April. Thus, the planting time can be advanced by 20 to 30 days and the yield could be increased by about 20 percent (Table 6.17). The actual method is: after planting, cover 1.2 or 2.4 mm wide film tightly on ridges or beds, and press it tightly with soil. Keep the bottom of the trench and film to about 15 cm. When buds break through the earth and push into the film, punch holes in the film to pull seedlings through. The temperature goes up by the end of June and the film mulch should be removed.

Table 6.17 Effect of film mulch on ginger growth and yield (1994)

Treatment	*Planting time (day/month)*	*Unearthing time of sprout (day/month)*	*Unearthing rate (%)*	*Plant ht (cm)*	*Stem thickness (mm)*	*Tillers/ plant*	*Yield (kg/ha)*
Film mulch	5/4	15/5	98.5	78.4	10.2	11.2	42,762.0
Film mulch	20/4	26/5	100	71.2	8.9	9.5	37,359.0
Control	5/5	4/6	100	65.6	8.5	8.6	35,269.5

Source: Xianchang et al. (1996)

Cultivation and Weeding

The rhizome of ginger grows underground; it requires loose soil with good aeration. Therefore, weeding and intercultivation are essential. Ginger plants grow slowly in the seedling stage, and this stage is in the rainy season and, hence, weeds grow vigorously. If timely weeding is not done, yield reduction results. So clean cultivation is important in good management to ensure strong plants and good yield. Now weedicides, such as nitrofen, chlomethoxyfen, and others are often used in the ginger field.

Irrigation

The roots of ginger are short and plump and require ample soil moisture for growth and hence often need irrigation. But ginger seedlings cannot endure waterlogging. So irrigation should be regulated to the water requirement characteristic of the crop so as to ensure vigorous and healthy growth.

The soil temperature is lower in the germinating stage. In order to increase it and ensure that seedlings emerge favorably, the field is usually irrigated before planting, and

this irrigation will do until seedlings appear, except when the soil is too dry. If the soil water content is low, the first irrigation should be given when 70 percent of the seedlings come out, usually in 25 to 30 days after planting, and the second should be two to three days afterward. Then the land is cultivated so as to hold soil moisture.

In the seedling stage the plants are small, grow slowly, and need less water. In the north of China, the seedling stage is in the drought season—at the end of spring or in the beginning of summer—so irrigation has to be given to keep the relative moisture content of the soil at about 70 percent. In the south of China, the temperature is lower and it rains more during the seedling stage, so deep drains should be provided. The air temperature increases in the later period, and depending upon the soil moisture, irrigation should be planned. During the vigorous growing stage it is turning cool in the north of China, when autumn begins, so ginger plants enter into the stage of vigorous growth; more and more tillers and leaves are produced, and rhizomes begin to expand. At this stage, plants need more water. In order to meet this water requirement during the vigorous growth, irrigation once every four to six days is essential so as to keep the relative humidity of soil at 70 to 80 percent.

Fertilizer Application

The period of ginger growth and development is long and hence this crop needs more fertilizer. So besides the base fertilizer, the crop needs additional applications in the course of growth and development. The requirements are different at different stages, and the absorption speed also is different. So a proper quantity of fertilizer should be given in every stage based on the crop requirements (Xizhen, 1997a, b).

The fertilizer requirement is very little in the germinating stage as the plants mainly grow using stored nutrition. In the seedling stage, again the plants need little fertilizer, the roots are not developed yet, and their capacity of absorption is still weak. So little fertilizer is required to promote seedling growth. In general, additional fertilizers are not required until plants reach about 30 cm in height and have one to two tillers. About 300 kg/ha salvolatile or phosphatic ammonium should be added at this time.

When the autumn begins, the growth becomes faster and the plant enters the vigorous growing stage. Then the plants need more fertilizer. Additional fertilizer should be supplied at the rate of 1,125 kg bean cake or 750 kg soybean and 750 to 1,125 kg compound fertilizer per hectare. The method is as follows: after the mulching straws are removed, a channel is dug, which is about 15 cm deep at the north side of every trench (transmeridional trench) or east side (south–north trench), fertilizer is spread in the ditch and covered with soil and irrigated. Toward the middle of September, rhizome development becomes active. To ensure sufficient nutrition for rhizome development, the third additional fertilizer should be supplied—450 to 750 kg/ha compound fertilizer is usually used at this time. The effect of fertilizer doses on growth and yield is given in Table 6.18.

For good rhizome development, earthing up is essential. This operation is carried out at about the beginning of autumn by taking soil from the ridges and applying it to the base of plants, turning the former trenches into ridges. After that, earth up for a second and a third time combining with irrigation, widen and thicken the ridges gradually, and create a moist, loose, fertile soil condition for rhizome growth and full expansion. In the south, the earthing up operation usually starts from the summer solstice.

Table 6.18 Effect of fertilizers on growth and yield of ginger (1996)

Treatment (kg/ha)	*Plant ht (cm)*	*Stem thickness (cm)*	*Tiller nos./plant*	*Leaf area (dm^2/plant)*	*Yield (kg/ha)*
N0, P112.5, K600	76.1	1.17	12.7	30.78	29,982.0
N600, P112.5, K600	87.2	1.32	18.0	50.47	48,700.5
N1200, P112.5, K600	79.8	1.18	14.7	33.18	36,556.5
P0, N600, K600	80.5	1.16	10.7	31.10	32,142.0
P225, N600, K600	77.1	1.21	11.8	30.45	36,313.6
K0, N600, P112.5	71.5	1.12	13.7	29.13	28,350.8
K1200, N600, P112.5	81.6	1.22	14.3	37.14	40,618.8

Source: Xizhen et al. (1997a).

Diseases and Pests

Ginger Blast (Known as Bacterial Wilt in Other Countries)

Ginger blast is a fatal disease that occurs universally in all ginger-growing areas. The yield may decrease by 10 to 20 percent on an average or over 50 percent in heavily infected plots. It is a serious threat to ginger production. Ginger blast is a bacterial disease caused by *Pseudomonas solanacearum* (now known as *Ralstonia solanacearum*). Besides ginger, this bacterium also infects tomato, eggplant, hot pepper, potato, and other solanaceous crops.

Following infection, the leaves droop, loosing their glossiness, then become yellow and whither from the bottom to top, leaf edges crimp and die at last. If stem is infected the base would show watersoaking, leaves turn yellow and then break at the base. Infected rhizome shows watersoaking, then turns brown and rots (for details see chapter 9–ed.).

Pathogenic bacteria mainly live through the winter in rhizomes and soil. The organisms can survive more than two years in soil and enter through wound and natural orifices of stems. The disease is spread in the following ways.

Seed: Contaminated seed rhizome is the primary infecting source and the main way of spreading the disease.

Soil: If diseased plants are left in the field, bacteria remain in the soil. If ginger is continuously planted in the same field, infection occurs as soon as the rhizome sprouts. So contaminated soil is another important source of ginger blast, especially in the traditional ginger-growing regions. Contaminated soil bacteria accumulate year by year, so the disease will become more and more widespread year after year.

Fertilizer: Some farmers use plant residues or topsoil to make manure and supply the same into the ginger field as base fertilizer. This practice adds *R. solanacearum* to the ginger field and may aggravate the disease.

Water: Irrigating water and rain are also a medium for spreading the disease. If water is polluted, *R. solanacearum* will flow into the field with water and cause the disease to occur.

In the north of China, ginger blast usually starts in July, reaches a peak in August to September, and declines by October. The time and degree of the disease are related to the temperature and rainfall. The optimum temperature for disease development is 26 to 31°C. In general, the higher the temperature is, the shorter the incubation time and course of the disease, and the quicker the disease spreads. In high-temperature and rainy weather, pathogen bacteria reproduce rapidly and spread through water and cause infection in a short time.

Prevention and Cure: The crop is susceptible to ginger blast at all stages of development and there is more than one way of disease spread. So it is difficult to prevent and control. At present, there is a lack of ideal bactericides and resistant cultivars. Therefore, only phytosanitation can prevent and keep the disease under control.

Rotation: Rotation of crops is an important way to reduce the bacterial population in soil and their spread, especially in diseased plots. In such plots, ginger should be planted only once in three years. Tomato, eggplant, hot pepper, potato, or other solanaceous crops should not be rotated, and land under the cultivation of these crops should not be used for growing ginger.

Rhizome Selection: Before ginger is harvested, select healthy and strong plants in the field, harvest them separately, and then store such rhizomes separately after fungicidal treatment. Before next year's planting season, be selective in choosing rhizomes with a view to eliminating the hidden bacterial source of ginger blast, which may be carried in the rhizome.

Field Selection and Soil Preparation: Select a sandy or loam plot—either a slopey land, or slightly elevated area that is well drained. Level it up and make suitable trenches that are about 15 to 20 m long. Drains need to be set out in fields to drain off rainwater. Supply clean fertilizer, and irrigate with germ-free water.

Control Disease Spreading: If a diseased plant is found in field, it should be rooted out together with the soil. Spread bleaching powder in the infected hole and all around, and irrigate. For every hole, use 0.125 kg of bleaching powder. Then cover it with germ-free soil.

Use of Bactericides: Dip seed rhizomes for 20 minutes in 1:1:100 Bordeaux mixture before they are broken off for planting. Dip the cut ends in fresh and clean plant ash to seal off wounds. Or soak rhizomes for 10 minutes in 1:100 formalin and seal them in plastic film for 6 hours before planting. If diseased plants are found, pull them out and treat the area in the way mentioned above and pour 50 percent carbendazim solution. This has the effect of preventing the disease from spreading continuously.

Ginger Leaf Spot or Phyllosticta Blight

Symptom: This disease affects leaves, occurring in the form of spots that are yellow to white, spindleshaped or long and round and 2 to 5 cm long. The middle of the spots turns thin and papery. In badly affected cases, the white spots spread over the whole leaf. Acicular conidiophores can be seen in diseased leaf.

Pathogen Spread: Ginger leaf spot is caused by the fungus *Phyllosticta zingiberi* Hori. This fungus survives in contaminated rhizomes or in the field in the debris left after harvesting. It perennates the winter in the form of mycelia and conidiospores in the soil. Conidiospores are the primary infecting source, which are spread through rainwater. The disease is promoted by warm and moist conditions, so it is severe in the warm rainy season, especially when plants are close, the soil is sticky, and the humidity is higher.

Prevention and Control:

1. Rotate crops for 2 to 3 years or more.
2. Plant in a higher elevated field that is conveniently irrigated and drained.
3. Do not supply too much nitrogenous fertilizer, and pay attention to application of N, P, and K fertilizer in stages in small split doses.
4. Spray 70 percent thiophenate–methyl liquefiable powder and 75 percent chlorothalonil liquefiable powder (1 g/1 l) in the early disease stage. Spray two to three times once every 7 to 10 days.

Colletotrichum Leaf Spot

Symptoms: This disease mainly affects leaves. Infected leaves show brown spots on the top and edges that spread inward and become ellipsoid or spindle-shaped speckles. Most of the spots have halos. Many spots coalesce and cause the leaves to turn brown and gradually dry rot.

Pathogeny: This disease is caused by *Colletotrichum capsici* (Syd.). Bullet at Bibsy and *C. gloeosporioides* (Penz.) Sacc. These pathogens mainly do harm to Zingiberaceae and Solanaceae plants.

Disease Spread: The pathogens live through winter in the form of mycelia and spores in diseased plants or in the soil. Conidiospores are the main infecting source, transmitting the disease through rainwater or small insects activity. Continous cultivation in the same area, higher humidity, and too much nitrogenous fertilizer favor the disease occurrence.

Prevention and Control:

1. Pay attention to rotation of crops (avoid solanaceous and zingiberaceous crops).
2. Eliminate the diseased plants thoroughly by burning them to keep field clean.
3. Pay attention to application of N, P, and K fertilizers in small split doses.
4. Prevent the movement of people or animals in the field.
5. Spray 70 percent thiophenate–methyl liquefiable powder 1g/1 l, solution, or, 30 percent suspension in the primary infection stage. Spray two to three times continuously once every 10 to 15 days.

Stem Borer (Ostrinia nubilalis Hiibner)

The stem borer is a serious insect pest. Besides ginger, it also damages corn, Chinese sorghum, and other crops.

Damage Symptom: The larvae of the borer enter through cracks or wounds in the leaf sheath and stem or heart leaf. They bore into the central portion and eat out the tissue. Stems and leaves turn yellow and wither. If seedlings were attacked, stems are easily broken off.

Form and Characteristics: The stem borer is a grayish yellow and brown moth. The body is 10 to 15 mm long. The forewings are grayish and yellow, and have seven little black points on the edges. The underwings are white. The male moth is smaller than the female; the color of its body and alae is slightly deeper. The antennae are flagelliform. The female moth's antennae are filar, and the black points on the forewing are not very evident. The eggs are 1.28 mm long, 0.78 mm thick, straw yellow in color, and flat elliptical in shape. The surfaces of the eggs have tortoiseshell-like marks. Eggs are deposited on the underside of leaves and arrayed in two rows. The larvae are 28 mm long; milk white when just hatched and straw yellow when mature, and having prominently purple lines at two sides. Pupae are 12 to 16 mm long, and red brown to dark brown in color, with white annular lines in the joints of every section.

Prevention and Control: Clean broken branches, withered leaves, and weeds and burn them. Spray 50 percent fenitrothion emulsion (2 ml/1 l water) or dichlorvos (1.5 ml/1l) or trichlorfon (1.5 ml/l). Spray 2–3 times a month from the beginning of June.

Black Cutworm

Damage Symptoms: The black cutworm is a widespread insect pest infesting many kinds of seedlings of many vegetables and field crops. It is a serious pest at the seedling stage. It usually harms the base of ginger plants by eating away the tissue and causing heart leaves to wither (dead heart), turn yellow, and then the plants collapse suddenly.

Form and Characteristics: The body of adult black cutworms is 16 to 23 mm long. The wingspread is 42 to 53 mm, and its color is dark brown. The forewing has two horizontal lines that separate the whole alae into three sections, and it has an obvious kidney-shaped spot with two black xiphoid stripes. The underwing is solid gray. The eggs are 5 mm long and shaped like a half ball, and they have an apophysis on the length and breadth of their surfaces. The primiparous eggs are milk white, then later some red spots and stripes appear on them and before incubation they become grayish black. The larvae are 37 to 47 mm long, grayish black except for the stern, which is tan and has two deep brown vertical stripes. Pupae are 18 to 23 mm long, red brown, and have a glossy appearance.

The black cutworm goes through several generations in a year. It lives through winter in the form of an old and a mature larva and pupa. It is the first-generation larvae that mainly damage ginger seedlings. They copulate and oviposit at night; every female moth can oviposit 800 to 1,000 eggs on an average. The larvae have strong tropism to a black light lamp and wine with sugar and vinegar. Larvae hide in soil during the daytime and come out at night. Black cutworms are found in warm and moist environments; the suitable temperature is 13 to 25°C.

Prevention and Control:

1. Eliminate weeds to destroy the alternate hosts.
2. Mix sugar, vinegar, distilled spirit, water, and 90 percent trichlorfon evenly in the proportion of 6:3:1:10:1, spread it in field to trap and kill flies.
3. Use 5 kg sautés chaff, wheat bran, or bean cake, add 200 g trichlorfon and suitable water, mix them well and spread in the field to trap and kill larvae.
4. Spray 2.5 percent deltamethrin (1 ml/3 l water), 90 percent trichlorfon (1 ml/800 ml water), or phoxim (1 ml/800 ml water) solution to the leaves to kill larvae.

Thrips

Thrips are insect pests. Besides ginger, they also damage other liliaceous plants, cucurbits, solanaceous plants, and many other vegetables. It can also do harm to plants such as tobacco, cotton and other crops.

Damage and Symptoms: Both adult thrips and their nymphs suck plant juice, damaging leaves. Such leaves usually have many fine and off-white spots. Under serious infestation, the leaves become scorched, twisted, and even dry up.

The insect body is 1 to 1.3 mm long and straw yellow to puce in color, but mostly hazel. Their plural eyes are amaranth in color, coarse grainshaped, and protrude slightly. Each antenna has seven sections. The male insect has no wings, whereas females have light filemot wings. The eggs are kidney shaped and kelly green in color. The young nymphs are white and transparent, and the older ones straw yellow to deep yellow and 0.9 mm long. The shape of the pupa is similar to that of an older nymph; the little wings have developed and the pupa can move but cannot eat.

Thrips undergo about 10 generations in a year in the north of China. They mainly live through the winter in the form of imagos (adult) or nymphs in the sheath of garlic or Chinese onion. Pupae live through the winter in soil, garlic, or Chinese onion field. Adults are very active; they can jump and fly. Thrips are photophobic and usually hide in a leaf axil or leaf shade during daytime. The best-fitting temperature for thrips is 23 to 28ºC with a relative humidity of 40 to 70 percent. Therefore, the damage is most serious in the last 10 days of May to the first 10 days of June every year. After July, once the rainfall increases, gradually the insect population goes down to a certain degree.

Prevention and Control:

1. Eliminate weeds, stumps, and plant debris in early spring, and burn or bury them to kill adults and nymphs.
2. Spray 50 percent dichlorvos 1 ml in one l or 40 percent dimethoate (1 ml/1 l), or 2.5 percent deltamethrin 1 ml in 3 l to leaves. One can also use 3 percent malathion powder and 1.5 percent dimethoate powder together in the proportion of 1:1 and dust on leaves directly in early morning before dew has disappeared.
3. Thrips are attracted to the blue color, so blue sticky boards can be fixed in fields to trap them.

Ginger Maggot

The ginger maggot is the main pest of ginger in storage. It also sometimes damages seed and plants in the field.

Damage Characteristics: Ginger maggots aggregate in moist dark places, and their larvae bore through rhizome skin and enter rhizomes and eat the inner tissue. Frass is extruded through the borehole, and the rhizome becomes rotten. There is still doubt whether this is a primary pest or a secondary pest attacking rotten rhizomes.

The adult moth is grayish brown. The male is 1.3 to 1.6 mm long and has a pair of forewings; the female is 1.7 to 2.1 mm long and has no wings. Eggs are ellipsoid and 0.025 to 0.03 mm long. Larvae are 4 to 5 mm long with a black head and pale white

body. Pupae are milk white at first, then become yellow brown, and finally become grayish brown before eclosion.

Ginger maggots can exist at 4 to 35°C and are fond of moist conditions, but the damage gets aggravated after the "Tomb-sweeping Day" (a Chinese festival) when the temperature goes up. Ginger maggots go through many generations in a year.

Management:

The following methods are mostly adopted in the ginger storage cellar.

1. Clear and clean the ginger cellar thoroughly before ginger is stored. Spray 80 percent dichlorvos (1 ml/ 1 l) solution in the cellar.
2. Put several small vials filled with dichlorvos (original liquid) in the cellar after ginger is put inside.
3. Sprinkle dichlorvos (original liquid) over firewood or sawdust and burn to sterilize the cellar.
4. Prevention in the field: Management method includes selection of seed carefully, elimination of affected ginger, and dipping seed ginger in 80 percent dichlorvos (1 ml/ 1 l) solution for 5 to 10 minutes.

Harvesting and Storing

There are three types of harvested ginger: (1) seed ginger, (2) tender ginger, and (3) fresh ginger.

Seed Ginger

Ginger is different from other crops—after seed ginger sprouts and the new plant starts growing, the original seed rhizome is not influenced further by plant growth and remains in good condition when the plant is harvested; its fresh and dry weights have not changed substantially. Seed ginger can be harvested together with fresh ginger before the first frost, or earlier after the plants established fully. The latter is usually called "dig up old ginger" in the north or "steal mother ginger" in the south. The actual method is: irrigate the field on a sunny day and make the soil moist. The next day, insert a narrow shovel or arrowhead-shaped bamboo slices through the side trench and push upward slightly to cut the place of attachment of the seed ginger and new ginger. Then take out the seed ginger and replace the plant back in the soil. It is also possible to remove the surface soil and take out seed ginger directly, and then cover the rhizomes.

The root is often damaged by the above operation and is likely to lead to infection by pathogens. Hence, this harvest of seed ginger ahead of harvest time is not recommended.

Tender Ginger

Harvest ginger ahead of maturity in the vigorous growing stage while ginger is fresh and tender. At this stage, the water content is higher in the rhizome, the tissue is tender, and has little fiber and low pungency. The rhizome has not developed completely yet, and hence the yield is low. It is used mostly, for example, in pickling, processing of sugar ginger slices, or acetate-water ginger sprouts.

Fresh Ginger

Ginger cannot endure frost, so it should be harvested before the early frost. Three to 4 days before harvest, irrigate the field and make the soil moist, and then dig the whole clump of rhizomes out with a shovel or other tool. Shake off the clay, break or remove stems from the base, get rid of roots, and clean. Then take the rhizomes into the cellar immediately.

Storing Ginger Rhizomes

The fresh ginger just harvested has many wounds and cuts, so it respires vigorously. It has no periderm or perfect protective tissue, so the water content is lost, which causes the epidermis to crumple, and this affects the commodity quality. Ginger has very strict storing requirements. Every ginger-growing area has different weather conditions and a different geographical position; accordingly, different storing procedures are adopted.

Storing in Cellar: This is a common storage method. Cellars are holes dug out of the earth in shady or covered places (in places with a higher water table, cellar storage is not possible). The opening of the cellar is about 80 cm to 1 m, and the length 1 to 1.5 m. Cavities are dug on the bottom of the cellar to increase the capacity. The entire cellar is used for storage (Figure 6.13).

The cellar should be cleaned before ginger is stored. If the cavities and the bottom are too dry, sprinkle some water to produce some humidity. Then spray some germicides such as 25 percent chlorothalonil, or 50 percent carbendazim (2 gm in 1 l) solution and insecticides such as 80 percent dichlorvos (1 ml/ 800 ml water). Then, spread wet sand about 5 cm thick at the bottom of cellar, put the ginger rhizomes into the cellar, arranging them from the inside to the outside. Leave a space of 30 cm from the opening of the cavity.

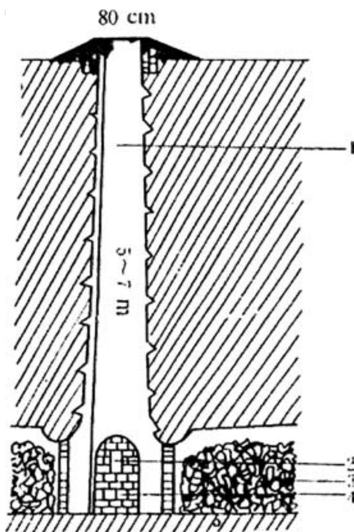

Figure 6.13 Diagrammatic sketch of ginger storing cellar.
1. Tube-shaped passage. 2. Vent. 3. Ginger. 4. Entrance of storing cavity.

The cellar's entrance is left open or is covered loosely with net in order to let in air. Ginger respires vigorously and releases a large amount of heat and carbon dioxide, making oxygen seriously deficient in the cellar. After 20 to 25 days, when the CO_2 concentration becomes normal, the entrance to the cellar can be covered with bricks or earthen bricks, leaving a 20 to 30 cm^2 blowhole. When the temperature dips low, the entrance of cellar also should be air proofed with slab stone. It is usually done in the last 10 days of November in the north and the last 10 days of December in the south of China.

Storing in Rectangle Horizontal Pits: The climate in the south of China is warm, and the water table is shallow, so a horizontal cellar can be used. Dig a rectangular pond 2 m deep and of appropriate length depending upon the quantity of rhizomes to be stored. The bottom should have a slight slant. Then dig a drainage channel separately at both sides. Ginger can be packed layer by layer from the higher end. Cover each layer with moist and fine sand until to about 50 cm from the ground. Finally, cover the top with a layer of fine sand (8 to 10 cm thick) on the top. Insert a few hollow bamboos or other tubes into the cellar for gas exchange. Then cover with wooden sticks as a rafter, and spread corn straw or other crop's stalks on it, and seal up the top to a level higher than the ground. When it is cold, block the entrance of the cellar and the bamboo tube holes tightly with straw (Figure 6.14).

Storing in Tunnel: In mountainous area or upland, a tunnel can be used to store ginger. Dig a tunnel (2.5 to 3.0 m long, 1.8 to 2.0 m high) in the hillside. Then dig the short tunnels on two sides and pits at the bottom. The storing method is the same as those of a cellar. Seal the entrance of the tunnel tightly in winter.

No matter what kind of method is used, the temperature in the cellar or tunnel must be kept to 11 to 13ºC and the humidity at about 90 to 95 percent. If the temperature is higher than 15ºC, ginger may easily sprout, whereas if it is lower than 10ºC ginger easily freezes. If the humidity is too low, ginger loses water, which causes the epidermis to crumble; whereas if it is too high, the cellar may accumulate water, which is not favorable to ginger. Ten days after rhizomes are put into a cellar, the epidermal cells begin to undergo suberization. After 1 month, the suberization process will be complete, forming a phellogen-like layer. At that time, wounded rhizomes heal up, the top of every rhizome turns round and smooth; this is called "rounding head" (see Figure 6.15). After that, the rhizomes can be stored and transported more conveniently.

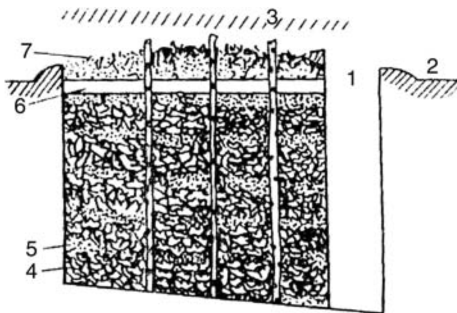

Figure 6.14 Vertical section sketch map of rectangle horizontal cellar.
1. Entrance of cellar. 2. Base of cellar. 3. Aerating bamboo tube. 4. Ginger. 5. Moist sand. 6. Covering branches, bamboo poles, straw layer. 7. Top soil.

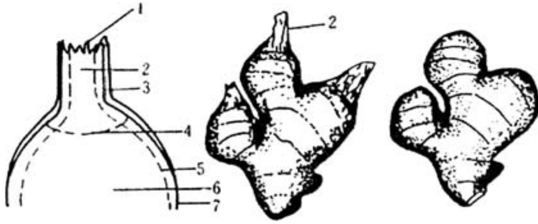

Figure 6.15 Sketch map of "rounding head" of rhizome.
1. Longitudinal sketch map of rhizome top. 2. Rhizome configuration before rounding head. 3. Rhizome configuration after rounding head.
(1) Scar of the fallen aerial stem. (2) Remnant of the aerial stem. (3) Leaf sheath. (4) Suberization layer. (5) Vascular bundle loop. (6) Thin-walled tissue of pith. (7) Epidermis.

Processing Technology

Ginger storage is influenced by its water content and other factors. Processing becomes another good method that can prolong the ginger preservation period. Processing into products can not only further increase economic profit, but also improve quality and flavor. So processing technology has become more and more important and more and more products have been developed. At present, many processed products are being sold in the market.

According to the methods and product characteristics, ginger processing and products can be classified into five kinds: salted products, chow-chow, pickled products, dry products, ale, and juice products.

Salted Process

The principle of the salted process is that the water can be separated out of ginger under high osmosis, whereas salt penetrates into ginger and makes it salty. This inhibits harmful microbial activity, allowing ginger to be preserved for a long time.

Salted Ginger: Fresh rhizomes are cleaned thoroughly, flayed, surface dried, and then put in salt. The proportion of ginger and salt is 10:3. The jar should be cleaned and wiped dry. Keep ginger and salt in jars layer by layer. Then transfer them from one jar to another every day. Thirty days later, seal the jar up, and the product can be saved for a long time. The product has a fresh yellow color, crisp and tender texture, moderate pungency and salty taste, and faint scent, and it is tasty and refreshing.

Salty Ginger Slice: Cut the cleaned and flayed ginger into slices of about 5 mm thick, and sun or bake them to about 10 percent water content. Then salt them layer-by-layer. The proportion of ginger and salt is 10:3 to 3.5. Fifteen to 20 days later, get rid of the surplus salt, dry the ginger slices, and store.

Salted Ginger Bud: Select tender rhizomes that are harvested ahead of time, clean and flay them, dip for 3 to 4 days in 20ºC brine and dip for 5 to 6 days in 20 to 21ºC brine (measured by Baume densimeter). The proportion of ginger and brine is 100:36. Then take ginger buds out and put them into a jar, press tightly layer-by-layer, and pour in 20 to 21ºC brine until the ginger pieces are immersed. Add salt on them (add 2 kg salt per 100 kg ginger sprouts). Seal up the jar and allow to bloat for 10 to 15 days. The product has a yellow and white color, moderate hotness, and salty taste.

Iced Ginger: Choose fresh and fleshy rhizome pieces, clean and peel the skin, and salt for 15 hours in jars. The proportion of ginger and salt is 100:12. Take them out and cut into leaf-shaped pieces of 3 mm thickness. Then salt them for 12 days in jars; the proportion of ginger and salt is 100:22, and stir once every 2 days to salt them fully. Then take them out and dry to 40 to 50 percent moisture on a bamboo mat. Put them into the former jars and salt again, and then air them until salt frost shows on the surface of rhizomes.

Bean Curd Ginger: Clean rhizomes and flay, cut them into thin slices, and air dry. Then salt them with 16 to 18 kg salt for every 100 kg of ginger pieces. Fill them into jars in the form of a layer of ginger with a layer of salt and seal them up. Ten days later, take the ginger pieces out, dry in hot air or under a fan to 20 percent moisture, then knead them to make them crumple and lose water. After that, put them into jars and salt for 2 to 3 days. Then take the ginger pieces out and airdry them for 3 to 5 days. The product appears as soft white pieces.

HotJam: Clean ginger and peel off skin, dry in the air, cut into slices, and sun for 1 to 2 days until skins are about 90 percent dry. Wash red peppers, remove stalk, and grind into hot paste. Then put the ginger slices in the paste in the jar, pour hot wine, and salt in a ratio of 100:35:2.5:28. These are packed in jars in the sequence ginger-chili paste and salt, layer-by-layer until the jar is almost full. Then pour wine slowly, cover, and seal the jar and store for 20 to 30 days to get the finished product.

Chow-Chow Process

The principle of the chow-chow process is increasing the sugar content and decreasing the water content of tissue to make a product having higher osmotic pressure, and thereby inhibiting the activity of harmful microbes. The sugar content of chow-chow products must be over 60 to 65 percent in order to achieve a reliable microbe-inhibiting action.

Sugar Ginger Slices: Select fresh, tender, and fleshy ginger rhizomes, cut them into thin slices of 0.5 cm thick, half cook (till the slices become transparent) in boiling water, and then cool, take out the ginger pieces and drop them into a water-filled jar. Chow-chow (delamination) them for 24 hours in 35 kg sugar per 100 kg ginger rhizome and then add 30 kg sugar again and boil to concentrate to syrup. Take ginger slices out, air dry, and put them into a wooden trough and mix with 10 kg-powdered sugar, and then sieve and remove the surplus powdered sugar. Thus a layer of white sugar coating sticks to the ginger slices. The product is yellow, has a faint scent, and is crisp, moderately hot, sweet and declicious.

Red Ginger Slices: Wash ginger rhizomes and peel off the skin and cut into slices. Rinse in water five to seven times. Then take them out, air dry, and candy them, until the ginger slices become yellow and transparent. Remove the slices and cool them and set the ginger slices in a jar. Add 35 kg sugar and 5 to 8 kg salt per 100 kg ginger. Thirty minutes later, part of the sugar and salt will dissolve and penetrate into the ginger slices. Then heat them at low temperature; some white sugar will congeal on the ginger slices. After that, add 3.5 g edible kermes dye for every 100 kg ginger slices and mix thoroughly. After 25 days, the red ginger slices will be ready.

Sugar and Vinegar Crisp Ginger: Wash ginger rhizomes and peel off the skin and salt them in jars. The proportion of ginger and salt is 100:20. Two days later, take them out and let them stand in water for 2 to 3 hours. Then salt once again using a 100:15 ginger-salt ratio. About 60 days later, the semiprocessed product will be ready.

Cut the semiprocessed product into slices 2 cm long, 2 cm wide and 0.2 cm thick. Put the slices in clear water for 17 hours, changing the water once in the middle of the course. Remove the slices and wash them with clear water. Then put them into a large bamboo basket and press with a stone for 1 hour, and then pour them into a jar. Pour 2ºC white vinegar into the jar and let it immerse the product completely. Take the ginger pieces out 1 day later, drop them in water for 1 hour, and transfer them into basins—fill 0.5 kg in each basin. Then add a little kermes carmine (10 to 30 g dissolved in 3 kg boiled water) and lemon yellow solution (10 g lemon yellow per 100 kg ginger rhizomes). Turn the slices over once every 0.5 hour. Two hours later, put the slices into a jar and let the pigment penetrate them. Then chow-chow according to the proportion of 1:1 (Ginger: sugar).

The process of chow-chow can be divided into three steps. During the first two steps, use 35 kg sugar per 100 kg ginger slices each, mix thoroughly, and lay aside for 1 day. In the third step 20 kg sugar is mixed into 100 kg of ginger rhizomes. Four to 5 days later, pour the sugar solution into a pan, heat to boil, and add 10 kg sugar and boil for 90 minutes over a low fire to concentrate sugar solution. Cool the concentrate to 60ºC and pour it into a jar and chow-chow for 4 to 5 days. Then concentrate the sugar solution again (60 minutes). After cooling, pour the sugar solution into the jar. Four to 6 days later, sugar and vinegar ginger is ready.

Flavored Ginger: Select fresh and tender rhizomes, wash them clean in water, and salt them for 10 to 15 days in a jar (turn over once every 5 days) with 22 to 25 kg salt for each 100 kg of ginger. Take the ginger pieces outside on a clear day and sun them until the pieces get a layer of salt frost covering. Then lay the pieces on wooden boards and pound them with a wooden mallet to make the pieces flat. Combine ginger pieces with 150 g saccharin, 200 g citric acid, 5 kg powder salt, 15 kg liquorice water per 100 kg ginger, mix thoroughly, and keep in the jars for 1 to 2 days. Then take the pieces out of the jars and dry them until a layer of salt frost covers the surface of the ginger pieces.

Sauce-Made Process: In this process the semifinished salted product is dropped into soy sauce or other sauces brewed from beans or wheat to allow it to absorb the flavor of soy. Then the product has a special color and delicious flavor and taste. The salt in soy or other sauces is germicidal and helps in preservation.

Pickled Ginger Products

Pickled Ginger Slices: Cut salty ginger products into thin slices of about 0.5 cm thick, add 105 to 110 l water per 100 kg slices, and soak in jars for 2 to 3 hours to desalt. Turn over once every 30 minutes, decant water, and this is pickled for 3 to 4 days with hot sauce using 60 kg sauce for every 100 kg ginger slices. Then remove the sauce and keep for 3 to 4 hours, and then put the pickled ginger slices into jars and pickle with 115 to 120 kg watery sweet soy sauce per 100 kg salty ginger. Ten to 25 days later, the pickled ginger slices are ready.

Pickled Ginger Bud: The material used to prepare pickled ginger bud is salty ginger bud. Select fresh and tender salty ginger buds, cut them into thin slices 1 cm thick, soak in clear water for 2.5 to 3 hours in a jar, and turn them over once every 30 minutes to make them desalt evenly. Then take them out, drop in clean water, and leave them for 4 to 5 hours. Remove the slices and pickle for 3 to 4 days with cooked sauce (use 60 kg sauce per 100 kg ginger buds) to get rid of part of the hot flavor. Take them out and allow the sauce to drain off for 3 to 4 hours, and put them into the jars, add 115 to 120 kg watery sweet soy sauce per 100 kg ginger buds, and pickle for 7 to 10 hours. Then take them out, add thick soy sauce, 6 kg powered sugar, 100 g monosodium glutamate, and 15 g sodium benzoate for 100 kg ginger buds, and soak for 4 to 5 days. The product is ready.

Dry Process

The principle of the dry process involves decreasing the water content of the product to a lower level so that microorganisms cannot decompose and multiply in the product. The enzymes present in ginger rhizomes will be killed, and such dry products can be preserved for a long time.

Ordinary Dry Ginger Slices: Clean and peel off the skin of the ginger rhizomes, and then air dry, and cut them into slices of 0.5 cm thick. Add 3.5 kg salt for every 100 kg fresh ginger slices, and pickle for 3 to 5 days layer-by-layer. When the salt dissolves and penetrates the ginger slices, take them out and dry in the air or in an oven. The dried product is the dry ginger slice. In general, every 100 kg fresh ginger can be made to yield 15 to 20 dry ginger slices.

Dehydrated Ginger Slices: Clean ginger and peel off the skin, air dry, and cut into slices 0.5 cm thick, and put into boiling water and rinse for 5 to 6 minutes. Then take them out and cool by washing in clean cold water. After that, spread the slices out evenly on trays and dry in an oven. The drying temperature should be changed from low to high; usually, from 45 to 50 to 65 to 70°C. Bake for 5 to 7 hours. When the ginger slices appear neither soft nor burnt and the water content reaches 11 to 12 percent, they can be removed from the oven and dried over a fire. Pick out the impure products and crumbs, put the quality products into plastic bags, and seal the bags. This product can be preserved for about 2 years.

Common Ginger Powder: Clean ginger and peel off the skin and then cut it into diamond-shaped pieces of 1 to 2 cm, dry in an oven and grind into powder. This common ginger powder can be preserved for a long time. It can be further sieved to produce fine ginger powder.

Flavored Ginger Powder: Grind the dehydrated ginger slices into powder, add 1 percent natural carotene, 1 percent glutamic acid sodium, and 6 percent powdered sugar, and mix them evenly. This product is sold as a flavored ginger powder and can be packed in plastic bags and sealed to preserve for a long time.

Ginger Oil and Juice Process

Ginger Oil: Ginger oil is usually extracted by distillation. The process of extraction involves cleaning the ginger rhizomes, washing in water, grinding to a paste or cutting

into small pieces, and distilling. Steam distillation is used. The oil distills out with the steam. The oil that is distilled out becomes condensed and collected and oil is separated from the water. In general, 100 to 300 ml of oil is extracted per 100 kg rhizomes.

Ginger Juice: Clean ginger rhizomes, dip into clear water having 1 percent soda for 5 hours, take them out and wash in water, cut them into 2 to 3 cm square pieces. Squeeze juice with juicer. Heat squeezed juice to 95 to 100ºC, then fill the juice into 250 ml bottles or cans and evacuate to 0.02 to 0.03 mPa, seal, and cool. Such vacuum-bottled juice can be stored for a long time.

Conclusion

China produces more ginger than other SEA countries, and the productivity of ginger is the highest in the world. In general, the productivity is around 30 to 50 tons per hectare depending on the cultivars. However, much higher productivity has been reported. So there is a potential for increasing the average productivity of ginger and to lower the area under ginger cultivation while maintaining production levels, so that the pressure on the land can be reduced to some extent. There is also a potential for developing newer products, especially in the soft drinks sector, to replace the conventional ones, and with the medicinal properties of ginger being highlighted, such soft drinks can easily become health drinks. Such value addition programs can bring in much more revenue. Ginger is intimately associated with the food habits of China, Vietnam, Thailand, Japan, and other SEA countries, and hence it is all the more important to develop newer cultivars that are resistant to pathogens and insect pests. In the absence of seed set and conventional sexual reproduction in ginger, one has to exploit the genetic engineering tools to attain this goal.

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7 Ginger in Africa and the Pacific Ocean Islands

P. A. Okwuowulu

Ginger first appeared in Europe in the ninth century. By the eleventh century, ginger was well known in England. Between 1292 and 1293, John de Montecorvino recorded the first description of ginger in his account of the Coromandel Coast. About this period, the Arabs introduced ginger into East Africa. Ginger production was reported in Malacca in 1416, and during the reign of Henry VIII, ginger was already recommended for cure of plague. The Chinese "preserved ginger" industry was already established by that time. The Spaniards brought ginger into the West Indies and Mexico soon after the conquest, and by 1547, ginger was being exported from Santiago to Spain. Francisco de Mendosa successfully transplanted ginger in the West Indies in 1567. About that time, the Portuguese introduced ginger into West Africa. Provatoroff and Fabrick (1972) gave an account of oil distilled from ginger in 1692.

Production Centers

Ginger is now grown in many African and Pacific Ocean Islands such as Ethiopia, Fiji, Ghana, Guyana, Jamaica, Mauritius, Nigeria, Philippines, Sierra Leone, Solomon's Islands, Trinidad, Tobago, and Uganda. New areas for ginger cultivation are springing up in Ethiopia but mainly as a backyard crop. Yield has reached 30 t/ha of fresh ginger rhizomes. In Fiji, the early European settlers introduced ginger as an export crop in 1890, and the production for domestic consumption began by Indian farmers early in the last century. Haynes et al. (1973) stated that regular cropping began in the Naitassari region at the initiative of Chinese growers in the 1950s. Source centers include the Suva Peninsula, especially in the Tamarua, Colo-Suva, and Tacinua districts, and within Sawani and Waibou as well as in Nabukaluka and Viria.

In Ghana, an early effort was made to establish a cooperative society to promote ginger at the University of Ghana Agricultural Station at Kade. Although production scarcely went beyond the subsistence level, new areas have sprung up since the launching of the Economic Recovery Program in 1983. Large-scale ginger production was taken up in the Kadzebi district. The total production in 1990 was 80,000 tons (Datsa, 1991), but the production declined in the succeeding years. In Jamaica the bulk of production areas are in the Christiana Area Land Authority, the hills of the south central parishes of Manchester, Clarendon, Trelawny, and St. Elizabeth, and the hills of St. James, Hanover, and Westmooreland (Prentice, 1959; Rodriquez, 1971).

Ginger export from Mauritius has declined because of increasing home demand and the rather static production. In 1990, 625 tons were produced. Guyana has a small-scale ginger production in the northwestern region, but there is also a renewed interest aimed to earn some foreign exchange.

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Nigeria is currently one of the largest producers and exporters of ginger, especially the split-dried ginger. Large-scale cultivation started in 1927 (Anonymous, 1970; Arene et al., 1986) in southern Zaria, especially within Jemma's federated districts and in the neighboring parts of Plateau (Bako, 1984). This occurred during the search for a crop to generate internal trade there (Erinle, 1988). Between 1927 and 1982, the production for export fluctuated and ultimately declined due to poor prices of export markets and because of the economic boom of mineral oil during the 1970s. Efforts have intensified to increase and spread the cropping area and widen the genetic base. Considerable success was achieved in this area following the results of the ecological adaptation trials (Arene et al., 1983) and the successful introduction of other cultivars (Maran, Himachal Pradesh, Rio de Janeiro, and Wynad local) from India in 1986 (Okwuowulu, 1992), which are already certified and released for cultivation.

The Philippines also produce ginger, especially in Los Banos, Laguna, Tanavan, Bantagas, Silang, and Carite. However, yield data are not immediately available. Sierra Leone is an age-old source of ginger. The production concentrates near rail lines around Freetown, Boia, Kennama, Pendemba, and Njala as well as in Mayamba districts and in parts of East Kano. In the 1950s average yields were 2,000 tons per year (Lawrence, 1984). Husbandry practice and capacity to compete effectively have limited increasing the production, and the figures remained almost static or declined in the ensuing years.

In the Solomon Islands the development opportunities are being explored. In Trinidad and Tobago ginger has remained one of the traditional spices; the area under cultivation in 1992 was more than 45 hectares. Uganda grows ginger as an occasional crop in banana gardens. More recently, the introduction of a high-yielding variety from Hawaii has been explored.

Planting

The conventional planting material for ginger has been the rhizome pieces obtained by splitting the fat ginger knobs into desirable seed ginger called "setts." The size of the setts ranges in various studies from 3 to 9, 5 to 10, 20 to 40 g and up to 70 to 80 g (Evenson et al., 1978; Paulose, 1973; Whiley, 1974;1980; Okwuowulu, 1988, 1992b; Melifonwu and Orkwor, 1990). Rodriquez (1971) reported the use of rhizome pieces 2 to 3 cm long, whereas Furutani et al. (1985) worked with setts measuring 2.5 to 5 cm long for field crop production. Nadgauda (1980) and Balachandran et al. (1990) used smaller sett weights, with dimensions of 8 to 10 mm being adequate for micropropagation studies. The proven optimum sett weight to grow, therefore, depends on the type of study.

The effect of sett size and weight on plant growth and yield responses are of interest and so far only partially discussed; for instance, by Whiley (1981) and Okwuowulu (1988a, 1992b, 1994). There is a need to relate the comparative seed rhizome rates estimated on a weight basis to the rhizome pieces in physical dimensions (centimeters) and to ascertain the relative yield differences for using a similar quantity of seed ginger. A greater critical need is to use the relationship to establish the optimum seed ginger to grow for various purposes. Furthermore, there are discrepancies about the relative seed rates adopted at equal sett weights and approximate intrarows within the same interrow spacing; the range being 1 to 1.5 t/ha (Prentice, 1957; Paulose, 1973; Menon, 1992). Further study is needed in this area. Little has been documented on dormancy—normally 6 weeks—and other plant factors.

Many ginger types exist under cultivation. They differ in characteristics varying in rhizome shape and quality and other inherent characteristics. Parry (1969) indicated different types of African ginger that possess strong pungency and aroma. A typical example is the black ginger; Yatsun biri of Nigeria. The Indian or Cochin ginger, generally of pale yellow to light brown, has a strong aromatic taste; while the Jamaica ginger, similar to the Brazilian ginger cv. Rio de Janeiro, possesses a somewhat high pungency but weak aroma. The bold yellow ginger, Taffin-giwa of Nigeria, is of this type.

Environmental Factors

Ginger is a crop of the tropics and subtropics. For optimum growth, ginger requires high organic matter and, therefore, may exhaust soils. According to Prentice (1957), Kannan and Nair (1965), and Paulose (1973), ginger grows well in clay loam, sandy loam, sandy clay loam, red loams, and lateritic soils. The normal pH range is 6 to 6.5. Topography is not critical because the crop grows well on tablelands, slopes, and undulating sites. The depth of the soil is also not critical because the tuberous stem is borne near the soil surface. The soil, however, needs to be worked to fine tilth and should be loose and friable in texture in order to offer minimum resistance to rhizome initiation, development, and bulking. Heavy clays and coarse sand, therefore, restrict root development.

Ginger has a wide range of temperature tolerance. Evenson et al. (1978) found 25 to 30ºC to be optimum. The temperature is often assumed to be adequate in most parts of the ginger-growing world, although Leverington (1975) noted that fluctuating temperatures might cause chilling injury. In more practical terms, most of the tropical environments in which ginger thrives do not have drastic fluctuating temperatures. Relating the soil temperature to the corresponding air temperature effect during crop growth is recognized and will make a worthwhile study.

Ginger requires a humid environment for good crop growth. The optimum rainfall (1,500 to 3,000 mm) is of a wide range and should compose of intermittent showers between the time of sowing and sprouting (within the first 6 weeks of crop life), followed by regular (preferably evenly distributed) rainfall during crop growth and bulking (from third to seventh month). Ginger is sensitive to water logging. At crop maturity (prior to harvesting), the rains should cease. Ginger is essentially rain fed, but supplementary irrigation may be used to augment its water requirement. A prolonged or erratic dry condition during crop growth leads to small-sized rhizomes. This calls for further investigation to ascertain how much off-season watering is used to prolong the vegetative growth phase and bulking duration for increasing the yield of rhizome.

The altitude requirement for growth of ginger varies from about sea level (e.g., 4 m as in Bori Nigeria) to 122 m (Umudike) to 462 to 769 m in Jamaica (Prentice, 1959) and up to 1,500 m as in Himachal Pradesh and hill tracts of Assam and West Bengal (Kannan and Nair, 1956; and Menon, 1992). Frost is, however, detrimental to crop foliage and destroys exposed rhizomes while excessive low temperatures induce and prolong dormancy (Caiger and Buckhurst, 1993). However, information on critical limits has not been available.

Similarly, the influence of wind speed and irradiance (quantitative and qualitative) needs to be explored since results of field trials on it is scanty. Crop growth within para-rubber (*Hevea braziliensis*) plots providing partial shading as compared to open field cropping in Nigeria reveals that ginger prefers warm, but long sunshine days to hot and

erratic and short ones. The other evidence on light effect is on flowering and anthesis relationship. (Thankama Pillai et al., 1978). Flowers start opening in the afternoon by about 3:00 P.M., or by a little after midday on bright sunny days in Nigeria (Okwuowulu, 1988a).

Land Preparation

It is normal to slash the natural vegetation and, through this operation, to collect mulch material. Ploughing follows, and, ideally, harrowing several times at 5-to-7 day intervals kills germinating weed seedlings. Rotovating may be desirable. Ginger is best sown on flat or raised beds (30 cm high); the culturally convenient length and width of plots being 25 m × 3 m, if the crop is not grown on ridges along the contour on slopy lands. Ploughing once but harrowing several times gives the most desirable tilth, which creates enough room for tuberous stem initiation and bulking.

Time of Planting

Although ginger survives naturally as a perennial rhizome, it is domesticated as a rain fed annual crop. Timing the planting to coincide with the rainfall pattern has been a major consideration as this determines the tuber yield to a large extent. Therefore, ginger is sown when the premonsoon showers begin during early April/May (Aiyadurai, 1966); in June or later, as the case may be, if the monsoon showers are late (Paulose, 1973). May/June is the most appropriate time for planting in Jamaica (Prentice, 1959), whereas in Fiji it is September to December (Haynes et al., 1973; Whiley, 1974, and Evenson et al., 1978). In Nigeria and Sierra Leone the ideal time to plant has been when the rainfall has become regular; usually by midApril in southeastern Nigeria (Okwuowulu et al., 1989). Early planting is associated with more uniform sprouting and ensures maximum crop duration for rhizome growth and development.

Row Spacing, Depth of Seed Placement, and Sowing

Ginger is sown on raised beds or on flat land. Spacing is 20 cm both within rows and between rows for ware (Process)-ginger production and 10 or 15 cm within and between rows using the minisett technique for seed ginger growing. Some available evidence indicates that the optimal depth for seed placement is 5 cm, but results of later studies (Okwuowulu, 1992a) show that under certain conditions, adopting a 5 cm depth predisposes the rhizomes to significant ($P = .05$) loss due to desiccation, especially if harvesting is delayed. Seed placement of up to 10 cm was recommended, especially in areas of plantation cropping where harvesting stretches from November to February (Okwuowulu, 1992a). Setts are manually prepared, 30 workdays are required to cut enough ginger to establish one hectare. It requires normally 150 workdays to plant one hectare of ginger, but this operation is amenable to mechanization using a modified motorized potato planter. This has an output of 0.1 ha per hour (Whiley, 1974, Anonymous, 1982).

Mulching

Mulching is an imperative cultural practice. The convenient mulching material usually includes wilted guinea grass (*Panicum maximum*) or leaves of dicotyledonous species, such as the Elizabeth weed (*Chromolaena odoratum*) and para-rubber (*Hevea braziliensis*). Wilted leaves at about 10 tons per hectare give the desirable 5 cm thick coverage at the time of planting. Mulching may be repeated with 5 t/ha mulch material, to be given immediately after the first weeding about 6 weeks from planting. Cutting or gathering enough mulching material and mulching 1 ha requires 150 workdays. The alternative mulch material (one readily available everywhere) is sawdust at a 5 cm thickness of coverage. This requires 30 t/1 ha, but this induces high carbon:nitrogen ratio (if it is not properly rotted) and makes application of more nitrogen fertilizer essential. This probably explains the high level of nitrogen fertilizer application in some ginger-growing areas.

It was already stated that ginger thrives best if the soil organic matter is high. Therefore, well-rotted dip-litter poultry manure or cow dung at 20 ts/ha easily becomes a substitute for or supplements mulching. The main advantage of the practice is the slow but lasting decay process leading to long-term release of the organic matter for the crop. Other current work, for example, the application of rotted rice mill-mud (Okwuowulu, 1988a) or white polythene beads as mulch material (Evenson et al., 1978) in garden-pot experiment, serves to reduce the adverse effect of variation in soil temperature, hence buffers the ambient seedling zone to achieve quick sprouting of ginger. Absence of mulching reduces sprouting to 30 percent or even lower. Mulching also increases the available/native organic matter content and has been demonstrated to minimize nematode infestation in Fiji (Haynes et al., 1973). Weed density is also significantly suppressed. However, the cost of the polythene beads is too high to warrant adoption of this mulching method at the present level of farming. But then, as the natural vegetation (grass or broad leaves) is becoming scarce, an attractive breakthrough in ginger production technology would be a success in the production of a ginger type (an ideotype) that will sprout whether or not the plot is mulched. An alternative is to develop a sprout-promoting treatment by application of some growth regulators. These are future imperatives for sustainable ginger agriculture.

Fertilizer Application

Ginger exhausts soils. The crop is mainly potassium (K) and nitrogen (N) exhausting; magnesium (Mg) and phosphorous (P) removal being intermediary (Nagarajan and Pillai, 1979; Lee et al., 1981). Results of analyses of vegetative plant parts give a similar trend. Plant parts development and yield response to timing of fertilizer application aimed at achieving fertilizer use efficiency is presented in Table 7.1. Levels of trace elements Mg/K maximum: arsenic 5, lead 10, copper 20, and zinc 50 are the prescribed levels fixed by processors in ginger of commerce (See also Roy et al., 1992). Therefore, application of minor elements is necessary for successful ginger technology. But the question is the rationale for fertilizer usage in ginger production if the economics of the process is carefully worked out. Fertilizer mix used varies from place to place, and is based on farmers' experience. The variable doses are of interest because of possible environmental pollution effects and to ascertain the marginal costs/merits of the fertilizer usage. These

Table 7.1 Fertilizer mix and use in various countries

Country	*Fertilizer mix*	*Rate (kg/ha)*	*N composition*	*Source*
Fiji	13:13:13	2000–5000	260–650	Haynes et al. (1973)
	13:13:21		—	Haynes et al. (1973)
India	8:8:16	600–1000	320–533	Kannan and Nair (1965)
India: Kerala State	8:8:6	450	240	Kannan and Nair (1965)
Nigeria	15:15:15	400–700	—	Arene et al. (1986)
	27:10:10	—	—	Enwezor et al. (1986)
Australia: Queensland	—	—	200 N 60 P	Whiley (1980)
Australia: Nambour	—	—	100 K 500 N 325 P 1000 K	Anonymous (1982)
Jamaica	—	—	—	Prentice (1959)

are critical because the cost of procuring and delivering fertilizer to the developing countries (the major ginger growers) are no longer subsidized. At the end of the day, reverting to the use of animal dung will prevail.

Weed Control

With good soil preparation (ploughing, harrowing, and rotovating) ensuring a fine tilth and adequate (5 cm) depth of mulch material and correct row spacing, sprouting of ginger progresses uniformly, with the first seedling emergence takes place in about 14 days. About 50 percent seedling emergence occurs within a month of planting. The first weeding is due about this stage. When the mulch material is made of Guinea grass (*Panicum maximum*) in improperly wilted state and grass studs, the need for extra care is emphasized because the ginger seedlings at early stages tend to resemble the *P. maximum* seedlings.

Weeding is done manually using the West African hand hoe; currently, 100 workdays are adequate to weed 1 ha and two to three weedings being adequate per cropping. Weed challenge and density are reduced to a bare minimum by adopting the correct row and column planting of 20 cm × 20 cm and by timely planting after field preparation. Chemical weed control by application of Diuron 80 at 3.4 kg a.i/ha (active ingredient /ha) followed by spot spraying paraquat (Whiley, 1981) or Diuron with surfactant may be used as a preemergence herbicide applied with boom sprayers at 4.5 kg/ha commercial product in 1,700 l of water per hectare. Other studies include those of Melifonwu and Orkwor (1990, 1994) (Table 7.2).

The common natural vegetation of each location constitutes the weed species there. In southeastern Nigeria, for example, the broad-leaf weed species include *Oldenlandia corymbosa* L.; *Dissotis rotundifolia* Sm., *Schwenkia americana* L., and *Cassia rotundifolia* Benth. Others are *Amaranthus spinosus* L., *Ageratum conyzoides* L., *Cleome ciliata* Schum. and Thonn, *Euphorbia hirta* (L.), and *Richardia braziliensis* Gomez. More frequently, the prevalent grasses include *Panicum maximum* Jacq., *Digitaria horizotlis* Willd., *Eleusine indica* (L.) Gaertn. and *Brachioria deflex* (Schumach) C.E. Habbard ex Robyns. *Mariscus alternifolius* Vahl., *Kyllinga nemoralis* (Forst.) Dandy ex Hutoch, *Kyllinga pumilla* Michx and *Cyperus*

Table 7.2 Effect of weedicides on weed control; weed dry weight, phytotoxicity, and fresh ginger yield at Umudike, 1990

Weed Control Treatments Phytoxicity rating at 8 WAP[a]		*Time of application (DAP) Vigor rating at 8 WAP*			*Weed control rating*[a] *Fresh ginger stem yield (t/ha)*	
Herbicides	*Rate (kg al/La)*			*8 WAP*	*16 WAP*	
Chloramben + Paraquat	3.0 + 1.0	0	8.6 6.8	5.6	4.8	4.1bcd
Chloramben + Paraquat	3.0 + 1.0	6	9.0 8.4	6.9	4.5	5.3ab
Chloramben + Paraquat	3.0 + 1.0	10	8.9 8.4	7.8	4.0	4.9bc
Chloramben + Paraquat	3.0 + 1.0	14	9.8 8.4	7.7	3.0	4.1bcd
Chloramben + Paraquat	3.0 + 1.0	18	9.1 8.4	7.9	2.5	2.6d
Oxidation + Paraquat	1.0 + 1.0	0	8.7 6.5	1.0	4.8	4.2bcd
Oxidation + Paraquat	1.0 + 1.0	6	8.9 8.7	1.0	4.8	5.5ab
Oxidation + Paraquat	1.0 + 1.0	10	9.4 8.8	1.7	4.5	5.0abc
Oxidation + Paraquat	1.0 + 1.0	14	9.5 8.9	2.0	3.5	3.3de
Oxidation + Paraquat	1.0 + 1.0	18	9.7 9.6	2.4	3.0	2.6e
Hoe-weeded control	—	4 + 8 + 12 + 16 WAP	8.5	1.0	5.0	5.8a
Unweeded check	—	—	1.0 0.0	1.0	4.5	2.4 e
SE±			0.68	0.31	0.410	.49

[a]Square root–transformed data. DAP: Days after planting WAP: Weeks after planting
Means within the same column followed by similar letters in columns are not significantly different at the 5 percent level by Duncan's multiple range test.
Source: Melifonwu and Orkwor (1994)

esculentus are the main sedges. *Ageratum conyzoides* L. and *Colosia trigyna* L. are also prevalent.

Manual weed removal using the West African hand hoe has the merit of being more thorough and truly selective on weeds than the chemical weed control measures. Pulvering the soil during hoe weeding (dry mulching) has an added advantage of creating a more conducive rhizosphere for roots to thrive in. This is achieved in manual weeding.

Maturity, Harvesting, and Yield

Maturity: In Nigeria ginger comes to harvest in 7 and 8 months, respectively, for the black and yellow ginger types. The maturity index is that leaves and shoot turn yellow and wither. The main factor is weather as ginger is essentially a rain fed crop and the rainy season does not exceed 6 months.

Harvesting: In Nigeria manual harvesting, predominately done by women and children, is the routine practice and is carried out using a garden fork to scoop off the topsoil bearing the rhizome. The rhizome and the soil particle adhering to it are scooped together. By a simple process of gently bouncing the clod up and down a few times in the pan of the fork, the soil particles fall off leaving the rhizome and the anchorage roots in the pan. In a large-scale harvesting, the crop is left exposed in the field for a couple of days to enable the roots to wilt. They are easily detached manually to obtain a clean

Table 7.3 Rhizome yields of ginger (t/ha) as influenced by planting date and harvest age in 1984 and 1987* Planting date (1984)

Harvest age (months)	*First*	*Second*	*Third*	*Fourth*	*Mean*
4	19.8	23.3	21.2	23.8	21.9
5	37.7	34.8	33.2	33.3	34.8
6	51.3	37.5	36.8	54.2	40.0
7	59.0	45.3	34.3	36.0	43.7
8	49.2	46.2	35.0	25.2	38.9
Mean	43.4	37.4	32.1	30.4	35.9
SE			0.5		
Planting date (1987)					
4	22.7	24.3	16.6	17.8	20.4
5	36.2	42.7	23.9	19.3	30.5
6	39.2	34.9	17.3	13.7	26.3
7	38.7	29.6	15.6	11.5	23.9
8	24.0	26.7	13.1	4.2	17.0
Mean	32.2	31. 6	17.3	13.3	28.6
SE			0.6		

*Source: Okwuowulu et al. (1989)

crop. Harvesting is easily done when the soil is moist. Harvesting when the soil is wet predisposes tubers to easy infestation by mould rot. Harvesting when the soil is dry leads to bruises that predispose tubers to fungal infestation. Harvesting 1 ha requires 225 workdays.

Yield: Yield is cultivar specific and is usually expressed on a fresh weight basis. Generally, the black ginger type yields less than the yellow ginger. Within cultivars, yield depends on sett weight, time of planting, and age at harvesting (Table 7.3); soil; environment; intrarow and interrow spacing; intercropping adopted; and disease and pest occurrence.

Sivan (1979) recorded some synchrony in the mode of development of the root, shoot, and rhizome initiation early in the crop life. Carbon assimilate partitioning is implicated in this. The partitioning of the photosynthetic products between the new plant organs governs the yield at any stage in the life cycle. When flowering, available assimilation of plants bearing normal foliage is partitioned between tuberization (sink) and maintenance of inflorescence-bearing shoots possessing only rudimentary leaves (restricted source condition); therefore, rhizome yield is necessarily reduced but to what extent has not yet been defined. The urge and ability of plants derived from small setts to bulk soon after rhizome initiation is large. This leads to suppression of inflorescence-bearing shoots as a means of increasing desirable current photosynthates in them. When large setts or whole rhizomes are sown, the demand for assimilates for bulking during early crop growth is relatively low; hence the plant can afford production of inflorescence-bearing shoots possessing only rudimentary leaves apart from normal foliage shoots (Okwuowulu, 1988a).

Increasing the sett weight produces a significantly higher yield of ginger (Table 7.4). Okwuowulu (1985, 1988b) discussed how the planted setts remain undecomposed at crop maturity. They are harvested as additional yields and may be detached during crop growth without significantly affecting yield (Table 7.5). A mean of 58 percent of the

Table 7.4 Effect of sett weight on rhizome yield of ginger

	Yield of rhizome (t/ha) Harvest multiplication				
Sett weight (g) planted	*Yellow*	*Black*	*Means*	*Yellow*	*Black*
5	18.75	9.35	14.05	15	8
10	23.33	12.22	17.78	9	5
15	28.78	16.00	22.38	8	4
20	31.28	19.22	25.20	6	4
25	34.98	22.43	28.70	6	4
30	36.00	21.85	28.93	5	3
35	37.83	27.28	32.55	4	3
40	40.42	32.78	36.60	4	3
Mean	31.42	20.14	25.77		
Lsd (0.05)	—	—	5.46		
	—	—	7.25		

The yield of yellow ginger has been consistently higher than black ginger at all the sett weights over the years. The crop is grown at 20 cm within rows 20 cm apart.
Source: Okwuowulu (1988a). Lsd: Least significant difference

Table 7.5 Effect of detachment of planted sett on the yield of varying ginger sett weights

	Days from sowing				
	60	90	0[a]	Means	Lsd (05)
Yellow ginger (g)					
5	13.25	15.04	16.60	15.84	2.07
10	14.63	17.48	20.11	17.11	
15	17.40	19.47	21.41	19.43	
200	18.49	19.57	21.00	21.30	
25	23.50	24.37	26.35	25.07	
Means	17.47	19.59	24.06		
					1.06
Black ginger sett size (g)					
5	12.87	13.84	11.29	12.66	
10	12.74	13.19	15.29	13.81	
15	15.01	12.75	14.27	15.47	
20	13.97	14.11	14.71	14.26	
25	15.49	15.71	23.85	18.34	
Means	14.02	14.80	15.93		
Lsd (05)				NS	

[a]No detachment.

Table 7.6 The percentage of parent setts recovered in a fully plantable condition at crop maturity

Sett size (g)	*Yellow ginger*	*Black ginger*	*Means*
5	67.8	48.8	57.8
10	88.3	64.3	76.3
15	69.6	64.3	66.9
20	91.1	64.0	75.5
30	87.7	60.0	74.8
35	83.3	69.7	76.5
40	91.0	81.3	86.2
Lsd (05)			9.0

Source: Okwuowulu (1986).

Table 7.7 The aggregate yield (t/ha) obtained from the same setts grown for 2 years

	Cumulative from the same setts in 1985 and 1986					*% of control plots*		
Sett size (g)	*Yellow (a)*	*Black (b)*	*Yellow (c)*	*Black (d)*	*Yellow(a + c)*	*Black (b + d)*	*Yellow (a + c)/a*	*Black (b + d)/b*
5	18.75	9.35	14.40	8.00	33.15	17.35	182.3	167.14
10	12.33	12.22	16.80	7.90	42.16	20.12	4	152.31
20	31.38	19.22	21.90	11.70	53.18	30.92	167.7	159.38

a and b, Yield obtained by sowing the fresh tuber in 1985;c and d, additional yield obtained by resowing the parent setts recovered in 1985.
Source: Okwuowulu (1986).

seed ginger from small setts and 86 percent from large setts can be recovered like this (Table 7.6). Recycling the setts has been suggested as a method of increasing the aggregate yield of a given sett (Table 7.7) and as a method of conserving scarce material (Okwuowulu et al., 1988).

The time of planting is important. Whiley (1981), Furntani et al. (1985), and Okwuowulu et al. (1990) have related yield with time of plating to age at harvests and found a highly significant interaction between them. Early planting enables plants to enjoy maximum bulking duration leading to increased yield even in contrasting weather. However, premature harvesting may be done deliberately for various end uses.

The optimum age to harvest ginger depends on the requirement of the consumer. Therefore, culinary- and confectionery-grade ginger (i.e., ginger marketed as a vegetable and as a preserve) is harvested at 4 to 5 months (Leverington, 1975; Sivan, 1979). The ginger of commerce is harvested much later. For pickling and salting, at 5 to 7 months, for dehydration, at 6 to 8 months; and for split-dried for export, at 7 to 10 months.

Between and within row spacing also determine yield. The yield of fresh ginger decreases at increasing intrarow spacing. As both factors also similarly lead to lower harvest–multiplication rates, the need now is to ascertain the limits of sett weights and corresponding intrarow spacing at which both yield and seed harvest multiplication are

high and, therefore, minimize yield losses. Numerous reports available (see later) on ginger diseases have scarcely quantified yield losses, which may be up to 30 percent due to one disease or pest or the other. Sharma and Jain (1977) had, however, expressed doubt about the exact effect of causal organisms on the yield reduction. This occurs more in the black ginger type (Nnodu and Okwuowulu, 1990).

Another point here is the ultimate dry-matter yield. Prentice (1959) estimated that green ginger gives about 30 percent dry ginger. The mean yield ranges from 14 to 37 t/ha (fresh weight basis) for sett weights of 5 to 40 g grown at 20 cm within rows, 20 cm apart. The corollary, however, has been that the greater physical yield of top-growth (the haulm) and roots is obtained in the black ginger, suggesting that it is less efficient to translate photosynthetic products into edible form.

Interculture

Field trials have been used to ascertain compatibility and productivity in intercropping mixtures. Ginger is successfully grown with appropriate populations of *Capsicum* pepper, vegetable okra, and a food crop such as maize (Figure 7.1a–c). Varying mixture

Figure 7.1a Ginger–bell pepper intercropping.

Figure 7.1b Ginger–okra intercropping.

Figure 7.1c Ginger–maize intercropping.

components enhance total crop yield through complementary yield advantages, which also give high productivity efficiency. Relative yield totals also remain higher than monoculture yield but maize components at >40,000 per hectare depress the ginger yield. Nonetheless, there is a better utilization of environmental factors, greater yield stability, a useful variability in the specific food supply and an ensurance against any failure of one component in the mixture. Moreover, planting and harvesting done in phases has ensured a relaxed spread of the crop supply to the household. It has also provided a better cash flow and maximizes output. Interaction due to this compatibility has persisted to occur in the form of complementary action and mutual cooperation rather than antagonism. The general evidence of benefits confirm Wrigley's (1969) report that intercropping leads to multiplying the net return of yield (kilo calories/hectare) as well as higher monetary returns to the grower.

Pests

In homesteads garden snail (*Helix aspersia*) infestation occurs at the young seedling stage of plants, especially at night and in the early morning. In the glasshouse the larval stage of an unidentified moth causes economic damage by defoliating the leaves and girdling the shoot (Okwuowulu and Emehute, 1985—plates 6 and 7). The nonoccurrence of this pest in the open field crop has been attributed to the presence of numerous preferred crops there. On the other hand, the grub of the shoot-borer *Dichochrosis punctiferalis* largely infests the crop at crop bloom (i.e., at about 5 months of crop age in Nigeria). A similar incidence was recorded in India (Jacob, 1980). Haynes et al. (1973) has reported damage by the root knot nematode (*Meloidogyne incognita*) and tuber scales (*Asperdiella hartii*). Leaf damage by insects occurs in Fiji. Akamine (1977) reported that the incidence of the Mediterranean fruitfly, some melonflies, and oriental flies is common in Hawaii as pests of ginger in the field. Trujillo (1964) reported that the presence of the Chinese rose beetle (*Adoretus sinensus* Burm.); fullers rose beetle (*Potomorous godmani* Crotch); some grasshoppers; scavenger flies, especially the syrphid fly (*Eumerus maginatus* Grins); otitid scavenger fly (*Eukesta quadrivitta* Mecq); and scarid gnot fly in Hawaii. By and large, the shoot borer is known to be the most destructive pest as observed by Kannan and Nair (1965). The leaf roller (*Udaspes folus*), the ginger maggot (*Calobata* sp.), the scale insects (*Aspidoetus hartii*), a reddish brown thrip (*Panchaetothrips indica*), and lace wingbug (*Stephanities typica)* are the other pests. Storage pests recognized are drugstore beetle (*Stegobium paniceum*), cigarette beetle (*Losioderma serrinocorno*), and scale insects.

Diseases

Many pathogens infest ginger plants. Serious diseases are caused by fungal, bacterial, viral, and nematode infections. The nonpathogenic maladies include sunburn, lime-induced chlorosis, and chilling injuries. They have been reported by Nnodu and Emehute (1988) to cause varying degrees of crop damage and yield reduction.

The Leaf Spot

Leaf spot is caused by *Phyllosticta zingiberi* (Nnodu and Okwuowulu, 1990). It is characterized by numerous circular or elongated yellow spots on the leaves. At a later stage,

the spots enlarge and turn brown with white papery centers. Some portions of the white areas may drop off, producing a shot-hole effect. Infected leaves may be torn into shreds, causing withering and premature death of plants (Mailum and Divinagracia, 1969). Grasses serve as reservoir hosts, whereas rainwater and wind are dispersing agents. The disease is widespread in the ginger-growing world and resists benomyl (Benlate 50w), mancozeb (Diathane m-45), and Kocide 101 (copper hydroxide) treatments in Nigeria. However, thiabendazole (Mertect 340-f) at 1.7 active ingredient (a.i) per hectare will significantly ($P = .05$) reduce disease severity and increase rhizome yield by more than 3 t/ha. Yellow ginger is less susceptible than black ginger. Avoiding density planting is useful in managing the disease.

Fusarium Yellow

Fusarium yellow is caused by *Fusarium oxysporium* f. sp. *zingiberi*. Pegg et al. (1974) reported that it was first recorded in Queensland in 1930. Infected plants remain yellow and are stunted in growth. The yellowing starts from the lower leaves. From infection to total collapse is gradual. Infected plants produce shriveled tubers and brown ground tissue. The spread is through seedborne inoculum. Good control is achieved by the use of clean seed ginger. A preplanting seed treatment with Benlate fungicide (250 g/100 l of water for 10 minutes) is also recommended.

Rhizome and Stem Rot

Sclerotium rolfsii causes rhizome and stem rot. The disease is characterized by the presence of white colony threads and sclerotia on the infected tissue. The fungus survives for a long time in the soil. Cultural crop rotation and rogueing out of infected plants are good control measures.

Rhizome Rot

Rhizome rot is caused by *Armillariella melea*, and is characterized by yellowing of leaves and a rhizome covered with black string-like fungal mycelia. The rhizomes begin rotting. A good control measure is provided when roots and stumps of trees in newly cleared bush are removed before sowing the crop.

Soft Rot of Rhizome

Pythuim spp. causes soft rot of rhizomes. When plants are pale with tips of the leaves turning yellow, this disease is suspected. At a later stage, there is premature, complete yellowing and drying of leaves. The bases of the shoots remain soft to the touch, whereas the rhizome is reduced to a soft decaying mass. Paulose (1973) reported that the disease is soilborne. Therefore, crop rotation is essential to manage this disease. Preplanting treatment of setts with ceresin (0.25 percent solution) has been recommended. Organic soil amendments such as cashew shell and sawdust supplemented with urea as a source of fertilizer at the time of planting have been found useful.

Storage Rots

Storage rots are caused by different fungi: *Penicillium* sp., *Rhizopus* sp., and *Fusarium* sp. Akamine (1962) reported that symptoms include discoloration of the rhizome surface by fungal mycelia accompanied by soft or dry rotting. For control, rhizomes should be

dipped in Captan (1 kg/100 l water) (100 ppm) or Benlate 1,500 ppm before storage. Store only healthy tubers.

Bacterial Wilt

Ralstonia solanacearum (*Pseudomonas solanacearum*) is the casual organism of bacterial wilt. The disease has been reported from many ginger-growing countries. The symptoms are wilting and yellowing of the lower leaves. The wilting extends upward to younger leaves. Wilted leaves are golden brown in appearance. Stems become watersoaked and leaves separate easily from the stem. Infected stems are darker in color. Pegg et al. (1974) reported that white milky exudates easily gush out when the stem and shoots are pressed between the fingers. The disease spreads by means of rhizomes, contaminated farm implements, and running water. Once the inoculum is in the soil, it persists for a long time. Crop rotation is the control. Tomato, potato, pepper, eggplant, and groundnut, which are susceptible to the bacterium, should be excluded in the rotation. Proper disposal of debris is important.

Bacterial Soft Rot

Bacterial soft rot is caused by *Erwinia carotorora.* The symptoms include soft rotting and an unpleasant odor of stem tubers. When a diseased tuber is pressed, it oozes a whitish colored liquid. Pegg et al. (1994) reported that the disease is mostly found in stored ginger. Minimal bruising or wounding of rhizomes is a step to ensure a disease-free product. Timely harvesting of ginger is a good preventive measure. Rhizomes should be allowed to cure before storing. Storage in a cool dry well-ventilated shed is recommended.

Mosaic Disease

Mosaic disease is caused by a virus. The symptom is mottling of leaves preceding stunted growth, as reported by Nambiar and Sharma (1974). Infected plants should be rogued and should not be used for seed ginger.

Nematode (Root Rot) Disease

Meloidogyne incognita and *Radopholus* are the nematodes that attack ginger. The presence of galls on feeder roots are main symptoms. There may be necrotic spots on the outer layer of the rhizome while small light-brown water-soaked spots appear inside (Haynes et al., 1973). Both crop rotation and the use of clean (uninfested) seed ginger are important. Vilson (1979) reported the persistence of burrowing nematodes in fields. Preplanting seed treatment in warm water (48ºC for 20 minutes) provides some check. Elimination of nematodes by tissue culture was reported by De Lange et al. (1987).

Storage Practices

Documentation on the research results of ginger storage is scanty. In the original form of storage the rhizomes were not harvested at crop maturity but maintained or left in the field in the growth environment. Ginger is a perennial crop and so survives many seasons by such an inherent biological perennation mechanism. Now that the crop has

become domesticated, deliberate storing of part of the harvest either for further planting or for processing has become prevalent. Nowadays, ginger is preserved or stored in the following forms:

1. Mature (fresh) ginger is stored for 3 to 5 months as planting material.
2. Green (fresh) ginger in syrup and salt.
3. Ginger of commerce—peeled and dried.
4. Unpeeled—split and dried.

The last three methods are specifically industrial concerns.

One of the early documentations on ginger storage was by Hall (1955) in Sierra Leone. Successful storage practice emphasized the inspection of stored ginger in accordance with the Agricultural Ordinance Regulation, which ensured seed quality control. An interesting finding exposed at this stage was detection of storage insects, mainly *Ahasverus advena* and *Carpophilus dimidiatus*. Akamine (1962) recommended dipping harvested and cleaned rhizomes in 0.05 to 1.0 percent sodium benzoate and 1 to 8 percent potassium sorbate for 5 minutes and thereafter storage in polythene bags as an effective safeguard against mold. Treatment with Orthocide 50 and Zerlate was also reported to have possibilities as a mold inhibitor in Hawaii. The later work, Akamine (1977), underlined sources of deterioration: weightlessness caused by desiccation, decay, sprouting, discoloration, and senescence. An optimum storage environment was established as 13ºC and 65 percent relative humidity.

In India, Kannan and Nair (1965) outlined similar sources of losses—rotting, sprouting, and shriveling. According to these workers, pit storage was the best. Tubers for storage were treated with 0.25 percent solution of wettable ceresin for 30 minutes against rot and stored in pits in a cool place protected from sun and rain. An alternative method was to put the ginger in sand or sawdust bedding, and then it was covered with planks or plastered with mud in which holes were made for ventilation. Paulose (1973) recommended storage in smoke houses. In this case, the rhizomes were first dipped in a thick solution of cow dung and dried before spreading on mats on raised supports.

A typical practice in Nigeria (Anonymous, 1970) was to leave the seed ginger unharvested (delayed harvesting) but mulched with grass 15 cm thick at the end of the rains. An alternative approach was to store in the shade on layers of sand or covered with grass. Okwuowulu and Nnodu (1988) treated rhizomes of varying ages with gibberellic acid (GA_3) 150 ppm and/or Benlate 750 ppm a.i., and stored in moist sawdust in locally woven baskets. The point of interest was the synergistic role of the chemical treatment on sprouting, rotting, and weight loss. The same season, Oti et al. (1988) reported successful storage when the application of the chemicals was eliminated. Rhizomes were also shown to retain their organoleptic properties during the 16 weeks of storage.

Conditioning of rhizomes during crop life has hitherto been taken for granted. However, in a preliminary study Okwuowulu (1992a) reported that adopting an equitable depth of seed placement has the effect of minimizing physiological breakdown in ginger destined for storage.

The main source of loss in seed ginger is sprouting. Storage life ends once sprouting has commenced. Currently, no sprout suppressant is available. The application of a high

concentration of maleic hyrazide (2000 ppm) significantly reduced only sprout growth but not the percentage of sprouted tubers (Akamine, 1962). Furthermore, application of methyl bromide as a fumigant during storage stimulated sprouting rather than suppressed it.

Application of desired doses of a physical mutagen, gamma rays, is found to prevent sprouting entirely. But this becomes a real problem because the stored material cannot become easily reinduced to sprout when desired for planting. According to Akamine (1962), sprouting could be prevented completely by lowering the oxygen tension. But then most of the current ginger-growing world may find this practice too sophisticated at the present time.

Some tips for successful storage include:

1. The harvest date (by month of the year) is not as critical as harvest age because ginger is planted in different months of the year.
2. Harvest when the soil is moist to minimize skin injury.
3. Bruising should be minimal; bruised surfaces shrivel faster and may decay more readily.
4. Expose harvested tubers in the open field for a couple of days so that the succulent anchorage roots can wilt and dry up. Dried anchorage roots are easily detached and leave minimal wounds on the tuberous stem. Cleaner crops are obtained.
5. Harvest the crop at correct maturity. Harvesting immature crops inflicts wounds on the rhizomatous stem during the detachment of the shoots. Immature rhizomes shrivel very fast. They are not plump. On the other hand, overmature rhizomes develop cracks on epidermal peeling and have shortened dormancy.
6. Minimize or avoid delayed harvesting. This leads to substantial losses through desiccation and shrinkage. Where fields are covered with grass at the end of the rains, the chances of bush burning and destruction are high during the dry season.
7. Avoid admixtures. Specific ginger is desired for specific needs. Admixing of cultivars or maturity types during storage may lead to price reduction at the selling point.
8. Conduct regular quality inspection of the stored ginger. This will help in timely detection of losses through various causes and help in adopting the required management measures.

On-Farm Processing

Ginger processing is standardized. The steps include:

- Harvesting
- Sorting

- Washing
- Peeling
- Drying
- Packaging
- Drying
- Grinding

Sorting involves separating the good rhizomes from the shriveled ones and extraneous matter (dry shoot and grass stumps, pebbles and sand). This is followed by primary grading of the rhizomes into small, medium, and large sizes. The small rhizomes are more often stored as seedginger for the next season's planting.

The sound/marketable ginger is packed in basins/barrows and is washed with several changes of clean water until a clean crop is obtained. A good indication of a clean crop is the absence of mold growth in the next couple of days; that is, prepeeling storage. The last two or three water runs remain stably clean. The current peeling process is manual at the local farmers' level and is mostly undertaken by women and children. Most of the losses in ginger processing occur at this stage if due care is not exercised. Manual peeling may not be the best method, but when trained hands are employed, good results are obtained. Sun/natural airdrying is cheaply employed by the local farmers where abundant solar energy is available. However, it prolongs the drying process and permits mold growth, especially when the turning process is relaxed. Mold growth adversely affects the product quality. Moreover, it is difficult to obtain uniform drying under solar energy. Motorized slicing and drying of ginger rhizomes were tested in Fiji (Sharma et al., 1980). Lime treatment is given to improve the rhizome appearance. This treatment also helps to control mold infection.

Insect and microbial infestations also occur. It is to meet specified standards of the export market that insect and microbial infestation controls are undertaken. Various fumigants are used, such as methyl bromide, ethylene di-bromide, ethylene oxide, and formate as recommended by Winarno and Stumbo (1971). However, for export products the use of fumigants should meet the requirements of the importing countries.

Further Processing

Currently, ginger is processed for three principal products: ginger powder, ginger oleoresin, and ginger oil. Harvesting should be adjusted to meet various end uses. The major ones are culinary spicing, flavoring spirits, bakery requirements, meat product curing requirements, ginger for other confections, and drink concentrates. During harvesting, rhizomes should be minimally bruised and the skin should not be carelessly peeled. The skin forms an impervious barrier to moisture loss. The appearance of the dried product is determined largely by the peeling efficiency. For instance, if the epidermal skin is not carefully removed, it causes rupturing and loss of the oleoresin cells embedded near the skin surface.

While drying, 60 to 70 percent of the harvest weight is lost during the attempt to achieve an acceptable moisture content of 7 to 12 percent (commercial grade). Utmost care is therefore taken at this stage. Moreover, admixed ginger commands a poor price because of specific product requirements; ginger with high pungency is better for perfumery and ginger with mild pungency is preferred for confectionaries.

Ginger Powder: Special types of pulverizers with adequate cooling systems are used for grinding ginger. They possess an accessory sieving unit with various types of meshes; the particle size generally depending on the requirement.

Ginger Oil Distillation: Ginger oil is obtained by steam distillation of the ground spice. The oil possesses an aroma and flavor that are cultivar specific. Cultivars with intrinsically high volatile oil and a good aroma and flavor are the best choice. The first step is grinding and sieving in 5 mm mesh. Materials that are superfinely ground often cake-up during distillation. Overheating during grinding should be minimized, and ground materials should not be unduly stored for long before distilling. The charging of ground ginger is done evenly to minimize the formation of a channel through which steam will pass without volatilizing the oil. The preferred method of packing has been to distribute the charge evenly on several perforated trays in the still. The distillation is easily achieved with adequate live steam. The condensed oil and water emitting from the condenser is fed into a Florentine flask and the oil accumulates on the surface. Some distillers cohobate the condensed water to minimize losses of some of the more water-soluble components of the oil. When this occurs, the condensed water is returned to the base of the still and reboiled.

Ginger oil contains a high proportion of low vapor pressure sesquiterpine components—and depending upon the size of the charge in the still and the pressure applied—distillation may last up to 20 hours.

Ginger Oleo'resin Extraction: Ginger oleoresin is a semisolid mass obtained by solvent extraction of ginger powder followed by removal of the solvent. It contains variable amounts of volatile oil, pungent principles, fatty oil, and other extractives of the spice soluble in the solvent. The oleoresin contains the full complement of organoleptics of the natural spice. To obtain the oleoresin, ginger is ground to a coarse powder, followed by a cold solvent extraction, and then stripping off of the solvent from the extract. The grind size, nominal aperture 400 to 500 microns, is in common use in Nigeria. Finer grinds tend to cake-up easily and also give slow rates of extraction. Extraction is effected in columns packed with ground spice by percolation and circulation of cold solvent. Alternatively, a counter current process employing a number of extractors mounted in series is used. Portions of the solvent extract are drawn off when containing at least 10 percent soluble solids and are distilled under reduced pressure to strip off the solvents. By this method, Ebewele and Jimoh (1988) observed quality deterioration, which became noticeable at 90ºC. They, therefore, recommended a much lower temperature. They also advocated the use of taller fractionation columns and carefully controlled distillation rates. To obtain good extraction yield, chemical constitution, and aromatic properties of the oleoresin product, solvents frequently employed include ethylene dichloride, trichlorothylene, acetone, and ethanol. Because of the low boiling point and consequent ease of solvent recovery, acetone is a favorite solvent.

For large batches, internally lacquered stainless steel drums and special density polythene drums are preferred.

Products

- The bulk of the ginger now sells as ginger powder, oleoresin, and ale products. Conveniently, the ginger oils are obtained as earlier described by distillation

advocated and adopted by the Federal Industrial Research Institute Oshodi (FIIRO) that gives up to 4 percent oil with simultaneous production of ginger oleoresin extracts. Commercial products exist in the following forms in Nigeria.

- Ale concentrates: Golden ale and the pale dry ale. The ale is a clear bright beverage with a sparkling, slight, but lasting, foam head.
- Ginger beer concentrates: This has a pleasant flavor and slightly pungent aroma. It was the traditional product prior to the introduction of a method of production and preservation of the beer.
- Ginger apple concentrate: The concentrate is used to make a ginger apple drink in which the main taste component is the soluble ginger extract prepared by encapsulation.
- Spicy ginger concentrates: This is used to flavor sweets, and is made from ginger oleoresin extracts mixed with orange oil.
- Ginger ice cream: The popular cream has as the recommended recipe 16 l of cream mixes, 5 g of ginger powder, appropriate volume of oleoresin and vanilla.
- Gingered soup: In homes ginger powder is preferred in the preparation of soup, especially the so-called pepper-soup in Nigeria.
- Gingered biscuits: The recipe has 250 g of ginger powder to 400kg of relevant biscuit dough. Other proportions are used to produce ginger cakes and ginger bread.
- Ginger in jollof rice cookies: In this case, fine ginger powder is sprinkled on prepared jollof rice to give it a desired hot, but pleasant, flavor.
- Ginger powder in Suya-meat: Ginger powder in appropriate quality is used in the preparation of suya mixes.

Processing for Market

Ginger is generally made available in two major forms. It is either available as fresh ginger used for preparation of candied ginger and ginger beer or as dried ginger available in the spice trade for oleoresin and oils. The procedure outlined by Meadows (1988) has been largely adopted.

For the green ginger product, the crop is harvested as earlier described, cured, put in baskets, covered with leaves, and sold as fresh green ginger. For the preparation of split-dry or African ginger, the rhizomes are split longitudinally, usually with a sharp table knife, spread on a mat-covered platform, and turned intermittently until it is properly dry. In certain cases, the cleared whole or split ginger is scalded in water for a couple of minutes before the drying process.

For the peeled or Jamaica-type ginger, the rhizomes are placed in a large vessel/basin containing water, and the outer skin carefully scraped off using a blunt knife. Much care is taken to peel off only the skin. The peeled fingers are washed in several changes of water before spreading in the sun for air drying. In Jamaica the rhizomes are blanched in 10 percent lye solution at 100ºC for 3 minutes.

Basic Uses

> **The divergence in taste of ginger between east and west may be highlighted by the fact that while figures show the French to eat 1 1b of ginger each year per head, the Koreans eat 18 1bs. (Anonymous, 1989)**

Ginger has been cultivated and processed for over 3,000 years. Nationally, it is increasingly marketed in fresh form, and internationally it is widely sold in dried and powdered forms for culinary purposes. When chewed in fresh form, ginger stimulates the flow of saliva. Ginger is stimulatory when inhaled and tends to keep the sweat pores open. It produces a feeling of warmth in the epigastrum. Ginger is an essential ingredient in treating colic to reduce constriction of the throat associated with tonsillitis; in dyspepsia and as an adjunct to purgatives to reduce their gripping action. Many value ginger as a carminative and aromatic stimulant for the gastrointestinal tract.

Cooks use ginger powder in soups and stews and often also as a stimulant in tea and pap. Ginger is versatile as a spice in ethnic cooking in many Oriental, African, and Afro-Caribbean dishes as flavoring, seasoning, and garnish.

Ginger beer, ginger wines, and also ginger ales are popular drinks, and ginger cakes, bread, biscuits, and cookies (gingersnaps) are eaten with relish. Ginger in fresh form is common in shops catering to the ethnic communities. Ginger in powdered form is sold in groceries. Ginger is available as oleoresin, as oil, or as concentrate in various perfumes, and is an ingredient in pickles, steamed puddings and sauces, chutneys, salad dressings, and fruit pies.

Anonymous (1970) and Nandakumar (1988) described the use of ginger in the manufacture of industrial ginger oil, ginger essence, and ginger oleoresin. Okwuowulu et al. (1988) reported that many traditionalists enjoy slices of fresh ginger served as complements with kolanuts (*Kola nitida* and *K. accuminata*), and when blended in prepared groundnut (*Arachis hypogea*) paste, goes well with eggplant, *Solanum macrocarpum* and *S. africanum*. In this form, ginger substitutes for *Aframomum melegueta* (Aligator pepper or grain of paradise) and *Denettia tripetala* (Nigerian pepper or fruit Murimi in Igbo language) in terms of pungency and pleasant flavor. Numerous other recipes and a new style of ginger powder have been developed (Chou et al., 1981). Preserved ginger (ginger in brine) is used for culinary purposes and ginger syrup and crystallized ginger in the food industry. Ginger has been occasionally used as a masking agent for mouth odor in dentrific and oral hygiene products.

Some Constraints

The need for research and development arises to assist the primary producers of ginger to reap equitable benefit from their production effort. Little attention has hitherto been devoted to crop improvement. Cultivation of poor yielders and prolonged exploitation of old stock is the first constraint. A large number of intermediaries and marketing chains (not within the control of the producer) have also constrained the farmer to reap even a marginal profit (Okwuowulu, 1997).

Selection of the best cultivar and adoption of available production regimens have helped the farmer to attain a high yield potential. Judged by the opportunity, resources, and

cost of production at the farmer's disposal, it was the best that could be obtained. On the other hand, high yields, in quantitative terms, are not always related to high quality; that is, earning a high price at the export market. For example, ginger furnishes an example of a situation in which preferences are expressed by consumers for specific characteristics of a particular country of origin for use in a particular application and where supply problems exist for certain types. For instance, the Jamaican ginger is highly prized for its fine flavor, whereas the Nigerian ginger is valued as mere raw material for distillation and extraction and hence attracts a drastically low price.

In the present scenario, the absence of desired improvement in the production technology makes ginger remain a crop that is hand picked, cleaned, and stored, which means that the farmer is at the mercy of the processor, who couldn't care less whether or not the primary grower breaks even or not. To make ginger production more profitable, it is necessary to develop high-yielding lines that are resistant to the major diseases. Constraint alleviation is an important requirement for a productivity increase. Much research inputs are needed for the development of high-yielding lines, resistance to biotic stress factors, and for alleviating constraints.

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8 Diseases of Ginger

N.P. Dohroo

Ginger is an herbaceous plant and many pests and diseases affect this crop (Dohroo and Edison, 1989; Dohroo, 1997). Of these, rhizome rot, bacterial wilt, yellows, *Phyllosticta* leaf spot, and storage rots are major diseases that cause economic losses (Nadda et al., 1996). In Kerala, bacterial wilt and rhizome rot are prevalent in all major ginger-growing areas (Dake, 1995). Thirty-nine microorganisms have been reported to be associated with ginger in the field or storage including two nematode species (*Meloidogyne incognita* and *Pratylenchus coffeae*) and one wilt bacterium. *Pythium aphanidermatum*, *Fusarium oxysporum, Ralstonia solanacearum* and *Pratylenchus coffeae* are potent pathogens causing soft rot, yellows, bacterial wilt, and dry rot, respectively, in the field or in storage (Srivastava et al., 1998).

Fungal Diseases

Soft Rot

Soft rot is also called rhizome rot or *Pythium* rot. Butler (1907) recorded the incidence of this disease for the first time from Surat (Gujarat) in India. The disease is prevalent in India, Japan, China, Nigeria, Fiji, Taiwan, Australia, Hawaii, Sri Lanka, and Korea. Nepali et al. (2000) reported the severity of rhizome rot in Nepal and found that the losses due to this disease were 25 and 24 percent in the field and storage, respectively. Distribution of *Pythium* species causing soft rot of ginger is shown in Table 8.1.

Table 8.1 Distribution of *Pythium* species causing soft rot of ginger

Sl. No.	*Organism*	*Location*	*Reference*
1.	*P. aphanidermatum* (Edson) Fitz.	Kerala Hyderabad (AP) Nagpur (Maharashtra) Madhya Pradesh Pusa (Bihar)	Sarma et al. (1979) Vaheduddin (1955) Shahare and Asthana (1962) Haware and Joshi (1974) Mitra and Subramanian (1928)
2.	*P. butleri* Subram. (Syn. *P. aphanidermatum*)	Kerala South Kanara (Karnataka) Ceylone	Thomas (1938) Thomas (1938) Park (1934)
3.	*P. delience* Meurs	Madhya Pradesh	Haware and Joshi (1974)
4.	*P. gracile* (de Bary) Schrent. (Syn. *P. aphanidermatum*)	Bengal, Gujarat Kerala Assam Fiji	Butler (1907) Sen (1930) Parham (1935)

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Table 8.1 (continued)

Sl. No.	*Organism*	*Location*	*Reference*
5.	*P. complectans* Braun	Ceylon	Park (1937, 1937)
6.	*P. graminicolum* Subram.	Ceylon	Park (1935)
7.	*P. myriotylum* Drech.	Kerala	Dake and Edison (1989)
		Poona	Uppal (1940)
		Bombay	Patel et al. (1949)
		Nagpur	Shahare and Asthana (1962)
		Taiwan	Lin et al. (1971)
		Ceylon	Park (1937)
		Hong Kong	Bertus (1942)
8.	*P. myriotylum* and *Fusarium solani*	Rajasthan	Mathur et al. (1984)
			Doorjee (1986)
9.	*P. ultimum* Trow.	Himachal Pradesh	Dohroo et al. (1987)
10.	*P. pleroticum* T.	Solan (Himachal Praesh)	Dohroo and Sharma (1985)
11.	*P. vexans* de Bary	Kerala	Ramakrishnan (1949)
12.	*P. zingiberum*	Osaka (Japan)	Takahashi (1954)
		Korea	Yang et al. (1988)

Table 8.2 Distribution of *Pythium* spp. in India (up to 1994)

Sl. No.	*Species*	*State*
1.	*P. aphanidermatum* (Edson) Fitzp. (including synonymous taxa)	Kerala, Andhra Pradesh, Maharashtra, Bihar, Madhya Pradesh, Karnataka, West Bengal, Gujarat, and Assam
2.	*P. myriotylum* Drech	Kerala, Maharashtra, Rajasthan, Himachal Pradesh
3.	*P. pleroticum* T.	Himachal Pradesh
4.	*P. vexans* de Bary	Kerala
5.	*P. ultimum* Trow.	Himachal Pradesh
6.	*P. deliense* Meurs.	Madhya Pradesh

In India this disease has been reported from almost all states, including Kerala, Rajasthan, Himachal Pradesh, Orissa, Maharashtra, Tamil Nadu, Andhra Pradesh, and Sikkim. Soft rot reduces the potential yield to a great extent in the field, storage, and market and may cause losses of even more than 50 percent (Joshi and Sharma, 1980). Crop loss depends on the growth stage at which infection starts. Total loss results if the infection occurs in the early stage of crop growth. In Kerala, the loss can be as high as 90 percent during heavy infection (Rajan and Agnihotri, 1989). Sinha and Mukhopadhyay (1988) reported losses up to 50 to 90 percent under storage (Table 8.2).

Symptoms

Ginger plants are susceptible to *Pythium* infection at all stages of growth. Buds, roots, developing rhizome, and collar regions are the main points of infection. When the seed rhizomes are infected, they fail to sprout due to the rotting of buds (Figure 8.1). After sprouting, the infection takes place through roots or through the collar region, finally

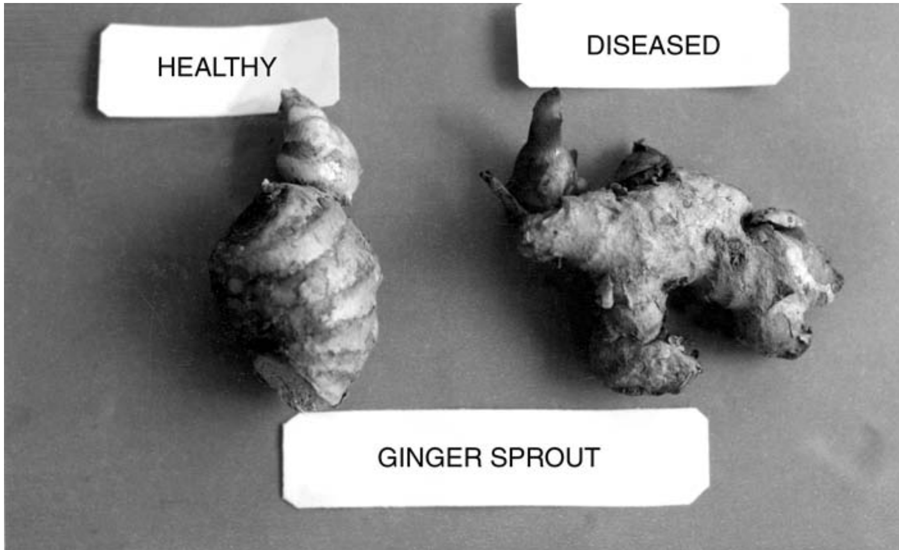

Figure 8.1 Ginger sprout affected with *Pythium ultimum*.

reaching the rhizome. Symptoms appear initially as water-soaked patches at the collar region. These patches enlarge and the collar region becomes soft and watery, and then rots. Sprouts turn yellow and collapse.

In mature plants, infection leads to yellowing of leaves. This yellowing starts from the leaf tip and spreads downward, mainly along the margins resulting in death of leaves. The dead leaves droop and hang down the pseudostem until the entire shoot becomes dry (Figures 8.2 and 8.3). The basal portion of the plant exhibits a pale translucent coloration. This area later becomes water soaked and soft to such an extent that the whole shoot either topples or can easily be pulled out.

Rhizomes first turn brown and gradually decompose, forming a watery mass of putrefying tissue enclosed by the tough skin of the rhizome (Figure 8.4). The fibrovascular strands are not affected and remain isolated within the decaying mass. Roots arising from the affected regions of the rhizome become soft and rot (Dohroo, 1982). The rotten parts emit a foul smell. Rotting attracts opportunistic fungi, bacteria, and insects. Severe infestation can lead to total crop loss (Figure 8.5).

The Pathogen

Butler (1907), who reported the disease for the first time, identified the causal organism as *Pythium gracile* Schenk. Several species of *Pythium* have since been reported to cause the disease in different parts of the world: *P. aphanidermatum* (Edson) Fitz. (Mitra and Subramanian, 1928), *P. butleri* Subram. (Thomas, 1938), *P. complectens* Braun (Park, 1934), *P. deliense* Meurs (Haware and Joshi, 1974), *P. gracile* (deBary) Schenk (Butler, 1907), *P. graminicolum* Subram. (Park, 1935), *P. myriotylum* Drechsler (Uppal, 1940; Park, 1941; Bertus, 1942), *P. vexans* deBary (Ramakrishnan, 1949), *P. pleroticum* T. Ito (Sharma and Dohroo, 1980), *P. zingiberum* (Ichitani and Shinsu, 1980), and *P. ultimum* (Dohroo and Sharma, 1985).

Figure 8.2 Rhizome rot symptoms.

Figure 8.3 Rhizome rot–affected rhizome and tillers.

Figure 8.4 Rhizome rot–affected rhizome showing decay.

Figure 8.5 A ginger field devastated by rhizome rot.

Butler and Bisby (1931) considered *P. butleri* and *P. gracile* to be identical with *P. aphanidermatum*. Three species of *Pythium*—*P. aphanidermatum* (Haware and Joshi, 1972), *P. deliense* (Haware and Joshi, 1974) and *P. myriotylum* are reported to be responsible for soft rot in Madhya Pradesh, India. On the West Coast of Madras in India, *Pythium* spp.

occurs in association with *Sclerotium rolfsii* and causes rhizome rot (Anonymous, 1953). Table 8.2 gives the *Pythium* species causing soft rot in various parts of India. *P. aphanidermatum* and *P. myriotylum* are the dominant species.

In Himachal Pradesh, *P. pleroticum* is found in association with *Fusarium equiseti. P. pleroticum* causes wet rot, whereas *F. equiseti* is responsible for dry rot under field and storage conditions (Sharma and Dohroo, 1980). Bhardwaj et al. (1988b) reported five pathogens of rhizome rot of ginger in Himachal Pradesh: *P. pleroticum, P. aphanidermatum, P. ultimum* (Dohroo, 1987), *F. equiseti,* and *F. solani*.

P. vexans has been observed at an altitude of 1,170 m in the Wynad area in Kerala, India. The temperature requirement of this species is lower than that of other species, with the maximum tolerance limit being 34ºC. For germination of *P. aphanidermatum* and *P. myriotylum*, the optimum temperature is about 34ºC (maximum is 40ºC), and for *P. pleroticum*, it is 25 to 30ºC. However, the optimum temperature for the growth and multiplication of *F. equiseti* is 30ºC (Dohroo, 1979). A warm and humid climate predisposes ginger plants to infection at the sprouting stage itself because of their tender and succulent tissues (Dake, 1995). There are two ways in which the disease is carried over and perpetuated: through diseased rhizomes and through oospores surviving in debris in soil. The infected rhizomes and roots remaining in the field form an important source of primary infection. Such plant parts may contain large numbers of perennating oospores. Oospores have also been detected in the scales of stored rhizomes (Thomas, 1938). The spread of the disease is typical of soilborne diseases because of fairly heavy and well-distributed showers during the crop season from June to October (Dake, 1995).

Pythium has well-developed mycelia often with appressoria. Zoosporangia are filamentous, and not differentiated from vegetative hyphae. The hyphae are colorless, although occasionally appear yellowish. *Pythium* has specific cultural requirements. On corn meal agar and potato carrot agar, most species do not produce aerial mycelia, whereas in oatmeal agar most species produce profuse aerial mycelia. Various colony patterns on agar media have been recognized that depend on the medium and incubation temperature (Van der Plaats Niterink, 1981). Van der Plaates Niterink (1981) gave the morphological characters of various species in his monograph on the genus.

Histopathological investigations of rhizome rot are lacking. However, it is known that *Pythium* spp. are intercellular as well as intracellular. Tissue degeneration occurs in advance of colonization of the host tissue. Dissolution of the middle lamella leads to soft rot symptoms. In this process of rotting amylase, invertase, macerating, and oxidative enzymes are found to play their roles (Dohroo, 1982; Dohroo et al., 1984b; Sharma and Dohroo, 1985; Dohroo, 1989b).

Disease Cycle

The primary source of soft rot is the oospore present in the diseased rhizome or the soil. The oospore germinates directly or indirectly. In the first case, the oospore produces a germ tube that elongates and either produces a sporangium or penetrates the host directly. In the second case, the oospore germinates, producing a sporangium and zoospores. It has been reported that host root exudate causes the accumulation of zoospores around the root zone and accelerates their encystment, germination, and infection (Tripathi and Grover, 1978). In addition, infection can also be by the appresoria formed by the hyphal elements.

Spread of disease is by waterborne zoospores or hyphal fragments. Such waterborne zoospores are attached to the ginger root, where they encyst and produce germ tubes that infect roots. The lesions appear at the point of entry within 72 hours under ideal weather conditions. Sporangia are produced on the surface of host lesions. Oospore formation takes place in the host tissue or in the soil. The oospores are dormant structures and help in perennation.

Several factors influence the *Pythium* infection and disease development. The important ones are weather and soil factors. High soil water, high relative humidity, and relatively low temperature favor the disease development and spread. Ginger planting often coincides with monsoon rains, and during this time, the soil water and ambient temperature (25 to 30°C) become conducive to the onset of disease (Sarma, 1994). Once disease starts, it spreads to the adjacent clumps mostly through soil water by means of zoospores and hyphal fragments. The disease is generally less in well-drained soils while water stagnation aggravates the disease incidence (Sarma, 1994).

Management Measures

Healthy Rhizome Selection: Infected rhizomes are the primary source of perennation and spread of soft rot. The best method to manage the disease is by the use of disease-free rhizomes for planting (Park, 1941; Bertus, 1942; Shahare and Asthana, 1962; Dohroo, 1993).

Narrow Ridge Cultivation: Kim et al. (1998) reported that narrow ridge cultivation reduced the disease (*P. myriotylum*) effectively compared to the unridged control plots in all the fields tested.

Mulching: Das (1999) showed that the plots mulched with maha neem (*Melia azadirachta*) leaves (2.5 kg/m^2) were completely free from rhizome rot (*P. aphanidermatum*).

Soil Solarization: Soil solarization is a soil disinfection practice achieved by covering moist soil with transparent polythene film during the period of high temperature and intense solar radiation. Such a situation leads to the eradication or substantial reduction of soilborne inocula, and consequently a substantial reduction in disease incidence (Katan, 1981) Compared to other soil disinfection methods, solarization is nonhazardous, more economical, and leaves no residue. Soil solarization as a process of preplant soil disinfection was first advocated by Katan et al. (1976), and is presently used widely all over the world.

Soil solarization involves the following steps: preparing the field to make it ready for planting, spreading a transparent polythene sheet evenly on the soil surface, taking care to avoid formation of air pockets, and sealing the side of the sheet. The polythene sheet should be ideally about 300 μ thick. Adequate soil moisture is necessary during solarization to increase the thermal sensitivity of the target organism, to improve heat conduction in the soil and to enable biological activity (Katan and De Vary, 1991). Soil is generally irrigated once before covering with polythene. Solarization should be done during the months of March to May under Indian conditions when the solar radiation is most intense. The soil should be kept covered for 45 to 60 days.

Soil solarization helps in pathogen and disease control, and as a result leads to significant yield increase (Davis, 1991). Solarization also helps in weed control. *Pythium* control through solarization has been reported by many workers (Chen and Katan, 1980;

Table 8.3 Effect of soil solarization on inoculum density (CFU/g soil) of *P. aphanidermatum*

Treatment	*15 days after*			*30 days after*		
Soil depth	0–10	10–20	20–30	0–10	10–20	20–30
S	41.66	33.33	8.33	33.33	50.0	158.39
NS	166.66	191.66	8.33	158.3	183.3	208.3

Reduction % (0–30 cm): 15 days after: 77%
30 days after 56%
S, Solarized; NS, Nonsolarized
CFU, colony-forming units.
Source: Panayanthatta (1997).

Cook et al., 1987; Vilasini, 1996; Panayanthatta, 1997). Panayanthatta (1997) has determined the inoculum density of *P. aphanidermatum* for 3 years in solarized and non-solarized soils at three depths (Table 8.3). The inoculum density on the 15th day after tarping was 41.66 colony-forming units (CFU)/g of soil in solarized plots compared to 166.66 CFU/g of soil in nonsolarized plots at 0 to 10 cm depth; 33.33 CFU/g and 191.66 CFU/g at 10 to 20 cm depth and 8.3 and 8.2 CFU/g of soil and 20 to 30 cm, respectively.

If solarization is done properly, it enhances the soil temperature from 37 to 52ºC, which is sufficient to kill most pathogenic fungi (Katan et al., 1976; Katan, 1981). The thermal inactivation point of *Pythium* species is between 37 and 50ºC. In *P. ultimum*, for example, the LD_{90} is achieved in 17.9 days at 37ºC and 33 minutes at 50ºC (Pullman et al., 1981). Soil solarization also set the soil for increased activity of antagonistic organisms (Katan et al., 1983). Rapid colonization of solarized soil by antagonistic *Trichoderma* has been demonstrated (Elad et al., 1980). Solarization is an important component of integrated disease management. Panayanthatta (1997) obtained a reduction in the rhizome rot incidence as a result of soil solarization (Table 8.4).

Chemical Control: Various types of seed treatments with different chemicals have been tried by various workers to kill the rhizome-borne inoculum. Treatment of rhizomes with 0.1 percent mercuric chloride for 24 hours (Park, 1935) or 90 minutes (Thomas, 1941; Kothari, 1966), Ceresan (0.25 percent) (Thomas, 1940; Anonymous, 1953), and Agrosan-GN (0.25 percent) treatment for 30 minutes are effective against rhizome rot (Thomas, 1941). Simmonds (1958, 1959) controlled the rhizome rot caused by *Fusarium oxysporum* by 10-minute immersion of rhizomes in standard mercurials at 2 lb/40 gal.c

Mathur et al. (1985) controlled rotting caused by *P. aphanidermatum* and *F. solani* with the help of Bayleton (triadimefon). Other fungicides tested, such as Fenaminosulf, Difolatan (captafol), Syllit (dodine), and Ridomil (metalaxyl), were also effective. Chemicals such as Antracol (propineb, 0.25 percent), Fycop and Blitox-50 (copper oxychloride, 0.3 percent) are also effective in the control of rhizome rot (Dohroo and Sharma, 1986).

Table 8.4 Effect of soil solarization on disease incidence and yield (3 years average)

Treatment	*Germination (%)*	*Disease incidence (%)*	*Yield per 3 m^2 bed (kg)*
Solarized	99.17	23.87	2.91
Nonsolarized	96.54	41.02	0.95

Dithane M-45 (mancozeb), Difolatan (captafol), Ziride, Captan, and metalaxyl have also been found to reduce the infection and increase the yield (Thakore et al., 1988).

Many workers have also tested different chemicals as soil drench against rhizome rot of ginger. Treatment of soil with Bordeaux mixture (4:4:50), perenox (0.35 percent) and Dithane Z-78 (0.15 percent) (Shahare and Asthana, 1962), soil drench with 0.1 percent $HgCl_2$ (Kothari, 1966), Thiram (0.5 percent), Ceresan wet (0.5 percent), Dithane (0.2 percent), methyl bromide (Ichitani, 1980), Dithane Z-78, Difolatan (Sharma et al., 1980), Aliette, Bordeaux mixture, Dithane M-45, and Difolatan (Anila and Mathur, 1987), and Ridomil granular application in soil have proven effective in reducing the rhizome rot (Dohroo et al., 1984a). Kim et al. (1998) reported that the soil disinfection by dazomet application showed the most prominent inhibition effects in field studies.

As the disease is both seedborne and soilborne in nature, the use of disinfected seed rhizomes and drenching the soil with a chemical simultaneously have proven more effective in comparison with either seed treatment or soil application alone. Dipping the seed rhizomes in Bordeaux mixture (BM) (2:2:50) and drenching the soil 8 days before sowing with BM satisfactorily controlled soft rot due to *P. myriotylum* (Bhagwat, 1960). Rosenberg (1962) found seed treatment with Aresan and soil fumigation with Trizone to be promising in the control of disease. In the Philippines, sowing of seed rhizomes after disinfecting in 0.06 percent mercury seed protectant for 90 minutes and addition of DDT or aldrin in soil against insects is recommended by Pordesimo and Raymundo (1963) for successful control of rhizome rot of ginger. The incidence of disease also has been reduced by treatment of seed with echlomezol and soil with methyl bromide. Application of echlomezol as a drench around sources of primary infection prevented further spread of the disease (Ichitani, 1980). Blitane (Zineb + copper oxychloride), Dithane Z-78, and Difolatan when used as drenches plus seed treatment also gave good results (Sharma et al., 1980).

Rathaiah (1987) observed that dipping or wetting of seed pieces 1 day before planting and soil drenching with a mixture of Ridomil + Captafol, 3 months after planting controlled rhizome rot and increased the yield of ginger. Fosetyl-Al, Metalaxyl, oxadixyl, propanocarb, and ethazole (epidiazole) also have been evaluated against *P. aphanidermatum* (Ramachandran et al., 1989). Of these fungicides, metalaxyl formulations (Ridomil 5 G and Apron 35 WS) gave best control of the disease when used as soil and seed treatments. Rhizome rot caused by *F. oxysporum* was controlled by soil treatment with 4 percent formaldehyde combined with treatment of rhizome planting material with Topsin-M at 0.1 percent. Rhizome treatment with 0.1 percent Bavistin or 0.3 percent Dithane M-45 and soil treatment with formaldehyde also have been found to be effective against *Fusarium* rot.

Srivastava (1994) managed soft rot (*P. aphanidermatum*) in Sikkim (India) effectively by drenching the soil with zineb or mancozeb following rhizome treatment with carbendazim and incorporating Thiodan dust into the soil to control insect invasion. Nath (1993) suggested planting of ginger under shade after treating with 1 percent formaldehyde. In Himachal Pradesh, rhizome treatment with Indofil M-45 + Bavistin (0.25 + 0.1 percent) and soil application of Phorate (12 kg/ha) managed rhizome rot and increased the yield (Table 8.5).

Soil amendments alter the soil reaction, change the spectrum of soil microflora, and thus affect the proportion of pathogens existing in soil (Dohroo, 1993; Dohroo et al., 1994; Dohroo and Pathania, 1997). In the case of ginger, Ghorpade and Ajri (1982) observed a reduction in rhizome rot incidence after addition of soil amendments like oil

Table 8.5 Effect of chemicals on the control of rhizome rot of ginger (1992–1994)

Treatment	*Disease incidence (%)*			*Mean*	*Yield (kg/3 m²)*			*Pooled*
	1992	*1993*	*1994*		*1992*	*1993*	*1994*	*Mean*
Bavistin	9.2	11.4	7.8	9.33	9.6	5.55	3.63	6.26
Indofil-45	19.0	12.0	6.3	12.43	9.5	4.75	4.4	5.9
Indofil-M 45 + Bavistin	3.2	5.3	6.0	4.83	12.8	6.0	4.61	7.93
Blitox-50	14.0	14.3	10.0	12.76	8.1	4.47	2.73	5.37
Captan	5.5	8.0	12.75	8.75	7.8	5.5	2.16	5.93
Ridomil MZ	8.2	12.6	12.5	11.1	7.0	5.4	2.3	5.7
Phorate	8.5	13.3	9.6	10.46	8.2	3.5	2.96	5.85
Phorate + Indofil M-45 + Bavistin	0.0	2.3	10.5	4.26	16.6	6.5	2.7	8.2
Control	25.4	20.0	12.4	19.26	8.6	3.4	2.51	4.56

Source: Report of work done on management of rhizome rot of ginger under AICRP on spices, UHF, Nauni.

Table 8.6 Effect of organic amendments on the incidence of rhizome rot and populations of nematodes in soil

Treatment[a]	*Disease incidence (%)*	*Nematode population*[b] *Meloidogyne incognita*	*Pratylenchus coffeae*	*Yield (kg/3 m²)*
Neem cake powder	4.0	47.0	0.0	6.23
Wood sawdust	8.2	100.0	0.0	3.45
Pine needles	2.4	0.0	0.0	4.10
Oak leaves	8.5	80.0	0.0	5.73
Control	10.0	180.0	0.0	1.86
$CD_{(0.05)}$	—	—	—	2.30

[a]Treatment at 4 kg/3 m² plot size
[b]Nematode population per 250 g soil sample.

seed cakes in the field. The amendments also increased the yield (Sadanandan and Iyer, 1986). Rhizome rots caused by *F. solani* and *P. aphanidermatum* are also reduced by amendments using oil cakes made from *Azadiracta indica* (Table 8.6), *Calophyllum inophyllum*, or *Pongamia glabra* (Thakore et al., 1987). Lee et al. (1990) studied the properties of suppressive and conducive soils on ginger rhizome rot in Korea.

Biological Control: Thomas (1939) suggested biological control of *Pythium* sp. using *Trichoderma lignorum* as an antagonist. He observed that the increased acidity of the medium resulting by the antibiosis effect of *T. lignorum* might be responsible for reduced growth of *Pythium.* Antagonism studies of *Trichoderma* sp. to *P. aphanidermatum*, *F. equiseti, F. solani, Cladosporium cladosporioides,* and *Mucor hiemalis* also have been studied in vitro (Bhardwaj and Gupta, 1987). *T. harzianum* and *Gliocladium virens* are also known to

inhibit the growth of *F. oxysporum* f. sp. *zingiberi* when it caused rhizome rot in ginger (Sharma and Dohroo, 1991).

Bhardwaj et al. (1988a) treated the rhizomes by steeping in a spore suspension of *T. viride* or smearing with *T. hamatum* and found effective inhibition against *P. aphanidermatum*. Prestorage steeping of rhizomes in *T. hamatum* suspension or by smearing with *T. viride* also showed inhibition against *F. equiseti*. Rathore et al. (1992) suggested that *T. viride* produce some nonvolatile substances that inhibit the growth of *P. myriotylum and F. solani*. Ram (1988) reported a significant reduction in rhizome rot when *Trichoderma viride* was applied to soil along with sawdust. Panayanthatta (1997) has isolated a biocontrol organism from native soils, and eight such isolates were tested under field conditions for the control of rhizome rot. Infected soil was treated with *Sorghum* grain preparation of antagonists before planting ginger. All treatments, except *Absidia*, improved rhizome sprouting significantly. The incidence and severity of rhizome rot was also less, and yield increased in such treatments (Table 8.7).

Rhizome treatment with *T. harzianum, T. aureoviride*, and *Gliocladium virens* and a nonresident isolate of *T. viride* reduced ginger rhizome rot, a rhizome- and a seed-borne disease caused by *F. solani* or *P. myriotylum* or both and significantly increased the yield (Ram et al., 2000). Shanmugam et al. (2000) indicated that *T. harzianum* and *T. viride* are potential antagonists against *P. aphanidermatum*. Bhat (2000) found that *Oxyspora paniculata* extracts gave highest inhibition of *P. aphanidermatum* while *Macaranga denticulata* extracts gave complete inhibition of *Pythium* sp.

Table 8.7 Effects of fungal antagonists on rhizome rot

Sl. No.	*Antagonist*[a]	*Germination (%)*	*Disease Incidence (%)*	*Disease Severity (%)*	*Yield (Fresh wt. of rhizome) g/pot*$^{-1}$
1.	*Trichoderma harzianum* GTH 1	100 (90.0)a	00.0 (00.0)c	00.0 (00.0)c	358.0a
2.	*Trichoderma hamatum* GTHA1	100 (90.0)a	00.0 (00.0)c	00.0 (00.0)c	344.0a
3.	*Trichoderma aureoviride* GTA 1	100 (90.0)a	10.0 (9.0)bc	7.49 (6.57)bc	219.0b
4.	*Aspergillus niger* GAN 1	100 (90.0)a	00.0 (00.0)c	00.0 (00.0)c	331.0a
5.	*Aspergillus niger* GAN 2	100 (90.0)a	22.5 (12.00)bc	16.42 (15.72)bc	179.0bc
6.	*Aspergillus terreus* GAT 2	97.5 (87.0)a	27.5 (25.5)b	221.72 (21.89)bc	232.0b
7.	*Penicillium sp.* GPE 1	100 (90.0)a	25.0 (21.0)bc	19.25 (17.54)bc	192.7bc
8	*Absidia cylindrospora* GAC 1	80.0 (67.5)b	36.6 (32.47)b	30.58 (27.36)b	140.3c
9.	Control (infested soil)	75 (66.0)b	80.55 (71.6)a	73.03 (64.94)a	043.5d

Figures in parentheses are Arcsin transformed values.
Figures followed by different letters are significant ($P \leqslant .05$).
[a]Sorghum grain preparations of the antagonists were used for preplanting soil application.
Source: Panayanthatta (1997).

Table 8.8 Variability in reaction to *P. aphanidermatum*

% Infection	*No. of accessions and examples*
100	45 Erattupetta, Nadia, Narasapattam, Rio de Janerio, Zahirabad
75–100	43 Burdwan, Himachal, Jugijan, Karakkal, Maran, Rajgarh, Taffingiva340
50–75	56 Edappalayam, Ernad-chernad, Jamaica, Kunduli-local, Zahirabad (607), Assam, Suprabha, Valluvanad
Below 50	4 Thinladium, Wynad-Kunnamangalam, Acc. 215, Acc. 250

The related taxa (*Zingiber zerumpet*, *Z. roseum*, and three other *Zingiber* species) tested were resistant to mildly susceptible.

Resistant Cultivars: Cv. Maran has been reported to show field resistance to ginger rot caused by *P. aphanidermatum* (Indrasenan and Paily, 1974). Setty et al. (1995a) evaluated 18 ginger cultivars against rhizome rot (*Pythium* sp.) and found that cultivars Suprabha and Himachal Pradesh showed less than 3 percent disease incidence.

Panayanthatta (1997) tested 148 accessions of ginger and 7 related taxa for assessing their reaction to rhizome rot caused by *P. aphanidermatum*. All the accessions were susceptible and the incidence was less in five accessions: namely IISR-73, 79, 215, and 250 (Table 8.8).

Yellows

Simmonds (1955) described ginger yellows for the first time in Queensland and later in Hawaii (Trujillo, 1963) and India (Haware and Joshi, 1973). It is a very serious stem rot disease, that in its severe form can devastate the ginger crop almost totally. In South Africa, *F. oxysporum* f. sp. *zingiberi* was found to cause yellows (Manicom, 1998).

Symptoms

On leaves, symptoms appear as yellowing of the two margins of the lower leaves, which gradually spreads over the entire leaf. Older leaves dry up first, followed by the younger ones (Trujillo, 1963). Plants may show premature drooping, wilting, yellowing, and drying in patches or in the whole bed (Figure 8.6). Plants, however, do not fall on the ground. The basal portions of the affected plants become soft and watery and the shoot can be easily pulled out from the mother rhizome. Plants may show stunting.

In rhizomes, a cream to brown discoloration accompanied by shriveling is commonly seen. Central rot is also prominent. Rotting of roots occurs and the rhizome formation is affected. In final stages, only the fibrous tissue remains within the rhizomes. A white cottony fungal growth may develop on the surface of stored rhizomes.

The Pathogen

The disease was first reported in 1955, and the cause was confirmed in 1958 (Simmonds, 1958). *Fusarium oxysporum* Schlecht was reported to be the causal fungus. Later on, Trujillo (1963) made elaborate studies on the cause and symptoms of this disease. He

Figure 8.6 Ginger severely affected with yellows disease.

reported the causal fungus of the disease to be *F. oxysporum* f. sp. *zingiberi* owing to the host specificity of the pathogen. Other species of *Fusarium* such as *F. solani* (Mart.) Sacc., *F. equiseti* (Corda) Sacc., and other unidentified *Fusarium* spp. were also reported to be associated with ginger rhizomes (Rosenberg, 1962). Sharma and Dohroo (1990) isolated five species of *Fusarium* associated with the disease and found *F. oxysporum* as the major cause of yellows, which was present in all the ginger-growing areas of Himachal Pradesh. Other species frequently isolated were *F. solani*, *F. moniliforme* (*Gibbrella fujikuroi*), *F. graminearum (G. zeae),* and *F. equiseti.*

Three isolates of *F. oxysporum* f. sp. *zingiberi* were obtained from diseased ginger plants collected from different areas of Himachal Pradesh. The first isolate was the most aggressive, resulting in 100 percent mortality of inoculated ginger seedlings, whereas isolates II and III caused 60 and 80 percent mortality, respectively (Dohroo and Sharma, 1992b).

A temperature range of 15 to 30°C, accompanied by very high humidity and the continuous presence of a free film of water is favorable (optimum 23 to 29°C) for the development of yellows disease (Sharma and Jain, 1978b). Maximum disease incidence occurred when the soil temperature ranged from 24 to 25°C and the soil moisture from 25 to 30 percent (Sharma and Dohroo, 1989). Agrawal et al. (1974) found that the medium incorporated with galled root (galls of *Meloidogyne incognita*) extract of ginger supported better growth of the pathogen than healthy root extract medium.

The disease spreads through infected rhizomes and soil (Rosenberg, 1962). The fungus survives in soil as chlamydospores, which may remain viable for many years in the field (Sharma and Jain, 1978a). Dohroo (1989a) has also reported seed transmission (Table 8.9) of the fungus. The secondary spread of the disease may take place through irrigation water and by mechanical means (Sharma and Jain, 1978a). Sharma (1977) has reported survival of *F. oxysporum* f. sp. *zingiberi* as a competitive saprophyte on agar plates. The

Table 8.9 Correlation of storage rot incidence with pre-emergence rot and yellows of ginger

	Disease incidence (%)		
Cultivar	*Storage rot (Z)*	*Pre-emergence rot (X)*	*Yellows (Y)*
SG (Rajgarh)	13.3	23.0	50.0
SG 212	37.5	52.0	57.5
SG 547	46.6	28.0	70.0
SG 551	66.6	26.0	76.6
SG 639	50.0	54.0	62.5
SG 30	52.5	54.0	72.5
SG 603	60.0	46.0	76.6
SG 646	50.0	29.0	70.0
SG 600	53.3	25.0	73.3
SG 666	7.5	17.0	26.6

rXY = 0.356 r^2XY = 0.127 SE(Z) = 1.94 $CD_{0.05}$ = 4.07
rXZ = 0.409 r^2XZ = 0.167 SE(X) = 1.27 $CD_{0.05}$ = 2.67
rYZ = 0.936 r^2YZ = 0.876 SE(Z) = 1.12 $CD_{0.05}$ = 2.35
Source: Dohroo (1989a).

infested soil also plays an important role in the spread of inoculum (Rana and Sharma, 2001).

Control Measures

Healthy Rhizome Selection: As the disease spreads through contaminated rhizomes, selection of healthy rhizomes has been found to be an effective control measure for the disease (Dohroo et al., 1988; Rana, 1991; Dohroo, 1993).

Intercropping: Intercropping ginger with *Capsicum* results in 76 percent control of yellows disease (Dohroo and Sharma, 1997).

Chemical Control: Various workers have suggested the control of yellows disease through chemicals. Simmonds (1958, 1959) suggested seed treatment with mercurial fungicides at 2 lb/40 gal of water (Teakle, 1965). Benzimidazole-type fungicides have also proven promising in the control of the disease (Anonymous, 1976). Trizone as soil fumigant and arasan as a seed treatment were also found promising (Rosenberg, 1962). Kothari (1966) observed better rhizome germination when treated with 0.1 percent $HgCl_2$ followed by thiram (0.5 percent), ceresan wet (0.5 percent), and Dithane Z-78 (0.2 percent) when the fungicides were applied as soil drenches or rhizome dips.

Biological Control: *F. oxysporum* f. sp. *zingiberi* is inhibited by antagonists like *T. harzianum* and *G. virens* under in vitro conditions (Sharma and Dohroo, 1991). The antagonistic effect of *Bacillus subtilis* on *F. oxysporum* f. sp. *zingiberi* under pot cultures has also been reported (Sharma and Jain, 1979). Mancozeb and carbendazim are found to reduce the disease when used with biocontrol agents (Table 8.10) like *T. harzianum, T. hamatum,* and *G. virens* as seed treatment and soil application (Dohroo, 1995).

Biotechnological Approach: Prachi et al. (2001) studied the effect of *Fusarium* toxin on ginger. Shoot buds of ginger encapsulated in 4 percent sodium alginate gel germinated

Table 8.10 Effect of fungicide seed treatment and biocontrol agents on the incidence of yellows and yield of ginger

	Disease incidence (%)			*Yield (kg/3 m^2)*		
Treatment	*1991*	*1992*	*Pooled*	*1991*	*1992*	*Pooled*
T_1	4.5	6.7	5.7	6.5	8.0	7.2
T_2	5.7	7.2	5.9	6.2	7.3	6.7
T_3	7.0	8.2	7.6	5.3	6.7	6.0
T_4	2.0	3.0	2.5	12.0	9.7	10.8
T_5	4.0	7.0	5.5	8.0	8.3	8.2
T_6	4.0	8.0	6.0	8.7	7.2	7.7
T_7	6.6	8.7	7.6	5.7	7.2	6.4
T_8	10.5	13.2	11.3	3.2	3.5	3.3
$CD_{(0.05)}$	1.2	1.1	1.0	1.2	1.0	1.0

T_1 = *Trichoderma harzianum* (H) + T_7; T_2 = *T. hamatum* (M) + T_7; T_3 = *Gliocladium virens* (G) + T_7; T_4 = H + M + T_7; T_5 = H + G + T_7; T_6 = M + G + T_7; T_7 = Mancozeb (0.25%) + carbendazim (0.1%) and T_8 = Control
Application rate of the soil biocides = 350 g/3 m^2
Source: Dohroo (1995).

well and showed no symptoms of ginger yellows (Sharma et al., 1994). High-frequency multiplication of disease-free ginger clones was also obtained, which also performed well under field conditions (Sharma and Singh, 1997).

Resistant Cultivars: The disease can be managed to a great extent by using resistant or less susceptible cultivars of ginger. Cultivars like SG 666 (Dohroo, 1989a) and Kerala local (Rana and Arya, 1991) have been reported to show less incidence of yellows under field trials in Himachal Pradesh. The callus cultures of some ginger cultivars (cv. Dadasiba and Maran) showed resistance to culture filtrate of the pathogen (Sharma and Singh, 1997).

Phyllosticta Leaf Spot

Ramakrishnan (1942) reported this leaf spot disease for the first time in Godavari and Malabar regions of India. Later on, the disease was reported from Sarawak (Anonymous, 1972). Sohi et al. (1964) have reported the disease in Himachal Pradesh, and it also occurs widely in Kerala state (Anonymous, 1974). Singh et al. (2000a) reported the disease from Chhatisgarh. This disease is now widespread in most ginger-growing countries.

Symptoms

Small, oval to elongated spots, measuring 1 to 10 mm × 0.5 to 4 mm appear on younger leaves. The spots have white papery centers and dark brown margins surrounded by yellowish halos (Ramakrishnan, 1942). The spots later increase in size and coalesce to form larger lesions (Figure 8.7A, B). The affected leaves become shredded and disfigured and may suffer extensive desiccation. As the plants put forth fresh leaves, they subsequently become infected. The crop attains a gray disheveled look as a result of infection (Sohi et al., 1964; Shukla and Haware, 1972).

Figure 8.7 *Phyllosticta* leaf spot of ginger. (A) General appearance of the infected plant.

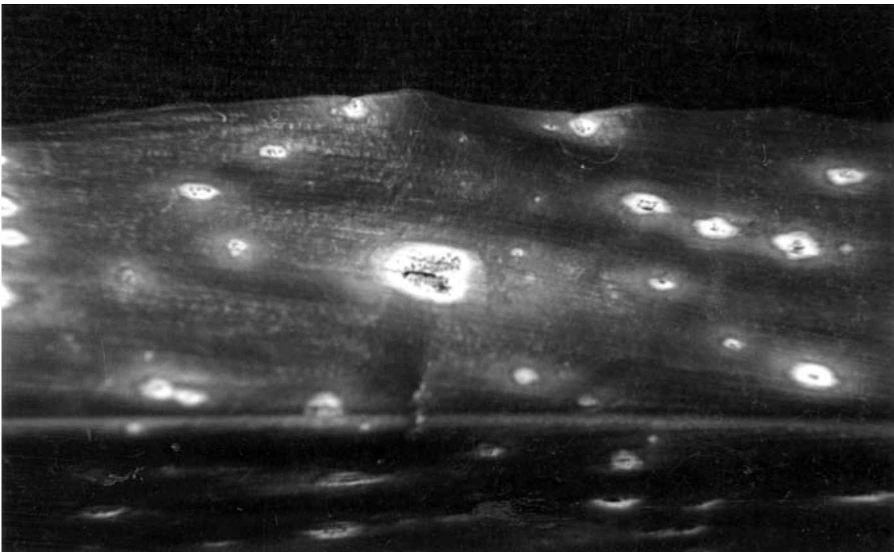

Figure 8.7 (B) Leaf spots, enlarged view.

The Pathogen

Leaf spot disease is caused by the fungus *Phyllosticta zingiberi* T.S. Ramakr. The fungus forms amphigenus, subglobose, dark brown, ostiolate pycnidia measuring 78 to 150 μm in diameter on the host. On standard media, the fungus forms pycnidia with 100 to 270 μm diameter bearing hyaline, unicellular, oblong, biguttulate spores measuring 3.7 to 7.4 × 1.2 to 2.5 (4.3 to 1.6) μm (Ramakrishnan, 1942).

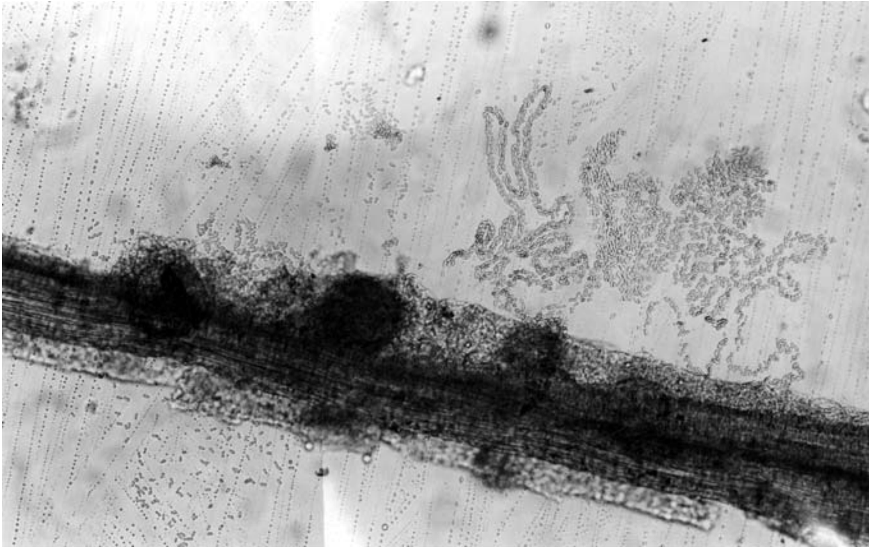

Figure 8.7 (C) Pycnidia and conidia of *Phyllosticta*.

The disease begins to appear toward the end of June when the plants are at the most susceptible stage (three- to four-leaf stage) and have received high cumulative rainfall that is conducive for the disease spread. During this period, the temperature varies between 23.4 and 29.6°C and relative humidity is between 80 and 90 percent. Later in July, when the number of rainy days and total rainfall increase, the disease aggravates and spreads fast. As the number of rainy days decrease, disease spread also decreases (Brahma and Nambiar, 1984). Ginger plants up to the age of 6 to 7 months are susceptible to the disease and 2-week-old leaves are most susceptible.

The diseased leaves present in the debris of an infected field serve as a primary inoculum in the next season. In leaves, pycnidiospores and mycelia remain viable for 14 months under laboratory conditions (Brahma and Nambiar, 1982). Pycnidia survive in the leaf debris at the temperature range of 30 to 35°C. The pycnidiospores remain viable in soil even at 25 cm depth for 6 months. The optimum temperature range for mycelial growth of *Phyllosticta* is 25.0 to 27.5°C, with maximum and minimum being 32.5 and 10.0°C, respectively. At 5 and 35°C, complete inhibition of mycelial growth was observed (Cerezine et al., 1995).

The extent of dispersal of the causal fungus depends upon the intensity of precipitation. A higher intensity of rain accompanied by wind seems to exert a greater impact on leaves, as a result pycnidia are splashed on more leaves and to greater distances, resulting in liberation of a greater amount of spores and spreading the disease incidence (Brahma and Nambiar, 1984).

Control Measures

Sanitation and Shade: The destruction of diseased crop debris by burning is an important practice to reduce the primary inoculum of the disease. The disease incidence is much less under shade. At the Indian Institute of Spices Research, Calicut, India, the germplasm collection maintained under open conditions became infected, whereas when

grown under shade net, the incidence of the disease was significantly less and the yield also increased significantly.

Chemical Control: The disease is controlled by one or two applications of Bordeaux mixture (Ramkrishnan, 1942). In Himachal Pradesh, Sohi et al. (1973) managed the disease by spraying Dithane Z-78 (0.2 percent) six times at 2-week intervals. They have also recommended other fungicides: Flit 406(0.3 percent), Dithane M-22 (0.2 percent), or Bordeaux mixture (1 percent). Grech and Frean (1988) compared five fungicidal treatments and found that Benomyl (0.1 percent) + mancozeb (0.2 percent) + soluble boron (0.1 percent) and iprodione (0.2 percent) reduced the average number of lesions per leaf and increased the yield. In Brazil, Cerezine et al. (1995) found the highest reduction in the disease progress with the use of chlorothalonil. With dithionan, copper oxychloride, folpet, mancozeb, and captan, the area under disease progress curve (AUDPC) was on an average 15 to 19 lesions/leaf. One spray of Bavistin (0.15 percent) and two sprays of Dithane M-45 (0.25 percent) gave good protection against the disease and resulted in higher yield under a pot culture experiment (Verma and Vyas, 1981). Bavistin was observed to persist for a longer period on the ginger leaves. Captan and mancozeb at 1,000 mg/ml and triadimenol at 100 mg/ml inhibited mycelial growth of the fungus completely whereas; iprodione, thiophanate-methyl and chlorothalonil at 1,000 mg/ml inhibited the mycelial growth partially (Cerezine et al., 1995). Das and Senapati (1998) reported that captan (0.3 percent) gave the best control of disease followed by mancozeb (0.3 percent) + thiophanate methyl (0.01 percent).

Resistant Cultivars: Setty et al. (1995b) studied the reaction of 18 cultivars of ginger to *P. zingiberi* for 6 months under the coastal climate of Karnataka state (India). None of the cultivars tested was resistant to the disease. However, the cultivars Narasapatom, Tura, Nadia, Tetraploid, and Thingpuri were classed as moderately resistant with a disease index less than 5 percent. Other cultivars, namely, Rio de Janeiro, Kunduli Local, Waynad Local, Kurupampady, Suravi, and Karakal, were susceptible with a disease index of more than 10 percent. In Himachal Pradesh, none of the tested material of ginger was rated resistant to *P. zingiberi*; however, eight lines showed moderate resistance (Dohroo et al., 1986b). Germplasm collections SG 554, VIS 18, and RGS-5 were reported to be resistant to *Phyllosticta* leaf spot (Singh et al., 2000a).

Helminthosporium Leaf Spot

McRae (1926) reported this disease for the first time in Pusa (Bihar).

Symptoms

The disease appears during the rainy season in the form of small oval spots measuring 4 to 5 × 2 to 3 mm in diameter on the leaves. The spots remain scattered on both surfaces of the leaves. The spots later enlarge in size. The mature spots have a centrally dead straw-colored area surrounded by a brown ring with a yellowish zone on the outside.

The Pathogen

McRae (1926) described the morphology of the species of *Helminthosporium* associated with the disease. Later on, Mitra (1930) reported that the species is a strain of *H. maydis*

Nisikado and Miyaka. Again in 1931, Mitra considered this strain to be different from the strain of *H. maydis* occurring on maize.

The conidiophores arise from the central dead area of the spot on the leaf, and the conidia are straight to crescent shaped with ends that are round, brown, have three to nine septa, and measure 43 to 109 μ in length and 11.5 to 20.0 μ in breadth. The fungus grows best between 25 and 35°C. The growth of the fungus is favored by darkness. The thermal death point of the fungus is between 63 and 64°C.

Control Measures

The disease has very limited occurrence. There are no reports in the literature on the management of this leaf spot disease.

Colletotrichum Leaf Spot

Sundraraman (1922) reported this disease from the Godavari district of Andhra Pradesh (India). Later Wallace and Wallace (1945) described the disease from the Tanganyika territory.

Symptoms

Symptoms manifest as small round to oval, light yellow spots on leaves and leaf sheaths. These spots gradually increase in size and often coalesce to form large discolored areas. Such infected areas often dry up at the center, forming holes. In the case of a severe attack, the entire leaf dries up.

The Pathogen

Butler and Bisby (1931) named the leaf spot–causing fungus *Colletotrichum zingiberi* (Sundar).

The disease makes rapid progress during the rains. Continued wet weather with high temperature favors the disease development. Shade is considered unfavorable for progression of the disease (Briton-Jones, 1933).

Control Measures

Two spray applications of Bordeaux mixture (1 percent) at an interval of 6 weeks effectively control the disease (Iyer, 1987). Removal and burning of affected plants also reduce the disease spread. Briton-Jones (1933) indicated that cultivation of a ginger crop under shade resulted in less disease incidence.

Pyricularia Leaf Spot

Nisikado (1927) reported this leaf spot disease from Japan. In India, Rathaiah (1980) described the occurrence of the disease in Assam. The disease has very limited occurrence.

Symptoms

Symptoms consist of small pale brown spots on the leaves and on the rhizome node near the soil line. The freckles, bearing sclerotium-like structures, sometimes coalesce to form

black blotches. Black blotches are also seen on the rhizomes, which may extend into the cortex. The pathogen also causes leaf blast symptoms. The blast lesions occur during July to September (Kotani and Kurata, 1992).

The Pathogen

Nisikado (1927) named the pathogen *Pyricularia zingiberi.* Rathaiah (1980) isolated the causal fungus from ginger leaves in Assam. In Tanzania, Teri and Keswani (1985) reported a new species of *Pyricularia* occurring on ginger and called it *P. grisea*. Sadasivam and Subramanian (1954) found *Pyricularia zingiberi* to be heterotrophic for thiamine.

P. zingiberi overwinters with sclerotium-like structures on the residues of diseased ginger and mioga (*Zingiber mioga*) plants. The source of primary infection for ginger plants appears to be the debris of diseased plants (Kotani, 1994).

Control Measures

Chemical Control: The disease can be controlled by applying Dithane M-45 in combination with Benlate (Anonymous, 1977). Treatments with Dithane M-45 followed by a mixture of mancozeb and Topsin-M also gave best control of the disease and an increase in the yield of ginger rhizomes (Anonymous, 1980). Kotani (1994) suggested soil fumigation with methyl bromide to kill the overwintering sclerotium-like structure.

Thread Blight

Sundram (1954) reported this disease on leaf blades of ginger in Malabar (Kerala state). The disease is not of much significance and occurs rarely.

Symptoms

Small water-soaked lesions appear on the leaf margins or other parts of the leaf during the initial stage of this disease. Later on, the infected leaves lose their turgidity, wilt, and may get detached from the sheath. Fine hyphal threads spread over the infected parts, and small brown sclerotia are present on the lower surface. The infected portion turns white and papery upon drying.

The Pathogen

The causal fungus was named *Pellicularia filamentosa* (Pet.) Rogars by Sundram (1954). Mycelial growth of the fungus consists of many branched hyphae of 6 to 10 μ thickness. In the course of 3 or 4 days, chocolate-brown sclerotia with a pubescent surface are abundantly formed in culture. These are generally larger than those formed on the host.

The disease spreads rapidly in wet weather and is limited by low relative humidity. The disease occurs during the monsoon season.

Control Measures

The control measures for the disease are based on the experiments at Pattambi, Kerala. It includes protective spraying with 1 percent Bordeaux mixture (5:5:50) before the start of heavy rains (Sundram, 1954). The disease is also checked by a spray of Bavistion (2 g/l).

Storage Rots

In storage, the following fungi attack ginger: *Fusarium oxysporum, Pythium deliense, P. myriotylum* (Sharma and Jain, 1977), and other (saprophytic) fungi such as *Geotrichum candidum* (Mishra and Rath, 1989), *Aspergillus flavus* (Geeta and Reddy, 1990), *Cladosporium lennissimum, Gliocladium roseum, Graphium album, Mucor racemosus, Stachybotrys sansevieriae, Thanatephorus cucumeris,* and *Verticillium chlamydosporium* (Dohroo and Sharma, 1992a). *Geotrichum candidum* caused complete rotting of inoculated rhizomes in 15 days at 25ºC and 100 percent relative humidity (Mishra and Rath, 1989). The fungus *A. flavus* in association with ginger rhizomes was implicated in the production of carcinogenic aflatoxin (Geeta and Reddy, 1990). *A. niger* and *Rhizoctonia solani* have been associated with ginger rhizomes producing pectinolytic and cellulolytic enzymes during pathogenesis in inoculated rhizomes (Agrawal and Gupta, 1986). Under storage, different fungi have been found associated with ginger rhizomes that result in rotting and decaying of the rhizomes (Dohroo, 1993). Different types of storage rots (Table 8.11) have also been reported by Dohroo (1995a).

Control Measures

Under storage conditions, postharvest dip treatment of Aureofungin (0.02 percent) and Benlate (0.2 percent) provided better control of the disease (Haware et al., 1973). Treatment of rhizomes with *T. viride* has also been observed to give more than 80 percent control of rhizome rot caused by *P. pleroticum* (wet rot) and *F. equiseti* (dry rot) by Dohroo and Sharma (1984). Sharma and Dohroo (1991) reduced the disease incidence under storage from 71.4 to 18.2 percent by steeping the rhizomes in carbendazim (0.1 percent) for 60 minutes. Bavistin (carbendazim) and carbendazim plus Dithane M-45 inhibited growth of *F. oxysporum* f. sp. *zingiberi* under in vitro conditions (Sharma and Dohroo, 1991).

Prestorage chemical treatments reduce the incidence of storage rots (Okwuowulu and Nnodu, 1988). They have observed postharvest (pre-storage) application of benomyl (750 ppm a.i.) and/or gibberellic acid (150 ppm) to be most effective in controlling the rots.

Dipping of rhizomes in imazalil or prochloraz at 0.8 g a.i. per liter and then storing at 10ºC gives good protection against the infection with fungi such as *Botryodiplodia, Aspergillus, Diplodia, Fusarium, Rhizoctonia,* and *Pythium* in storage (Grech and Swarts,

Table 8.11 Pathogenicity of fungi associated with storage rot of ginger

Fungi	*Type of rotting*	*Rot (%)*	*Incubation period (days)*	*Rotting after 25 days*
Pythium ultimum Trow	Soft rot	12.0	7.4a	Complete
Fusarium oxysporum Schl.	Dry rot	50.0	15.4b	Medium
Verticillium Sp. *Chlamydosporium* Goddard	Red rot	19.0	19.8c	Partial
SE			0.32	
$CD_{(0.05)}$			0.71	

Source: Dohroo (2001).
a: minimum, b: moderate, c: maximum

1990). A combination of mancozeb and carbendazim treatment to rhizomes controlled storage rot of ginger (Dohroo et al., 1986a; Dohroo and Malhotra, 1995; Dohroo, 2000).

Among the various fungicides used for dipping the rhizomes before storage to prevent storage rots caused by various fungi, mancozeb is known to persist longer than carbendazim when the rhizomes are steeped in fungicide solutions for 60 minutes (Sharma et al., 1992). Mancozeb residues were observed even after 120 days of storage. However, the health risk in carbendazim-treated rhizomes is low as compared to mancozeb if they are consumed after peeling (Table 8.12).

Dohroo and Korla (2000) conducted studies to find out the effect of suitable harvesting stage and curing time of rhizomes on storage rot of ginger (Tables 8.13 and 8.14). They found that the best time for harvesting ginger is in the first 2 weeks of December, and 48 to 60 hours curing of rhizomes decreased the incidence of disease.

Dohroo and Sharma (1984) studied biocontrol of rhizome rot of ginger in storage with *T. viride*. Besides, Dohroo (2001) studied the effect of seed treatment with fungicides and *T. harzianum* on the control of disease. Among the various fungicides, seed rhizome treatment with 0.2 percent Bavistin, 0.2 percent Topsin, 0.3 percent Dithane M-45, and combinations of Bavistin and Dithane gave a high level of protection to seed rhizomes.

Table 8.12 Persistence of mancozeb and carbendazim residues in rhizomes of ginger

	Residue level (mg/kg)	
Sampling interval (days)	*Mancozeb*	*Carbendazim*
0	57.8	23.5
15	26.1	12.1
60	12.9	4.5
120	2.8	—
RL 50	30.8	26.5
WP	131.6	59.1

Table 8.13 Effect of harvesting stage on storage parameters and rot of ginger

Harvesting stage (days after planting)	*% Loss*	*Disease incidence (%)*	*% Recovery*
209	13.17 (21.27)c	1.25 (6.398)b	86.83 (68.74)c
214	12.50 (20.70)c	1.167 (6.193)b	87.50 (69.03)c
219	8.83 (17.27)b	0.25 (2.307)a	91.17 (72.73)b
224	5.50 (13.55)a	0.33 (3.262)b	94.50 (76.45)a
229	15.50 (23.18)d	9.00 (17.44)c	84.50 (66.82)d
234	24.00 (29.67)e	49.17 (44.52)d	76.00 (60.33)e
239	25.50 (30.87)e	49.83 (44.91)d	74.50 (59.13)f
SE	0.50	0.85	0.50
$CD_{(0.05)}$	1.10	1.87	1.10

Figures in parentheses are angular values.
Figures followed by same letters are statistically identical.

Table 8.14 Effect of curing of rhizomes on storage parameters and rot of ginger

Curing duration (hours)	*% Loss (wt.)*	*Disease incidence (%)*	*% Recovery*
0	40.50 (39.52)e	34.00 (35.67)d	59.50 (50.48)d
12	25.00 (30.00)d	28.50 (32.48)c	75.00 (60.00)c
24	23.67 (29.11)c	28.00 (32.28)c	76.33 (60.89)c
36	24.50 (29.66)c	26.50 (31.09)b	75.50 (60.34)c
48	13.00 (21.13)b	6.80 (14.48)a	87.00 (68.87)b
60	10.50 (18.90)a	6.07 (14.28)a	89.50 (71.10)a
SE	0.39	0.37	0.39
$SC_{(0.05)}$	0.87	0.83	0.87

Figures in parentheses are angular values.
Figures followed by same letters are statistically identical.
Source: Dohroo and Korla (2000).

Storage of rhizomes under cool conditions may prolong storability by reducing weight loss and sprouting, but this practice may result in higher pathogen incidence than storage at room temperature. Packing of rhizomes in PVC film also reduces weight loss but increases the incidence of fungal infection (Lana et al., 1993). Dohroo and Kohli (2001) gave a complete package for safe storage of seed ginger.

Viral Diseases

Mosaic Disease of Ginger

Ginger mosaic virus was isolated from affected ginger plants by So (1980). The symptoms appear as a yellow and dark green mosaic pattern on leaves. The affected plants show stunting.

The virus causing mosaic disease in ginger has spherical particles with a diameter of 23 to 38 nm. It shows a positive serological reaction with antiserum to cucumber mosaic virus (CMV). The virus is known to be transmitted by sap to different plants known to be hosts of CMV (So, 1980). Nambiar and Sarma (1975) did not obtain sap transmission from ginger to ginger, ginger to *Nicotiana tabacum* var. Harrison special, *N. tabacum* var. *rustica, N. tabacum* var. *xanthii, N. glutinosa, Elettaria cardamomum, Curcuma longa,* and *C. aromatica*.

Hot-water and hot-air treatments of rhizomes from affected plants at 45 and 50ºC for 3, 6, and 12 hours did not alleviate symptoms (Nambiar and Sarma, 1975).

Chlorotic Fleck Virus

This is a viral disease first described by Thomas (1986). He detected the virus in ginger imported into Australia from a number of countries. The geographical distribution of the virus is uncertain, but is thought to include India, Malaysia, and Mauritius.

The ginger chlorotic fleck virus (GCFV) has isometric particles approximately 30 nm in diameter, with a sedimentation coefficient of 111s, and can readily be purified from infected ginger leaf tissue. The purified preparations contain a major portion of single-stranded RNA, MW 1.5×10^6 daltons, and a major coat protein, mw 29×10^3 daltons. At pH 7, the particles form a single zone in both cesium chloride and cesium sulfate

gradients, with buoyant densities of 1.355 g/cm^3 (fixed virus) and 1.297 g/cm^3 (unfixed virus), respectively.

The virus is mechanically transmitted by *Myzus persicae, Pentalonia nigronarvosa, Rhopalosiphum maidis,* or *R. padi* (Thomas, 1986). Possible affinities of GCFV with the sobemovirus group have also been described by Thomas (1986). The viral diseases of ginger are controlled in tissue cultures by heating to 50ºC for 5 minutes (Gao et al., 1999).

Big Bud

This disease is caused by the tomato big bud organism. Pegg et al. (1974) reported the disease in Queensland and suspected it to be a *Phytoplasma* disease. The affected plants cease to grow and leaves become bunched at the top of the stem. As the disease advances, plants turn yellow and die.

The pathogen has a wide host range, and the disease is transmitted by leaf hoppers. No special control measure has been tried due to very limited occurrence of the disease. However, in seed production areas, affected plants are removed and destroyed.

Nematode Diseases

Ramana and Eapen (1995) reported several plant parasitic nematodes on ginger and among them *Meloidogyne* spp., *Radopholus similis* and *Pratylenchus* spp. are the major ones of economic importance in that they cause significant damage to ginger plants. Sheela et al. (1995) found *Meloidogyne incognita, R. similis, Rotylenchulus reniformis, Helicotylenchus multicinctus, Pratylenchus* sp., *Tylenchorhynchus* sp., *Hoplolaimus indicus, Criconemoides* sp., and *Xiphinema* sp. in the rhizosphere of ginger in Kerala (India). *M. incognita* and *R. similis* are the major nematode species.

Vadhera et al. (1998) conducted studies during 1991 to 1994 on nine genera of plant parasitic nematodes associated with ginger in six districts of Madhya Pradesh (India). *M. incognita* was predominant with 63 percent absolute frequency of occurrence in the state.

Rama and Dasgupta (2000) reported nine nematode species—*R. reniformis, H. indicus (B. indicus), Pratylenchus coffeae, P. brachyurus, H. multicinctus, H. dihystera, Criconemella ornata, Xiphinema elongatum,* and *Scutellonema brachyurun*—that were associated with the ginger rhizosphere in northwest Bengal. *R. reniformis* recorded the highest relative density (54.8) and pathogenic significance ranking. *H. indicus* and *P. coffeae* have the highest relative biomass and relative frequency, respectively. *P. coffeae* and *R. reniformis* are more influenced by cropping pattern, age of plantation, and soil moisture as compared to other nematode species.

Disease Management

Cultural Control: Das (1999) observed a positive response to mulching—green leaves of mahaneem (*Melia azadirachta*), karanj (*Pongamia glabra*), acacia *(A. nilotica),* eucalyptus (*Eucalyptus citriodora*), and mango (*Mangifera indica*) at 2.5 kg/m^2 or paddy straw and paddy husk at 2.5 kg/m^2—on the germination percentage, tiller numbers, and the final

rhizome yield over the nonmulched control. The highest germination percentage and maximum tiller numbers per individual clump were observed with paddy straw mulching but had more number of root galls. The plots treated with mango, karanj, and mahaneem leaves indicated the possible nematicidal properties of these leaves, but mahaneem leaves had final soil nematode populations below the initial level.

Chemical Control: Ray et al. (1995) reported the soil application of carbofuran at 3 kg a.i./ha, 3 weeks after planting of ginger decreased avoidable yield losses due to *Meloidogyne incognita* to the extent of 26.3 percent. Gall index values were correspondingly high in control plots as compared with treated ones.

Denematization by hot-water treatment at 45°C for 3 hours disinfested ginger rhizomes, which resulted in the increased number of pseudostems and shoot-root weight. When such disinfected ginger rhizomes were planted in the field, there was a 19 to 34 percent increase in yield over control.

Integrated Management: Mohanty et al. (1995) reported that preplanting application of neem (*Azadirachta indica*) cake (1 t/ha) followed by postplanting application of carbofuron (1 kg a.i./ha) 45 days after planting gave the best result in terms of suppression of *M. incognita*, disease intensity, and increased yield of ginger.

Minor Diseases

Leaf Spots

Dhar et al. (1981) reported *Leptosphaeria* leaf spot on ginger from Meghalaya and *L. zingiberi* was described as the causal fungus. Other leaf-spotting fungi such as *Coniothyrium zingiberi* and *Cercoseptoria* sp. (Rathaiah, 1981) also have been reported from ginger. No control measures have been described for these leaf spots. *Curvularia lunata (Cochliobolus lunata)* has been reported to infect ginger in Bihar by Sinha et al. (1987). Sundararaman (1927) observed *Vermicularia zingibereae* on leaves, petioles, and rhizome scales of ginger. *Septoria zingiberi* was found associated with ginger leaves (Sundram, 1961).

Banded Leaf Blight

Rhizoctonia (Corticium) solani is associated with ginger leaves and pseudostems (Deighton, 1927) and rhizomes that are left too long in the ground (Park, 1932). This fungus is also found prevalent on ginger in Himachal Pradesh. The fungus causes white spots on leaves and causes the aboveground parts of plants to die prematurely (Deighton, 1936). However, no control measures have yet been suggested. Suhag and Rana (1985) described the leaf blight caused by *Rhizoctonia bataticola (Macrophomina)* from Haryana state. Rathaiah and Gogoi (2000) reported the effect of pigeon pea shade on the reduction of this disease. Under heavy shade, the disease intensity was about five times less than that in the open.

Basal Rot

Basal rot is caused by *Sclerotium rolfsii (Corticium rolfsii)* and is reported to occur in India (Haware and Joshi, 1973). This fungus previously was shown to be capable of attacking

green leaves (Bertus, 1929) and rhizomes (Park, 1937) in Ceylon and stored rhizomes in India (Mehrotra, 1953).

Park (1937) suggested immersion of rhizomes in 1:1200 solution of mercuric chloride for 90 minutes against this fungus. Mukherjee et al. (1999) suggested that *Trichoderma pseudokoningii* strain MTCC3011 suppressed the growth of *S. rolfsii*.

Violet Rot

Ito (1949) reported that the violet rot pathogen, *Helicobasidium mompa* Tanaka, infected ginger.

Black Rot

A dry rot of ginger rhizomes is of common occurrence in the Philippines and Jamaica. The causal organisms associated with the black rot disease have been reported to be *Rosellinia zingiberi* Stevens and *Atienza* sp. in the Philippines (Stevens and Atienza, 1931) and *R. bunodes* in Jamaica (Smith, 1929).

Dry Rot

Sarma and Nambiar (1974) reported the disease from Kerala in India, and the causal organism was identified as *Macrophomina phaseolina* (Tassi) Goid.

Basal Sheath Rot

Magar and Mayee (1988) observed basal sheath rot, which is a new disease of ginger from Parbhani (Maharashtra). The disease is characterized by yellowing and rotting of the joint tissue between the rhizome bud, and the leaf sheath, and collapse. Among the four plant parasitic organisms isolated from affected plants, *Aphelenchus* (nematode) and a *Fusarium* sp. infected ginger. Individually, both the organisms induced only one part of the disease syndrome. A joint infection (fungus-nematode), however, produced all the symptoms of basal sheath rot.

Chirke Virus

Raychaudhuri and Ganguli (1965) reported chirke virus on ginger, which is a common parasite of large cardamom in India.

Vesicular–Arbuscular Mycorrhizal Association

Taber and Trappe (1982) recorded association of vesicular-arbuscular mycorrhizal (VAM) fungi with ginger for the first time. The mycorrhizal spores isolated were of the *Glomus* type. Philip and Iyer (1994) have observed *Glomus mylticale* as the VAM fungi associated with ginger. Dohroo and Gupta (1996) and Sharma (1996) reported maximum occurrence of *Glomus* spp. in ginger soil. They identified *G. mosseae, G. intradix, G. canadida, G. pulvinatum, G. intraradices, G. caledonicum, G. deserticola, G. invermaicum,* and *G. claroideum* from ginger rhizosphere soil.

Conclusion

Eight fungal, two viral, one *Phytoplasma*, and various nematode diseases of ginger besides nine minor diseases have been discussed. These diseases of ginger affect the crop at one

or the other developmental stage resulting in huge losses to the growers and ginger industry as well. Mixed infection in rhizomes of ginger by one or the other pathogen has also been reported. Many of the diseases are either rhizome- or soil-borne or both. Since the crop is vegetatively propagated, very little variability exists in the ginger germplasm all over the world. Integrated management practices are thus the only practical solution to combat ginger foliar and rhizome diseases.

A pesticide-conscious world is looking for pesticide residue–free food products, especially spices, as they are often used without any cooking. Disease-free clean ginger seed needs to be grown within the framework of organic farming. Ginger seed (rhizome) needs to be healthy, and this warrants further research in growing such rhizomes by the management practice of either exclusion or exclusion by eradication in suppressive sandy loam soils. The use of locally available organic amendments and mulches in ginger requires comprehensive studies in monitoring pathogen vis-à-vis antagonistic microflora during the growth period of the crop. An active program for developing disease-resistant genotypes through genetic engineering approaches may be the only lasting solution for the disease problem in ginger.

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9 Bacterial Diseases of Ginger and Their Control

A. Kumar and A.C. Hayward

Ginger (*Zingiber officinale* Rosc.) is an important source of spice and essential oil, and both products are obtained from the underground stem or rhizome, which also serves as planting material. Apart from India, ginger is also grown in China, Hawaii (USA), Indonesia, Jamaica, Japan, Malaysia, Nigeria, Queensland (Australia), Sierra Leone, and the Philippines. In India, Kerala, Karnataka, Himachal Pradesh, Sikkim, Meghalaya, Assam, and other northeastern states cultivate this crop very extensively. India contributes up to 45 percent of total global production of ginger (Peter, 1997). Here ginger is cultivated in an area of about 58.1 thousand hectares with a total production of 889.4 thousand tons. Diseases are one of the major constraints of production of ginger, and of these bacterial wilt (Figure 9.1) (also called "Mahali" or "Ginger blast") is one of the most serious. Apart from wilt, rotting of bacterial origin has been recorded very infrequently (Choi and Han, 1990; Nnodu and Emehute, 1988; Sarmiento, 1959). The rot diseases are classified as bacterial soft rot and bacterial rhizome rot depending on the causative organism (Choi and Han, 1990).

Crop Loss and Distribution

Bacterial wilt of ginger inflicts serious economic losses in many ginger-growing countries on small and marginal farmers who depend on this crop for their livelihood. Although it is difficult to estimate the economic losses that can be attributed directly or indirectly to bacterial wilt, it ranks as one of the most serious and damaging diseases of bacterial origin in the world in terms of the actual number of plants killed each year in major crops such as banana, ginger, groundnut, potato, tobacco, and tomato (Sequeira and Kelman, 1976). The disease is endemic on other host plants in most of the ginger-growing regions in the world. Under conducive conditions, it causes loss in yield up to 100 percent in many ginger-growing states in India (Thomas, 1941; Sarma et al. 1978; Mathew et al. 1979; Dohroo 1991; Dake, 1995). According to an Indonesian report, bacterial wilt of ginger is estimated to cause annual losses up to 75 billion rupiah (Supriadi, 2000). Bacterial wilt of ginger is widespread and exceedingly destructive in several countries, a situation made worse by the easiness with which the pathogen is carried within the planting material.

Ever since the first report by Thomas of bacterial wilt of ginger from the Malabar region in the Madras presidency in 1941, voluminous information about the disease has accumulated, which is an indirect reflection of the economic importance of the disease. Since then the disease has been reported in Australia (Hayward et al., 1967; Pegg and Moffett, 1971), China (Li et al., 1994), Hawaii (Rosenberg, 1962; Quinon et al., 1964), Indonesia (Sitepu et al., 1977, Mulya et al., 1990), South Korea (Choi and Han, 1990), Malaysia

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Figure 9.1 Bacterial wilt of ginger.

(Lum, 1973), Mauritius (Orian, 1953), Nigeria (Nnodu and Emehute, 1988), and the Philippines (Zehr, 1969, 1970). The disease spreads rapidly when conditions of high temperature and rainfall are favorable for the disease development. The disease devastated the ginger crop in an area of 5 ha at the Horticultural Research Station, Ambalavayal, India, in 1978 (Mathew et al., 1979).

Symptoms of the Disease

A wilting and yellowing of the lower leaves, which extends upward until all the leaves appear golden yellow in appearance is the first recognizable symptom of bacterial wilt in ginger. As the disease progresses, the pseudostem becomes water soaked and readily breaks away from the underground rhizome. The vascular tissue of the stem darkens to a black color and symptoms progress very rapidly until the ginger plant collapses (Pegg et al., 1974). Diseased rhizomes are usually darker than healthy ones and have water-soaked areas with pockets of milky exudates. When diseased rhizomes or pseudostems are cut, white milky exudates flows freely from the cut surface (Figure 9.2). High concentrations of bacteria in the vascular tissue deprive the plant of water and nutrients from the soil, which adversely affects plant development and ultimately results in death (Buddenhagen and Kelman, 1964). Infected ginger plants become stunted and chlorotic and the lower leaves dry out gradually before the plant is finally killed. The inner core of the rhizome, including the vascular tissue, is rotten leaving the outer epidermis intact. However, it is not clear whether the rotting is due to the primary pathogen or caused by secondary saprophytic microflora or microfauna.

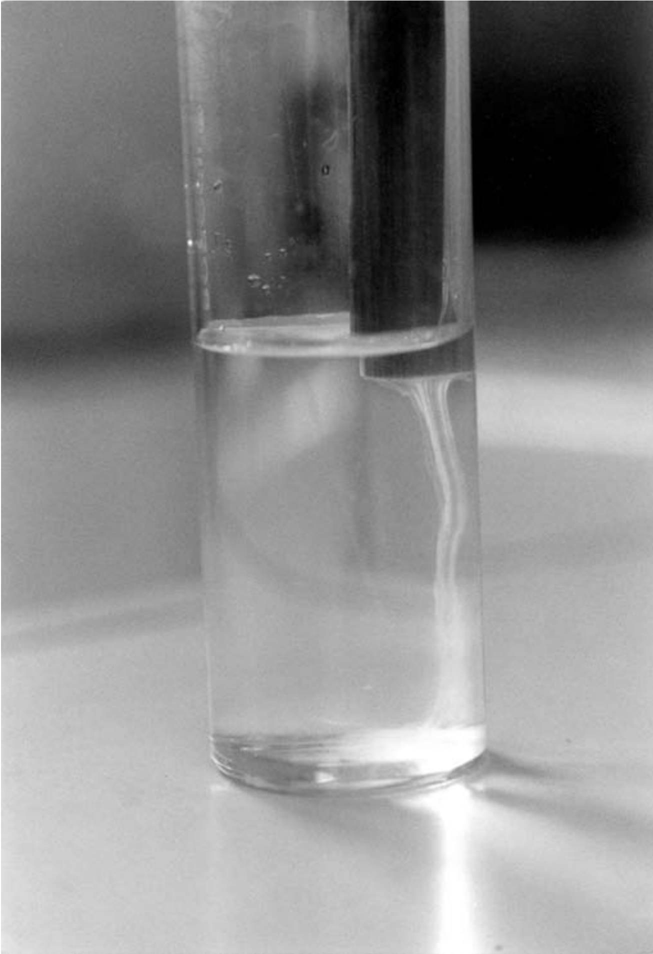

Figure 9.2 Bacterial ooze from the cut end of the pseudostem of ginger.

In susceptible host plants this pathogen disrupts water transport, alters physiology, and induces a severe, usually total, bacterial wilt (Hayward, 1991). Complete wilt commonly occurs 3 weeks after inoculation. The most notable symptom of the disease is rapid wilting of foliage primarily due to vascular dysfunction (Denny et al., 1990). Intercellular spaces of the root cortex and vascular parenchyma are subsequently colonized and cell walls are disrupted, facilitating spread through the vascular system (Vasse et al., 1995). In xylem vessels, bacterial populations reach very high levels ($>10^{10}$ cells/cm of stem in tomato), concomitant with wilting and plant death. The bacterium then returns to the soil, living as a saprophytic organism until it infects a new host plant. Studies using artificial inoculation methods and avirulent mutants suggest that the production of copious amounts of extracellular polysaccharide is the key factor in virulence and the major requirement for infection via roots as well as wilting and killing of the host plant.

The Pathogen

Bacterial wilt of ginger is caused by a prokaryote, *Ralstonia solanacearum* Yabuuchi (Smith), (synonym *Pseudomonas solanacearum* E.F. Smith), that has a wide host range including both dicots and monocots. *R. solanacearum* (Yabuuchi et al., 1992, 1995) is gram negative, rod shaped, and motile with one or more polar flagella or nonmotile without flagella. Erwin Frink Smith originally described the pathogen as *Bacillus solanacearum* in 1896. *R. solanacearum* belongs to the rRNA homology group II pseudomonads based on rRNA:DNA homology (Palleroni et al., 1973) and to the beta subclass of Proteobacteria. The bacterium is endemic in most subtropical and tropical regions of the world. Colonies of *R. solanacearum* on tetrazolium medium are distinguished from other bacterial colonies by their fluid smooth white appearance with red central whirling pattern (Figure 9.3) (Kelman, 1954). Conventionally, strains of *R. solanacearum* are grouped into races based on host range and biovars based on the ability to oxidise or utilize selected sugars (Buddenhagen et al., 1962; Hayward, 1960, 1964). The two groupings have been used in epidemiological studies, although they are imperfectly correlated, except that biovar 2 is equivalent to race 3. Almost all isolates from naturally infected ginger have proven to be either biovar 3 or biovar 4; they show variable degrees of pathogenicity to ginger. Isolates from ginger in Queensland showed a differential disease reaction correlated with biovar (Hayward et al., 1967). Biovar 4 produced a wilt on ginger in 14 or 21 days after stem and root inoculation, respectively, whereas biovar 3 isolates produced a wilt 6 weeks postinoculation. Biovar 4 was accordingly described as producing a rapid wilt and biovar 3 a slow wilt. The relationship between virulence on ginger and biovar is not consistent. In India, for example, where biovar 3 has been

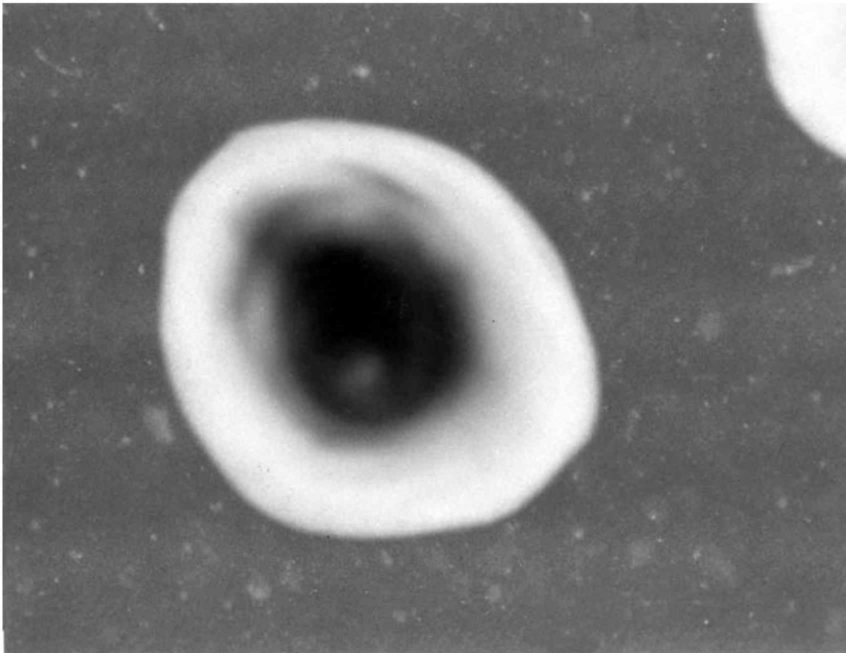

Figure 9.3 Typical colony of *R. solanacearum* causing bacterial wilt of ginger.

identified on ginger (Sarma et al., 1978), a rapid wilt of ginger was produced on inoculation.

Studies have shown that biovar 3 isolates from ginger cause slow browning of the leaves over a period of 6 weeks, whereas biotype 4 isolates from ginger caused typical wilting in *Lycopersicon esculentum* L.*,* *Solanum tuberosum* L.*,* *Zinnia elegans* Jacq*,* *Capsicum frutescens* L.*,* *Physalis peruviana* L., and *Solanum melonga* L. in 7 to 14 days. *R. solanacearum* from other hosts such as tomato, *Chromolaena*, chili, and potato was nonpathogenic on ginger. It is interesting to note that the *R. solanacearum* isolates from *Chromolaena*, a common weed of ginger fields, were not pathogenic on ginger even though they belong to biovar 3. Similarly, isolates from potato, tomato, and capsicum were not pathogenic to ginger (Kumar and Sarma, 2004). However, in India biovar 3 causes wilt in ginger in 5 to 7 days after artificial stem inoculation and in 7 to 10 days following soil inoculation of the pathogen (Kumar and Sarma, 2004). Biovar 4 is encountered infrequently in India. Zheng and Dong (1995) reported the predominance of biovar 3 in China among 129 isolates of *R. solanacearum* causing bacterial wilt of plants including ginger.

R. solanacearum is a heterogeneous species showing significant genotypic and phenotypic diversity (Cook et al., 1989; Hayward, 1991, 1994). In Hawaii, strains affecting *Strelitzia* (bird of paradise) and ginger, both relatives of banana, were affected by two different strains, neither of which could wilt triploid banana (Quinon et al., 1964). Two clusters within strains of *R. solanacearum* have been reported based on restriction fragment length polymorphism (RFLP) (Cook et al., 1989*)*; Division 1 includes biovars 3, 4, and 5 and Division 2 biovars 1, 2, and N2. Division 1 was referred to as an Asian subdivision and Division 2 as an American subdivision because of the geographic origin of the isolates represented. A subcluster of *R. solanacearum* isolates belonging to Division 2 (Cook et al., 1991) has recently been recognized by Taghavi et al. (1996) based on 16S rRNA gene sequence information; this subcluster contains isolates from Indonesia and also *Pseudomonas syzygii* and the blood disease bacterium. This close relationship of *R. solanacearum,* the blood disease bacterium, and *P. syzygii* led Taghavi et al. (1996) to coin the term "*R. solanacearum* species complex" to describe the complexity of the species as revealed by RFLP analysis and sequencing of conserved genes. The use of 16S rRNA gene sequences for the classification and identification of *R. solanacearum* has shown up to 99 percent similarity between isolates. *R. solanacearum* isolates from ginger similarly showed a very high degree of homology (Kumar et al., 2004). Other measures of genetic diversity are needed before it can be concluded that there is limited genetic diversity among ginger isolates. Wilt of the ornamental gingers—*Hedychium flavum, H. coronarium,* and *H. gardenarianum*—is caused by *R. solanacearum* and the strains causing wilt are similar (Aragaki and Quinon, 1965). *Zingiber zurumbet,* a close relative of edible ginger, is susceptible to bacterial wilt caused by ginger strains of *R. solanacearum* (Figure 9.4). Isolates of *R. solanacearum* from ginger on tetrazolium medium are similar in appearance. This and other evidence suggests that strains of *R. solanacearum* from ginger may have evolved in a particular location and then spread to other parts of the world through planting material. All of the ginger strains belong to the Asian division of Cook et al. (1989).

Bacterial soft rot and rhizome decay is caused by either *Pectobacterium* (*Erwinia) carotovorum* subsp. *carotovorum* or *Pectobacterium (Erwinia) chrysanthemi* (M. Stirling, personal

Figure 9.4 Susceptibility of *Z. zurumbet* to *R. solanacearum*.

communication) and bacterial rhizome rot is caused by *Pseudomonas marginalis* in Korea (Choi and Han, 1990) and Nigeria (Nnodu and Emehute, 1988). However, their importance under field conditions is not known. Bacterial rot caused by *Pseudomonas zingiberi* has been reported from China (Li et al. 1994).

R. solanacearum is considered to be one of the most important plant pathogenic bacteria as it causes great economic losses worldwide (Hayward, 1991). The bacterium has an unusually wide host range; plant species susceptible to the pathogen have been observed to occur in over 50 plant families (Hayward, 2000). The host range includes solanaceous plants (tomato, potato, tobacco, eggplant), leguminous plants (such as groundnut, French bean), monocotyledons (mainly banana, ginger), and several tree and shrub hosts (such as mulberry, olive, cassava, eucalyptus). Recently it was shown that certain ecotypes of the model plant *Arabidopsis thaliana* are also susceptible to the pathogen (Deslandes et al., 1998).

Epidemiology and Modes of Infection and Transmission of Bacterial Wilt on Ginger and Other Hosts

R. solanacearum can survive in the soil for long periods in the absence of host plants. There are conflicting reports on the longevity of *R. solanacearum* strains in soil, especially in the absence of protected sites (Graham and Lloyd, 1979) and on its resistance to desiccation. Soil types have been differentiated as being either conductive or suppressive to bacterial wilt (Hayward, 1991); their indirect influence on soil moisture determines the population size of antagonistic microorganisms, which affect, in turn, the persistence of *R. solanacearum.* Many workers have stressed the complexity of the epidemiology of bacterial wilt and involvement of many interacting factors (Kelman, 1953; Buddenhagen and Kelman, 1964; Hayward, 1991). Dissemination on infected vegetative planting material is of major importance in the case of banana, ginger, and potato and the potential for spread may be local or international. Some early evidence indicated that true seed might serve as a means of dispersal of the pathogen. In the case of groundnut, the pathogen is potentially seedborne, but early attempts to demonstrate seed transmission proved negative (He, 1990). It now appears that the pathogen does not survive in the dry seed normally used for planting. However, at high seed moisture content as in succulent plants like ginger rhizomes, survival and transmission are possible. When moist seeds from wilted groundnut plants are harvested and planted immediately in sterile soil, wilting of seedlings occurs. If the moisture content of harvested seed is above 10 percent, then survival is possible in storage; below this level there is no prolonged survival (Zhang et al., 1993a). Irrigation and the "wetting and drying" cycles that occur in the soil may tend to move cells up and down the soil profile and at times concentrate them in the rhizosphere. Also, the application of fertilizers during the growing season may influence root growth and the rhizosphere dynamics of the bacterium. Brown rot of potato caused by *R. solanacearum* race 3 (biovar 2) occurs in some cool temperate environments in which latent infections commonly occur in progeny tubers (Ciampi and Sequeira, 1980; Hayward, 1991). There is no comparable evidence of latent infection of either banana or ginger being affected by bacterial wilt under relatively cool conditions. Rhizomes used as planting material may show no obvious symptoms and serve as a means of dissemination of the disease.

Vaughan (1944) proved that apparently healthy tomato seedlings taken from infected seedbeds were responsible for dispersal of the pathogen when replanted in areas hundreds of miles away. Insect dissemination of *R. solanacearum* to banana (Moko disease) is uniquely important in that disease. In banana insects carry bacteria mechanically from the ooze issuing from diseased banana inflorescences to healthy inflorescences (Buddenhagen and Elsasser, 1962). There is little evidence of insects being of the same importance in dissemination of *R. solanacearum* on other hosts. However, it should be noted that a related pathogen, *P. syzygii*, the cause of Sumatra disease of cloves in Java and Sumatra, is transmitted by tube-dwelling cercopids of the genus *Hindola* (Homoptera: Cercopoidea: Machaerotidae). Few insect pests affect ginger, but their role in disease spread in the field cannot be ruled out. Leaf infection has been reported in a few instances in nature and can occur by inoculation under conditions of high humidity and temperature (Hayward and Moffett, 1978; Moffett et al., 1981). Aerial transmission through rain splash dispersal of epiphytic populations on tobacco leaves has been described in Japan (Hara and Ono, 1985). The worldwide distribution and damaging nature of bacterial

wilt on many crops suggests that *R. solanacearum* is an ecologically competent pathogen able to survive in the absence of its host, and in some circumstances overwinter in temperate zones and survive the dry season in tropical areas (Persley, 1986).

The modes of invasion of *R. solanacearum* differ from those of most other bacterial plant pathogens. Since ginger is planted as broken seed pieces termed "seed rhizomes," the soilborne bacterial inoculum has ample opportunity to invade the cut ends of the rhizomes during plant emergence. Infection occurs through wounds in roots or rhizomes or at sites of secondary root emergence. The bacterium colonizes the intercellular spaces of the root cortex and vascular parenchyma and produces extracellular enzymes that break down the pectic compound in the host plant cell wall and middle lamella facilitating spread through the vascular system (Vasse et al., 1995). In xylem vessels bacterial populations rapidly reach a very high level (Figure 9.5) (10^{10} cells/cm of stem in tomato) concomitant with wilting and plant death. The bacterium is then released to the soil, living as a saprophyte until able to infect new host plants. Infection from rhizomeborne inoculum is assumed as a result of simultaneous multiplication of bacterium and plant cells and eventual blockage of the vascular elements by the bacterial cells.

Latently infected planting material is the major means of dispersal of *R. solanacearum* between locations, states, countries, and continents (Hayward, 1991). Traditionally, ginger is cultivated in previously fallowed soil or virgin soil. The occurrence of bacterial wilt in such fields is indirect evidence of the rhizomeborne nature of *R. solanacearum* in ginger (Pegg et al., 1974; Indrasenan et al., 1981; Kumar et al., 2002). Bacterial wilt of banana has long been known to be passively disseminated, primarily on seed pieces, by root wounding during transplanting or by tools and by root-to-root spread (Rorer, 1911; Sequeira, 1958). Serological evidence for the rhizomeborne nature of *R. solanacearum* in ginger has been reported (Prasheena 2003, Supriadi et al., 1995). In vegetatively propa-

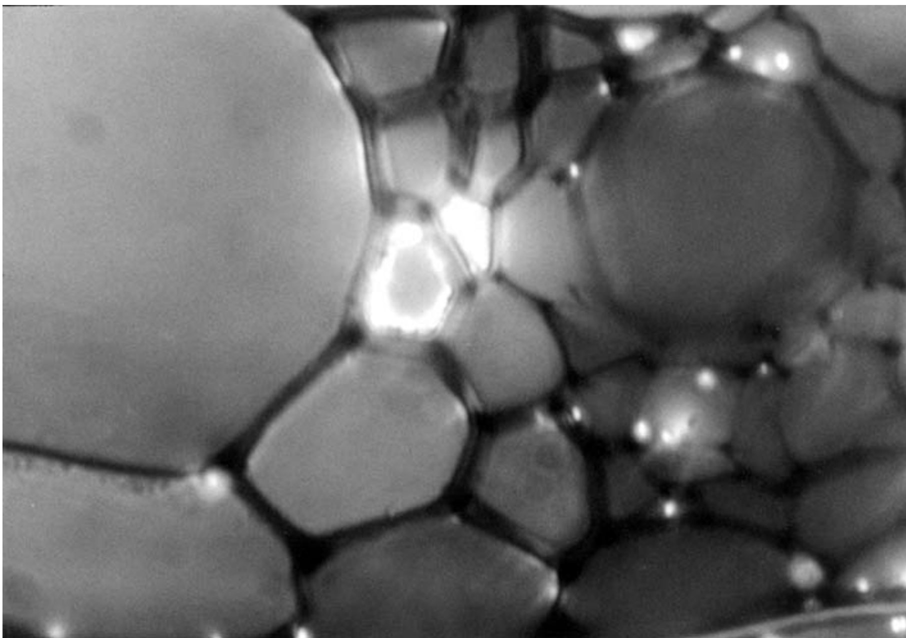

Figure 9.5 Colonization of xylem element in ginger by *R. solanacearum*.

gated crops such as potato, banana, and ginger, infected planting material is the major means of dispersal of *R. solanacearum* from place to place and also from season to season (Buddenhagen, 1961). Spread of the potato race in tubers is important in parts of Africa, Australia, and South America, and this race has been introduced in England and Sweden in tubers from Egypt and other Mediterranean countries (Anonymous, 1960). Since the pathogen is mainly transmitted through tuber seed, the use of healthy planting material is the most effective means to control the disease (Hayward, 1991).

Root-to-root spread of the bacterium has been recorded (Kelman and Sequeira, 1965) but there is little evidence of long-distance spread from field-to-field except in circumstances where floodwater is responsible for the movement of infested soil and infected plant debris (Kelman, 1953). A synergistic interaction between the root knot nematode, *Meloidogyne incognita,* and bacterial wilt has been reported. It has been shown that the intensity of bacterial wilt on tomato increased with an increased number of nematodes in the field (Hutagalung and Widjaya, 1976). However, nematicide application did not result in bacterial wilt control.

Survival of *R. solanacearum* in Soil, Planting Material, and Weeds

In Mauritius bacterial wilt is known to be endemic all over the island, including forest soils and sugarcane fields (Ricaud and Felix, 1971). Soil contaminated with bacterial wilt even to a high level may not give a high wilt incidence when susceptible plants are grown without adequate moisture, which confirms the role of high soil moisture in bacterial wilt incidence (Felix and Ricaud, 1978). Long-term survival of *R. solanacearum* in soil has long been attributed to the weed population in the field prior to cultivation. There is evidence of the saprophytic and parasitic survival of the bacterium in the rhizosphere of certain weeds in Queensland (Pegg and Moffett, 1971; Moffett and Hayward, 1980). However, there are few reports on the role of weedborne populations of the bacterium in actual bacterial wilt epidemics.

Being a vascular pathogen, it is presumed that *R. solanacearum* survives in ginger rhizomes at a very low inoculum level without affecting the normal state of the ginger. In general, the bacterial wilt pathogen will not multiply in intact rhizomes during storage unless the dormancy is broken and sprouting initiated. *R. solanacearum* can survive better under conditions of high soil moisture than in desert areas even under irrigation (Buddenhagen and Kelman, 1964). *R. solanacearum* survives in soil as well as the seed piece, and this forms a potential source of primary inoculum for the ensuing crop (Indrasenan et al., 1981). The potato race (race 3) is a low-temperature–adapted pathovar and it survives at cool temperatures in plant debris and latently infects potato tubers. *R. solanacearum* race 1, also a pathogen of potato, differs from race 3 in geographical distribution and the ability to survive under different environmental conditions (Graham et al., 1979). Alternative weed hosts and nonhost plants play an important role in the survival of *R. solanacearum* in the absence of susceptible crops (Granada and Sequeira, 1983). *R. solanacearum* has the ability to invade the roots of resistant cultivars of host species, such as tomato and persimmon, and nonhosts, such as bean and corn, without any symptoms. Disease control is made difficult by the ability of the pathogen to survive in the absence of a susceptible host (Granada and Sequeira, 1981). Lum (1973) found that both biovars 3 and 4 survived in soil for 20 months during a severe drought in Malaysia.

Control of Bacterial Wilt of Ginger

Various control measures has been tried to combat the disease with limited success. Bacterial wilt is a major problem and one of the constraints in the production of ginger and other vegetable crops because of its wide host range, the genetic variability it exhibits, and the complexity of its epidemiology and modes of transmission. The general strategies for management of bacterial wilt are: selection of healthy rhizome material from a disease-free area; selection of field with no previous history of bacterial wilt; preplant treatment of rhizomes by application of heat or chemicals; strict phytosanitation in the field, including restrictions on movement of farm workers and irrigation water across the field; clean cultivation and minimum tillage; crop rotation with nonhost plants such as paddy and maize; insect pest and nematode control in the field; and soil amendments, including biological control agents. Some of these control methods are considered in greater detail in the following.

Selection of Healthy Rhizome Material from Disease-Free Area

The use of rhizomes collected from previously disease-affected areas as planting material invariably results in severe disease when such material is planted in virgin soil or fallowed soil or even soil that has been rotated with nonhost crops. This experience emphasizes the need for pathogen-free seed in order to prevent disease outbreaks. In the absence of effective chemical and biological control methods, the best possible approach would be planting of pathogen-free rhizomes in pathogen-free soil in order to avoid or prevent the occurrence of bacterial wilt epidemics (Pordesimo and Raymundo, 1963; Supriadi, 2000). Techniques have been standardized to detect the pathogen in rhizome using nitrocellulose membrane-enzyme linked immunosorbent assay (NCM-ELISA) (Kumar et al., 2002) (Figure 9.6). In spite of the availability of excellent pathogen-detection technologies to detect the pathogen in rhizomes, soil, and irrigation water, their use in the indexing of planting material is negligible among ginger farmers. Although very sensitive and selective, these techniques for detection of *R. solanacearum* in ginger rhizomes are not readily adapted to the processing of large volumes of planting material; they are almost impractical under the farming conditions of developing nations in Asia and, therefore, they have not been adopted. The only method that has been used is selection of seed rhizomes from disease-free fields is visual inspection. This unscientific method of planting material selection often results in severe epidemics of bacterial wilt disease in India and other southeast Asian nations. Moreover, pathogen-free rhizomes are not readily available to all farmers owing to scarcity of seed material during peak seasons of planting, especially in crops like ginger, which require 1 ton of seed rhizome per acre of land.

Selection of Field with No Previous History of Bacterial Wilt

Site selection is one of the most important factors that contribute to the successful control of bacterial wilt of ginger. It has been observed that a soil with no history of bacterial wilt often results in healthy crops of ginger if the rhizomes are free from the pathogen. Traditionally, ginger is cultivated in a previously fallowed soil, virgin forest soil, or rubber plantations after 20 to 25 years of rubber crop in the Kerala state of India. This long crop rotation often results in a healthy crop of ginger. Another alternative is to plant underneath perennial trees or in social amenity forests with

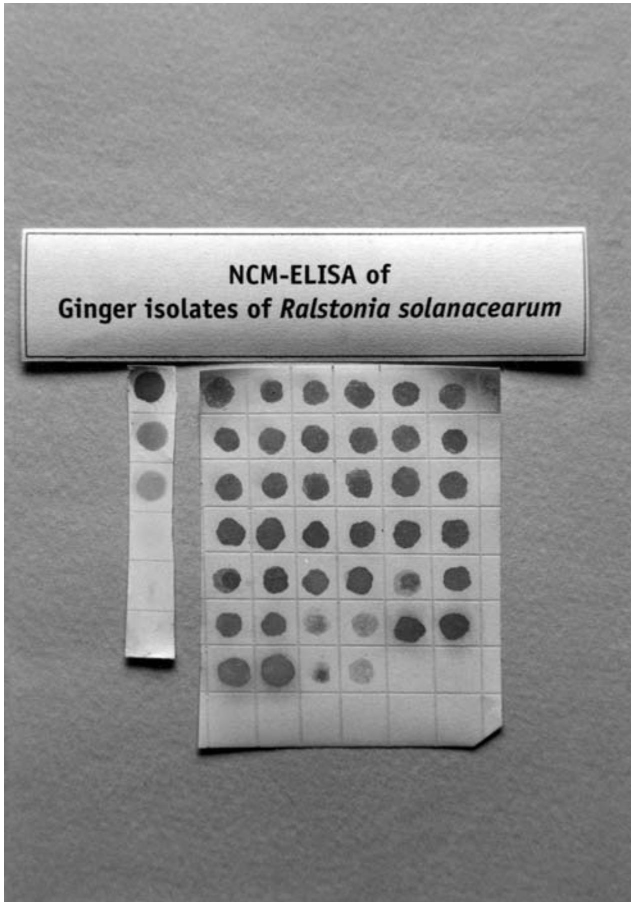

Figure 9.6 NCM-ELISA of ginger isolates of *R. solanacearum.*

regulated shade (Supriadi, 2000). French (1994a,b) has pointed out that pathogen-free soil and the use of certified seed tubers contribute most to the avoidance of brown rot of potato, and it is likely that the same is true for the avoidance of bacterial wilt of ginger. Soil can also be indexed for the presence of the pathogen by sensitive methods like the polymerase chain reaction (PCR). Techniques have been standardized to detect the pathogen in soil using double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) and PCR (Kumar et al., 2002; Priou, 2001; Priou et al., 1999, 2002). The PCR-based method for detection of the bacterium in soil has been based on universal primers specific for *R. solanacearum* (Opina et al., 1997, Kumar, unpublished data) (Figure 9.7).

Heat Treatment of Soil by Solarization

Solarization of soil prior to planting has been widely used to control soilborne pathogens and pests in various crops including potato, ginger, onion, carrot, and peanut, without consequential damage to the environment as occurs when methyl bromide is used for

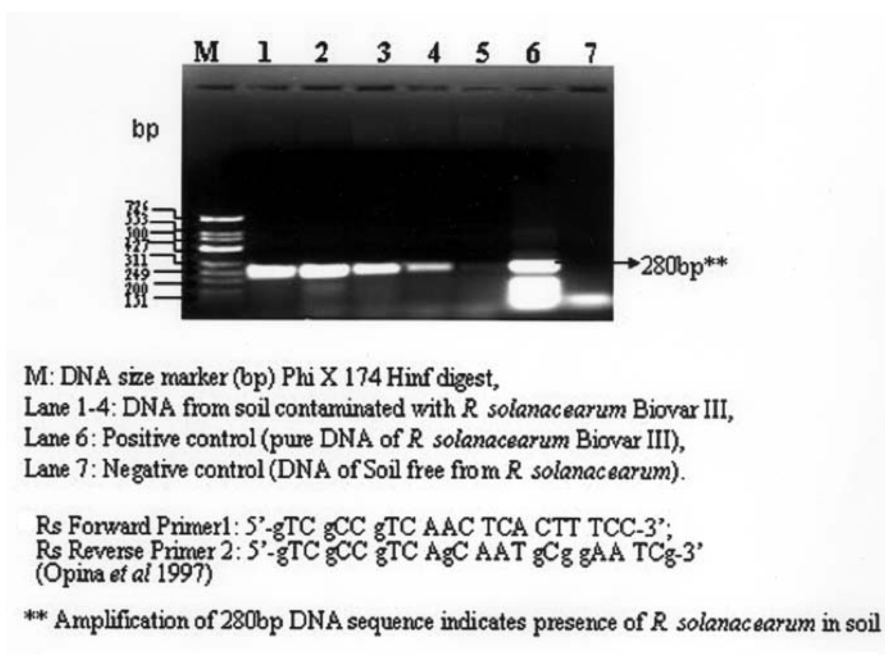

Figure 9.7 PCR-based assay for the detection of *R. solanacearum* (Rs) in soil using RS specific primers.

shallow-rooted, short-season crops (Katan and DeVay, 1991; Stapleton, 1994). Solarization does not leave any toxic residue. It is a hydrothermal process dependent for success on moisture of the sample for maximum heat transfer. In more temperate regions soil is covered with clear plastic in order to trap solar radiation and raise the temperature sufficiently to suppress or eliminate soilborne pathogens and pests (Katan 1981; Katan and DeVay, 1991; Kumar et al., 2003). Polyethylene is a suitable cover because it transmits the germicidal component of sunlight. Solarization can be effective against a broad spectrum of soilborne diseases caused by pests such as fungi, nematodes, and bacteria. But the effectiveness of this method is directly linked to climate (Katan and DeVay, 1991). Solarization causes complex biological, physical, and chemical changes that improve plant growth, quality, and yield for up to several years (Stapleton, 1994). Solarization has already proven to be an effective pest control tool for tomato, pepper, and eggplant production in northern parts of Florida and California (Gamliel and Stapleton, 1993). The success of soil solarization is based on the fact that most plant pathogens and pests are mesophiles, which do not produce heat-resistant spores, and they are unable to survive for long periods at high temperature. Death of the organisms at high temperature involves inactivation of enzyme systems, especially respiratory enzymes (DeVay et al., 1990). The greater the temperature, the less time needed to attain a lethal effect. Solarization studies have shown that: solarization reduces or eliminates pathogens and pests prior to planting, crop yields can be significantly increased, and the beneficial effect of solarization can extend through several growing seasons (Afek et al., 1991).

Chemical Treatment of Soil and Rhizomes for Bacterial Wilt Control

Hartati and Supriadi (1994) provide evidence of the activity of streptomycin and oxytetracycline both on the surface and inside tissue of ginger rhizomes soaked in solutions of antibiotics. Similar observations were made by Mulya et al. (1986) for effective bacterial wilt management in ginger. Disease control using commercial chemicals such as antibiotics, fertilizers, and fungicides has not been very successful. Fumigants such as chloropicrin have been used with some success for the control of bacterial wilt of tomato (Enfinger et al., 1979), but in general fumigation is not economically feasible over large areas. Ishii and Aragaki (1963) suggested soil fumigation with methyl bromide at 3 lb/100 ft^2 to get good control of bacterial wilt of ginger. The bactericide Kekuling, applied to the rhizosphere of ginger five times during growth of the crop as a wettable powder formulation at dilutions of 1:500 to 1:1200, has been reported to provide good control of bacterial wilt of ginger under field conditions in China (Zhang et al., 1993).

Preplant Rhizome Treatment by Heat

Disinfection of seed pieces prior to planting is an important approach to the control of bacterial wilt of ginger; as noted earlier, contaminated planting material is one of the primary inoculum sources for field infection. Since no chemical and biological control approaches are available for control, a possible alternative is heat treatment to inactivate or kill bacteria, fungi, and nematodes (Janse and Wenneker, 2002). Pathogens are killed either directly by heat or weakened by sublethal heat to the extent that they are unable to damage the crop. Heat can be induced in rhizomes by hot water (Tsang and Shintaku, 1998), hot air, water vapor, solar energy, and microwaves (Kumar et al., 2003). Of these, hot air, hot water, and water vapor have been used for many years as effective treatments for planting material to rid them of various pathogenic microorganisms including nematodes (Colbran and Davis, 1969). Each of the approaches are discussed below.

Heat Induction by Hot Air

Heat inactivation using hot air has had wide application in the control of postharvest disease and insect pests in fruits and vegetables (Couey, 1989). The use of nonsaturated heated air is a potential treatment for disinfection of ginger seed pieces. Exposure of ginger seed pieces to hot air at 75 percent relative humidity (RH) until their center temperature reaches 49ºC(112ºF) for 30 minutes or 50ºC (122ºF) for 30 minutes results in minimal injury to the host without an adverse effect either on germination or subsequent growth. Rhizomes harvested from plants grown from seed pieces inoculated with *R. solanacearum* and subsequently heat treated with hot air at 75 percent RH until their central temperature reached 49ºC for 30 minutes were free of the bacterial wilt pathogen. The bacterial wilt pathogen was destroyed in ginger seed pieces treated with hot air at 75 percent RH, and this method is recommended for disinfection (Tsang and Shintaku, 1998). Heat treatment also serves to release the seed piece from dormancy. To be effective, heat treatment must be long enough to penetrate the seed piece to its full depth, but not so prolonged as to be injurious to the host. Selection of similar sized seed pieces is an aid in maintaining uniform thermal gradients in a batch. There are many examples of the use of heat to kill pathogens without affecting the viability of the planting units (Waterworth and Kahn, 1978; Kuniyasu, 1983; Shiomi, 1992; van der Hulst and de Munk, 1992; Dhanvantari and Brown, 1993; Tsang and Shintaku,

1998). In ginger planting of seed pieces after exposure to 50 ºC for 30 minutes often resulted in healthy plantlets in Hawaii (Tsang and Shintaku, 1998).

Heat Induction by Hot Water

Soaking of ginger seed in hot water at 50ºC for 10 minutes (Nishina et al., 1992; Trujillo, 1963) is the usual preplant preparation in Hawaii. Shorter exposure times give insufficient heat penetration,, and longer soaking periods result in heat injury to the seed piece and growth of stunted crops (Nishina et al. 1992).

Heat Induction by Rhizome Solarization

Disinfection of rhizomes with solar radiation, a method called rhizome solarization, has been developed for bacterial wilt management (Figure 9.8) (Kumar et al., 2003). This is one of the most ecofriendly and energy-efficient methods available for rhizome treatment. Rhizome temperatures of 40 and 50ºC were recorded after 1 and 2 hours of solarization from 9:00 A.M. to 11:00 A.M. on a bright sunny day (January to May in India) (Prasheena, 2003). Plants emerging from solarized rhizomes often escape the disease due to in situ killing of the pathogen in the seed rhizome or in the vascular tissue itself (Kumar et al., 2003). Serological evidence for elimination of *R. solanacearum* from ginger rhizomes has been reported (Prasheena, 2003). When rhizomes are exposed to solar radiation, the rhizome temperature rises especially in the vascular region. Incidentally, the thermal inactivation point for *R. solanacearum* is 46 to 50ºC at 30 minutes of continuous exposure in vitro (Kumar et al., 2003). However, data obtained

Figure 9.8 Effect of rhizome solarization on bacterial wilt incidence in ginger 1. Untreated rhizomes. 2 & 3-Solarized rhizomes.

from studies in vitro with bacterial suspensions are not comparable to the situation where the bacterium is well protected in the vascular tissues of ginger rhizomes. To achieve the requisite temperature inside the vascular tissue or in a site where the pathogen is located, 2 hours of rhizome solarization are sufficient. A temperature of over 49°C was recorded in almost all the locations. The consistency with which the rhizome temperature increases in the rhizome once again confirms the effectiveness of rhizome solarization for heat induction in rhizomes (Prasheena 2003). However, one of the major sources of variability in heat build up vis-à-vis the fate of pathogen, *R. solanacearum,* is variation in the size and shape of the rhizome. As the size increased the heat build-up was also increased. Larger rhizomes recorded 1 to 3°C higher temperatures than the smaller rhizomes. The variation in the heat build up in the rhizome could be due to the fact that the larger seed rhizome has a larger surface area to trap the sunlight that, in turn, results in a higher temperature in the rhizome (Prasheena, 2003). The relationship between rhizome size and heat build-up has been recorded (Tsang and Shintaku, 1998).

Rhizomes collected from ginger plants emerged from solarized infected rhizomes tested negative for *R. solanacearum* in NCM-ELISA (Kumar et al., 2003). This result corroborates the finding of Tsang and Shintaku (1998) that the bacterial wilt pathogen was killed due to heat exposure as assayed by PCR using primers specific for *R. solanacearum*. This could be due to heat killing of the microbial cells on ginger rhizomes including *R. solanacearum* as the rhizome temperature recorded after 2 hours of rhizome solarization was 50°C. The effect of rhizome solarization on microbial populations has been reported (Prasheena 2003). Tsang and Shintaku (1998) reported that *R. solanacearum* was eliminated from ginger rhizomes when the rhizome was exposed to heat for 30 minutes at 50°C. Negative results obtained in postenrichment *double antibody sandwich* (DAS)-ELISA for *R. solanacearum* in solarized rhizomes confirms that the bacterium does not survive in solarized rhizomes (Table 9.1) (Anila, 2003; Prasheena, 2003). The assay clearly indicates that rhizome solarization is capable of disinfecting the rhizomes infected by *R. solanacearum* either artificially or naturally. The temperature generated inside the rhizome may have decreased the numbers of viable bacteria in the rhizome. As surface

Table 9.1 Fate of *R. solanacearum* in solarized ginger rhizomes as detected by DAS-ELISA

		A405 value[a]			
		RS inoculated		*Uninoculated*	
Treatment	*Rhizome temperature (°C)*	*Outer surface*	*Vascular tissue*	*Outer surface*	*Vascular tissue*
Unexposed	31.4	0.273 (0.103)	1.450 (0.413)	0.309 (0.196)	0.428 (0.033)
1 h solarized (10:30—11:30 am)	50.1	0.280 (0.004)	0.512 (0.457)	0.219 (0.130)	0.669 (0.771)
2 h solarized (10:30 am–12:30 pm)	56.2	0.296 (0.109)	0.80 (0.264)	0.214 (0.098)	0.356 (0237)
	Negative control value: 0.333				

[a]Mean of two readings. Data in parentheses are standard deviation values.
A405 values greater then three times that of negative control are positive samples.
Absorbance was read at 405 nm 1 hr after adding the substrate solution.

washings of the unexposed rhizomes show a negative result for the presence of *R. solanacearum*, it has been concluded that *R. solanacearum* survives in the vascular tissues of inoculated or infected rhizomes.

Heat Induction by Microwaves

The effect of microwave treatment on microorganisms appears to be related to heat induction (Vela and Wu, 1979). However, some metabolic effect not related to heating may occur (Barker and Fuller, 1969). The microwave oven has been used as a research tool in several different investigations (Diprose et al., 1978). Susceptibility of microorganisms on seed to microwave heating is determined by altering the power level, amount of sample, and water content, as well as exposure time (Thomas et al., 1979; Puri and Barraclough, 1993). If the test sample (rhizome or seed) is homogeneous, the entire microwave energy penetrates all parts simultaneously and heat is generated evenly throughout the material; since the surface of ginger can lose energy by convection, conduction, or radiation, dielectric heating can result in the interior of the sample becoming hotter than the outside. Treatment of 1 kg soil for 150 seconds is sufficient to eliminate populations of *Pythium, Fusarium*, and most nematodes in soil. *Fusarium* species tolerated high-aerated steam temperatures than *Rhizoctonia* species, but *Fusarium* was less tolerant to microwave treatment (Bollen, 1969). The effect of 2,450 MHz heating on plant pathogens and soil microorganisms has been reported (Ferris, 1984). When infected rhizomes were subjected to microwaves for 30 seconds, the resulting plantlets were free from bacterial wilt under greenhouse conditions (Figure 9.9) (Kumar

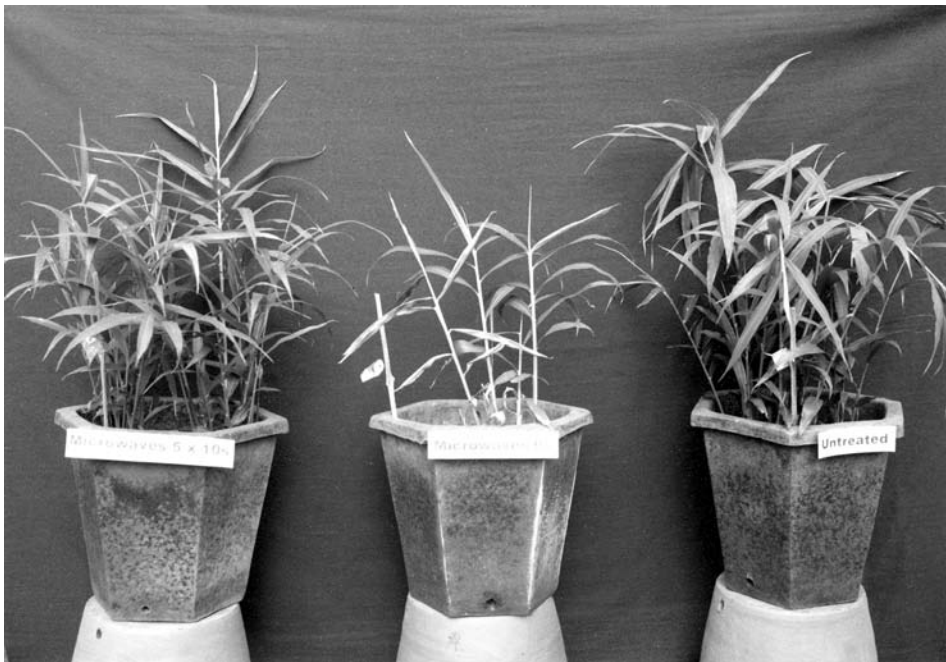

Figure 9.9 Effect of rhizome microwaving on bacterial wilt incidence in ginger. 1. Healthy control. 2. Untreated rhizomes. 3. Microwaved rhizomes.

et al., 2003). However, at longer exposure, germination of the rhizomes was adversely affected (Kumar et al., 2003).

Cultural Methods

An effective method to reduce the occurrence of bacterial wilt of potato in infested potato fields in Peru is crop rotation with maize (Elphinstone and Aley, 1993). In China 3 years of rice cultivation reduced the bacterial wilt incidence of groundnut from 8.3 percent to 1.5 percent (Wang et al., 1983). In India rotation with finger millet or maize reduces wilt of eggplants and tomato (Sohi et al., 1981). In pot culture experiments soil amendments were effective in controlling bacterial wilt (Chang and Hsu, 1988), and similar results were obtained in field trials (Hartman and Yang, 1990; Elphinstone and Aley, 1993). Pegg and Moffett (1971) suggested that the grower should attempt to eradicate weeds known to harbor biovar 3, which has a wide host range including ginger. Experience in India has shown that crop rotation with nonhosts such as cereals and millets results in a reduction in the wilt incidence in the ensuing crop of ginger, but more work is required on cultural methods of disease management comparable to that done with other hosts of *R. solanacearum.*

Identification of Resistance Sources for Control of Bacterial Wilt of Ginger

In vitro and in vivo techniques are available for screening the germplasm for bacterial wilt tolerance in ginger. Almost all cultivated edible ginger is susceptible to bacterial wilt. Over 600 accessions screened for bacterial wilt tolerance using a soil inoculation method were found to be susceptible to the disease. Incorporating the toxic metabolites of *Ralstonia* in the culture medium was used for in vitro selection; however, surviving plantlets were found to be susceptible to bacterial wilt in the field (A. Kumar, unpublished data). An efficient in vitro screening technique for tolerance to bacterial wilt has been developed at the Indian Institute of Spices Research, Calicut. Live bacterial cells are added to tissue culture bottles containing ginger plantlets; this method enables screening of large numbers of plantlets in tests of 2 weeks' duration. Susceptible plants became chlorotic (Figure 9.10). A differential reaction of ginger accessions to bacterial wilt was reported by Indrasenan et al. (1982).

Biological Control

Successful biological control agents have the ability to compete with other members of the soil microflora and also to produce antibiotics or induce a response in the host that favors growth of the biological control agent while inhibiting the growth of *R. solanacearum*. Bacterial antagonists and avirulent strains of *R. solanacearum* are effective in the control of wilt in groundnut (He, 1990). The bacterial antagonists include *Pseudomonas fluorescens* (Kempe and Sequeira, 1983; Ciampi-Panno et al., 1989; Gallardo et al., 1989), *Pseudomonas glumae* (Wakimoto, 1987; Furaya et al., 1991), *Pseudomonas cepacia* (Aoki et al., 1991), *Bacillus* species (Fucikovsky et al., 1989), and *Erwinia* species (Fucikovsky et al., 1989). Avirulent mutants of *R. solanacearum* (Chen and Echandi, 1984; Kempe and Sequeira, 1983) show promise for bacterial wilt control (Trigalet and Trigalet-Demery, 1990). Other biological agents have not been very effective in natural environments due to poor colonization and because the level of protection is not sufficient for commercial use (Chen and Echandi, 1984). Endophytic antagonists derived from wild-type strains

Figure 9.10 In vitro screening technique for bacterial wilt tolerance.

are potential control agents (Frey et al., 1993). Some genetically engineered avirulent mutants of *R.solanacearum* with lesions in the *hrp* gene cluster have the ability to colonize the host plant multiplying in the rhizosphere and rhizoplane and inside the collar and lower part of the stem. These mutants induce a host defense response, and also have the ability to produce bacteriocin with a wide spectrum of activity, which makes them promising agents for the biological control of bacterial wilt under field conditions.

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10 Insect Pests of Ginger

S. Devasahayam and K.M. Abdulla Koya

Ginger is infested by various species of insects, among which the shoot borer (*Conogethes punctiferalis* Guen.) and rhizome scale (*Aspidiella hartii* Sign.) are major pests in the field and during storage of rhizomes, respectively. Other insects that have been reported to affect ginger belong to diverse families and can be classified into sap feeders, leaf feeders, and rhizome feeders. Dry ginger is also infested by many species of insects, most importantly the cigarette beetle (*Lasioderma serricorne* (Fab.), the drug store beetle (*Stegobium paniceum* L.) and the coffee bean weevil (*Araecerus fasciculatus* DeG.). The information on ginger's insect pests in India has been reviewed by Jacob (1980), Koya et al. (1991), and Premkumar et al. (1994). Various aspects of distribution, damage, life history, seasonal incidence, host plants, resistance, natural enemies, and management of these insect pests around the world have been consolidated in this chapter. A list of insects recorded on ginger in the world has also been tabulated in Table 10.1.

Table 10.1 List of insects recorded on ginger

Genus/Species	*Plant part affected*	*Distribution*
Order: Isoptera		
Family: Termitidae		
Odontotermes obesus Holm.	Rhizome	India
Order: Hemiptera		
Family: Aphididae		
Pentalonia nigronervosa Coq.	Leaf	China, India
Family: Pseudococcidae		
Pseudococcus sp.	Rhizome	Fiji
Unidentified	Rhizome	India
Family: Coccidae		
Aspidiella hartii Ckll.	Rhizome	India, Sierra Leone
Aspidiotus destructor Sign.	Rhizome	Fiji
Family: Diaspididae		
Howardia biclavis (Com.)	Rhizome	—
Order: Thysanoptera		
Family: Thripidae		
Thrips tabaci Lind.	Leaf	India
Order: Coleoptera		

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Table 10.1 (Continued)

Genus/Species	*Plant part affected*	*Distribution*
Family: Scarabaeidae		
Adoretus sinicus Burm.	Leaf	Hawaii
Heteronychus arator (Fab.)	Shoot	Australia
Holotrichia consanguinea Blanch.	Rhizome	India
H. corocea (Hope)	Rhizome	India
H. fissa Brenske	Rhizome	India
Family: Elateridae		
Unidentified	Rhizome	Hawaii
Family: Anobiidae		
Lasioderma serricorne (Fab.)	Dry rhizome	Bangladesh, Egypt, India, Japan, Philippines, Sierra Leone, Sri Lanka, UK, West Indies
Sitodrepa panicea L.	Dry rhizome	West Indies
Stegobium paniceum L.	Dry rhizome	Bangladesh, India, Nigeria
Family: Bostrychidae		
Tribolium castaneum (Hbst.)	Dry rhizome	India, West Indies
Family: Lyctidae		
Lyctus africanus Lesne	Dry rhizome	Egypt
Family: Cleridae		
*Necrobia rufipe*s DeG.	Dry rhizome	China
Family: Sylvanidae		
Ahasverus advena Watl.	Dry rhizome	Australia
Oryzaephilus surinamensis (L.)	Dry rhizome	India, Sierra Leone
Rhizopertha dominica (F.)	Dry rhizome	Bangladesh
Family: Tenebrionidae		
Tenebroides mauritanicus (L.)	Dry rhizome	India
Family: Chrysomelidae		
Pharangispa alpiniae alpinae Gressitt & Samuelson	—	Solomon Islands
P. a. bella Gressitt & Samuelson	—	Solomon Islands
P. a. georgiana Gressitt & Samuelson	—	Solomon Islands
P. a. marginata Gressitt & Samuelson	—	Solomon Islands
P. purpureipennis Maulik	—	Solomon Islands
Family: Cerambycidae		
Unidentified	Rhizome	South Africa
Family: Anthribiidae		
*Araecerus fasciculatus (*DeG.*)*	Dry rhizome	India, Sierra Leone
Family: Curculionidae		
Sitophilus granarius L.	Dry rhizome	West Indies
Caulophilus oryzae (Gyllen.)	Dry rhizome	USA
C. latinasus Say	Dry rhizome	UK
Hedychorus rufofasciatus M.	Leaf	India
Order: Diptera		
Family: Mycetophilidae		
Leia arsona	Rhizome	UK
Unidentified	Rhizome	Korea
Family: Sciaridae		
Bradysia sp.	Rhizome	Korea
Phytosciara zingiberis	Rhizome	Japan

Psiloscaria flammulinae	Rhizome	Japan
Family: Micropezidae		
Calobata sp.	Rhizome	India
C. *indica*	Shoot, Rhizome	India
Mimegralla coeruleifrons Macq.	Rhizome	India
Family: Chloropidae		
*Chalcidomyia atricorni*s Mall.	Shoot, Rhizome	India
Formosina flavipes Mall.	Shoot, Rhizome	India
Merochlorops flavipes	Rhizome	India
Paracamarota sp.	Rhizome	India
Family: Celyphidae		
Celyphus sp.	Rhizome	India
Family: Syrphidae		
Eumerus albifrons Wlk.	Rhizome	India
E. pulcherrimus Bru.	Rhizome	India
Order: Lepidoptera		
Family: Gracillaridae		
Acrocercops irradians Meyr.	Leaf	India
Family: Tineidae		
Opogona sacchari (Bojer)	Rhizome	Brazil
Setomorpha rutella Zell.	Dry rhizome	India
Family: Oecophoridae		
Blastobasis byrsodepta Meyr.	Rhizome	Sierra Leone
Family: Pyralidae		
Conogethes punctiferalis Guen.	Shoot	India, Sri Lanka
Ephestia sp.	Dry rhizome	India
E. kuehniella Zell.	Dry rhizome	Egypt
Ostrinia furnacalis Guen.	Rhizome	Australia, China, Solomon Islands
Pyralis manihotalis Guen.	Dry rhizome	India
Plodia interpunctella Hbn.	Dry rhizome	Egypt
Family: Hesperidae		
Udaspes folus Cram.	Leaf	India
Family: Noctuidae		
Heliothis sp.	Shoot	Australia
Spodoptera litura (F.)	Leaf	Malaysia
Unidentified	Leaf, Shoot	Australia, Hawaii

Major Insect Pests

The shoot borer and rhizome scale are major insect pests of ginger.

Shoot Borer *(Conogethes punctiferalis* Guen.*)*

The shoot borer is ginger's most serious pest, especially in India, but little information is available on its distribution in various areas in the country. In Kerala (India), 23.6 to 25.0 percent of pseudostems were damaged by the pest at Kottayam and Idukki districts (Nybe, 2001). The shoot borer is also widely prevalent in Asia, Africa, America, and Australia, but authentic records of the pest on ginger are limited. The shoot borer is known by many other common names generally indicative of the crop and plant part infested. It has been suggested that the shoot borer is a combination of more than one

Figure 10.1 Ginger pseudostem infested by shoot borer.

species, especially in Australia and South East Asia (Honda, 1986a, 1986b; Honda et al., 1986; Robinson et al., 1994; Boo, 1998).

The larvae of shoot borer bore into pseudostems and feed on the growing shoot of ginger plants, resulting in yellowing and drying of infested pseudostems. The presence of bore holes on the pseudostem, through which frass is extruded, and the withered central shoot are characteristic symptoms of pest infestation (see Figure 10.1). Studies on yield loss caused by the pest in Kerala indicated that when 50 percent of the pseudostems in a plant are affected, there was a significant reduction of 38 g of yield per plant (Koya et al., 1986). Yield losses of 25 percent have also been reported when 23 to 24 percent of a plant's pseudostems are infested and the pest was reported to cause 40 percent yield loss in Kottayam and Idukki districts in Kerala (Nybe, 2001).

Life History

The adults are medium-sized moths with a wingspan of 18 to 24 mm; the wings and body are pale straw yellow with minute black spots (see Figure 10.2). There are five larval instars; fully grown larvae are light brown with sparse hairs and measure 16 to 26 mm in length (see Figure 10.3). The dimensions of adults and larvae may vary depending on the host plant in which they are raised. Jacob (1981) reported the morphometrics of various stages when reared on turmeric. Thyagaraj et al. (2001) suggested a method for determining the shoot borer's sex based on the size and morphology of male and female pupae.

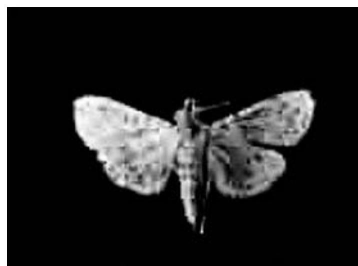

Figure 10.2 Shoot borer, adult.

Figure 10.3 Shoot borer, larva.

No information is available on the life history of the shoot borer on ginger. However, its life history has been studied on other Zingiberaeceous crops such as turmeric and cardamom. Such studies on turmeric conducted at Kasaragod (Kerala) under laboratory conditions (temperature range: 30 to 33ºC; relative humidity range: 60 to 90 percent) indicated that the preoviposition and egg periods lasted for 4 to 7 and 3 to 4 days, respectively. The five larval instars lasted for 3 to 4, 5, 3 to 7, 3 to 8, and 7 to 14 days, respectively. The prepupal and pupal periods lasted for 3 to 4 and 9 to 10 days, respectively. Adult females laid 30 to 60 eggs during its lifespan, and 6 to 7 generations were completed during a crop season in the field. Variations were also observed in the life cycle (up to 30 days during August to October and up to 38 days during November to December) during various seasons (Jacob, 1981).

At Thadiyankudisai (Tamil Nadu, India), the duration of shoot borer's life history on cardamom varied considerably during summer (temperature range: 16 to 29ºC; relative humidity range: 65 to 85 percent) and winter (temperature range: 16 to 25ºC; relative humidity range: 49 to 92 percent). The preoviposition, egg, and larval periods lasted for 2 to 3, 6 to 7, and 21 to 32 days, respectively, during summer, and 17 to 18, 6 to 8, and 40 to 62 days, respectively, during winter. The prepupal and pupal periods lasted for 2 to 3 and 10 to 12 days, respectively, during summer, and 4 to 7 and 17 to 27 days, respectively, during winter (Varadarasan, 1991).

Seasonal Incidence

No information is available on the seasonal population dynamics of the shoot borer on ginger. However, the damage was reported to be higher in the field during August, September, and October in Kottayam and Idukki districts in Kerala (Nybe, 2001).

Host Plants

The shoot borer is highly polyphagous and has been recorded on 65 host plants belonging to 30 families (see Table 10.2). Many of the hosts of the shoot borer are economically important plants, and the pest infests various parts of these plants, such as buds, flowers, shoots, and fruits

Table 10.2 List of host plants of *Conogethes punctiferalis*

Common Name	*Scientific Name*	*Family*	*Distribution*
Custard apple	*Annona* sp.	Annonaceae	Australia
Cherimoya	*A. cherimola* Mill.	Annonaceae	India
Hollyhocks	*Alcea rosea* L.	Malvaceae	India
Cotton	*Gossypium* sp.	Malvaceae	Australia, India
Silk cotton tree	*Ceiba pentandra* (L.) Gaertn	Bombacaceae	India, Indonesia
Cocoa	*Theobroma cacao* L.	Sterculiaceae	India, Sri Lanka
Carambola	*Averrhoa carambola* L.	Oxalidaceae	—
Orange	*Citrus* sp.	Rutaceae	Australia, China, Japan
Tangor	*C. nobilis* Lour.	Rutaceae	—
	Fortunella sp.	Rutaceae	China
Grape	*Vitis vinifera* L.	Vitaceae	India
Longan	*Dimocarpus longan* Lour.	Sapindaceae	China
Rambutan	*Nephelium lappaceum* L.	Sapindaceae	Malaysia
Soapnut	*Sapindus emarginatus* Vahl.	Sapindaceae	India
Soapnut	*S. laurifolius* Vahl.	Sapindaceae	India
Mango	*Mangifera indica* L.	Anacardiaceae	India
Sumac	*Rhus chinensis* Mill.	Anacardiaceae	Japan
Bean	*Canavalia indica*	Fabaceae	Australia
	Cassia sp.	Fabaceae	Australia
Fever nut	*Caesalpinia bonducella* Flem.	Fabaceae	India
Soybean	*Glycine max* (L.) Merr.	Fabaceae	Australia
Tamarind	*Tamarindus indica* L.	Fabaceae	India
Hawthorn	*Crataegus pinnatifida* Bunge	Rosaceae	China
Loquat	*Eriobotrya japonica* (Thunb.) Lindl.	Rosaceae	China
Apple	*Malus domestica* Borkh.	Rosaceae	Japan
Cherry	*Prunus japonica* Thunb.	Rosaceae	China, Japan
Peach	*P. persica (*L.) Batsch	Rosaceae	Australia, India, Thailand
Pear	*Pyrus communis* L.	Rosaceae	China, India
Granadilla	*Passiflora* sp.	Passifloraceae	Australia
Papaya	*Carica papaya* L.	Caricaceae	Australia, Phillipines
Garuga	*Garuga pinnata* Roxb.	Rubiaceae	India
Dahlia	*Dahlia* sp.	Compositae	Australia
Sunflower	*Helianthus annuus* L.	Compositae	Sri Lanka
Perssimon	*Diospyros kaki* Thunb.	Ebenaceae	Japan, Korea
Teak	*Tectona grandis* L.	Verbenaceae	Burma, Indonesia
Amaranth	*Amaranthus* sp.	Amaranthaceae	India
Black pepper	*Piper nigrum* L.	Piperaceae	—
Guava	*Psidium guajava* L.	Myrtaceae	Australia, India

Pomegranate	*Punica granatum* L.	Lythraceae	India
Avocado	*Persia americana* Mill.	Lauraceae	India
Queensland nut	*Macadamia integrifolia* Maiden & Betche	Proteaceae	Australia
Castor	*Ricinus communis* L.	Euphorbiaceae	Australia, Bangladesh, India, Indonesia, Papua New Guinea
Chestnut	*Castanea mollissima* Blume	Fagaceae	China
Oak	*Quercus* spp.	Fagaceae	Korea
Oak	*Q. acutissima* Carrutt.	Fagaceae	Japan
Jack	*Artocarpus heterophyllus* Lam.	Moraceae	India
Mulberry	*Morus* sp.	Moraceae	India
Fig	*Ficus carica* L.	Moraceae	India
Alligator pepper	*Aframomum melegueta* Schum.	Zingiberaceae	India
	Alpinia sp.	Zingiberaceae	India
Galangal	*A. galanga* (L.) Sw.	Zingiberaceae	India
	Amomum sp.	Zingiberaceae	India
	A. microstephanum Baker	Zingiberaceae	India
Greater cardamom	*A. subulatum* Roxb.	Zingiberaceae	India
Turmeric	*Curcuma longa* L.	Zingiberaceae	India, Sri Lanka
Yellow zedoary	*C. aromatica* Salisb.	Zingiberaceae	India
Mango ginger	*C. amada* Roxb.	Zingiberaceae	India
Cardamom	*Elettaria cardamomum* Maton	Zingiberaceae	India, Sri Lanka
Ginger lily	*Hedychium coronarium* J. Konig	Zingiberaceae	India
Yellow ginger lily	*H. flavescens* Carey ex Rosc.	Zingiberaceae	India
Ginger	*Zingiber officinale* Rosc.	Zingiberaceae	India, Sri Lanka
Banana	*Musa* sp.	Musaceae	Australia
Sugarcane	*Saccharum officinarum* L.	Poacea	Australia
Sorghum	*Sorghum bicolor* (L.) Moench	Poacea	Australia, India
Maize	*Zea mays* L.	Poacea	Australia, China
Cedar	*Cryptomeria japonica* (L. f.) D. Don	Taxodiaceae	—

Source:
1. *Review of Applied Entomology—Series A/Review of Agricultural Entomology,* CAB International, Wallingford.
2. Crop Protection Compendium (2002), CAB International, Wallingford.
3. *CABPESTCD*, CAB International, Wallingford.
4. Koya et al. (1991).

Resistance

The reaction of various types of ginger to shoot borer in the field was studied by Nybe and Nair (1979), who reported that among the 25 cultivars of ginger screened, the pest infestation was minimum in Rio de Janeiro and maximum in Valluvanad, although not significant.

Natural Enemies

Various natural enemies of the shoot borer have been reported, especially from Sri Lanka, China, Japan, and India. *Dolichurus* sp. (Sphegidae), *Xanthopimpla* sp. (Ichneumonidae), and *Phanerotoma hendecasisella* Cam. (Braconidae) were recorded as parasitoids of shoot borer from Sri Lanka (Rodrigo, 1941). *Apanteles* sp. (Braconidae), *Brachymeria lasus* West. (Chalcidae), and *Temelucha* sp. (Ichneumonidae) were recorded as parasitoids of shoot borer infesting longan (*Dimocarpus longan* Lour.) in China (Huang et al., 2000). *Trathala flavoorbitalis* (Cam.) (Ichneumonidae) and *B. obscurata* Walk. from China, along with *Apechthis scapulifera, Scambus persimilis* (Ichneumonidae), and *B. obscurata* from Japan, have also been documented as natural enemies of the pest (CABI, 2002).

A number of natural enemies have been documented in India. The entomopathogenic nematode *Steinernema glaseri* (Steinernematidae) has been recorded on larvae of shoot borer (CABI, 2002). *Angitia (Dioctes) trochanterata* Morl. (Ichneumonidae), *Theromia inareolata* (Braconidae), *Bracon brevicornis* Wes., *Apanteles* sp. (Braconidae), *Brachymeria euploeae* West. (Chalcidae) (David et al. 1964), and *Microbracon hebetor* Say. (Braconidae) (Patel and Gangrade, 1971) were documented as natural enemies of the pest infesting castor. *Brachymeria nosatoi* Habu and *B. lasus* West. were recorded as parasitoids of the pest by Joseph et al. (1973). More than 20 parasitoids have been found parasitising the shoot borer infesting cardamom, and they include *Palexorista parachrysops* (Tachinidae), *Agrypon* sp., *Apechthis copulifera*, *Eriborus trochanteratus* (Morl.), *Friona* sp., *Gotra* sp., *Nythobia* sp., *Scambus persimilis*, *Temecula* sp., *Theronia inareolata*, *Xanthopimpla australis* Kr., *X. kandiensis* Cram. (Ichneumonidae), *Bracon brevicornis* Wes., *Microbracon hebator*, *Apanteles* sp., *P. hendecasisella* Cram. (Braconidae), *Synopiensis* sp., *Brachymeria australis* Kr., and *B. obscura* (Chalcidae) (CPCRI, 1985; Varadarasan, 1995).

Mermithid nematode (Mermithidae), *Myosoma* sp. (Braconidae), *X. australis* (Jacob 1981), *Hexamermis* sp. (Mermithidae), and *Apanteles taragamme* (Devasahayam, unpublished) have been documented on shoot borer infesting ginger in Kerala. In addition, general predators like dermapteran (*Euborellia stali* Dohrn (Carcinophoridae), asilid flies (*Philodicus* sp. and *Heligmoneura* sp.) (Asilidae), and spiders (*Araneus* sp., *Micaria* sp., and *Thyene* sp.) have also been recorded on the pest in Kerala (Jacob, 1981). The virus that has been recorded to infect shoot borer is *Dichocrocis punctiferalis* NPV (Baculoviridae) (Murphy et al. 1995).

Management

In spite of the serious damage caused by shoot borer, very few field trials have been conducted with insecticides for the control of the pest on ginger.

Chemical Control: Koya et al. (1988) evaluated six insecticides at Peruvannamuzhi (Kerala) and found that all of them were effective in controlling the pest when sprayed at monthly intervals from July to October. Among the insecticides, malathion 0.1 percent resulted in minimum pest infestation on the pseudostems and was on par with monocrotophos 0.05 percent, quinalphos 0.05 percent, endosulfan 0.05 percent, and carbaryl + molasses 0.05 percent. Koya et al. (1986) have evolved a sequential sampling strategy for monitoring the level of pest infestation in a field of ginger as guidance for undertaking control measures.

The pesticide residues of the promising insecticides, such as malathion 0.1 percent, endosulfan 0.05 percent, and monocrotophos 0.05 percent, which were sprayed during July to October (four sprays), were determined. The residues of all the insecticides were

below the detectable limits (<0.001 ppm) in dried ginger rhizomes at harvest, indicating the safety of the recommendations for the management of the pest (Devasahayam, unpublished).

Biological Control: Two commercial products of *Bacillus thuringiensis,* namely Bioasp and Dipel, were evaluated, along with malathion for the management of the shoot borer in the field at Peruvannamuzhi. The trials indicated that all the treatments were effective in reducing the damage caused by the pest compared to control when sprayed at 21-day intervals during July to October. Spraying Dipel 0.3 percent was the most effective treatment, resulting in a significantly lower percentage of infested pseudostems on the crop (Devasahayam, 2000).

Choo et al. (1995) evaluated the pathogenecity of entomopathogenic nematodes against the shoot borer. *Steinernema* sp. and *Heterorhabditis* sp. caused 90 and 100 percent mortality, respectively, of test insects in the laboratory when 20 nematodes per larva were inoculated. Choo et al. (2001) later reported that the LC_{50} for *S. carpocapsae* Pocheon strain and *H. bacteriophora* Hamyang strain were 5.6 and 5.8, whereas their moralities were 96.9 and 96.5 percent, respectively, for these strains.

Integrated Management: An integrated strategy including cultural methods, such as pruning of freshly infested shoots during July to August (at fortnightly intervals) and chemical methods such as spraying of insecticide (malathion 0.1 percent) during September to October (at monthly intervals), was effective for the management of shoot borer, resulting in a cost-benefit ratio of 1:4.6. By adopting this integrated strategy, two insecticide sprays could be avoided, thus causing less harm to the ecosystem (Devasahayam unpublished).

Sex Pheromones: Many workers have demonstrated the presence of sex pheromones in the shoot borer (Konno et al., 1980, 1982; Liu et al., 1994; Kimura and Honda, 1999). Trials on the efficacy of sex pheromones in the field have also been reported on various crops (other than ginger) from China, Japan, Korea, and India (Cai and Mu, 1993; Liu et al., 1994; Chakravarthy and Thygaraj, 1997, 1998; Jung et al., 2000)

Rhizome Scale (*Aspidiella hartii* Ckll.)

The rhizome scale is distributed mainly in the tropical regions of Asia, Africa, Central America, and the Caribbean Islands, but authentic records of the pest infestation on ginger in various parts of the world, including India, are limited.

Damage

The rhizome scale infests rhizomes of ginger both in the field and in storage. In the field, the pest is generally seen during the later stages of the crop, and in severe cases of infestation the plants wither and dry. In storage, the pest infestation results in the shriveling of buds and rhizomes, and severe infestation adversely affects the sprouting (see Figure 10.4). The pest infestation results in a weight loss of 14.0 and 22.5 percent when stored for 128 days and 175 days, respectively (Hargreaves, 1930).

Life History

The adult female of the rhizome scale is minute, circular, and light brown to grey, measuring about 1.5 mm in diameter (see Figure 10.5). Females are ovo-viviparous and

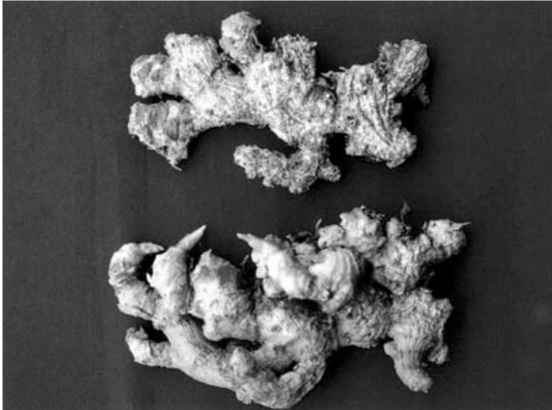

Figure 10.4 Ginger rhizome infested by rhizome scale (top-infested rhizome; bottom-healthy rhizome).

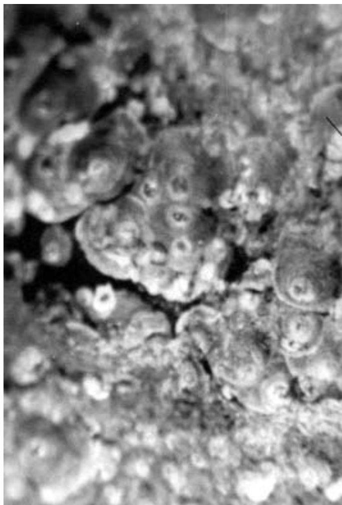

Figure 10.5 Rhizome scale, adults.

also reproduce parthenogenetically. Little information is available on the life history of the pest on ginger. A single female lays about 100 eggs, and the life cycle from egg to adult is completed in about 30 days (Jacob, 1982, 1986). The pest completes its life cycle in 11 to 20 days on yams (*Dioscorea* spp.) (Palaniswami, 1991).

Host Plants

In India, the rhizome scale has been reported to infest turmeric (*Curcuma longa* (L.) Ayyar, 1940), elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson = (A.) *companulatus*) (Regupathy et al., 1976), yams (*Dioscorea alata* L., *D. esculenta* (Lour.) Burkill and *D. rotundata* Poir) (Palaniswami et al., 1979), taro (*Colocasia esculenta* (L.) Schott.) (Pillai and Rajamma, 1984), and tannia (*Xanthosoma sagittifolium* (L.) Schott.) (Jacob, 1986).

In other countries, the rhizome scale infests yams in the West Indies (Ballou, 1916), the Panama Canal Zone in Central America (Fisher, 1920), Nigeria (Onazi, 1969), and the Ivory Coast (Sauphanor and Ratnadass, 1985). It specifically affects sweet potatoes in Africa (Sasser, 1920) and tannia in the West Indies (Catoni, 1921).

Natural Enemies

The natural enemies recorded on the rhizome scale at Kasaragod include *Physcus* (*Cocobius*) *comperei* Hayat (Aphelinidae), *Adelencyrtus moderatus* Howard (Encyrtidae), and two species of mites. Parasitization by *P. comperei* brought down the population of the rhizome scale by about 80 percent in three months (Jacob, 1986). At Peruvannamuzhi, apart from *Cocobius* sp., a predatory beetle and ant were observed to predate on the rhizome scale (Devasahayam, 1996).

Management

Dipping the seed rhizomes in quinalphos 0.1 percent for five minutes after harvest and before planting was found to be effective in controlling rhizome scale infestation on ginger (CPCRI, 1985). Soaking the rhizomes in quinalphos 0.025 percent or fenthion 0.025 percent for 30 minutes was also reported to be effective in preventing the infestation (Maicykutty et al., 1994). Dipping the seed rhizomes in quinalphos 0.075 percent and storage in dried leaves of *Strychnos nux-vomica* L. was also promising for the management of the rhizome scale (IISR, 2002).

Minor Insect Pests

The minor insect pests of ginger include sap feeders, leaf feeders, and rhizome feeders.

Sap Feeders

The only species of thrips recorded to infest ginger is onion thrips *Thrips tabaci* Lind. from India (Chadha, 1976). Reports from India and China indicate that the banana aphid, *Pentalonia nigronervosa* Coq., infests ginger leaves. *Pseudococcus* sp. and unidentified mealybugs have been recorded on ginger rhizomes from Fiji and India, respectively (Ehrhorn and Whitney, 1926; Vevai, 1971). Apart from *A. hartii*, other species of scale insects, such as *Aspidiotus destructor* Sign. (Anon, 1927) and *Howardia biclavis* (Com.) (Chua and Wood, 1990), have also been recorded to infest ginger rhizomes.

Leaf Feeders

The grasshopper, *Atractomorpha ambigua* Bol., has been recorded to feed on ginger leaves in China (Ma, 1935). Chrysomelid beetles, such as *Pharangispa purpureipennis* Maulik, and four subspecies of *P. alpinae* have been recorded on ginger from the Solomon Islands (Maulik, 1929; Gressitt and Samuelson, 1990). The curculionid *Hedychorus rufofasciatus* M. has been recorded on ginger from India (Nair, 1975). The Chinese rose beetle (*Adoretus sinicus* Burm.) has been recorded to damage the foliage of Hawaiian ginger plants. Spraying of carbaryl has been suggested for the management of the pest (UH, 2001).

A few species of leaf-feeding caterpillars have been recorded on ginger, with the turmeric skipper *Udaspes folus* Cram. being the most serious, especially in India. The pest has also been recorded from China and Malaysia as infesting ginger (Hill 1983).

The larvae of the leaf roller cut and fold the leaves, remain within, and feed on them. The egg, larval, and pupal periods last for 4 to 5, 13 to 25, and 6 to 7 days, respectively, on ginger (Abraham et al., 1975). The pest is abundant in the field from August to October. Koya et al. (1991) reviewed the natural enemies and alternate hosts of the pest. The other leaf-feeding caterpillars that affect ginger include *Acrocercops irradians* Meyr. from India (Meyrick, 1931) and *Spodoptera litura* (F.) from Malaysia (Hill, 1983). The larvae of cutworms have been known to feed on the basal portion of pseudostems and sometimes on the first leaf in Australia and Hawaii. In Hawaii, fumigation of the soil with methyl bromide prior to planting and application of diazinon have been suggested for managing the pest (DPI, 2001; UH, 2001).

Rhizome Feeders

Various species of dipteran maggots bore into rhizomes and roots, and they are generally seen in plants affected by rhizome rot disease. The maggots recorded on ginger include *Calobata indica* (Maxwell-Lefroy and Howlett, 1909), *Chalcidomyia atricornis* Mall., *Formosina flavipes* Mall. (Malloch, 1927), *Mimegralla coeruleifrons* Macq. (Khaire et al., 1972), *Celyphus* sp. (Nair, 1975), *Leia arsona* (Hutson, 1978), *Eumerus albifrons* Walk. (Sathiamma, 1979), *Phytosciara zingiberis*, *Psilosciara flammulinae* (Ogawa et al., 1985), *E. pulcherrimus* Bru. (CPCRI, 1986), *Gymnonerius* sp. (Koya, 1988), and *Bradysia* sp. (Lee et al., 2001).

Ghorpade et al. (1983) conducted surveys in Maharashtra (India) and reported that *M. coeruleifrons* was endemic in Sangli and Satara districts and resulted in 31 percent reduction in ginger yield. Surveys conducted in Kerala indicated that *M. coeruleifrons* was the most common species occurring in ginger rhizomes, and 26.4 percent of the diseased rhizome samples examined contained maggots (Koya, 1988). Sonatakke (2000) reported that 40 to 42 percent of the unprotected crop in Orissa (India) was damaged due to an infestation by *M. coeruleifrons*. Garg (2001) conducted surveys in Sirmour district in Himachal Pradesh (India) and reported that 32.6 to 50.0 percent of the rhizome samples were infested by *C. indica*.

The life history of *M. coeruleifrons* on ginger was studied in Maharashtra, Kerala, and Orissa. The pest completed its life cycle in 32 to 35 days, 20 to 28 days, and 46 days, respectively, in these areas (Ghorpade et al., 1988; Koya, 1989; Sontakke, 2000). *Trichopria* sp. (Diapriidae), *Spalangia gemina* Boucek (Pteromalidae), and an unidentified spider were recorded as the natural enemies of *M. coeruleifrons* (CPCRI, 1977; Ghorpade et al., 1982; Koya, 1990). The life history of *C. indica* was studied at Himachal Pradesh, and the total life cycle was completed in 14 to 18 days (Garg, 2001).

Many workers investigated the association of dipteran maggots with diseased rhizomes. The presence or absence of maggots did not make any difference in the initial incidence of the disease (Iyer et al., 1981). Premkumar et al. (1982) reported that 42 percent of the diseased rhizomes examined had *Pythium* sp. alone, and 58 percent had *Pythium* sp. and maggots. None of the rhizomes were infested with maggots alone. Radke and Borle (1982) found that the rotting of rhizomes due to disease occurred first and later the flies preferred such rhizomes for egg laying. Surveys conducted in Kerala indicated that 33.6 percent of the diseased rhizomes contained maggots (*M. coeruleifrons* and *E. pulcherrimus*); none of the healthy rhizomes contained maggots (Koya, 1988). However, Ghorpade et al. (1988) mentioned that the feeding activity of maggots was responsible for the introduction of microorganisms such as *Fusarium* sp., *Pythium* sp., and *Sclerotium* sp. and

nematodes of the genera *Tylenchus, Helicotylenchus, Meloidogyne,* and *Dorylaimida* in the field. However, studies conducted under controlled conditions in the greenhouse and in the field involving inoculation with *M. coeruleifrons* and *Pythium* sp. in various combinations clearly indicated that the maggots could infest only diseased ginger rhizomes and hence cannot be considered as a primary pest of the crop (Koya, 1990).

Koya and Banerjee (1981) reported that aldicarb, carbofuran, and methyl parathion were effective in reducing the pest infestation in trials with various insecticides against *M. coeruleifrons* on ginger. Garg (2001) suggested treating seed rhizomes with chlorpyriphos before sowing, and spraying with the same chemical 1 month after germination for the management of *C. indica*.

The treatment of ginger seed rhizomes with 0.4 percent hexachlorocyclohexane (HCH) and fields with one, two, or three applications (60, 90, and 120 days after planting) of 10 percent HCH dust in Maharashtra for the management of *M. coeruleifrons* resulted in residues of 0.44 ppm in rhizomes from a crop that received the seed treatment and three applications of insecticides. The residues were below 0.1 ppm in rhizomes, which received only two applications. The residues of HCH in the soil ranged from 0.60 to 1.09 ppm in plots, which received one to three applications (Dhatkhile and Dethe, 1987). The same authors subsequently reported that when the seed rhizomes were treated with 0.4 percent of HCH before planting, and when three applications of 7 kg ai/ha were carried out after planting, residues of 0.41 ppm were detected in the rhizomes at harvest. The soil residues ranged from 0.41 to 0.97 ppm (Datkhile and Dethe, 1988).

The larvae of an unidentified cerambycid were reported to tunnel into and completely destroy ginger rhizomes at Hazyview in South Africa (Willers 1990). Koya et al. (1991) reported infestation of 2- to 3-month-old ginger plants by *Holotrichia fissa* Brenske at Peruvannamuzhi. The grubs fed on the tender rhizomes and sometimes at the base of the pseudostems, resulting in the yellowing of shoots and the mortality of the plants. *H. coracea* (Hope) also bored into rhizomes in Shimla district (Himachal Pradesh), resulting in large, circular holes; the damage ranged from 5.7 to 26.5 percent at harvest (Misra, 1992). At Sikkim (India), *H. seticollis* Mosher causes serious damage to ginger in many areas. The egg, larval, and pupal stages lasted for 10 to 15, 170 to 220, and 30 to 40 days, respectively. Collection of beetles during adult emergence periods along with drenching the soil with quinalphos 0.05 percent or chlorpyriphos 0.08 percent was effective for managing the pest (Varadarasan, 2000). *H. consanguinea* Blanch. has been known to feed on rhizomes and roots, which has caused the drying of plants at Sirmour district in Himachal Pradesh. Treating the seed rhizomes and the field with chlorpyriphos before sowing has been suggested for managing the pest (Garg, 2001).

Opogona sacchari (Bojer) on ginger rhizomes from Brazil (Seymour et al., 1985) has been intercepted in the United Kingdom. *Araecerus fasciculatus* (DeG), *Pyralis manihotalis* Guen., and *Setomorpha rutella* Zell., which predominantly infest dry ginger, also bore into fresh ginger rhizomes (Jacob, 1986). The termite *Odontotermes obesus* Holm. has been reported to feed on rhizomes and roots, causing ginger plants to wither and dry, and also leading to the secondary fungal infection of rhizomes at Sirmour district in Himachal Pradesh. The pest infestation could be managed by treating seed rhizomes and the field with chlorpyriphos before sowing and avoiding the use of sugarcane straw as mulch (Garg 2001). Wireworms have also been reported to damage ginger plants in Hawaii. Fumigating the soil with methyl bromide prior to planting and applying diazinon have been suggested for managing the pest (UH, 2001).

Major Insect Pests of Stored Ginger

Various insects have been reported to infect dry ginger. They mainly belong to the orders Coleoptera and Lepidoptera, with the cigarette beetle (*Lasioderma serricorne* (Fab.), the drug store beetle (*Stegobium paniceum* L.) and the coffee bean weevil (*Araecerus fasciculatus* DeG) being the most serious.

Distribution

The insect pests of dry ginger are cosmopolitan in the warmer parts of the world, occurring mainly in Asia and Africa. In temperate regions, they are common in heated stores. Abraham (1975) reported that the cigarette beetle and coffee bean beetle were the most common pests of dry ginger in Kerala, and 30 to 60 percent of the samples were infested by these pests. Studies on insect pests of stored ginger in commercial stores in Kerala indicated that a significantly high population of cigarette beetle was noticed during August and October when compared to December at Kozhikode, Ernakulam and Idukki districts (Joseph et al., 2001a).

Damage

The larvae of cigarette beetle and drug store beetle tunnel into dry ginger and contaminate it with an abundant production of frass (see Figure 10.6). The larvae and adults also make extensive holes in the produce. The adults of cigarette beetle do not feed but tunnel through the produce to leave the pupal cocoon, creating extensive holes. Both adults and larvae of coffee bean weevil are injurious to dry ginger rhizomes that are completely fed, and only the outer covering is left intact.

Studies on the damage caused by storage pests to ginger in Kerala indicated that the weight loss to the stored produce by the pest infestation increased gradually from the second month onwards (Joseph et al., 2001b).

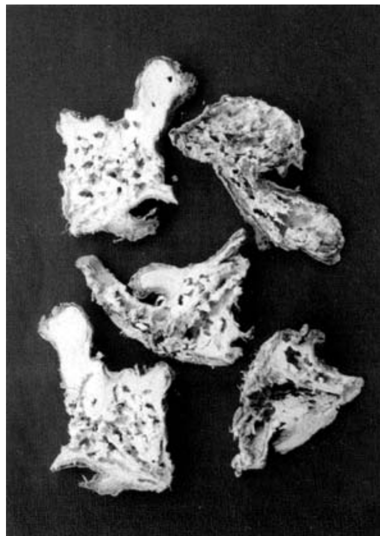

Figure 10.6 Dry ginger rhizomes damaged by cigarette beetle.

Life History

Adult cigarette beetles are small (3 to 4 mm), brown beetles with smooth elytra that have fine hairs. The head is strongly protected under the pronotum, especially when alarmed and the antennae are serrated. The eggs are creamy white, and the larvae are whitish grey with dense hairs. The larvae are very active when young but become sluggish as they age. There are 4 to 6 larval instars, and the later instars are scarabaeiform. Pupation occurs within a silken cocoon, and the pupa is brown. The incubation period lasts for 9 to 14 days, the larval period for 17 to 29 days, and the pupal period for 2 to 8 days in Kerala (Abraham, 1975). The life history of cigarette beetle infesting ginger has also been studied in Japan (Shibuya and Yamada, 1935) and Egypt (El-Halfawy, 1977). Laboratory studies on growth and food intake of cigarette beetle on various spices have indicated the order of preference as cumin > anise > ginger > turmeric powder > turmeric (Jacob 1992).

The drug store beetle resembles the cigarette beetle superficially but is smaller with striated elytra, and the distal segments of the antenna are clubbed. The larvae are pale white with the abdomen terminating in two dark horny points in fully grown specimens. The eggs are cigar-shaped and hatch in six days. The larval period lasts for 10 to 20 days, and the pupal period lasts for 8 to 12 days (Abraham, 1975).

The coffee bean weevil is a small (3 to 5 mm), grey, stout beetle with pale marks on the elytra and with long, clubbed antennae. The eggs are oval and are laid in small pits dug on the rhizomes by the female beetles. Pupation takes place within the infested rhizomes. The entire life cycle lasts for 21 to 28 days (Abraham, 1975). Studies on the development and life span of the coffee bean weevil on various food materials, including ginger, indicated that tapioca and maize were more favorable than black gram, ginger, and arecanut (Ragunath and Nair, 1970).

Studies on the olfactory responses of adults of *L. serricorne* and *S. paniceum* to various spices, including ginger, indicated that in *L. serricorne*, the highest attraction value of 42.6 percent was observed in turmeric when compared to 28.5 percent in ginger. However, in the case of *S. paniceum*, the attraction value to ginger was only 1.9 percent (Jha and Yadhav, 1991).

Hosts

All the storage pests infest a wide range of produce, including cocoa and coffee beans, cereals, spices, dried fruits, oil seeds, confectionery products, processed foodstuffs, and even animal products.

Natural Enemies

Several natural enemies, including predatory mites, hemipterans, coleopterans, and hymenopterous parasitoids, have been found on storage pests. Predatory mites such as *Acaropsellina solers* (Kuzin) (Cheyletidae) (Rizk et al., 1980), *A. docta* (Berl.) (Cheyletidae) (Al-Badry et al., 1980), *Pyemotus tritici* (Pyemotidae), *Cheyletus* spp. (Cheyletidae), *Chortoglyphus gracilipes* (Chortoglyphidae CABI, 2002), and *Blattisocius tarsalis* (Ascidae) (Riudavets et al., 2002), have been recorded as natural enemies of *L. serricorne*.

The predatory beetles and bugs recorded as natural enemies include *Tribolium castaneum* (Hbst.) (Bostrychidae) (Jacob and Mohan, 1973), *Peregrinator biannulipes* (Montr. and Sign.) (Yao et al., 1982), *Xylocoris flavipes* (Reuter) (Anthocoridae), *Alloeocranum biannulipes*

(Reduviidae), and *Termatophyllum insigne* (Miridae) (Tawfik et al., 1984–1985), which prey on *L. serricorne* and *S. panniceum*. *Tenebroides mauritanicus* (L.) (Tenebrionidae) and *Thaneroclerus buqueti* (Lefevre) (Cleridae) prey on *L. serricorne* (CABI, 2002), and *Tilloidea notata* (Klug) (Cleridae) preys on *S. paniceum* (Iwata, 1989) and *Cheyletus* sp. *Pyemotes* sp. and *Tydeus* sp. (Cheyletidae) prey on *A. fasciculatus* (Stusak et al.,1986).

The hymenopterous parasitoids that are natural enemies of *L. serricorne* include *Cephalonomica gallicola* (Ashmead) (Bethylidae; Kohno et al., 1987), *Anisopteromalus calandrae* (Howard), *Israelius carthami*, *Perisierola gestroi* (Bethylidae), and *Lariophagus distinguendus* (Forst) (Pteromalidae) (CABI, 2002) *Pteromalus cerealellae* (Pteromalidae) parasitizes both *L. serricorne* and *S. paniceum* (Brower, 1991).

Management

Various strategies have been suggested for the management of storage pests, including storage in suitable containers, fumigation, radiation, and the application of insecticides. Thirumalarao and Nagarajarao (1954) reported that fumigating bags of dry ginger using methyl bromide or calcium cyanide for 24 h or using ethylene dichloride or carbon tetrachloride for 48 h, with an initial external dusting with lindane 0.65 percent once a month, prevented the pest infestation up to an year. Abraham (1975) suggested impregnation of jute bags lined with alkathene (500 guage) with malathion 0.2 percent or fumigation with methyl bromide for 6 h to prevent the pest infestation. Jacob (1986) suggested fumigation with aluminium phosphide tablets in an airtight store for 2 to 3 days to control the pest infestation. Muthu and Majumdar (1974) have furnished the concentration, time of exposure, and residual effects of various fumigants recommended for controlling insect infestations in various spices, including ginger and turmeric. Padwal-Desai (1987) has also studied the lethal dose of gamma radiation required for stored pests of various spices.

Emehute (1997, 1998) evaluated three storage containers (130 μm thick polythene bag, 20 μm thick polythene bag, and brown paper sampling bag) for their effectiveness in protecting dried ginger rhizomes against *S. paniceum*. After seven months, rhizomes stored in 130 μm thick polythene bags and brown paper sampling bags closed by rubber bands remained uninfested by the pest.

Evaluation of dried leaf powders for protecting dry ginger rhizomes from infestation by cigarette beetle has indicated that the storage of dry ginger in PET containers with *Glycosmis cochinsinensis* (Lour.) Pierre ex Engl. or *Azadirachta indica* A. Juss leaf powder was promising in checking the pest infestation (IISR, 2002).

Sex pheromones have been identified in *L. serricorne* and *S. paniceum* (Barratt, 1974, 1977; Kuwahara et al., 1975; Chuman, 1984; Chuman et al., 1985) and have been used for monitoring the population of these species in stores. Aggregation pheromones have also been identified in *A. fasciculatus* (Singh, 1993; Novo, 1998).

Minor Insect Pests of Stored Ginger

The other coleopterans infesting stored, dry ginger rhizomes include *Oryzaephilus surinamensis* L. (Hargreaves, 1927), *Necrobia rufipes* DeG (Whitney, 1927), *Caulophilus latinasus* Say. (Munro and Thomson, 1929), *Lyctus africanus* Lesne. (Zacher, 1934), *Sitodrepa panicea* (L.), *Sitophilus granaria* (L.), *Tribolium castaneum* (Hbst.) (Larter, 1937), *Tenebriodes*

mauritanicus (L.) (Abraham, 1975), *C. oryzae* (Gyllen) (Whitehead, 1982), *Rhizopertha dominica* (F.) (Rezaur et al., 1982), and *Ahasverus advena* Waltl. (LPPC, 1985).

The lepidopterans infesting stored dry ginger include *Blastobasis byrsodepta* Meyr. (Hargreaves, 1929), *Ephestia* sp. (Abraham, 1975), *E. kuehniella* Zell., *Plodia interpunctella* Hbn. (El-Halfawy et al., 1978), *Pyralis manihotalis* Guen. and *Setomorpha rutella* Zell. (Jacob, 1986). Usually, measures are not recommended for the control of the previously discussed minor pests. A clean environment in the storing room can keep most of them away.

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11 Postharvest and Industrial Processing of Ginger

K.V. Balakrishnan

Ginger is a rhizomatous plant grown throughout southeastern Asia, China, and in parts of Japan, Australia, Latin America, Jamaica, and Africa. The dried rhizome, which constitutes the ginger of commerce, is one of the most popular and oldest of spices. Many cultivars of ginger are grown in the producing countries that differ primarily in the flavor profile. Jamaican ginger is considered to be the finest grade, having the most delicate aroma and flavor (Guenther, 1952, 1958) and of a very light, buff color. The Cochin ginger from the state of Kerala, India, ranks second. It has a characteristically pleasing lemon-like aroma and light brown color, and is sometimes preferred over the Jamaican ginger. Calicut ginger, also from Kerala, is only a geographical variant of Cochin ginger. African ginger (mainly from Nigeria and Sierra Leone) is usually considered to rank third; it exhibits a coarser flavor and darker color than the Jamaican and Cochin types.

Ginger is commercially available in various forms such as green ginger, dry ginger, ginger powder, ginger oil, ginger oleoresin, and preserved ginger.

Green Ginger

The ginger crop matures in about 8 to 10 months after planting depending on the variety. By this time, the leaves become yellow and gradually dry up. The rhizomes tend to become fibrous with maturity. A substantial quantity of green (fresh) ginger is consumed worldwide as vegetable. Ginger for vegetable use should be fleshy with a low fiber content and, therefore, harvesting is done from the sixth month onwards.

For preparing green ginger, the clumps are lifted carefully with a spade or digging fork. The rhizomes are then carefully separated from the plant. The rhizomes in a clump are highly irregular in shape and close to each other. This favors the inclusion of soil and dirt in the interspaces, which have to be removed by thorough washing. If necessary, the interspaces are picked clean using pointed bamboo splinters. The adhering roots are also removed. After washing, the ginger is lightly dried in the sun before being marketed in this form.

Dry Ginger

Although there is substantial consumption of fresh ginger worldwide, most of the produce is converted into dry ginger. Traditionally, the drying of the spice was carried out in highly unsystematic and unhygienic ways, as a result of which the product often failed to conform to the quality standards of international trade, especially on microbiological

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grounds. Modern farmers have, however, acquired considerable awareness on the quality specifications and follow good agricultural practices recommended by promotional bodies (Spices Board, 1991, 1995, 1999).

Preparation

Drying of ginger basically involves two stages—peeling the rhizomes to remove the outer skin and sun or mechanical drying to a safe moisture level. For converting to dry ginger, the crop is harvested at full maturity. Harvested rhizomes are kept soaked in water overnight and rubbed well to clean them (Directorate of Cocoa, Arecanut and Spices Development, 1982; Spices Board, 1995). After cleaning, they are removed from the water. The outer skin is then scraped off with a bamboo splinter or wooden knife having pointed ends. An iron knife is not recommended as it may leave black stains on the peeled surface, affecting the appearance, or may lead to color fading. Peeling serves to remove the scaly epidermis and facilitate drying. During peeling, it should be ensured that the cortical parenchyma, which is rich in essential oil cells, is not removed or cut as it would cause loss of volatile oil and, thereby, decrease the aroma of the peeled rhizome.

Scraping the ginger is a laborious and delicate process. Some commercial undertakings have tried using machines fitted with abrasive rollers (Sills, 1959; Natarajan et al., 1972), but with little success. Ginger rhizomes have an awkward shape for a machine to deal with, particularly when only a very thin outer layer of skin has to be removed. As the time of abrasive peeling increases, more and more outer skin and tissue layers are lost, resulting in a progressive decrease of oil content. Hand peeling, which is superior to mechanical peeling, in getting a dried product of uniform appearance, size, and color, continues to be the most popular method.

Trials have also been carried out by dipping the rhizomes in boiling water for a short time prior to peeling (Guenther, 1952; Natarajan et al., 1972; Lawrence, 1984). Ginger treated with boiling water gives a dark final product, and hence this treatment is not recommended. It is reported that peeling of ginger is rendered easier by dipping in boiling lye, followed by washing, and then steeping in an acid solution (Randhawa and Nandpuri, 1970). This process consists of putting the ginger meant to be peeled in a wire-gauze cage and dipping into boiling lye for the required period. The lye solution causes the separation of the skin of the rhizome from the flesh beneath the epidermal layer. Dipping for 5, 1, and 1/2 minutes in boiling lye solutions of 20, 25, and 50 percent concentration, respectively, are reported to give satisfactory results. The ginger is then washed in running water and finally kept in 4 percent citric acid solution for about 2 hours. However, this process is not commercially practiced.

The peeled rhizomes are washed and dried uniformly in the sun for 1 week. Freshly peeled rhizomes should be handled in clean containers only. Any dirt that happens to stick to the wet scraped surface of the rhizome will adhere to it on drying. Ginger should be dried on clean surfaces to ensure that any extraneous matter does not contaminate the product. Drying is usually carried out on clean concrete floors or plain uncoated bamboo mats. Care should be taken to avoid mold growth on the rhizomes while drying. During the first few days of drying, each rhizome is turned at least once per day to ensure that it is dried uniformly. Growers generally spread the ginger out in the morning to dry in the sun and take it in at night so that it does not become infected with mildew. In order to get rid of the last bit of the skin or dirt, the dry rhizomes are rubbed together. In some countries, after washing, the fresh rhizomes are sliced thin for faster dehydration.

In most growing areas, the scraped ginger is dried in the sun. But where unfavorable seasonal conditions prevail, improved drying methods using mechanical or solar dryers are also used. In mechanical dryers, 135°F is reported to be the highest temperature at which ginger for the spice market could be dehydrated (Richardson, 1966). Above this temperature, the color tends to become darker.

Rhizomes must be dried to a moisture level of 8 to 10 percent and stored properly to avoid infestation by storage pests. Improperly dried ginger is susceptible to microbial growth. Storage of dry ginger for very long periods is not desirable. In such cases, fumigation with permitted chemicals becomes necessary. The yield of dry ginger from mature fresh rhizomes is 16 to 25 percent depending on the cultivar. To give a smooth finish to the dried rhizome, it is sometimes recommended to soak the cleaned and peeled raw rhizomes in water and then in 2 percent limewater for 6 hours before drying (Kannan and Nair, 1965).

Ginger that is cleaned, peeled, and dried with no other processing is known commercially as rough or unbleached ginger. This serves as the starting material for the preparation of ginger powder, essential oil, and oleoresin.

Bleached Ginger

Relatively smaller quantities of ginger are also converted to bleached form. Bleached ginger is produced by dipping scraped fresh ginger in a slurry of slaked lime, $Ca\ (OH)_2$, followed by sun drying (Spices Board, 1995). As the water adhering to the rhizomes dries off, they are again dipped in the slurry. This process is repeated until the rhizomes become uniformly white in color. Dry ginger can also be bleached by this method. Liming gives ginger a better appearance and less susceptibility to the attack of insect pests during storage and shipping.

Chloride of lime, sulfurous acid, and alkali sulfites also have been suggested for bleaching ginger (Natarajan et al., 1970). Coating with chalk or plaster is also practiced to improve the appearance and to keep pests away.

However, major importing countries prefer unbleached ginger since bleached ginger usually contains calcium beyond permissible limits, which is regarded as objectionable in foodstuffs (Spices Board, 1995).

Quality Criteria for Dried Ginger

A major share of the ginger grown in producing countries is exported in dry form. Trade in spices is governed by numerous national as well as regional regulations. For example, dried ginger exported to the United States must conform to the specifications laid down by the American Spice Trade Association (ASTA) and the regulations enforced by the United States Food and Drug Administration (FDA). Important quality criteria for ginger are the following:

Cleanliness

The major concern of importing countries has been on the cleanliness of the spice. Material imported into the United States should meet the cleanliness specifications stipulated by the ASTA. ASTA cleanliness specifications (ASTA, 1999) for ginger are given in Table 11.1.

The cleanliness specifications of the FDA are essentially in line with that of ASTA. However, the FDA has also laid down some Defect Action Levels (DAL), which are not

Table 11.1 ASTA cleanliness specifications for ginger

Parameter	*Upper limit*
Whole insects, dead (by count)	4
Excreta, mammalian (by mg/lb)	3
Excreta, other (by mg/lb)	3
Mold (% by weight)[a]	3
Insect defiled/infested (% by weight)[a]	3
Extraneous/foreign matter (% by weight)	1

[a]Moldy pieces and/or insect-infested pieces by weight.

Table 11.2 Defect Action Levels (DAL) for ginger (FDA)

	Level
Insect filth and/or mold	Average of 3% or more pieces by weight are insect infected and/or moldy
Mammalian excreta	Average of 3 mg or more of mammalian excreta per pound

covered by ASTA. If the defects exceed the DAL, the spice will be detained and subjected to reconditioning (cleaning to remove the defect). If defects cannot be removed by reconditioning, the lot may be destroyed or returned to the supplier. Table 11.2 shows the DAL for ginger (FDA, 1995).

Microbiology

The presence of microorganisms in food products is critical from the point of view of human health. Pathogenic organisms can lead to foodborne diseases. Unhygienic drying and improper storage contribute to the growth of microorganisms on spices. Importing countries have stipulated the limits for microbiological load in spices. Microbiological specification under German law (Table 11.3) (Spices Board, 2002) is a typical example.

Pesticide Residues

Uncontrolled application of chemical pesticides at various stages of plant growth results in the accumulation of pesticide residues in spices; sometimes to levels beyond the acceptable limits. With the emerging disclosures derived from advanced clinical studies

Table 11.3 Microbiological specification for spices under German law

Parameter	*Standard value (per gram)*	*Danger value (per gram)*
Total aerobic bacteria	10^5	10^6
Escherichia coli	Absent	Absent
Bacillus cereus	10^4	10^5
Staphylococcus aureus	100	1000
Salmonella	Absent in 25 g	Absent in 25 g
Sulfite-reducing clostrides	10^4	10^5

on the carcinogenic properties of various pesticide residues, the importing countries are tightening the tolerance limits. A number of pesticides have already been banned or restricted for use and many more are under vigilant scrutiny. Pesticide residue continues to be a serious problem in all the spices for export. The U.S. and German regulations on the pesticide residues are listed in Tables 11.4 and 11.5, respectively (Spices Board, 2002).

Aflatoxins

Another major issue in the quality of the spice is the presence of aflatoxins. Aflatoxins are a group of secondary metabolites of the fungi *Aspergillus flavus* and *A. parasticus* and

Table 11.4 Tolerance levels for pesticide residues in ginger under U.S. regulations

Pesticide	*Tolerance Limit, ppm*
Lindane	0.50
BHC	0.05
Heptachlor	0.01
Heptachlor epoxide	0.01
Trifluralin	0.05
Ethylene oxide	50
Propylene oxide	300
Diquat	0.02
Dichlorvos	0.50
Dalapon	0.20
Aluminum phosphide	0.10
2,4-D	0.10
Glyphosate	0.20
Methyl bromide	100

Table 11.5 Tolerance levels for pesticide residues in spices under German regulations

Pesticide	*Tolerance Limit, ppm*[a]
Aldrin and Dieldrin	0.1
Chlordane	0.05
Sum of DDT isomers	1.0
Endrin	0.1
HCH without Lindane	0.2
Heptachlor and Epoxide	0.1
Hexachlor benzol	0.1
Lindane	0.01
HCN and Cynides	15.0
Bromides	400.0
Carbaryl	0.1
Carbofuran	0.2
Chlorpyrifos	0.05

Table 11.5 (continued)

Pesticide	*Tolerance Limit, ppm*[a]
Methyl chlorpyrifos	0.05
Cypermethrin (sum of all isomers)	0.05
Deltamethrin	0.05
Diazinol	0.02
Dichlorvos	0.1
Diclofop methyl	0.1
Dicofol (sum of isomers)	0.02
Dimethoate	0.5
Disulfoton	0.02
Dithiocarbamate	0.05
Endosulfan (sum of all isomers)	0.05
Ethion	0.05
Fenitrothion	0.05
Fenevalerate (sum of all isomers)	0.05
Copper based pesticides	40.00
Malathion	0.05
Methyl bromide	0.05
Mevinphos	0.05
Omethoate	0.05
Parathion and Para oxon	0.1
Methyl Parathion & Methyl Para oxon	0.1
Phorate	0.05
Phosalone	0.5
Phosphamidon	0.05
Pyrethrin	0.5
Quinalphos	0.01
Quintozen	0.01

[a]The limits mentioned against the first 10 pesticides are specific for spices and the remaining are the general limits for all plant foods.

are rated as potent carcinogens. Inadequate and unhygienic drying leads to the growth of these fungi on the spice. Aflatoxins in spices are generally classified into four—B_1, B_2, G_1, and G_2. B_1 and B_2 are produced by *A. flavus*, whereas G_1 and G_2 are produced by *A. parasticus*. Of these, B_1 is the most virulent carcinogen and has received the most attention.

The tolerance limits for aflatoxins under German law (Spices Board, 2002) as well as EC Regulation (Commission of the European Communities, 2002) are given in Table 11.6.

Trace Metals

Levels of trace metals are also considered as a quality criterion for spices. Maximum limits for various trace metals in ginger (powder) under Japanese specifications are listed in Table 11.7 (Spices Board, 2002).

Table 11.6 Tolerance levels for aflatoxins in spices

	Aflatoxin	*Limit, ppb max*
a. German law:	$B_1 + B_2 + G_1 + G_2$	4
	B_1	2
b. EC regulation:	$B_1 + B_2 + G_1 + G_2$	10
	B_1	5

Table 11.7 Maximum permissible limits for trace metals in ginger powder under Japanese specifications

Metal	*Upper limit, ppm*
Magnesium	2000
Zinc	33
Copper	3.7
Aluminum	42
Arsenic	0
Boron	1.5
Barium	15
Beryllium	0.038
Chromium	0.4
Manganese	270
Molybdenum	0.47
Nickel	0.97
Antimony	2.2
Selenium	0.14
Silicon	21
Tin	4.4
Lithium	0
Strontium	1.2
Titanium	0
Bismuth	0
Cadmium	0
Gallium	0
Lead	0
Tellurium	0

Commercial Requirements

As per International Standard specifications, ginger, whole and pieces, shall comply with the requirements specified in Table 11.8 (ISO, 1980).

Grading of Ginger

Once the ginger is dry, it is sorted and graded. To ensure the quality of spices exported from the country, the government of India introduced the scheme of compulsory Quality

Table 11.8 ISO specifications for ginger

Characteristic	*Requirement*
Moisture content, % (m/m), max	12.0
Total ash, % (m/m) on dry basis, max	
a. unbleached	8.0
b. bleached	12.0
Calcium (as calcium oxide), % (m/m) on dry basis, max	
a. unbleached	1.1
b. bleached	2.5
Volatile oil, mL/100 g on dry basis, min	1.5

Control and Pre-shipment Inspection in 1963. Spices are graded based on the standards fixed for the purpose. These grades are popularly known as the Agmark grades. For ginger, the grading takes into consideration the size of the rhizome; its color, shape, extraneous matter; the presence of light pieces; and the extent of residual lime (in the case of bleached ginger). The various grades in Indian ginger under Agmark and their specifications are given in Table 11.9 (Directorate of Marketing Inspection, 1964).

In addition, all grades should conform to the following general characteristics:

- Shall be the dried rhizomes of *Zingiber officinale* Roscoe, in pieces, irregular in shape and size, pale brown in color, with fiber content characteristic of the variety, and with peel not entirely removed.
- Shall have characteristic taste and flavor, be wholesome, and shall not have rancid or bitter taste or musty odor.
- Shall be reasonably dry and reasonably free from mold and insect infestation.
- For “garbled” grade, the light pieces are removed by garbling.
- For “bleached” grade, the rhizomes are lime bleached.
- Maximum tolerance of 3 percent shall be allowed in the size of the rhizomes.
- Extraneous matter means all foreign matter including the exhausted or spent ginger.
- For N.S. (nonspecified) material, the specifications of the spice will be as stated in the contract.

Agmark certification is currently not mandatory for export trade. However, it is still valued as a mark of quality. Indian Standard Specifications for ginger are almost in line with the Agmark specifications. These specifications classify ginger into six grades. The minimum rhizome size is 20 mm (IS, 1993).

Chemical Composition of Ginger

Ginger rhizomes contain volatile oil, fixed oil, pungent compounds, starch and other saccharides, proteins, crude fiber, waxes, coloring matter, and trace minerals. The presence of vitamins and amino acids also has been reported. The relative percentages of these components vary with cultivar, soil, and climatic differences. Starch is the most abundant of the constituents, comprising of 40 to 60 percent of the weight of the dry rhizome (Lawrence, 1984). Crude protein, total lipids, and crude fiber have been reported

Table 11.9 Agmark grade designations of ginger, whole, and their requirements

Grade	Size of rhizome	Extraneous matter, % by wt, max	Very light pieces, % by wt, max	Lime as CaO, % by wt, max
Garbled, Nonbleached Calicut (NGK)	Not less than 15 mm in length	2.0	—	—
Ungarbled, Nonbleached Calicut (NGK) Special	Not less than 15 mm in length	3.0	4.0	—
Ungarbled, Nonbleached Calicut (NUGK) Good	Not less than 15 mm in length	4.0	6.0	—
Ungarbled, Nonbleached (NUGK) N.S. (Nonspecified)	Not less than 15 mm in length	*	*	—
Garbled, Nonbleached Cochin (NGC)	Not less than 15 mm in length	2.0	—	—
Ungarbled, Nonbleached Cochin (NUGC) Special	Not less than 15 mm in length	3.0	4.0	—
Ungarbled, Nonbleached Cochin (NUGC) Good	Not less than 15 mm in length	4.0	6.0	—
Ungarbled, Nonbleached Cochin (NUGC) N.S.	Not less than 15 mm in length	*	*	—
Garbled, Bleached Cochin (BGC) Special	Not less than 15 mm in length	2.0	—	3.5
Ungarbled, Bleached Cochin (BUGC) Special	Not less than 15 mm in length	3.0	4.0	4.0
Ungarbled, Bleached Cochin (BUGC) Good	Not less than 15 mm in length	4.0	6.0	6.0
Ungarbled, Bleached Cochin (BUGC) N.S.	Not less than 15 mm in length	*	*	*
Garbled, Bleached Calicut (BGK)	Not less than 15 mm in length	2.0	—	3.5
Ungarbled, Bleached Calicut (BUGK) Special	Not less than 15 mm in length	3.0	4.0	4.0
Ungarbled, Bleached Calicut (BUGK) Good	Not less than 15 mm in length	4.0	6.0	6.0
Ungarbled, Bleached Calicut (BUGK) N.S.	Not less than 15 mm in length	*	*	*

to vary between 6.2 and 19.8 percent, 5.7 to 14.5 percent, and 1.1 to 7.0 percent, respectively, in different cultivars (Jogi et al., 1972). Minute glands containing essential oil and resin are scattered throughout the rhizomes, but are particularly numerous in the epidermal tissues (Guenther, 1952; Mangalakumari et al., 1984).

Table 11.10 shows the composition (% w/w) of dry ginger suggested by the Central Food Technological Research Institute (CFTRI), India, based on the chemical analysis of various raw ginger samples (Natarajan et al. 1970). The nutritional data for a typical sample of dry ginger are given in Table 11.11 (Farrell, 1985).

Singh et al. (1975) tentatively characterized the components in ginger lipids using thin-layer chromatography. Partial glycerides, free fatty acids, triglycerides, phosphatidic acids, lysolecithins, phosphatidylinositols, lecithins, and digalactosyl diglycerides were identified. Capric, lauric palmitic, stearic, oleic, linoleic, and linolenic were the major

Table 11.10 Chemical composition of dry ginger

Volatile oil, %	1.25 to 2.81
Crude fiber, %	1.4 to 9.5
Cold alcohol extract, %	1.12 to 3.9
Total ash, %	6.11 to 9.58
Acid insoluble ash, %	0.3 to 1.23
Crude protein, %	8.1 to 11.6
Starch, %	41.54 to 55.06
Water extract, %	10 to 20
Acetone extract, %	5.11 to 11.71

***Table** 11.11* Nutritional data for 100 g dry ginger

Water	9.4 g
Food energy	347 kcal
Protein	9.1g
Fat	6.0 g
Total carbohydrate	70.8 g
Fiber	5.9 g
Ash	4.8 g
Calcium	116 mg
Iron	12 mg
Magnesium	184 mg
Phosphorus	148 mg
Potassium	1342 mg
Sodium	32 mg
Zinc	5 mg
Niacin	5 mg
Vitamin A	147 IU
Other vitamins	insignificant

acids they found in the fatty oil. The presence of caprylic, myristic, pentadecanoic, heptadecanoic, and arachidic acids has also been reported (Lawrence, 1984).

Ginger rhizomes also contain a number of amino acids. Presence of aspartic acid, threonine, serine, glycine, cysteine, valine, isoleucine, leucine, and arginine has been reported (Takahashi et al. 1982).

Ginger Powder

Ginger powder is made by pulverizing the dry ginger to a mesh size of 50 to 60 (Natarajan and Lewis, 1980). Ginger powder forms an important component in curry powder. It also finds direct application in a variety of food products.

A number of specifications have been formulated by various agencies for the quality control of ginger powder. Indian Agmark specifications (Directorate of Marketing Inspection, 1964) for "Standard" grade ginger powder is given in Table 11.12. In addition, it should be free from mold growth, insect infestation, or musty odor.

Table 11.12 Agmark specifications for "Standard" grade ginger powder

Moisture, % by weight, max	13.0
Total ash, % by weight, max	8.0
Ash insoluble in dilute HCl, % by weight, max	1.0
Water soluble ash, % by weight, min	1.7
Cold-water–soluble extract, % by weight min	10.0
Calcium (as CaO), % by weight, max	2.0
Alcohol soluble extract, % by weight, min	4.5

The Indian Standard (IS, 1993) and International Standard (ISO, 1980) specifications, as well as specifications laid down by the Prevention of Food Adulteration Rules 1955, India (PFA, 1996), for ginger powder are given in Tables 11.13 to 11.15, respectively.

Ginger Oil

Dry ginger contains 1.5 to 2.5 percent essential oil (volatile oil), which imparts the characteristic aroma to the spice. The oil is devoid of the pungent taste of ginger.

Table 11.13 Indian standard specifications for ground ginger

Moisture, % by mass, max	12.00
Total ash, % by mass, max	7.00
Water soluble ash, % by mass, min	1.70
Acid insoluble ash, % by mass, max	1.00
Cold water soluble extract, min	10.00
Lead (Pb), ppm, max	10.00
Calcium (as CaO) max	1.00
Alcohol soluble extract, min	4.50
Extraneous matter, % by mass, max	2.00

Table 11.14 ISO specifications for ground ginger

Moisture content, % (m/m), max	12.0
Total ash, % (m/m) on dry basis, max	
a. unbleached	8.0
b. bleached	12.0
Calcium (as calcium oxide), % (m/m) on dry basis, max	
a. unbleached	1.1
b. bleached	2.5
Volatile oil, ml/100 g on dry basis, min	1.5
Water-soluble ash, % (m/m) on dry basis, min	1.9
Acid insoluble ash, % (m/m) on dry basis, max	2.3
Alcohol soluble extract, % (m/m) on dry basis, min	5.1
Cold water soluble extract, % (m/m) on dry basis, min	11.4

Table 11.15 Prevention of food adulteration (PFA) rules, 1955

	Specifications for Ginger Powder
Moisture	Not more than 13.0% by weight
Total ash	Not more than 8.0% by weight
Acid-insoluble ash in dil HCl	Not more than 1.0% by weight
Water-soluble ash	Not less than 1.7% by weight
Cold-water–soluble extract	Not less than 10.0% by weight
Calcium (as CaO)	Not more than 4.0% by weight on dry basis
Alcohol (90% v/w) soluble extract	Not less than 4.5% by weight
Volatile oil	Not less than 1.0% (v/w)

Distillation of the Oil

Essential oils are the volatile organic constituents of fragrant plant matter. They are generally composed of a number of compounds, including some that are solids at normal temperatures, possessing different chemical and physical properties. The aroma profile of the oil is a cumulative contribution from the individual compounds. The boiling points of most of these compounds range from 150 to 300ºC at atmospheric pressure (Table 11.16) (Guenther, 1972). If heated to this temperature, labile substances would be destroyed and strong resinification would occur. Hydrodistillation permits the safe recovery of these heat-sensitive compounds from the plant matter.

Table 11.16 Boiling points of some common essential oil components, ºC

(at atm pressure)		***(at atm pressure)***	
alpha-Pinene	154.75	Citral	228.00
Camphene	159.50	Geraniol	229.65
Myrcene	171.50	Carvone	230.84
alpha-Phellandrene	175.79	Thymol	231.32
Cineole	176.40	Safrole	234.50
p-Cymene	176.80	Cuminic aldehyde	235.50
Dipentene	177.60	Carvacrol	237.70
Fenchone	193.53	Anethole	239.50
Linalool	198.30	Cinnamic aldehyde	251.00
beta-Thujone	201.00	Eugenol	252.66
Citronellal	206.93	Caryophyllene	260.50
Borneol	212.00	Isoeugenol	266.52
l-Menthol	216.00	Zingiberene	269.50
alpha-terpineol	217.50	Dillapiole	285.00
Dihydrocarvone	222.40	Coumarin	301.72
Bornyl acetate	223.00	*alpha*-Santalol	301.99
Citronellol	224.42	*beta*-Santalol	309.00

Hydrodistillation involves the use of water or steam to recover volatile principles from plant materials. The fundamental feature of hydrodistillation is that it enables a compound or mixture of compounds to be distilled and subsequently recovered at a temperature substantially below that of the boiling point of the individual constituents.

Principle of Hydrodistillation

During hydrodistillation, water and essential oil form a heterogeneous system of immiscible liquids. By the principle of distillation of mutually immiscible liquids, the total vapor pressure of the mixture at its boiling point will be equal to the sum of their partial vapor pressures. Hence, the vapor pressure exerted by each component is less than its vapor pressure if present alone at its boiling point. Therefore, the boiling temperature for any two-phase liquid will always be lower than the boiling point of either of the pure liquids at the same total pressure. Thus, in the case of an essential oil, the constituent compounds distill at temperatures below 100ºC when boiled with water at atmospheric pressure. From the vapor pressure data of individual compounds, it is possible to calculate their boiling points on steam distillation and the relative ratio of oil to water in the distillate at different pressures. The composition of the vapor formed from a two-phase liquid mixture depends on the partial pressures of the pure liquids. The ratio of the weights of the two components in the vapor (and the distillate) is expressed as the ratio of their partial vapor pressures multiplied by the ratio of their molecular weights (Guenther, 1972). Thus, for oil-water system,

$$\frac{W_{H2O}}{W_{Oil}} = \frac{P_{H2O}}{P_{Oil}} \times \frac{M_{H2O}}{M_{Oil}}$$

where W_{H2O} = weight of water in the distillate
W_{Oil} = weight of oil in the distillate
P_{H2O} = vapor pressure of water at still temperature
P_{Oil} = vapor pressure of oil at still temperature
M_{H2O} = molecular weight of water
M_{Oil} = molecular weight of the oil (assuming that this is constant, determined as an average figure)

Hydrodistillation Methods: Hydrodistillation of plant material may be carried out by one of the following techniques (Guenther, 1972): Water distillation, water and steam distillation, and steam distillation.

WATER DISTILLATION

In this method, the raw material to be distilled is charged in the still. Water is added to immerse the charge, leaving sufficient vapor space. The quantity of water should be

adequate for the material to move freely in boiling water, thus avoiding localized overheating and subsequent charring of the material. The water is boiled under direct fire or by steam jacket or closed steam coil. It may be necessary to add more water as the distillation proceeds to prevent any dry material from being exposed to direct heating. The vapor is condensed and oil separated from water, taking advantage of their mutual immiscibility and difference in specific gravity. This method is normally used where the raw materials tend to agglutinate and form large compact lumps through which steam cannot penetrate. Water distillation suffers from the following drawbacks (Guenther, 1972):

- Water distillation is a slow operation. It requires more number of stills, more space, and more fuel, and is the least economical of the three techniques.
- It is difficult to exhaust the material completely. High boiling and somewhat water-soluble components cannot be completely recovered from the large quantity of water. The distilled oil, therefore, will be deficient in these components.
- Certain components, such as esters and aldehydes, are likely to deteriorate under the prolonged contact with boiling water.
- The exhausted plant material forms a slurry with water that is difficult to handle and dispose.
- If the deoiled material is required for further processing, additional dewatering and drying steps would be necessary.
- Boiling water may dissolve some of the nonvolatile active components in the plant material, which are lost during dewatering. The oleoresin from the deoiled material could, therefore, be of inferior quality.

However, the simplicity of the method makes it suitable for small-scale distillation of essential oils.

WATER AND STEAM DISTILLATION

Here the plant material is supported on a perforated grid inside the still. The lower part of the still is filled with water to a level below the grid. The water is heated to generate steam. The steam, usually wet and at low pressure, rises through the charge carrying the essential oil. The advantage of this method over water distillation is that the raw material is not in contact with boiling water. The exhausted plant material can be handled easily as it does not form slurry with water.

STEAM DISTILLATION

This is the most widely used industrial method for the isolation of essential oil from plant material. Here the steam is produced outside the still, usually in a steam boiler. Steam at optimum pressure is introduced into the still below the charge through a perforated coil or jets. Steam distillation is relatively rapid and is capable of greater control by the operator. The steam pressure inside the still could be progressively increased as distillation proceeds for complete recovery of high-boiling constituents. The still can be emptied and recharged quickly. With the immediate reintroduction of steam, there is no unnecessary delay in the commencement of the distillation process. Oils produced by this method are of more acceptable quality than those produced by the other methods.

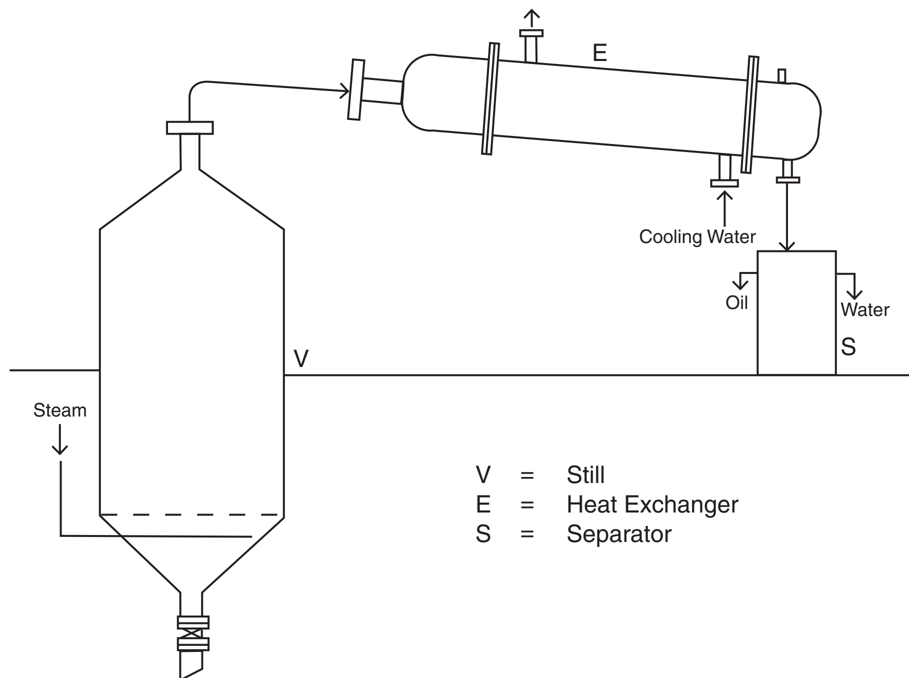

Figure 11.1 Steam distillation assembly.

Ginger oil is commercially produced by steam distillation of the comminuted dried spice. The spice is powdered and charged in a stainless steel still of optimum dimensions. The still is attached to a heat exchanger (condenser) and a separator. Direct steam is admitted from the bottom of the still. The steam, which rises through the charge, carries along with it the vapors of the volatile oil. The oil vapor-steam mixture is cooled in the condenser. The oil is separated from water in the separator and collected in glass or stainless steel bottles. The oil is thoroughly dried and stored airtight in full containers in a cool dry place protected from light. A schematic layout of a steam distillation assembly is given in Figure 11.1.

Physicochemical Properties of the Oil

The volatile oil derived from dried ginger is a free-flowing, pale greenish yellow liquid possessing the characteristic aroma but not the pungent taste (bite) of the spice. Ginger oil is soluble in ether and insoluble in water. The odor of the oil is quite lasting.

Physical properties such as specific gravity, refractive index, and optical (angular) rotation serve as yardsticks for the primary qualification of ginger oil. Food Chemicals Codex (FCC) specifications for ginger oil (FCC, 1996) are given in Table 11.17.

Table 11.17 FCC Specifications for Ginger Oil

Angular rotation	Between -28° and -47°
Heavy metals (as Pb)	Passes test
Refractive index	Between 1.488 and 1.494 at 20°C
Saponification value	Not more than 20
Specific gravity	Between 0.870 and 0.882 at 25°C

COMPOSITION OF GINGER OIL

Essential oils, in general, contain volatile compounds of many classes of organic substances. Guenther (1972) has classified the essential oil components into four main groups:

- Terpenes, related to isoprene or isopentene
- Straight-chain compounds, not containing any branches
- Benzene derivatives
- Miscellaneous (compounds other than those belonging to the first three groups, specific for a few species)

The most characteristic group of compounds present in essential oils are the terpenes. Terpenes comprise of hydrocarbons of the formula $(C_5H_8)_n$ and their oxygenated derivatives. Their building block is the hydrocarbon isoprene (C_5H_8). The class of terpenes is determined by the number of isoprene units in the chain as disclosed by the value of n. When $n = 2$, the resulting C_{10} group is referred to as monoterpenes, whereas $n = 3$ yields sesquiterpenes, $n = 4$, diterpenes, and so on. Strictly not all terpenes are represented by the formula; exceptions exist. The oxygenated derivatives of terpene hydrocarbons include, for example, aldehydes, ketones, alcohols, esters, and phenols, which contribute to much of the perfumery value of the essential oil. Terpenes may be further classified into acyclic, monocyclic, bicyclic, and tricyclic compounds.

Even though the chemistry of the volatile components in ginger oil has been studied for a long time, modern analytical techniques have served to decipher the composition quite exhaustively. The main constituent of the ginger oil is the sesquiterpene zingiberene ($C_{15}H_{24}$) (Figure 11.2).

Lawrence (1984) carried out an extensive investigation on the composition of ginger oil using a combination of distillation, column chromatography, gas chromatography, nuclear magnetic resonance spectroscopy, infrared spectroscopy, and mass spectrometry. The results showed that the oil, which was found to be very complex in nature, contained about 83 percent hydrocarbons and 10 percent oxygenated constituents with the rest unidentified. A summary of the constituents identified is given in Table 11.18.

The presence of a number of other compounds have also been reported by various investigators for oils of different origins (Brooks, 1916; Guenther, 1952; Herout et al., 1953; Jain et al., 1962; Varma et al., 1962; Nigam et al., 1964; Connell and Sutherland, 1966; Provatoroff, 1967; Connell, 1970; Connell and Jordan 1971; Kami et al. 1972; Bednarczyk and Kramer, 1975b; Bednarczyk et al., 1975a; Salzer, 1975; Masada 1976; Sakamura and Hayashi, 1978; Natarajan and Lewis, 1980; Govindarajan 1980; Smith and Robinson, 1981; MacLeod and Pieres, 1984; van Beek et al., 1987; Chen and Ho,

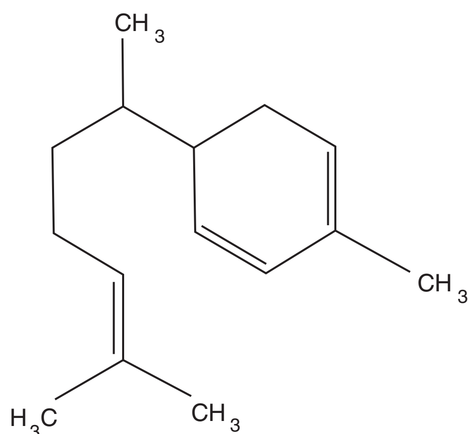

Figure 11.2 Zingiberene.

Table 11.18 Composition of ginger oil

Hydrocarbons:		
alpha-thujene	*alpha*-pinene	camphene
beta-pinene	sabinene	*delta*-3-carene
myrcene	*alpha*-phellandrene	*alpha*-terpinene
limonene	*beta*-phellandrene	*gamma*-terpinene
cis-ocimene	toluene	*p*-cymene
alpha-p-dimethylstyrene	undecane	dodecane
tridecane	tetradecane	cyclosativene
cyclocopacamphene	coaene	sesquithujene
beta-ylangene	*beta*-elemene	*gamma*-elemene
trans-*alpha*-bergamotene	trans-*beta*-farnesene	caryophyllene
selina-4,11-diene	selina-3,11-diene	selina-3(7),11-diene
alpha-amorphene	zonarene	10-epizonarene
alpha-cadinene	*gamma*-cadinene	*delta*-cadinene
cis-*gamma*-bisabolene	pentadecane	hexadecane
heptadecane	octadecane	nonadecane
eicosane	henicosane	docosane
tricosane	*beta*-bisabolene	zingiberene
beta-sesquiphellandrene	germacrene B	germacrene D
beta-curcumene	*ar*-curcumene	calamenene
Oxygenated compounds:		
butanol	2-menthylbutanol	3-menthylbutanol
pentanal	hexanal	trans-2-hexanal
nonanal	decanal	undecanal
citronellal	myrtenal	phellandral
neral	geranial	acetone
2-hexanone	2-heptanone	2-nonanone

Table 11.18 (Continued)

methyl heptanone	cryptone	carvotanacetone
2-butanol	2-methyl-but-3-en-2-ol	cis-*p*-menth-2-en-1-ol
trans-*p*-menth-2-en-1-ol	*alpha*-terpineol	citronellol
geraniol	cuminyl alcohol	cubebol
nerolidol	elemol	cis-sesquisabinene hydrate
beta-bisabolol	zingiberenol	10-*alpha*-cadinol
alpha-eudesmol	*beta*-eudesmol	cis-*beta*-sesquiphellandrol
2-heptyl acetate	2-nonyl acetate	trans-*beta*-sesquiphellandrol
bornyl acetate	citronellyl acetate	*alpha*-fenchyl acetate
1,4-cineole	1,8-cineole	*alpha*-terpinyl acetate
2-nonanol	linalool	2-heptanol
isopulegol	terpinolene epoxide	cis-sabinene hydrate
perilline	caryophyllene oxide	*alpha*-naginatene

1988; van Beek, 1991). Table 11.19 lists the other components identified by these investigators.

Studies (Connell and Jordan, 1971) have shown that the gas chromatographic (GC) pattern is related to distinctive aroma differences between oils from different sources. Recognizable variations have been observed between the respective peak areas of Jamaican, African, and Cochin ginger oils. However, subtle aromatic differences in oils from the same cultivar are attributed not to major terpenic and sesquiterpenic hydrocarbon peaks, but to unidentified minor components (Govindarajan, 1980).

Considering the major group of components and the changes taking place during storage, Salzer (1977) suggested the following determinants of quality for ginger oil:

- Citral and citronellyl acetate are important codeterminants of odor.
- Zingiberene and *beta*-sesquiphellandrene are the main components of the freshly prepared oil. These components are converted to *ar*-curcumene with storage.
- The ratio of zingiberene + *beta*-sesquiphellandrene to *ar*-curcumene is indicative of the age of the oil.

A typical GC chromatogram of the oil is given in Figure 11.3.

Organoleptic Properties

The specific gravity, refractive index, and optical rotation are the primary quality determinants of ginger oil, occasionally supplemented by GC composition of the constituents. Even if the physical properties and the level of major components as disclosed by the chromatogram exhibit similarity, variation in the minor components can influence the organoleptic profile of the oil. For applications that cannot accommodate any flavor variations, repeated supplies of the oil have to possess consistent flavor quality. Sensory analysis of the oil by trained panel remains the ultimate method for validating flavor quality in such cases.

Table 11.19 Other components reported in ginger oil

n-heptane	camphor	guaiene
n-octane	citral	nerol
cumene	zingiberol	n-propanol
n-nonane	acetaldehyde	propionaldehyde
tricyclene	n-isovaleraldehyde	methyl heptanone
terpinolene	decyl aldehyde	methyl acetate
alpha-farnescene	geranyl acetate	diethyl sulfide
delta-elemene	methyl allyl sulfide	methyl heptanone
trans-*beta*-farnescene	acetates and caprylates	chavicol
gamma-muurolene	glyoxal	methylglyoxal
allo-aromandendrene	n-nonanol	diethyl sulfide
trans-*beta*-ocimene	methyl allyl sulfide	ethyl propionate
alpha-cubebene	furfural	octanal
6-methyl hept-5-en-2-one	2,6-dimethylhept-5-enal	dihydroperilline
nonyl aldehyde	2-nonanol	rosefuran
isoborneol	camphor	*alpha*-terpineol
p-cymen-8-ol	2-undecanol	2-undecanone
sec-butanol	d-borneol	geranyl acetate
methyl isobutyl ketone	ethyl acetate	lauric acid
methyl isoeugenol	farnesal	xanthorrhizol
ethyl isopropyl sulfide	3-methyl butanal	cyclohexane
thujyl alcohol	ethyl isopropyl sulfide	terpinen-4-ol
n-butyraldehyde		

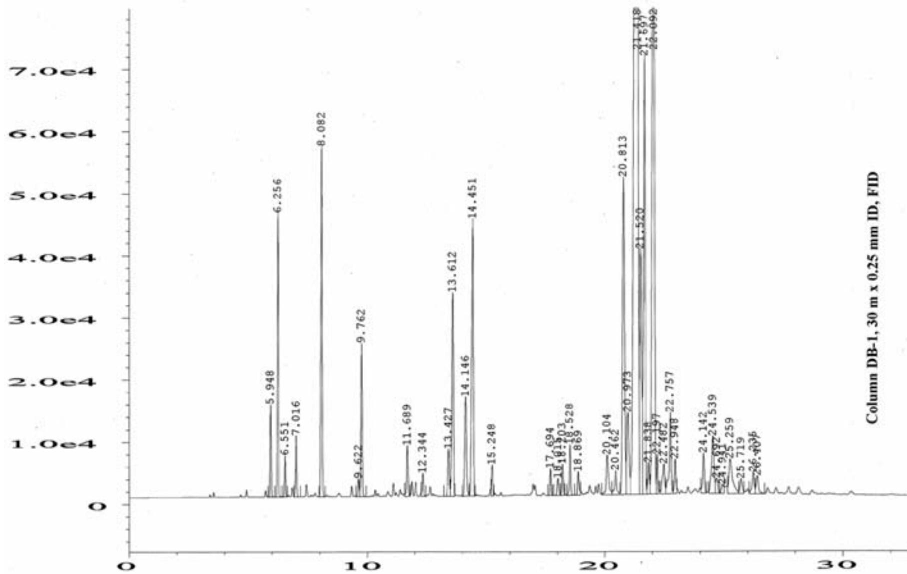

Figure 11.3 Typical GC chromatogram of ginger oil.

Govindarajan et al. (1978) and Govindarajan (1980) carried out detailed studies on the flavor quality and profile through the use of the thin-layer chromatographic (TLC) aromagram technique. The study of a large number of samples led these workers to confirm: (1) the flavor profile previously formed by column chromatography and panel technique; (2) the observation that the hydrocarbons in ginger volatiles do not contribute significant aromatic components to total aroma; (3) the principal differences between the flavor of raw ginger and dry ginger are due to the level of citral (neral and geranial); (4) the ginger aroma should have the proper blend of lemony, camphory, stale coconut (sweet rooty), and flavory aromatic notes; and (5) the full flavor requires the impact of the pungency and possible slight bitterness and freshness component.

The flavor profile gives more information, which is of practical significance, and these profiles can be projected visually. Figure 11.4 shows the aroma profiles of two samples of ginger oils: (A) a commercially distilled oil and (B) a carefully prepared, quick dried laboratory distilled oil. The gas chromatographic (GC) profiles of these two oils were

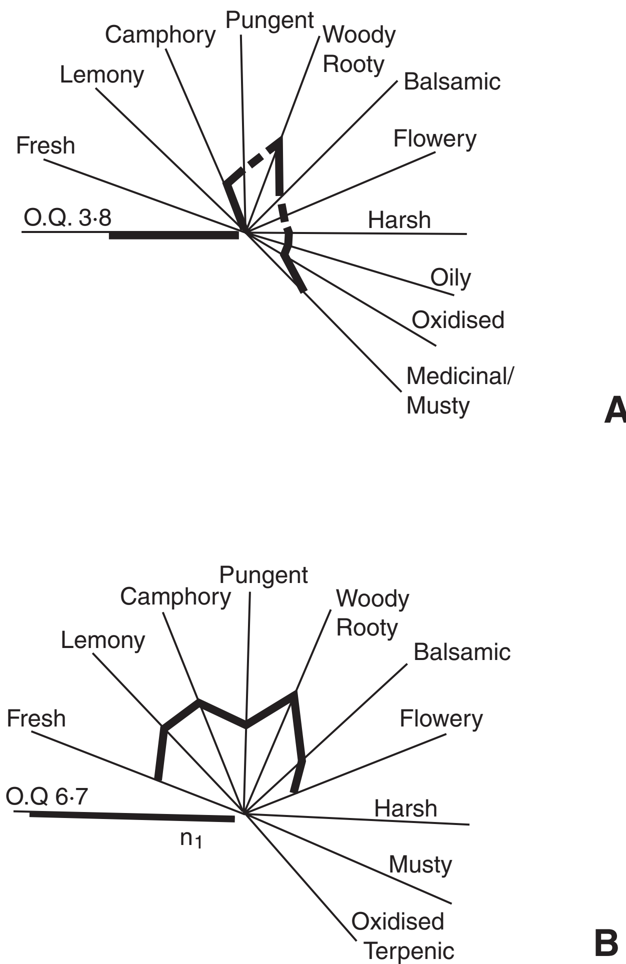

Figure 11.4 A. Flavor profile of commercial ginger oil. B. Flavor profile of laboratory ginger oil. O.Q = overall quality

similar except for the lower citral content and higher amounts of high-boiling compounds in the commercial oil. However, the intensity of aromatic components in the profile of the commercial sample are all very low except the woody/rooty note and the defective medicinal/musty notes. The overall quality score of the commercial oil is only 3.8, whereas the laboratory-distilled oil secured a score of 6.7.

Oil of Green (Fresh) Ginger

Essential oil can also be distilled from fresh ginger. When ginger is dried, numerous complex chemical changes take place within the tissues and the freshness of the spice is lost. Oil from fresh ginger retains the true aroma of the fresh spice and finds application in delicate flavor and perfumery formulations. An analysis of oil prepared from green ginger is given in Table 11.20 (Natarajan et al., 1970).

Ginger Oil from Scrapings

The ginger scrapings, normally thrown away by the farmers, also can be utilized for the recovery of oil (Moudgill, 1928; Varier, 1945; Natarajan and Lewis, 1980). Moudgill and Varier obtained 0.9 percent and 0.8 percent oil, respectively, from air-dried scrapings of Cochin ginger. The properties of these oils are given in Table 11.21. The oil contains all major components present in normal ginger oil. However, the odor of the oil is heavy and earthy and the color is darker

Characteristics of Ginger Oil

Ginger oil possesses the following characteristics that make it a better substitute for the raw spice in a number of applications (Balakrishnan, 1991):

- Represents the true aroma of the spice
- Does not impart color to the end product

Table 11.20 Properties of oil from green ginger

Specific gravity (25ºC)	0.8702
Ref. index (25ºC)	1.4895
Optical rotation	(−) 40º
Acid number	1.41
Ester number	6.20

Table 11.21 Properties of oil from air-dried scrapings of Cochin ginger

Parameter	*Moudgill*	*Varier*
Specific gravity	0.8816 (27ºC)	0.8905 (30ºC)
Optical rotation	−9.85º (30ºC)	−5.2º
Refractive index	1.4862 (25ºC)	1.4859 (30ºC)
Acid number	1.0	0.90
Ester number	10.0	6.10
Ester number after acetylation	103.0	72.2

- Has uniform flavor quality
- Is free from enzymes and tannins

However, the oil lacks the nonvolatile principles that contribute to the taste characteristics of the spice.

Oleoresin Ginger

The essential oil of ginger derived by steam distillation represents only the aromatic, odorous constituents of the spice; it does not contain the nonvolatile pungent principles for which ginger is highly esteemed. The oleoresin, obtained by extraction of the spice with volatile solvents, contains the aroma as well as the taste principles of ginger in highly concentrated form.

The oleoresin represents the wholesome flavor of the spice—a cumulative of the sensation of smell and taste. It consists of the volatile essential oil and the nonvolatile resinous fraction comprising taste components, fixatives, antioxidants, pigments and fixed oils naturally present in the spice. The oleoresin is, therefore, designated as "true essence" of the spice and can replace spice powders in food products without altering the flavor profile.

Manufacturing Process

Removal of a soluble fraction from a permeable solid phase with which it is associated by selective dissolution by a liquid solvent is technically known as leaching (Perry and Chilton, 1973). Although this term originally referred to the percolation of liquid through a fixed bed, it later became generic to all solid-liquid extractions (Treybal, 1968). In spice extraction, the process is commonly referred to as solvent extraction. The presence of a solid phase distinguishes this process from liquid-liquid extraction.

The oleoresin of ginger is obtained from the spice by solvent extraction. The process essentially comprises the following three steps: (1) contacting the spice powder and solvent in the extractor to effect the transfer of the functional components from the spice to the solvent, (2) separation of the resulting solution from the powder, and (3) distillation of the extract to recover the product. Extractors may be batch type or continuous.

Figure 11.5 gives the schematic representation of the operation in a batch extractor. Repeated washing with the solvent would be necessary to exhaust the spice. The solute concentration in the extract progressively diminishes with each wash.

Operation in a single extractor is rarely encountered in industrial practice. In industrial extraction, a number of batch contact units are arranged in a row called the extraction battery. Solids remain stationary in each extractor and are subjected to a multiple number of contacts with the extracts of progressively diminishing concentrations from the previous one. The final contact of the nearly exhausted solids is with fresh solvent while the concentrated solution leaves in contact with the fresh solids in another extractor. The concentrated solution is distilled while subsequent washings are directed to the next freshly loaded extractor. The extractors are discharged and reloaded one at a time. The operation using a battery of extractors can be represented as in Figure 11.6. This system enjoys the flexibility of batch extraction, but at the same time, the efficiency approaches that of continuous countercurrent operation once an equilibrium is established. The number of extractors in a battery varies from three to six.

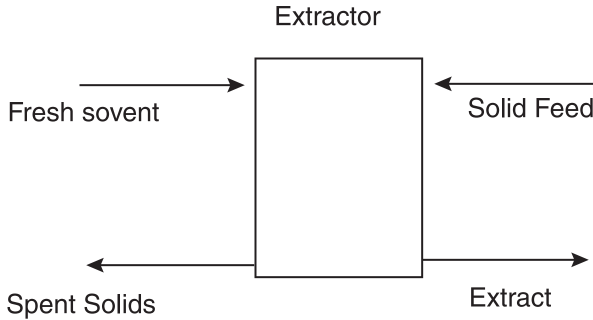

Figure 11.5 Solid-liquid operation in an extractor.

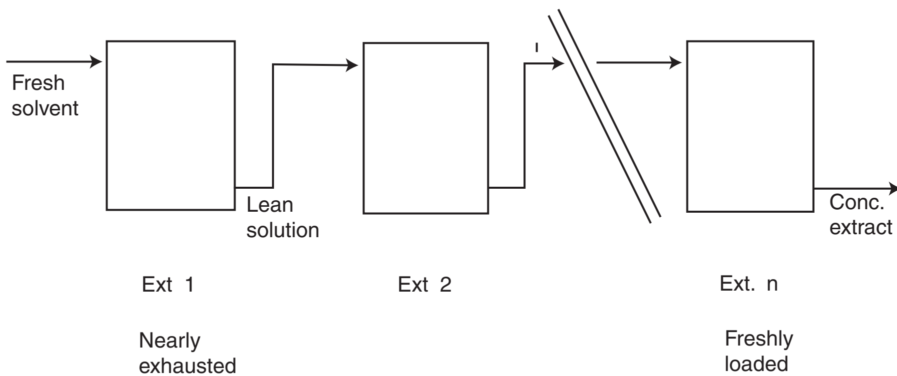

Figure 11.6 Extraction in a battery of extractors.

For the extraction of ginger, the spice is disintegrated to a predetermined particle size and loaded in the extractors. The raw material should be cleaned free from dirt, foreign matter, filth, insect, rodent, and microbial contamination. It should be dried to an optimum moisture level since excessive moisture affects the percolation rate and product quality. Extractors are stainless steel cylindrical vessels with provisions for charging the feed from the top and removing the spent spice from the bottom. A perforated plate supported on a grid at the bottom of the extractor holds the charge. Extractor capacity ranges from 200 to 2000 kg based on the scale of operation. Solvent, admitted from the top, is sprayed onto the charge. As the solvent percolates down the charge, it dissolves the active principles from the spice. The concentrated solution obtained is filtered and the solvent distilled off. Repeated washings would be necessary to exhaust the spice. Lean solutions are directed to the next freshly loaded extractor. Once the spice is fully exhausted, the solvent adhering to the spent spice is recovered by injecting live steam. The bulk of the solvent from the extract is distilled out in an evaporator. The distilled solvent is recycled. Removal of the final traces of solvent is carried out in a desolventizer under controlled conditions of temperature and pressure to safeguard the delicate flavor principles. The level of residual solvent in the product is brought down well below the limits prescribed by regulatory bodies. The schematic layout of a simple batch extraction plant is shown in Figure 11.7. Figure 11.8 shows a commercial plant.

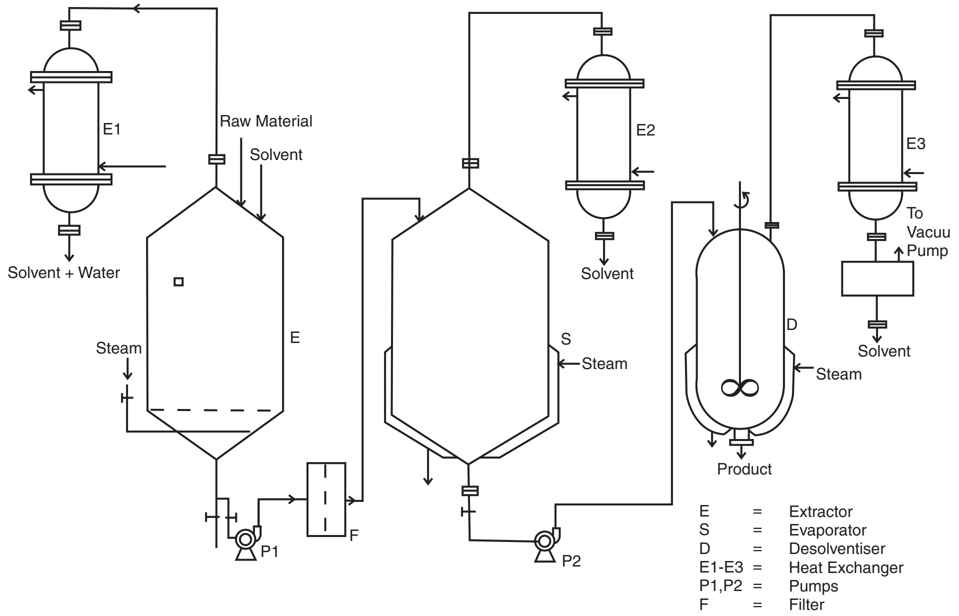

Figure 11.7 Schematic layout of a solvent extraction plant.

Figure 11.8 A spice extraction plant (batch extraction).

Continuous countercurrent extraction has also been recently introduced for spices. The extractor for continuous operation essentially consists of a moving belt that carries the feed through the extraction zone. Lean solutions of the extract of progressively diminishing concentration are sprayed onto the feed as it moves toward the discharge end. The exhausted spice is stripped off the residual solvent and discharged. The concentrated solution is distilled to remove the solvent. Continuous extraction is economical only if a minimum steady feed rate is guaranteed. Figure 11.9 shows a commercial continuous extraction plant.

As discussed earlier, oleoresin is a composite of the volatile and the nonvolatile flavor principles of the spice. These two fractions can be retrieved from the spice separately using a two-stage extraction process or together through a single-stage process.

Figure 11.9 A spice extraction plant (continuous extraction).

Two-Stage Extraction: Here the clean dry spice is ground and first steam distilled to obtain the volatile oil. This oil represents the aroma of the spice. The deoiled spice is then subjected to solvent extraction to recover the nonvolatile taste principles. The aroma and taste fractions are proportionately blended to give the oleoresin of the spice. Figure 11.10 gives the flow diagram for a typical two-stage ginger extraction. Two-stage extraction provides flexibility in product formulation. Since the aroma and pungency fractions are isolated individually, their relative percentages in the endproduct can be varied to meet exact customer specifications.

Single Stage Extraction: The process can also be carried out in a single stage bypassing the steam distillation step (Figure 11.11). However, this method restricts the flexibility in finetuning the oleoresin to the customers' specifications.

The oleoresin of ginger is a dark brown viscous liquid and usually contains 25 to 35 percent volatile oil. The yield of oleoresin from dried ginger is normally 4 to 6 percent, but varies with the variety and the extraction medium.

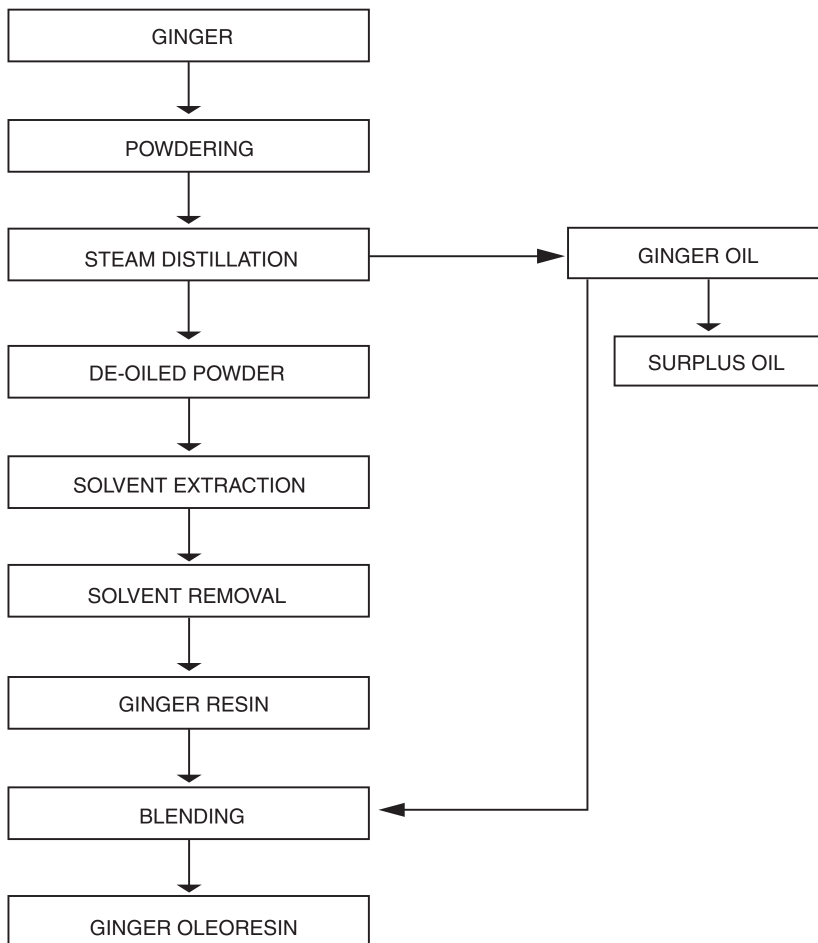

Figure 11.10 Steps in two-stage extraction.

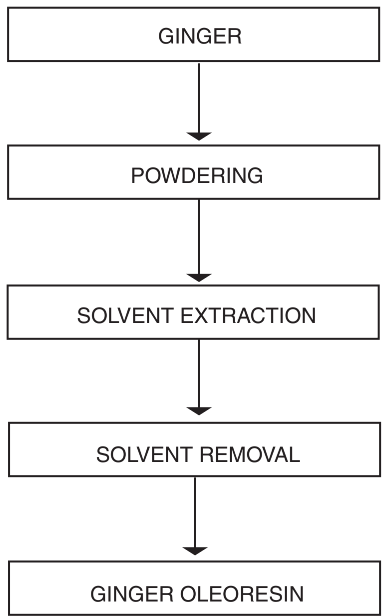

Figure 11.11 Steps in single-stage extraction.

Factors Affecting the Extraction Efficiency

The major factors affecting the efficiency of solvent extraction are:

The Particle Size: To achieve adequate solute-solvent contact in solvent extraction, the raw material should be comminuted. Solute is usually surrounded by a matrix of insoluble matter. The solvent must, therefore, diffuse into the mass and the resulting solution must diffuse out. Grinding of the raw material will greatly accelerate the leaching action since more of the solute is exposed to the solvent. Each plant material has a characteristic shape, size, texture, and hardness. The choice of size-reduction equipment depends on these factors. Even though size reduction enhances the transfer of solute to the solvent, very fine powder tends to restrict the percolation of the solvent through the charge due to decrease in the porosity of the bed. This will adversely affect the extraction rate. It is, therefore, necessary to select an optimum particle size for extraction.

Extraction Medium: The selection of solvent primarily focuses on an optimum quantity of extractives of the desired quality and not necessarily maximum yield. A good extraction solvent should:

- Be able to dissolve the active principles selectively and minimise the extraction of undesirable constituents.
- Be chemically pure, since residues of impurities can impart objectionable off-flavor to the product.
- Be reasonably low boiling to facilitate distillation. However, too low a boiling point can lead to excessive loss of solvent during processing.
- Be chemically inert, i.e., should not react with the constituents of the product.

- Have low specific and latent heats.
- Be nontoxic and should not pose health hazards.
- Be nonflammable and nonexplosive.
- Be readily available and reasonably priced.
- Be acceptable under the food laws of the country where the product is to be used.

Spice extraction involves the use of organic solvents. Regulatory bodies have specified permissible limits of the residues of various solvents in the oleoresin. Limits laid down by the Code of Federal Regulations of the FDA (CFR,1995) for common extraction solvents for spices are listed in Table 11.22.

Acetone, methanol, isopropanol, methylene chloride, ethyl acetate, and ethyl alcohol are popular extraction solvents for ginger. Ethylene dichloride is an efficient extractant; however, its use is restricted due to alleged carcinogenicity.

Temperature of Extraction: Generally, an increase in temperature improves extraction efficiency. This, in turn, helps to reduce the solvent quantity and the process time. Extractors can be provided with steam jackets to heat the contents or hot solvent may be sprayed onto the charge. However, high temperatures may lead to the extraction of excessive amounts of undesirable compounds from the spice, which can affect the quality of the product.

Extraction Using Supercritical Fluids

Conventional spice extraction involves the use of organic solvents, which can leave their residues in the final product. Moreover, at the distillation temperature, some deterioration or chemical modification of the labile components is also likely.

Supercritical fluid extraction (SFE) is a novel isolation method that can overcome the above issues. An oleoresin, free from chemical alterations brought about by heat and water and without solvent residues and other artifacts, can be obtained by this method. Carbon dioxide (CO_2) is the popular medium for the supercritical extraction of spices.

Principle of Supercritical Fluid Extraction

Supercritical fluid extraction involves the use of a compound above its critical temperature and pressure as extraction medium.

Figure 11.12 gives the phase diagram for a substance. The equilibrium curves for the three states—solid, liquid, and gas—meet at TP, the triple point of the substance. At

Table 11.22 Limits for residual solvents in spice oleoresins

Solvent	*Limit, ppm max*
Acetone	30
Ethylene dichloride	30
Hexane	25
Isopropyl alcohol	50
Methanol	50
Methylene chloride	30

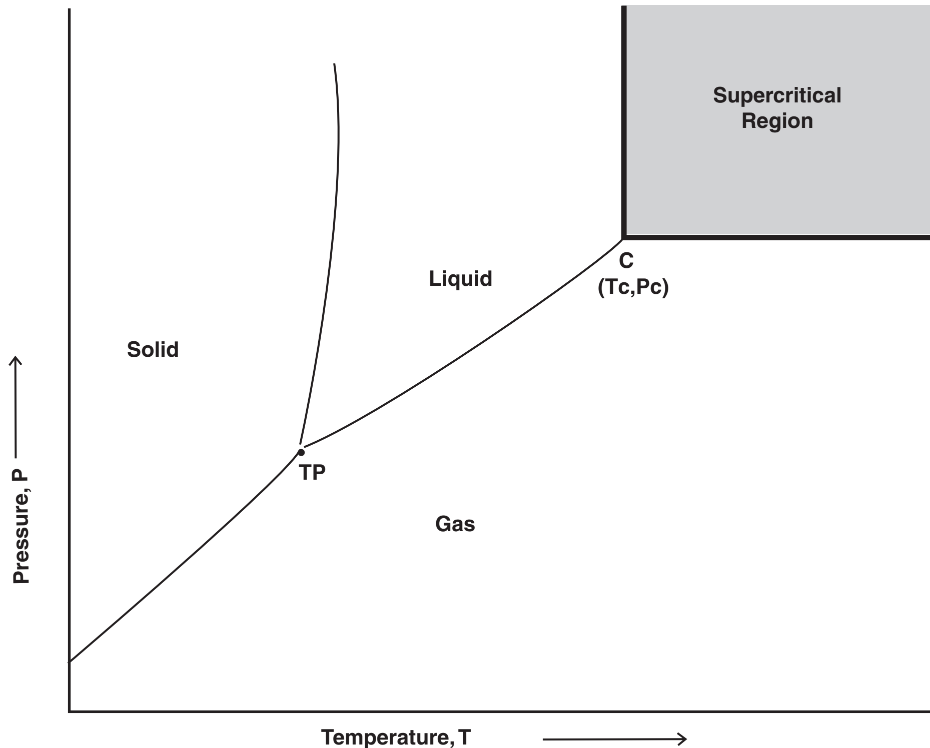

Figure 11.12 Phase diagram.

the TP, all the three phases coexist. Moving along the gas-liquid equilibrium curve, we reach a point where a pure gaseous compound cannot be liquefied regardless of the pressure applied. This is the critical point for the compound. The temperature at the critical point is the critical temperature, and the vapor pressure of the gas at the critical temperature is the critical pressure. A supercritical fluid (SCF) is any compound at a temperature and pressure above the critical values. In Figure 11.12, C is the critical point at the end of the gas-liquid equilibrium curve and the shaded area indicates the supercritical fluid region.

In the supercritical environment only one phase exists. The fluid, as it is termed, is neither a gas nor a liquid and is best described as intermediate to the two extremes. This phase retains solvent power approximating liquids, whereas the penetration power into the solid matrix is contributed by the transport properties common to gases. Therefore, the rates of extraction and phase separation are significantly faster than for conventional extraction processes. Furthermore, the pressure and temperature of the fluid in the supercritical region can be altered to effect selectivity in the extraction.

Carbon Dioxide as Extraction Medium

Carbon dioxide is the most commonly used supercritical fluid for spice extraction; primarily due to its low critical parameters (31.1°C, 73.8 bar), low cost, and nontoxicity.

Spice extraction using supercritical carbon dioxide (SCO_2) has the following advantages over conventional solvent extraction:

- Supercritical operation provides greater flexibility since the solvation power and selectivity for the solutes can be easily manipulated by altering the temperature-pressure conditions. This facilitates the recovery of products with predesigned physicochemical properties.
- Conventional extraction media are organic solvents with varying levels of toxicity. Even with the most efficient solvent-removal techniques, residual solvents in parts per million (ppm) levels are likely to be present in the end product. SCO_2 extraction eliminates such solvent residue problems.
- Carbon dioxide is nonflammable, noncorrosive and nontoxic. Hence, storage and handling do not pose any health hazard.
- It is a part of the environment and hence does not precipitate any environmental issues.
- CO_2 is relatively less expensive. It can be recycled and reused in the system.
- The operation can be carried out at lower temperature, thus preserving the heat-sensitive flavor components.
- CO_2 is chemically inert and does not react with the components of the solute. Moreover, CO_2 can act as a blanket and prevent oxidative degradation of these components.

However, the extractor and accessories for supercritical fluid extraction have to be designed to operate under high pressure. A schematic layout of supercritical extraction assembly is displayed in Figure 11.13. The pump draws liquid CO_2 from the collection/storage vessel, compresses it to the required pressure, and transfers it to the extraction vessel through a heat exchanger where it is heated to the extraction temperature. The CO_2 containing the dissolved product is directed to the separator. The pressure and/or temperature of the CO_2 is reduced in the separator, causing the product to become separated. Several separators maintained at progressively decreasing pressure/temperature might be used so that fractions of the extract with different qualities can be collected

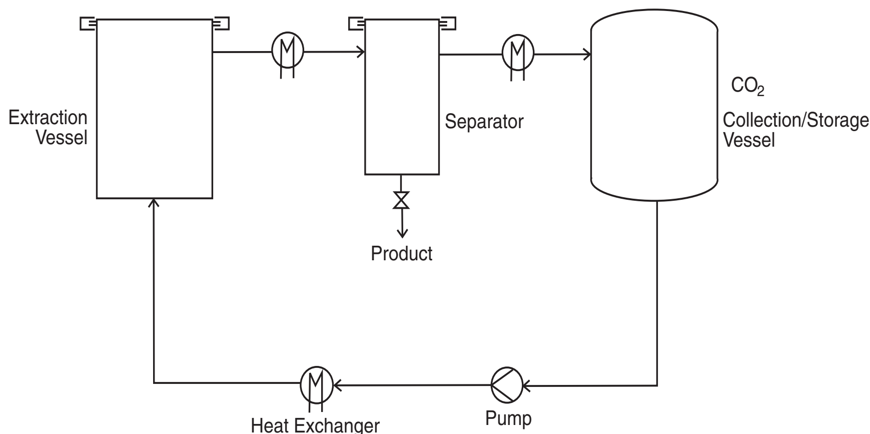

Figure 11.13 Supercritical fluid extraction (SFE) assembly.

separately. The gaseous CO_2 from the separator is liquefied in a refrigerated heat exchanger and collected in the collection/storage vessel for recycling.

Chemical Composition

In fresh ginger, the pungency is almost entirely contributed by gingerols (Nambudiri et al., 1975; McHale, et al., 1989). Gingerols are homologues of 1-(3-methoxy-4-hydroxyphenyl)-3-keto-5-hydroxyhexane (Zhang et al., 1994). The major homologues identified are 6-, 8-, and 10- gingerols (Chen et al., 1986c). The prefixes indicate the length of the alkyl chain of the aldehydes—hexanal, octanal, and decanal—that would be obtained by alkaline fission of the gingerols (Connell and Sutherland, 1969). Gingerols are thermally labile and can undergo changes during processing and storage. Two degeneration pathways have been established (Connell, 1969; Smith, 1982; McHale et al., 1989; Zhang et al., 1994; Lawrence, 1984):

- Dehydration to shogaols, which is a mixture of the three corresponding homologues.
- Retro-aldol condensation to zingerone, 4-(3-methoxy-4 hydroxyphenyl)-2-butanone), another pungent component, and aliphatic aldehydes that can cause off-flavors.

The oleoresin of ginger contains gingerols as well as the degeneration products. Gingerols are the main pungent principles in the oleoresin, amounting up to 20 percent (Natarajan and Lewis, 1980), depending on the variety. The percentage of gingerols also varies with the level of volatile oil in the oleoresin. In stored samples of the oleoresin the proportions of shogaols and zingerone were found to be higher than in newly processed ones, with a corresponding decrease in gingerol content (McHalle et al. 1989). The highly pungent component in gingerols is the 6-gingerol and poorly pungent are 8- and 10-gingerols. Pungency level of shogaols also follow the same pattern (Raghuveer and Govindarajan, 1978). The distribution of the three gingerols is reported to differ widely with the cultivars (Verghese, 1997). Total gingerols in the oleoresin of freshly processed Cochin ginger with 25 to 30 percent volatile oil is usually 14 to 16 percent and the 6-, 8- and 10-gingerols are present in the ratio of approximately 4:1:1.2. The transformation of gingerol to shogaol and zingerone is shown in Figure 11.14 (Raghuveer and Govindarajan, 1978; Chen et al., 1986b). Conversion of gingerols into either of these two compounds indicates loss of quality. Conversion to zingerone seems to be a relatively slow process compared to the shogaol route (Govindarajan and Govindarajan, 1979).

The extent of transformation of gingerols to shogaols depends on the processing conditions. Chen et al. (1986a) analyzed the liquid carbon dioxide extract of freeze-dried ginger by combined thin-layer chromatography-high-performance liquid chromatography-mass spectrometry (TLC-HPLC-MS) and found 6-, 8-, and 10-gingerols to contribute almost the entire pungency. 6-Shogaol was detected only in traces. Other shogaols as well as zingerone were absent. Heat and acid are reported to accelerate the dehydration of gingerols to shogaols (Connell, 1969).

The level of pungency in the spice and its oleoresin are important quality determinants. Traditionally, organoleptic methods have been used for assessing the pungency (Wood, 1987). These methods are, however, highly subjective and yield results that vary considerably. Thin-layer and column chromatography have been suggested for the quanti-

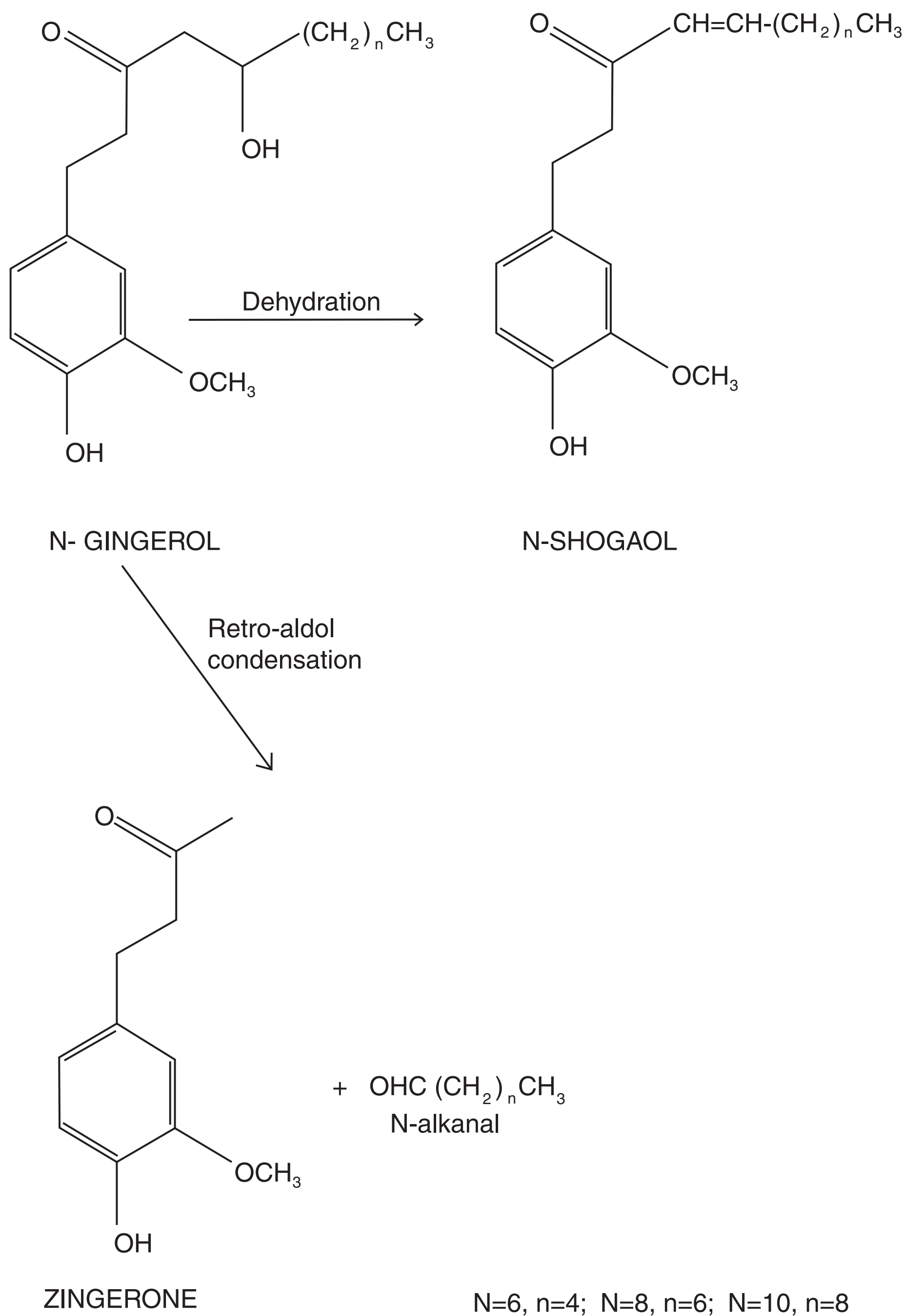

Figure 11.14 Transformation of gingerols.

tative estimation of pungent principles of ginger (Osisiogu, 1973; Kucera and Kucerova, 1974; Nambudiri et al. 1975; Govindarajan and Govindarajan, 1979). GC and combined GC MS (Masada et al., 1973, 1974; Harvey, 1981; Middleditch et al., 1989) are improvements; but gingerols are susceptible to breakdown under the high temperature used in GC (Connell and McLachlan, 1972; Smith, 1982; Baranowski, 1985). HPLC has been found to be a more efficient tool in tracking the ginger pungency components (Smith, 1982; Baranowski, 1985; Chen et al., 1986b; Wood, 1987; Zhang et al., 1994; ISO, 1995). The principal difficulty with gingerol determination has been the lack of a stable and easily purified analytical standard. Gingerols are labile oily liquids, which are difficult to purify. Since the capsaicinoids and gingerols and their analogues have closely related chemical structures, the possibility of selecting from among them one easily purified analytical standard for determination of both the groups of compounds by HPLC was investigated. It was found that caprylic acid vanillyl amide (CVA), one of the minor naturally occurring capsaicinoids, but an easily synthesized crystalline compound, was very suitable for this purpose (Wood, 1987; ISO, 1995).

The following conclusions have emerged from the investigations of Ananthakrishna and Govindarajan (1974):

- There is much difference in the pungency stimulated by the three homologues.
- The major component 6-gingerol has the highest potency.
- Contrary to the earlier assumptions, the formed 6-shogaol is twice as pungent as the parent 6-gingerol.
- The higher homologues of shogaols are only weakly pungent.
- Quality deterioration by breakdown of gingerols does not happen easily at the temperature and pH conditions of normal processing and storage conditions.

Zhang et al. (1994) also reports higher pungency for shogaols compared to the gingerols.

In addition to these major compounds, the presence of a number of minor components has also been reported in ginger oleoresin (Connell and McLachlan, 1972; Murata et al., 1972; Masada et al., 1973, 1974; Harvey, 1981; Smith, 1982; Chen et al., 1986a). Table 11.23 lists the pungent components identified in ginger oleoresin. A typical HPLC chromatogram of ginger oleoresin is given in Figure 11.15.

Green Ginger Oleoresin

The oleoresin extracted from fresh ginger retains the fresh aroma and wholesome flavor that closely matches the parent spice. The oleoresin of fresh ginger is termed green ginger oleoresin. Green ginger oleoresin finds application in flavor formulations where the fresh note of the spice is the prime quality determinant.

Modified Oleoresin

Sometimes a straight extracted oleoresin may require modification to suit specific applications. It can be fortified with distilled essential oil to achieve a balance between pungency and aroma. The strength of the oleoresin can be adjusted to the required level by dilution with permitted diluents. Diluents also improve the flow properties of the product.

Table 11.23 Pungent components in ginger oleoresin

3-gingerol
4-gingerol
5-gingerol
6-gingerol
8-gingerol
10-gingerol
12-gingerol
14-gingerol
methyl-6-gingerol
mehyl-8-gingerol
methyl-10-gingerol
methyl-12-gingerol
4-shogaol
6-shogaol
8-shogaol
10-shogaol
6-methylshogaol
8-methylshogaol
4-paradol
6-paradol
zingerone
4-gingediol
6-gingediol
8-gingediol
10-gingediol
6-methylgingediol
4-gingediacetate
6-gingediacetate
6-methylgingediacetae
4-gingerdione
6-gingerdione
8-gingerdione
dihydrogingerol
hexahydrocurcumin
desmethylhexahydrocurcumin

The oleoresin may be rendered water soluble using permitted emulsifiers or converted to powder form by dispersing on dry carriers such as flour, salt, dextrose, or rusk powder.

These plated products impart the strength of good-quality freshly ground spices and can be easily incorporated in food.

Microencapsulated Ginger Oil and Oleoresin

Microencapsulated extracts are microfine particles of oils and oleoresins coated with an envelope of an edible medium such as starch, maltodextrin, or natural gums so that the flavor is locked within the tiny capsule. The encapsulated product is usually prepared

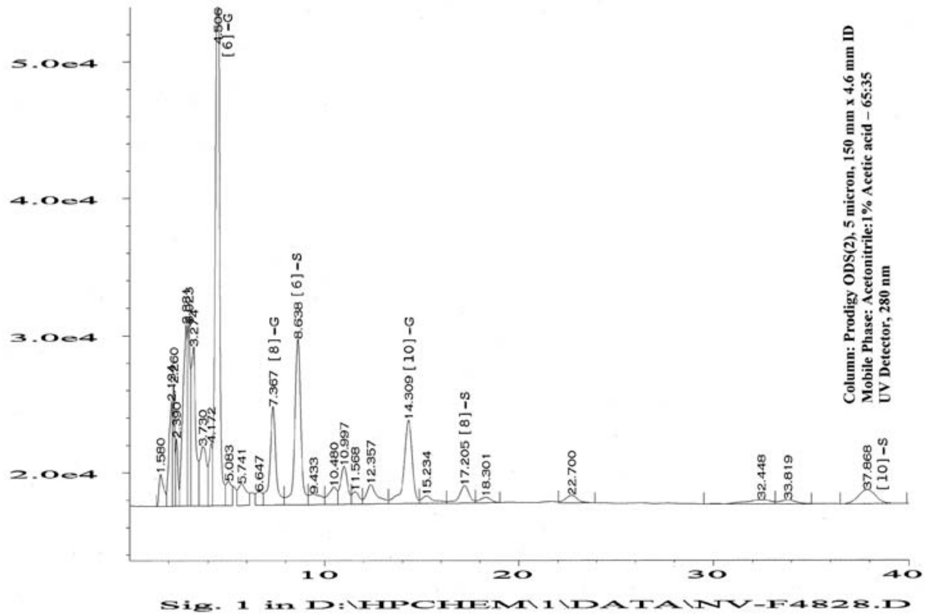

Figure 11.15 Typical HPLC chromatogram of ginger oleoresin.

by spray-drying technique. When incorporated in food, the outer coating dissolves off, thereby releasing the flavor. Encapsulated oleoresins can be designed to contain a predetermined level of the core material.

Ginger oil as well as oleoresin can be microencapsulated/spray dried to convert to powder form with an improved shelf life and application convenience. Microencapsulation serves the following purposes:

- Controls the release of the core material
- Locks the flavor to ensure against loss on storage
- Offers convenience in handling by converting liquids and semisolids into free-flowing powder
- Provides uniform dispersibility in the food matrix

Figure 11.16 gives the flow diagram for the microencapsulation/spray drying of spice oils and oleoresins.

Preserved Ginger

Traditional methods of preserving ginger by immersion in brine or syrups consisting of a mixture of dissolved sugars have been practiced for centuries (Brown, 1969a). The quality requirements of ginger for making preserved ginger are different from those for dried ginger. The ginger for the preserve should not be very hot or fibrous and hence should be harvested at an earlier stage than that for drying and further processing.

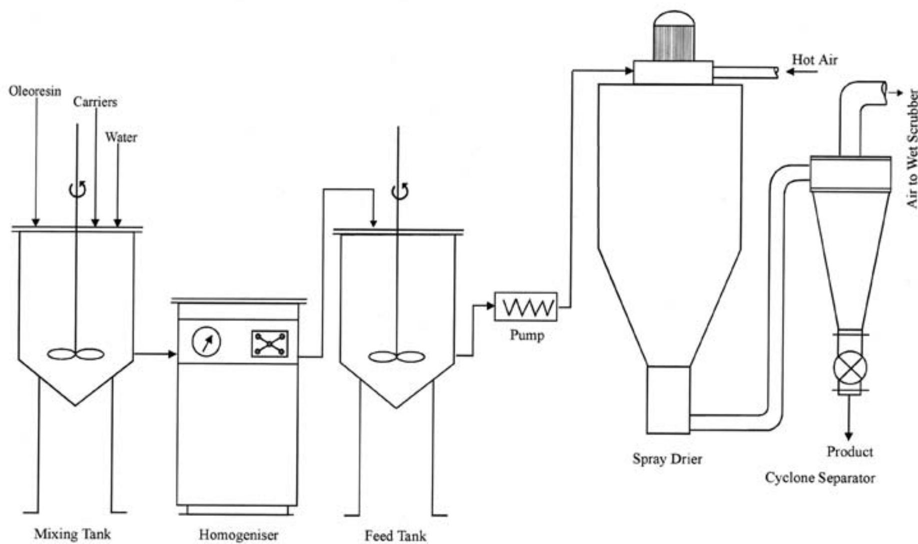

Figure 11.16 Microencapsulation/spray drying.

Ginger in Syrup: In commercial sugar syruping, the peeled rhizomes are normally held in a preserving solution prior to treatment to prevent possible mold formation (Ingleton, 1966). The preserving solution is usually brine at a concentration range of 14 to 17 percent. The preserving solution is drained out on a loose mesh sieve. The salt must be washed off the rhizomes before the sugar treatment. Sometimes the rhizomes are also given a boiling treatment prior to syruping to soften it (Brown, 1969a). The ginger is then diced into pieces of required size and shape and immersed in sugar syrup. Alternatively, the sugar syrup may be circulated through the ginger pieces held in vats. The syrup concentration is gradually increased to minimize shrinkage. Process conditions are so selected to ensure optimum sugar absorption (Brown, 1969a, 1969b, 1969c). The invert sugar:sucrose ratio requires close control to prevent crystallizing of the syrup. It has been found that the optimum reducing sugar concentration is 25 to 33 percent of the total sugars. The optimum pH for syruping has been reported to be 4.3 for the desirable flavor. The ginger, after attaining the desirable level of absorption, is packed in its own syrup in small glass jars. The addition of honey up to 15 percent of the weight of the syrup produced a distinctive flavor in ginger in syrup.

Ginger in Brine: Tender rhizomes are also preserved in brine. This is used for making sauces and pickles and can also form the raw material for syruping after the salt has been removed by boiling in water (Sills, 1959).

Crystallized Ginger: Another version of preserved ginger is the crystallized or candied ginger produced by taking the ginger-in-syrup process a stage further. For producing crystallized ginger, the ginger is further dipped in syrups of progressively increasing concentration (Ingleton, 1966; Brown, 1969b). Optimum process conditions are followed for satisfactory sugar absorption, weight gain, desirable color, and desirable

texture. The ginger is then removed from the syrup, rolled in castor sugar in a rotating drum, and dried in air-draft dehydrators (Leverington, 1969; Brown, 1969b). The product is cooled and packed in sealed polythene bags. In crystallized ginger, the pieces are small but of regular size and uniformity of cut. Different additives may also be incorporated to give a noticeable improvement in crispness of texture as well as to modify the flavor (Natarajan et al., 1970). Solutions of gelatin of varying strengths and temperatures, as well as hot pectin solutions, were found to be suitable adhesives to hold the sugar crystals onto the ginger (Leverington, 1969).

These candies are perfect to settle the stomach and soothe the throat, especially in travel. They may be popped into the mouth and chewed to enjoy the sweet heat. They also help to relieve the heaviness after a full meal. Candied ginger can be chopped and used as toppings on ice cream or added in cookies or cakes.

Ginger Puree and Ginger Paste: Ginger puree consists of fresh ginger that has been peeled, washed, sanitized, cooked briefly, and ground. The puree may be stored frozen or permitted preservatives may be added to keep the quality. Ginger paste, on the other hand, is salted and seasoned. Commercial packs contain salt, oil, acetic acid/vinegar, permitted preservatives, and occasionally other spices.

Smooth and instant ginger in these forms adds convenience to cooking. Ginger puree and paste are used in stir fries, soups, sauces, cakes, breads, puddings, chutneys, creams, fillings, and marinades.

Uses of Ginger and Ginger Products

Ginger is perhaps the most widely used spice, both for flavoring as well as medicinal purposes.

Flavoring Applications

Culinary: Fresh ginger is an essential ingredient in the preparation of oriental dishes, both sweet and savory, from entrees to desserts. It finds application in almost all meat, poultry, seafood, and vegetable preparations. Ginger contributes a freshness to foods that other spices do not (Farrell, 1985). A tenderizing effect has been observed when meat is cooked with slices of fresh ginger (Lawrence, 1984). Tender rhizomes are used in pickling. Ginger is extensively used in the preparation of different types of condiments and to flavor breads, cakes, biscuits, cookies, candy, jelly, toffees, and beverages.

Ginger Bread: Ginger bread is prepared by incorporating finely grated fresh ginger, cold pressed ginger juice, or ginger powder in the dough. Occasionally, this is supplemented with other spices such as garlic, cinnamon, and clove.

Ginger Biscuits, Cookies, and Cakes: These traditional family favorites are unique in their warm spicy flavor. Typical dosage is one teaspoon of ginger powder for four cups of flour. Sometimes small quantities of cinnamon and nutmeg are also added.

Ginger Drinks: Ginger drinks provide a cool, refreshing beverage as well as health benefits to the consumer. The most popular ginger drinks are the ginger ale and the ginger beer, which are carbonated ginger-flavored soft drinks. Even though the two terms are used interchangeably, sometimes the term “ginger beer” is associated with the spicier ginger ales. Ginger ale can be conveniently prepared at home. Even though a

vast number of recipes are available, the essential steps for a typical preparation may be summarized as follows:

To 50 g grated or crushed ginger, add 5 L of boiling water. Add 500 g sugar and stir to dissolve. Leave to cool. When the contents cool to lukewarm, strain and add 15 g yeast. Flavoring agents like lime or lemon juice, vanilla essence, or other spices may also be added at this stage to suit the taste. Cover the container opening with a clean cloth and leave in a warm place overnight. Remove any scum from the top of the mixture, strain, and transfer the clear liquid into sterilized bottles. Seal the bottles with screw-caps and leave for 2 days at room temperature. Leaving the bottles at room temperature too long will cause overcarbonation and the drink will taste too yeasty. Refrigerate to finish the aging process. Add sparkling water or club soda and serve. The quantities of ingredients may be altered to suit the taste. Drinking ginger ale or ginger beer has all the benefits of consuming ginger.

Ginger Wine: Ginger wine is a popular beverage that is very warming in the winter weather. It is brewed by the fermentation of grapes or raisins with sugar, ginger, and yeast. Fifty grams of ginger would be required for 1 L of wine. The wine is usually stored 3 to 4 months for aging. It may be served as is or blended with alcoholic drinks.

Ginger Tea: Ginger tea is a standard remedy for sore throat, colds, and flu. This is an infusion prepared by steeping grated fresh ginger in boiling water for 5 to 10 minutes. The liquid is strained and mixed with honey or sugar to taste. Some lemon juice also may be added. This soothing tea may be taken hot in winter and iced in summer. This tea is also good to take after a meal to aid digestion. Powdered dry ginger can also replace the fresh ginger for making ginger tea.

Ginger Syrup: Ginger syrup can make perfectly spiced sweet ginger drinks. To make ginger syrup, boil 50 g of finely chopped ginger in sugar syrup containing one cup of sugar in two cups of water. Simmer and cook for 1 hour. Strain the liquid and add vanilla or lemon essence to taste. Cover and refrigerate. This syrup will keep for several days. The concentrated syrup may be extended with carbonated or plain water. The syrup could also be drizzled over ice cream.

The syrup from candied/crystallized ginger processing can also be used in the same way.

Ginger Coffee: Ginger coffee is a blend of roasted coffee powder and ginger powder. A hot beverage is prepared by boiling the powder in water. Milk and sugar are optional. Ginger coffee is a cordial beneficial in the cold weather and is a remedy for colds, cough, and flu.

Ginger is also the major ingredient in "masala" tea, a spicy tea popular in some parts of India.

Uses of Ginger Oil and Oleoresin

Ginger oil and oleoresin can replace raw ginger in all flavoring and medicinal applications. These concentrates, which can be standardized to the required level of aroma and taste, overcome all the disadvantages associated with the raw spice, especially with respect to flavor consistency and shelf life. They are extensively used in the processed food industry for formulating seasonings for meat, poultry, seafood, and vegetable preparations. They

Table 11.24 Approximate dosages of ginger oil and oleoresin for typical applications

Ginger Oil	
Nonalcoholic beverages	17 ppm
Ice cream, ices etc	20 ppm
Candy	14 ppm
Baked goods	47 ppm
Condiments	13 ppm
Meats	12 ppm
Ginger Oleoresin	
Nonalcoholic beverages	79 ppm
Ice cream, ices etc	36–65 ppm
Candy	27 ppm
Baked goods	52 ppm
Condiments	10–1000 ppm
Meats	30–250 ppm

also find application in flavoring baked goods, confectionery, beverages, cordials, liqueurs, spicy table sauces, and in pharmaceutical preparations for cough syrups and creams for the relief of joint pains. Ginger oil finds a limited use in perfumery, where it imparts an individual note to compositions of the Oriental type. It is also recognized as a masking agent for mouth odor in dentifrices and oral hygiene products. Toothpaste flavored with ginger oil has a unique refreshing taste.

Approximate dosages of ginger oil and oleoresin for typical applications are given in Table 11.24 (Fenaroli, 1975). The figures are only indicative and vary with regional preferences. Exact dosage levels may be determined through application trials.

A relatively new area of application of essential oils is aroma therapy. Ginger oil finds extensive application in aroma therapy, in the treatment of rheumatism, arthritis, nausea, hangovers, travel and seasickness, colds and flu, congestion, coughs, sinusitis, sore throat, diarrhea, colic, chills, and fever.

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12 Production, Marketing, and Economics of Ginger

M. S. Madan

Ginger is an important commercial crop grown for its aromatic rhizomes, which are used both as a spice and for medicinal purposes. India accounts for about 30% followed by China (20%) in total world production. The world production is approximately 0.75 to 0.8 million tons of ginger from an area of around 0.3 million hectares (Table 12.1). During the same period, the export was around 20% of total world production valued at US $105.73 million. Even though India is the largest producer of ginger in the world, it occupied only the seventh position in export during 1999 and 2000; after China, Thailand, Brazil, Taiwan, Nigeria, and Indonesia. The major importing countries are the United Kingdom, United States, Japan, and Saudi Arabia.

Table 12.1 Production in major ginger-producing countries (1998–2000) (Area: Ha, Production: tons)

Country	*Area*	*%*	*Production*	*%*
Traditional	**14,5344**	**45.84**	**650,330**	**84.37**
Bangladesh	6,879	2.17	38,000	4.93
China	13,200	4.16	160,000	20.76
Dominica	45	0.01	100	0.01
Dominican Republic	400	0.13	1,500	0.19
Fiji Islands	65	0.02	2,500	0.32
India	83,220	26.25	281,160	36.48
Jamaica	180	0.06	620	0.08
Korea	4,255	1.34	7,950	1.03
Malaysia	1,000	0.32	2,500	0.32
Nigeria	17,400	5.49	90,000	11.68
Philippines	4,700	1.48	28,000	3.63
Sri Lanka	2,000	0.63	8,000	1.04
Thailand	12,000	3.78	30,000	3.89
Newcomers	**15,261**	**4.81**	**12,4948**	**16.21**
Australia (1990)	150	0.05	4,500	0.58
Bhutan (1980)	350	0.11	3,100	0.40
Cameroon	1,370	0.43	7,500	0.97
Costa Rica	1,600	0.50	21,000	2.72
Ethiopia (1993)	150	0.05	400	0.05
Ghana	0.00	60	0.01	
Indonesia (1981)	10,000	3.15	77,500	10.05

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Table 12.1 (Continued)

(Area: Ha, Production: tons)				
Country	*Area*	*%*	*Production*	*%*
Kenya (1989)	55	0.02	150	0.02
Madagascar (1992)	8	0.00	30	0.00
Mauritius (1985)	70	0.02	200	0.03
Nepal (1985)	1,200	0.38	3,200	0.42
Pakistan (1994)	78	0.02	28	0.00
Reunion (1985)	30	0.01	500	0.06
Saint Lucia (1985)	25	0.01	60	0.01
Uganda (1990)	50	0.02	120	0.02
United States (1985)	125	0.04	6,500	0.84
Zambia	0.00	100	0.01	
World	**31,7055**	**100.00**	**770,778**	**100.00**

Source: FAO (2003) (figures in parentheses indicate earliest year of initiating production).

Major ginger growing states in India are Kerala, Meghalaya, Orissa, West Bengal, Andhra Pradesh, Karnataka, Sikkim, and Himachal Pradesh. Official statistics on area, production, and productivity, although conflicting, are available through FAOSTAT (statistical data base of FAO) and SPICESTAT (Spices Statistical database of the Integrated National Agricultural Resources Information system [INARIS] of the Indian Council of Agricultural Research, India located at the Indian Institute of Spices Research, Calcut, Kerala, India). However, the trade-related figures available are comparatively complete and make a distinction between dried and fresh ginger. A multitude of processed ginger products entering into the world market are not taken into account separately. Despite certain limitations in the availability, this chapter makes use of the time series data obtained from the FAO and other agencies to analyze the trend in countrywise area, production, export, and import. The aim of this effort is to get some broad indications on the possible changes that have taken place in the crop economy during the last three decades since 1970–1971 and further prospects based on observed trends.

Production

World Scenario

Table 12.2 shows the growth of ginger production during the past 25 years for major producing countries. During 1975 through the 1980s, India was the major producer of ginger with a 30 to 35% share in total world production, followed by China, which accounted for approximately 15%. China could have increased its share in the world production from 12% in 1975 to over 24% in the recent past. China (24%), India (28%) and Indonesia (15%) are the top three producers, accounting for about two-thirds of the total world production.

The supply of ginger on a countrywise basis is computed by looking at area, production, and exports. The analysis brings out inconsistencies in yield and area expansion than to go deep into the factors responsible for the changes. In order to make a meaningful analysis, ginger-producing countries are grouped into two major categories: traditional producers and newcomers. The groupings suggest that up to 1980 there were about 15

***Table** 12.2* Production in major ginger-producing countries (1975–2002)

	% Share in total by				*World production*
Period	*India*	*China*	*Indonesia*	*Others*	*(Mt)*
1975	30.67	11.68	—	57.65	147,213
1980	33.47	20.75	—	45.78	246,316
1985	35.37	12.89	12.56	39.18	390,259
1990	31.35	11.05	16.27	41.33	491,153
1995	30.11	20.00	11.34	38.55	728,376
2000	28.58	23.70	15.52	32.20	962,060
2002	27.83	23.98	15.18	33.01	988,182

Source: FAO (2003).

countries engaged in the production of ginger. Since ginger cultivation and processing is labor intensive, most of the African countries have neglected this crop, and consequently they are not very active now in the world market. However, many other countries have entered into the field, and the number has almost doubled to date. The average share of newcomers in total production during the recent past (1998 to 2001) is 16.21%, and is rapidly increasing. Among the newcomers, Indonesia, which started production around 1981, accounts for about 10% of total world production, but the share of other newcomers was not that significant (6.2%) during the same period. However, it is a fact that many new countries are becoming interested in the production of ginger, and many have entered into the production arena during the last 5 to 6 years (Datta et al., 2003).

Area Expansion

An analysis of world scenario for growth in terms of acreage under ginger reveals:

- China recorded the highest growth in acreage during 1991 to 2002 (10.969%) among all ginger-producing countries. Indonesia and India, the other major producers, to show a moderate growth of 5.6% and 3.06%, respectively, during the same period.
- Other countries showing considerable growth in land under ginger during this period are Sri Lanka (0.26%), the United States (5.92%), Costa Rica (7.57%), Mauritius (1.31%), Bangladesh (1.34%), and Nigeria (5.8%). On the other hand, countries like Uganda (−20.35%), Fiji (−8.29%), Pakistan (−13%), and Jamaica (−10.41%) have experienced a rapid decline in acreage during this period. Most of these countries were newcomers.
- The Philippines (−3.35%), Nepal (−3.35%), are Thailand (−4.69%) are the other countries to record comparatively less decline in acreage.
- An interesting phenomenon observed in terms of fluctuations in growth in acreage is that a high growth in area in a particular period for a country is generally followed or preceded by a period of low and negative growth.
- There is no striking difference between performances of traditional growers and newcomers. In terms of growth in acreage, some newcomers have fared well, whereas some have failed badly. The same argument holds true in respect to the traditional ginger-producing countries as well.

Growth in Production

The world scenario in terms of growth in production highlights the following recent trends (Datta et al., 2003):

- China recorded the highest growth (11.39%) during 1991 to 1997, followed by Mauritius (11.15%) and Kenya (9.95%). The next in order are Nigeria (8.56%), Malaysia and Sri Lanka (both 6.78%), Madagascar (5.96%), and South Korea (4.36%).
- On the other hand, a number of countries have recorded a high negative growth. Uganda experienced the highest (−21.67%), followed by Fiji (−17.24%).
- In between these two extremes lie the rest, some showing moderate positive and the others showing moderate negative average growth.

As regards growth, the cyclical nature of the growth pattern was observed over the decades for both area and production. Barring Fiji, the nature of fluctuations in acreage and production was almost identical (in terms of both peak and trough) for other countries. Again, as in acreage, the growth pattern in production is also not group specific.

Yield

In terms of productivity performance, the world scenario gives the following picture:

- Barring Fiji, South Korea, the Philippines, and Nigeria, the traditional growers of ginger, cyclical fluctuations are not that sharp in other countries.
- The fluctuations are highly erratic in Fiji, recording a high negative growth during 1971 to 1980 and a very high positive growth in the next decade, only to come down to around 3% in 1991 to 1997.

In order to analyze the salient features of major ginger-producing and ginger-consuming countries individually, an effort is made to present countrywise details separately.

India

Ginger is grown in almost all the states of India. However, major ginger-producing states are Kerala, Orissa, Meghalaya, West Bengal, Karnataka, Sikkim, Andhra Pradesh, and Himachal Pradesh. Kerala accounts for the major share of both area (19%) and production (19%) of ginger in India. This figure has remained more or less unchanged over the last three decades. Orissa state stands second followed by Meghalaya. These three traditional ginger-growing regions of the country account for nearly 40% of the total production in the country.

In south India, although ginger cultivation was confined mostly to Kerala in the earlier years, during the last 8 to 10 years it is making fast inroads in to the paddy fields of Karnataka and Tamil Nadu. In Karnataka commercial cultivation of ginger is picking up in the districts of Coorg and Chikmagalur, with a reported area of approximately 4,500 hectares. Korikanthimath and Govardhan (2001a, b) claims that in the Kodagu district of the state alone nearly 4,000 hectares of paddy land has been converted for

cultivation of ginger. Enterprising farmers from the adjacent Waynad district of Kerala lease paddy fields for cultivation of ginger. Fresh ginger harvested during the months of January to March had buyers from Nagpur, Mumbai, and Bangalore. A sizeable quantity of fresh ginger goes to the traditional ginger-growing districts of Ernakulam and Kottayam in Kerala for further processing into dry ginger. In Kerala, the Waynad and Idukki districts contribute the most toward the export of quality ginger from the state. Incidentally, these two districts have the maximum production density for ginger in the country.

Karnataka farmers sometimes have a practice of putting back a certain portion of the year's ginger crop in the ground and preserve it as "old ginger" for the next year. The reason for this is the low price in the market at the time of harvest. During the next season, this same old ginger will grow further. More rhizomes will develop, and farmers hope that at that time they will get a better price for both the old ginger and the new rhizomes. Himachal, Maran, and Rio de Janeiro are the major cultivars grown in the region (Spices Board, 1988).

Production Economics

Examination of time series data indicates that the coefficient of variation for the farm price of ginger was higher than that of production over a period, indicating the violent fluctuation in the price of ginger in the country. This fluctuating prospect had a greater impact on the production economics of the farming community. The problem can be better understood from the fact that farmers buy seed rhizomes for prices as high as Rs.50/kg at times, but their harvested crop could fetch them only less than one-fifth of this price. In order to avoid the price-related risk, the farmer cultivates ginger as a intercrop under various cropping systems, although a pure crop is not uncommon. In the major ginger-growing state of Kerala, nearly one-fourth of the cultivated area is in the uplands as pure crop whereas the major area (45%) is in the garden land category and the rest is under a mixed cropping system. A study on economics found that the banana + ginger system fetched more net income of Rs.2, 74,808 per hectare followed by the banana + ginger + vegetable cowpea intercropping system (Rs.1,92,578/−). The benefit–cost ratio was also highest in the banana + ginger system (2.28), whereas the lowest benefit–cost ratio (1.56) was recorded for the banana + turmeric system (Regeena and Kandaswamy, 1987). The estimated per kilogram production cost in Kerala for a pure crop of ginger during 2001 to 2002 was Rs.5.52, and it was comparatively more than that in Karnataka (Rs.3.84) owing to higher labor costs and other added costs toward chemical fertilizers (IISR, 2002). Ginger is a high-labor and input-demanding crop. A survey conducted by the Kerala Agricultural University also ascertained the fact that the Kerala farmers use large quantities of fertilizers. The share of fertilizer cost amounted to 26% in Kerala, whereas it was only 10% in Karnataka (IISR, 2002). As regards the labor requirement, the actual enumeration done to estimate the operation-wise labor requirement indicates that the ginger requires nearly 337 workdays/ha for the entire period of cultivation excluding marketing. The estimated standard cost-return budget for ginger in India is given in Table 12.3, which also reflects the fact that more than 65% of the total cost incurred is toward labor and seed material purchase. It can be further observed that the ginger farmer gets a marginal benefit, which can be wiped out easily due to unexpected losses in production and a slight fall in price. However, there exists a comparatively higher benefit–cost ratio when the marketed end product is dry gingers.

Table 12.3 Cost-return budget for ginger (Rs./ha)

SI No.	*Description*	*Input/ha*	*Value Rs.*	*% share*	*Owner/tenant share*	*% cost*
	Unpaid labor (man days)	67.0	—			
	Unpaid (Rs. Per day)	80.00	—			
1	Unpaid labor	Cost>	5,360.00	5.49		
	Hired Labor (man days)	270.0	—			
	Cost (Rs./day)	80.00	—			
2	Hired labor	Cost>	21,600.00	22.13		
	Seed material (kgs)	1,600.0	—		Fertilizer	100.0
	Cost (Rs./kg)	22.50	—		Bought seed	100.0
3	Seed ginger purchase	Cost>	36,000.00	36.88	Fertilizer and manure	100.0
	Own material	0.0	—		Mulch	100.0
	Own material (Rs./kg)	0.00	—		Plant protection	100.0
4	Own material	Cost>	0.00			
	Manure/compost (Mt)	20.0	12,000.00			
	Chemical fertilizer N (kgs)	60.0	782.00		Fertilizer	Cost (Rs./unit)
	Chemical fertilizer P (kgs)	50.0	978.00			
	Chemical fertilizer K (kgs)	120.0	370.00		Manure/compost	600.00
	Mulching material (Mt.)	20.00	4,000.00		N	13.03
5	Total fertilizer & mulch	Cost>	18,130.00	18.57	P	19.56
	Chemical	2.40	—		K	3.08
	Seed treatment cost (Rs./kg)	380.00	—			
6	Seed treatment (Rs./ha)	Cost>	912.00	0.93		
	Plant protection (nos)	4.00	—			
	Plant protection (Rs./spray)	2,000.00	—		Interest rate	11%
7	Plant protection (Rs./ha)	Cost>	8,000.00	8.20		
	Irrigation (Rs./ha)		2,300.00			
	Miscellaneous (Rs./ha)		500.00			
8	Drying		17,280.00			
	Interest on variable Cost @11%	Costs>	4,809.31			
	Total variable costs (Rs.)		97,611.31			
	Total production cost Rs.	(fresh)	97,611.31	100.00	Return for fresh ginger:	
	Returns over variable	Costs (Rs.)	12,388.69		Yield (t/ha)	20.0

Returns over total	Costs (Rs.)	12,388.69	Price/t	5,500.00
Variable cost per	t	4,880.57	Gross income (Rs.)	110,000.00
Total cost per Mt	(Rs.)	4,880.57	Production (t)	20.00
Breakeven yield Mt at Rs.	5500.00	17.7		
Benefit–cost ratio	1.13			
Total production cost Rs.	(dry)	114891.31	Return for dry ginger:	
Returns over variable Costs	(Rs.)	53109.00	Yield (t/ha)	3.2
Variable cost per	t	35,903.44	Price/t (Rs.)	52,500.00
Total cost per Mt	(Rs.)	35,903.44	Gross income (Rs.)	168,000.00
Benefit–cost ratio	1.46			

N, nitrogen; P, phosphorus; K, potassium.

A study conducted in Maharashtra to work out the economics of ginger production revealed that the average production cost per quintal (100 kg) was Rs. 1,012.04 and the estimated cost–benefit ratio was 1.38 for cost. Here also the cost of seed rhizome has eaten up almost 42.6% of the total costs involved in ginger production (Gaikwad et al., 1998).

Korikanthimath and Govardhan (2001b) conducted a study to compare the economics of cultivation of ginger in uplands and paddy fields of Karnataka, which indicated that the cost–benefit ratio is more favorable in paddy fields (1.7) when compared to upland cultivation (1.11). This higher profitability is mainly due to higher productivity (23.5 t/ha) achieved in the paddy fields when compared to the yield level of 13.5 t/ha in the upland.

Trends in Area, Production, and Productivity

The time series data on area, production, and productivity of ginger along with the growth index worked out for the period from 1970 to 2000 are presented in Table 12.4 and Figure 12.1. A perusal of the period-wise performance indicates a significant increase in production over the years.

Area: The area under ginger has shown an increasing trend over the years from 1970 to 2000, with occasional fluctuations being attributed to the ups and downs in price. Low remuneration in a year owing to an unfavorable price generally leads to a reduction in area and production in subsequent years.

Production: Indian production of ginger has been increasing steadily from 29.59 thousand tons in 1970 to 1971 to 263.17 thousand tons during 1999–2000. An increase of nearly 789% in production is due to the combined improvement in both area and productivity. The states Meghalaya and Kerala together accounted for more than 65% of total production in the country. If we make a region-wise grouping, the southern

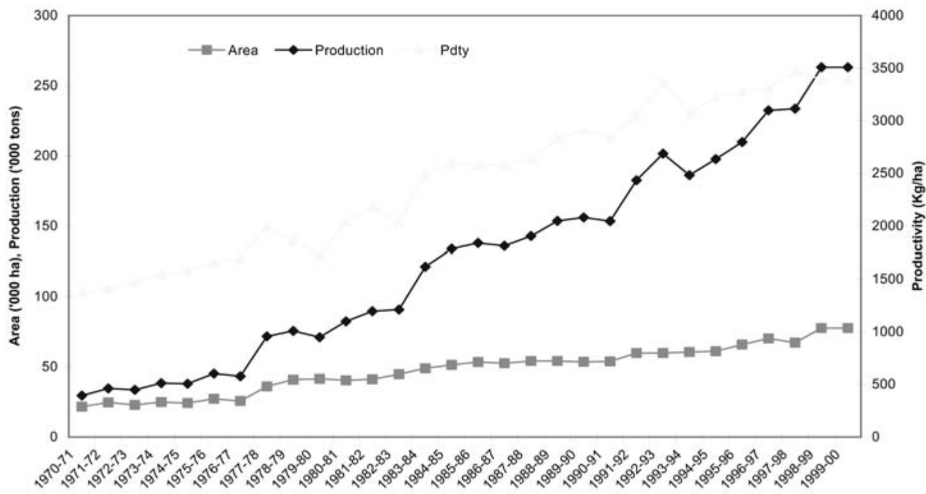


Figure 12.1 Area production, and productivity of ginger in India (1970–1971 to 1999–2000).

Table 12.4 Area, production, and average yield per hectare of ginger (dry) in India

Year	*Area ('000 ha)*	*Growth index*	*Production ('000 tons)*	*Growth index*	*Yield (kg/ha)*	Growth index
1970–71	21.59	53.37	29.59	35.89	1371	100
1971–72	24.59	60.79	34.71	42.10	1412	102.99
1972–73	22.88	56.56	33.63	40.79	1470	107.22
1973–74	24.86	61.46	38.46	46.65	1547	112.84
1974–75	24.14	59.68	37.91	45.98	1573	114.73
1975–76	27.2	67.24	45.15	54.77	1660	121.08
1976–77	25.65	63.41	43.39	52.63	1691	123.34
1977–78	36.02	89.05	71.7	86.97	1991	145.22
1978–79	40.8	100.87	75.72	91.85	1856	135.38
1979–80	41.42	102.40	71.14	86.29	1717	125.24
1980–81	40.45	100.00	82.44	100.00	2038	148.65
1981–82	41.11	101.63	89.71	108.82	2182	159.15
1982–83	44.72	110.56	90.83	110.18	2031	148.14
1983–84	48.96	121.04	121.31	147.15	2478	180.74
1984–85	51.51	127.34	133.86	162.37	2599	189.57
1985–86	53.52	132.31	138.02	167.42	2579	188.11
1986–87	52.65	130.16	136.01	164.98	2583	188.40
1987–88	54.24	134.09	142.84	173.27	2633	192.05
1988–89	54.23	134.07	153.57	186.28	2832	206.56
1989–90	53.56	132.41	156.12	189.37	2915	212.62
1990–91	53.93	133.33	153.45	186.14	2845	207.51
1991–92	59.83	147.91	182.65	221.56	3053	222.68
1992–93	59.87	148.01	201.63	244.58	3368	245.66
1993–94	60.58	149.77	186.2	225.86	3074	224.22

1994–95	61.09	151.03	197.65	239.75	3235	235.96
1995–96	65.98	163.11	209.88	254.59	3279	239.17
1996–97	70.29	173.77	232.51	282.04	3308	241.28
1997–98	67.2	166.13	233.66	283.43	3477	253.61
1998–99	77.61	191.87	263.17	319.23	3391	247.34
1999–2000	77.61	191.87	263.17	319.23	3391	247.33

region, comprising Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh, accounts for 52.4% of production with a 42.4% area during 1990 to 1991 to 2000 to 2001. Distribution of the ginger-producing area as a percentage of the total cropped area and production (district-wise) worked out clearly indicates the concentration of ginger cultivation in the states of Kerala and Meghalaya and their dominance in ginger production in the country.

The state-wise area, production, and productivity of ginger for three periods—1982 to 1983, 1992 to 1993, and 1998 to 1999—are given in Table 12.5. As it can be seen from Table 12.5, against the national average yield of around 3,371 kg/ha achieved during 1992 to 1993, states such as Meghalaya, Andhra Pradesh, Sikkim, and Tamil Nadu have been consistently recording a higher level of yield. Tamil Nadu achieved the highest yield of 19,450 kg/ha during the period and has attained a record productivity

Table 12.5 Statewise area, production, and productivity of ginger in India (Area: '000 ha, Production: '000 tons, Productivity: kg/ha)

States		*1982 to 1983*			*1992 to 1993*			*1998 to 1999*		
		Area	*Production*	*Productivity*	*Area*	*Production*	*Productivity*	*Area*	*Production*	*Productivity*
Kerala	Actual	12.36	30.48	2466	15.34	50.39	3285	14.57	49.95	3428
	%	27.64	33.56	25.64	24.98	18.77	18.98			
Meghalaya	Actual	5.82	24.05	4132	6.64	40.8	6145	9.55	49.06	5137
	%	13.01	26.48	11.10	20.23	12.31	18.64			
Orissa	Actual	5.44	5.41	994	9.54	14.28	1489	13.52	26.91	1990
	%	12.16	5.96	15.95	7.08	17.42	10.23			
West Bengal	Actual	3.15	4.97	1577	6.86	12.76	1860	9.4	18.84	2004
	%	7.04	5.47	11.47	6.33	12.11	7.16			
Sikkim	Actual	3.04	5.88	1934	3.54	19.14	5407	2.49	4.32	1735
	%	6.80	6.47	5.92	9.49	3.21	1.64			
Karnataka	Actual	2.38	3.1	1302	2.13	2.81	1319	3.94	5.26	1335
	%	5.32	3.41	3.56	1.39	5.08	2.00			
Andhra Pradesh	Actual	2	3.5	1750	2.06	7.27	3529	1.91	6.77	3545
	%	4.47	3.85	3.44	3.60	2.46	2.57			
Himachal Pradesh	Actual	1.9	0.48	252	1.64	1.2	732	1.81	0.87	481
	%	4.25	0.53	2.74	0.59	2.33	0.33			
Tamil Nadu	Actual	—	—	—	0.90	16.10	17889	0.58	18.22	31414
	%									
Others	Actual	8.63	12.96	1100.85	12.07	53.08	3127.07	20.42	101.19	5336.5
	%	19.30	14.27	20.18						
					26.31	26.31	38.45			
All India	—	—	—	59.82	201.63	3371	75.57	252.00	3366	

Source: DASD (Directorate of Arecanut and Spices Development) (2002), Government of India, Calicut, India; DES (Directorate of Economics and Statistics) (2001), New Delhi, India.

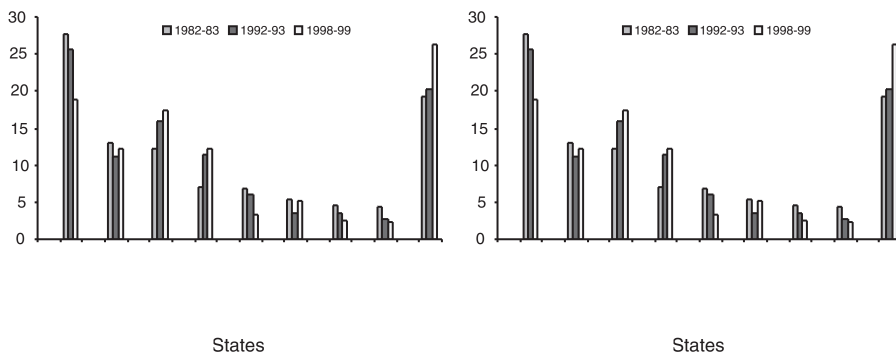


Figure 12.2 Area production, and productivity of ginger in India (1970–1971 to 1999–2000).

of 31,683 kg/ha during the 1998 to 1999 crop year. The insignificant change in area in Tamil Nadu is taken care of by a significant growth in yield in the state, thereby helping it to register a healthy growth in production. Nagaland, Mizoram, Arunachal Pradesh, and Meghalaya are the other states in the order of achieving higher productivity (more than 5,500 kg/ha) during the same period. Arunal Pradesh registered 7,164 kg/ha, Meghalaya, 5,137 kg/ha, Mizoram 5,000 kg/ha; while Orissa registered the lowest figures (1,990 kg/ha) (DASD, 2002).

Productivity: Further analysis of the time series data between the period 1970 and 1971 to 1997 and 1998 indicated that the yield level of ginger in the country increased over the years from 1,371 kg/ha during 1970 to 1971 to 3,391 kg/ha during 1997 to 1998. The yield level that was approximately 1,371 kg/ha during 1970 to 1971, did not show much improvement until the end of 1980 except for occasional fluctuations toward the higher side (up to 1,991 kg/ha during 1977 to 1978), it seems that the yield increase during this period did not contribute much to the increase in production. The increase in production during that period was largely due to an increase in cropped area. However, the productivity level improved from 1980 to 1981 onward and reached an average of 3,188 kg/ha during 1990 to 1991 to 1998 to 1999. Productivity registered during 2000 to 2001 was more than two times the productivity of 1970 to 1971. The estimated growth index for the year 1998 to 1999 in production was 254 percent over the base year (1970 to 1971).

To ascertain the impact of area expansion and productivity on production during different periods, periodwise data were analyzed using a simple technique followed by Librero et al. (1988). Results presented in Table 12.6 show that there is a positive sign in all the three parameters indicating the steady improvement in production due to both area expansion and productivity increase. However, the detailed component analysis reveals that the change in productivity had a more positive role in the first two periods, whereas in the last period area expansion played a major role in production expansion.

Growth Estimates: In order to obtain the long-term trends in area, production and productivity in major ginger-producing states in India, semilogarithmic growth equations were estimated, which indicated that the overall trend in area under ginger registered an average annual growth of 4.3% for the period from 1990 to 1999. Growth

Table 12.6 Change in ginger production, area, and the relative contribution of changes in area and yield on the change in production for selected periods

	1980–1981/ 1984–1985 to 1985–1986/ 1989–1990	*1985–1986/ 1989–1990 to 1990–1991/ 1994–1995*	*1990–1991/ 1994–1995 to 1995–1996/ 1999–2000*
Change in:			
Production	40.22	26.84	30.47
Area	18.28	10.10	21.47
Productivity	19.54	15.01	8.16
Change in production due to change in:			
Area	49.66	40.48	73.11
Productivity	52.81	58.83	29.49

Note: Analysis based on the method followed by Librero et al. (1988).

in production was at the rate of 6.11% during the same period, indicating a slight improvement in productivity, which was approximately 1.82% for the period.

Production Constraints

A status paper prepared by the Spices Board (1990) on the ginger crop highlights the fact that mostly small and marginal growers cultivate ginger in India. They face many problems and constraints that hamper the productivity of ginger. Major production constraints in ginger cultivation as given by various workers including the Spices Board of India (Kithu, 2003; Sarma and Jackson, 2003; Selvan and Thomas, 2003) are:

1. Low productivity (3,391 kg/ha) compared to an achieved average productivity of more than 1 lakh kg/ha elsewhere in the world.
2. Prevalence of an innumerable number of traditional cultivars, which are mostly poor yielders. Absence of an adequate supply of quality planting materials of improved cultivars.
3. Being a predominantly rain-fed crop, failure of rains and increased labor costs are some of the factors responsible for the higher cost of cultivation of ginger in India.
4. Nonadoption of integrated plant protection measures to control pests and diseases such as rhizome rot causes heavy production and postharvest losses in the crop in many parts of the country.
5. Lack of suitable postharvest processing for ginger rhizomes and poor marketing facilities, especially in the northeastern states of the country, results in poor returns to the farming community.
6. Lack of remunerative prices in subsequent years leads to less enthusiasm to cultivate ginger or leads to neglect of the crop.

Keeping the above facts in mind, there is an urgent need to develop cropping systems with ginger as a component. Although it is being cultivated as an intercrop in coconut

and arecanut plantations, we are yet to develop ideal systems with attention to the cost–benefit factor, soil disturbance, shade and root effect, and other factors.

China

In China, ginger is grown extensively in all central and southern provinces. It is cultivated as an annual or as a perennial crop. China emerged as the second largest producer of ginger during the year 2002 (23.98% of the world production) after India. During 1990, China's production was 54,284 tons, accounting for 11.05% of the total world production. Within 10 years time the production level has increased more than four times to account for nearly one-fourth of the world production. This achievement is mainly because of the high productivity of 115,104 kg/ha, and the highest recorded level (120,641 kg/ha) was in 1996.

In international trade China also enjoys the first position due to the quality of Chinese ginger; less fiber content, bigger size, and price competitiveness. China occupied first position in exporting ginger from 1994 (52.05% of total exports) until 2000, accounting for 61.59% of the total world exports. Chinese exports accounts for 61% of the annual imports of more than 91,000 tons by Japan. Other importing countries also prefer Chinese ginger for its cheap price and acceptable quality parameters.

Ginger is also exported in crystallized form in earthenware jugs and in syrup in wooden kegs. Harvesting of ginger in China starts in April and extends into June. Harvested young ginger is transported to processing plants in Chiang Rai for export; mostly to Japan. Young ginger is preserved in bottles of vinegar and eaten like pickles.

Australia

Commercial cultivation of ginger in Australia was first started at Buderim in southeast Queensland in the early 1940s, mainly for the domestic fresh ginger market. Ginger is now grown in the Caboolture, Nambour, and Gympie areas for processing at Yandina. Twenty-four growers currently represent the Australian ginger industry with approximately 150 ha under cultivation. The bulk of production is processed, with smaller volumes being sold on the domestic and exports markets. Buderim Ginger Ltd. is the only ginger-processing facility in Australia. This factory, through production quotas and a differential pricing system, controls the quality and quantity of ginger production for processing. Most growers derive the majority of their income from processed ginger. A few also supply the domestic fresh ginger market, and only two to three growers export fresh product. In 1987, Royal Pacific Foods began exporting Buderim ginger to the United States. Now the Australian products under the brand name "the Ginger People," are freely available on the shelves of many well-known food chain stores the world over. The Australian ginger farmer has achieved a reasonably higher productivity against the world average (Table 12.7).

Table 12.7 Ginger yield in Australia

Harvest	*Time of harvest*	*Yield t/ha*
Early	Late Feb.–early March	12–50
Early-late	April–Aug.	20–50
Late-late	Mid Jun–Early Oct.	38–75

Thailand

Thailand's agriculture sector produces about 32,000 tons of ginger in a year. The crop is cultivated extensively in the northern part of the country, especially in the mountains. Ninety percent of the production comes from the hills. Thailand had a slow increase in production over the period. Without much improvement in the recorded productivity of 25,000 kg/ha, improvement in the overall production was achieved through area expansion. The estimated normal growth rate for the period 1990 to 2002 was 2.7%, 2.81%, and 0.10%, respectively, for area, production and productivity.

Ginger from Thailand is noticeably distinguishable from other ginger by its plumpness, roundness, and short internodes. The dried "Golden" ginger is packed and exported.

Marketing

Products of Commerce

Three primary products of ginger rhizome are traded in the world market: fresh ginger, preserved ginger in syrup or brine, and dried ginger. Preserved ginger is prepared from the immature rhizome, whereas the pungent and aromatic dried spice is prepared from harvesting and drying the mature rhizome. Fresh ginger, consumed as a vegetable, is harvested both when immature and mature. The preserved and dried products are the major forms in which ginger is internationally traded. Fresh ginger is of less importance in international trade, but this is the major form in which ginger is consumed in the producing countries. Dried ginger is used directly as a spice and also for the preparation of its extractives—ginger oleoresin and ginger oil (ITC, 1995).

Commercial ginger in India is graded according to the region of production, number of fingers contained in the rhizome, size, color, and fiber content. In Indian states such as Himachal Pradesh, grading of ginger is done only in the state. The first grade, popularly known as "Gola" in the local market, comprises very bold and round bits of dry ginger, having maximum dry matter and low fiber contents. The second grade, known as "Gatti," includes bits of bold, round to oblong pieces, which are smaller than gola. The third and fourth grades are smaller bits having low dry matter and high fiber contents (Jaiswal, 1980). For export purposes, Calicut and Cochin ginger are graded into special, good, and nonspecial grades depending on the size of the rhizomes and the percentage of the presence of extraneous material.

Dried ginger has been traditionally traded internationally in the whole or split forms and is ground in the consuming centers. Export of the ground spice from the producing countries is on an extremely small scale. The major use of ground dried ginger on a worldwide basis is for domestic culinary purposes, whereas in the industrialized Western countries it also finds extensive use in the flavoring of processed foods. Ground dried ginger is employed in a wide range of foodstuffs, especially in bakery products and desserts (Anonymous, 1996).

Ginger oleoresin, an important value-added product, is obtained by solvent extraction of dried ginger and is prepared both in certain industrialized Western countries as well as in some of the spice-producing countries; most notably in Australia and India. This product possesses the full organoleptic properties of the spice—aroma, flavor, and pungency—and finds similar applications to those of the ground spice in the flavoring of processed foods. The oleoresin is also used in certain beverages and to a limited extent in pharmaceutical preparations. The new process developed by the Regional Research

Laboratory, Trivandrum, for extracting oil and oleoresin from fresh ginger, will lead to a higher recovery of the oil with superior organoleptic qualities, and will drastically reduce spoilage of fresh ginger during the harvesting season. This technology, which is highly suitable for the northeastern states, can utilize the cheap raw material available during the harvesting season to convert it into high-priced value-added products. The operating cost of a fresh ginger-processing facility is much lower than that for a conventional plant. Further, drying, peeling, and so forth are dispensed with, and since the processing is done during the ginger harvesting season, the raw material inventory can be reduced drastically. It is expected that adoption of this new technology can boost the country's prospects in adding value to the export basket of Indian ginger.

Ginger oil is distilled from the dried spice mainly in the major spice-importing countries of Western Europe and North America, as well as in some of the spice-producing countries such as India. This product possesses the aroma and flavor of the spice but lacks the pungency. It finds its main application in the flavoring of beverages and it is also used in confectionery and perfumery. Preserved ginger is prepared mainly in China, Hong Kong, Australia, and India, but smaller quantities of fresh ginger are processed in some importing countries too. It is used both for domestic culinary purposes and in the manufacture of processed foods such as jams, marmalades, cakes, and confectioneries (Sreekumar and Arumughan, 2003).

Market Structure

Regarding the market structure, there are a number of firms and individuals actively participating in the ginger trade especially in the case of dried ginger. A large number of dealers, brokers, and various other intermediaries between the dealer and the user or even between the dealer and the dealer exist both in exporting and importing countries. Singapore, London, New York, Hamburg, and Rotterdam are major trading centers. In the case of preserved ginger, Hong Kong is the major trading center. Fresh ginger is marketed through the fruits and vegetables trade network.

The prevailing marketing channel for ginger in India is seen in Figure 12.3, with slight variation between the regions. To begin with, farmers, after retaining the needed quantity for seed purposes and for domestic consumption, sell off a portion of their output to commission agents/village traders, who collect the produce at the farm gate. The produce thus collected is taken to the nearest assembly market in the taluk/block, from where it is transported to the regional/district level main marketing centers. Farmers having a large production base often take their produce to local and/or regional markets directly. Once the product reaches the regional (taluk/district) level markets, it is cleaned, graded, and then packed in sacks of about 60 kg. From here it is moved to terminal markets like Kochi, Chennai, Bombay, Bangalore, Kolkotta and New Delhi. Except in states like Kerala, where the ginger is dried and marketed for export purposes, in all other states harvested fresh ginger is marketed following the channels of vegetable marketing in the region. In some of the states fresh ginger is listed along with the vegetables covered under market regulation.

In terms of the ratio between the farm harvest price and retail price, it was observed that the ratio was higher in 1989 than in 1995. Moreover, fluctuations in the ratio were also less in 1989. The ratio between the farm harvest prices and the wholesale price has also gone down in recent years.

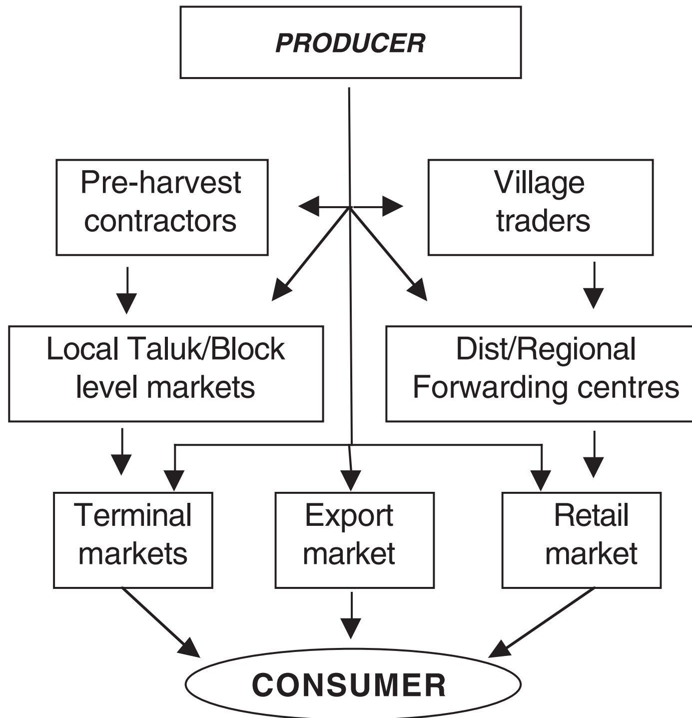


Figure 12.3 Commodity distribution system for ginger in India.

Factors of Demand/Export

Major factors that contribute to the export demand/potential of a commodity is quality. In ginger quality parameters are fiber content, volatile oil content, and nonvolatile ether extract.

Ginger grown in different parts of the country varies considerably in its intrinsic properties and its suitability for processing. This is perhaps more important with regard to preparing dried ginger than preserved ginger. The size is particularly relevant with the processing of dried ginger, and medium-sized rhizomes are generally the most suitable. Some areas grow ginger types yielding very large rhizomes, which are marketed as fresh ginger, but are unsuitable for converting to the dried spice owing to their high moisture content. This causes difficulties in drying, frequently a heavy wrinkled product is obtained, and the volatile oil content is often low and below standard requirements. From the above point of view, ginger produced in certain pockets of Kerala has more export demand/potential in the world market.

Indian Dried Ginger: Two types of Indian ginger entering the international market are Cochin and Calicut; named after the two major production areas on the Malabar Coast of Kerala. The bulk of Indian exports is of rough scraped, whole rhizomes. In addition to this, some bleached or limed ginger is also produced, but this is mainly exported to the Middle East, as it is not favored in European and North American markets. Cochin and Calicut gingers have volatile oil contents in the range of 1.9 to 2.2%. They are

characterized by a lemon-like aroma and flavor, which is more pronounced with the Calicut spice. They are starchier but are almost as pungent as Jamaican ginger. Their nonvolatile ether extract content is about 4.3%. They are widely used for blending purposes, and ginger beer manufacturers prefer these types (Spices Board, 1992).

Economics of Dried Ginger Production

In India, production of the dried ginger of commerce is confined exclusively to the state of Kerala and the product is of two types—Cochin and Calicut. The Cochin type, which is preferred over the Calicut type, is grown in central Kerala, mainly concentrated in the districts of Ernakulam and Idukki; and the Calicut is grown in the Malabar region including the Waynad district in northern Kerala. The estimated cost of production of dry ginger in Kerala is given in Table 12.8.

There is no recognized commercial variety of dried ginger produced in other parts of the country. Kerala ginger is considered to be one of the best due to its lower fiber content, boldness, and characteristic aroma and pungency. Gingers produced in other states have more fiber content, and are largely used for internal consumption in the form of green ginger. Kerala accounts for over 60% of the total dried ginger production and about 90% of India's ginger export trade. Cost and returns involved in making dried ginger following the recommended method of natural sun drying is in Table 12.8. As it can be seen from Table 12.3, the farmer gets the benefit–cost ratio of 1.46 when compared to 1.13 in the case of fresh ginger marketing.

In contrast to Jamaican gingers, which are clean peeled, Indian dried gingers are usually rough peeled or scraped. The rhizomes are peeled or scraped only on the flat sides of the hands; much of the skin between the "fingers" remains intact. The dry ginger so produced is known as the rough or unbleached ginger of commerce, and the bulk of the dried ginger produced in central Kerala consists only of this quality. Sometimes Indian gingers are exported unpeeled. For the foreign market, both Cochin and Calicut gingers are graded according to the number of "fingers" in the rhizomes: B, three fingers; C, two fingers; D, pieces. In addition to these two well-known types of Indian ginger, another type, Calcutta ginger, is occasionally seen in the market (Pruthi, 1989).

Table 12.8 Economics of dry ginger production

SI No.	*Item of expenditure*	*Cost (Rs.)*
1.	Cost of raw fresh ginger 1000 kgs @ 5.50/kg	5,500.00
2.	Peeling: 18 persons @ Rs.80/day	1,440.00
3.	Drying: 8 workdays @ Rs.80/day	640.00
4.	Polishing and packing	960.00
5.	Gunny bags for packing	200.00
	Total cost	8,440.00
	Gross returns for 200 kg @ Rs.52.50/kg	10,500.00
	Net return	2,060.00

Source: Madan (1999).

World Scenario

As ginger is mainly used as a spice and condiment, its per capita consumption is not high enough to sustain its world level production with the growing number of new producing countries taking recourse to international trade in ginger. However, the market information indicates that there is a "hot trend" in the U.S. market, that is, an increasing demand for spices like chilies, ginger, and black pepper. There is also a growing demand for ginger and ginger products worldwide. A recent development noted in ginger trade has been the increasing use of ginger oils and oleoresins and powdered and processed ginger in major importing countries, especially in Europe and the United States.

Main Suppliers

Major exporters of dry ginger are India and China. Among the other exporting countries are Indonesia, Brazil, Sierra Leone, Australia, Fiji, Nigeria, and Jamaica. Indonesia, Taiwan, China, and Thailand are major exporters of fresh ginger to the world market. Others are Brazil, Costa Rica, Malaysia, Fiji, India, Nicaragua, and certain Caribbean islands such as St. Lucia and St. Vincent. Important suppliers of preserved ginger are Hong Kong, which reexports the refined fresh ginger, and Australia (ITC, 1995).

In order to analyze the issues related to the export and import trades, the study has distinguished two groups of countries:

1. Producer-exporters (countries engaged in cultivation of ginger and usually exporting the surplus over domestic consumption; occasionally, however, they may import ginger as well from some other countries).
2. Re-exporters

The relative contribution of the above two groups is given in Table 12.9.

Table 12.9 Percentage share of different groups in total world export of ginger

	Producer-exporters		*Reexporters*	
Year	*Qty*	*Value*	*Qty*	*Value*
1965	78.50	61.06	21.50	38.94
1970	98.53	95.37	1.47	4.63
1975	96.62	94.61	3.38	5.39
1980	74.49	73.86	25.51	26.14
1985	69.60	70.58	30.40	29.42
1990	66.32	69.76	33.68	30.24
1995	84.28	77.07	15.72	22.93
Average	81.19	77.47	18.81	22.53

Source: FAO (2003).

World Trade

Distribution Channels

Specialized importers still play an important role in the ginger trade. A list of importers can be obtained from the International Trade Centre (ITC).

Dry Ginger

The traditional distribution system for dry ginger has declined as a result of an increase of purchasing by dealers and processors direct from the source. There also has been an increase in trade in some countries among certain ethnic communities, Asian in particular, who have developed their own system of distribution based on direct trading with the producing countries and a network of small retail outlets.

Fresh and Preserved Ginger

The marketing structure for fresh and preserved ginger is that characteristic of fresh vegetables. The rise of supermarket chains has eroded the position of wholesalers since some importers sell direct to supermarkets. In some importing countries, however, ginger in its fresh form is seen almost exclusively in shops catering to ethnic communities.

Export

During 1994, China contributed 52.05% of total ginger export, followed by Thailand (16.77%), Indonesia (9.73%), Brazil (6.24%), Taiwan (3%), Costa Rica (2.23%), India (1.98%), Nigeria (1.61%), Vietnam (1.37%), Malaysia (1.36%), and the United States (0.93%). China and Thailand maintained top positions until end of 2000; during 2000, China contributed 61.59%, followed by Thailand 23%, Brazil 4.41%, Taiwan 2%, Nigeria 1.75%, Indonesia 1.46%, and India 1.17% of the total exports of ginger (Figure 12.4).

Ginger exports from Jamaica and Sierra Leone are considered to be of high quality on account of their superior flavor and clean appearance. However, the price of Jamaican ginger is very high, which has led importers to search for cheaper alternatives. Today, the ginger from Australia is regarded as being high-quality due to its standardized and clean appearance and its steady price. Grinders have favored the ginger from China, but

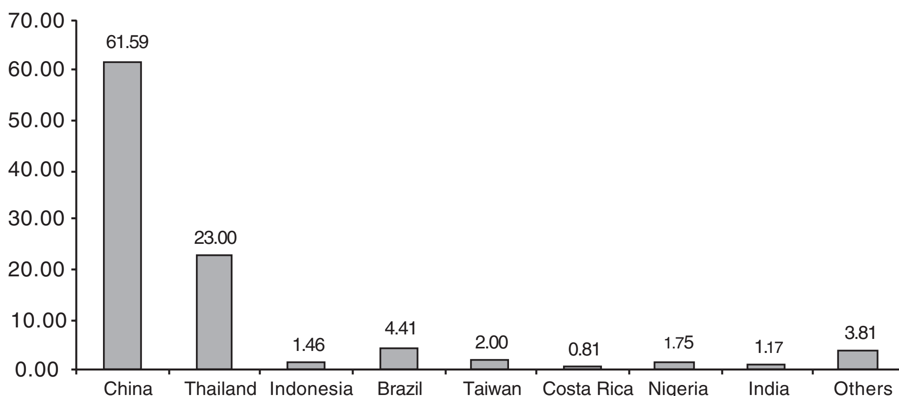


Figure 12.4 Country-wise contribution (%) to world ginger market (2000).

the use of the bleaching agent sulfur dioxide has adversely influenced Chinese exports to Europe and North American countries. In the Middle East, however, it is still widely used. Nigerian ginger is particularly used for oil extraction (ITC, 1995). As mentioned earlier, except in the case of Japan and the United States no separate statistics are available for the three different forms of ginger traded.

In order to see the trend in returns from trade earned by the exporting countries, Datta et al. (2003) has used a simple index (VADD) defined as:

$$\text{VADD} = \text{unit value of exports} - \text{unit value of imports}$$

Where
Unit value of exports = (total value of exports/total qty. exported
Unit value of imports = (total value of imports/total quantity imported)

They have ranked all countries in terms of VADD in decreasing order and reported that:

- out of the top 15 countries, only three belong to the producer-exporter group. The rest all are from the reexporters group;
- Only two are the traditional producers.
- Of the major producers, India ranked 40th with a VADD of 0.38, followed by China at 44th place with a VADD of 0.21. In the case of Indonesia, the estimate for VADD turned out to be negative at (−)0.13, meaning that Indonesia imported ginger at a higher unit value than at which it exported.
- Thus, reexporters have, in general, succeeded in achieving a greater value addition to their export of ginger into the world market.

As it can be seen from Table 12.10, the unit price (US $2.18/kg) earned by the European Union (EU) countries (reexporters) from export is much more than the average unit price (US $1.53/kg) earned by other producer exporters to EU countries. The Netherlands, Germany, and the United Kingdom are the major reexporters of ginger in Europe.

Export Performance by India

The world scenario viewed from the Indian perspective provides a complex situation for the ginger economy. India, being the largest producer of raw ginger in the world, has the potential to play a major role in the world trade for ginger. However, the potential is yet to be realized and the position has remained stagnant over the years in terms of the contribution to the total world export of ginger. Table 12.11 shows the export of ginger from India from 1970 to 2000. During 1970 to 1971, it was only 3156 tons, earning foreign exchange worth Rs. 26.094 millions. Then it further rose to 29,737 tons during 1996 to 1997 with a foreign exchange earning of Rs.592.441 millions. Figure 12.5. shows the increasing trend of both the production and export of ginger over the years. However, the quantity exported as the percentage of the total production has gone down to less than 5% in recent years.

Datta et al. (2003) has analyzed the export performance of the Indian ginger economy between 1961 and 1996 and has the following features.

Table 12.10 European Union: countrywise imports of ginger from country of origin (Qty: Tons, Value: US $'000)

	1992		1993		1994		1995		1996		Unit
Countries	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*price*
Intra-Eu	672	1254	566	1146	860	1746	1129	2472	1568	3419	2.18
Extra-EU	12406	16022	11762	14925	12464	16151	13507	19013	15367	23533	1.53
Of which from:											
Brazil	2573	3385	3859	5348	3333	4426	2913	4532	2848	4279	1.50
Costa Rica	788	908	871	958	935	996	1300	1956	2860	4113	1.44
China	1366	2481	1321	2151	2514	3202	3263	3863	2573	3690	1.43
Thailand	2331	2864	837	1059	1070	1812	1778	2570	2173	3406	1.57
South Africa	571	864	379	820	303	625	742	1276	861	1480	1.72
Nigeria	2256	1596	1758	915	1524	931	991	868	1075	1253	1.17
Indonesia	398	521	771	818	707	1001	356	417	476	733	1.54

Source: ITC. (1995)

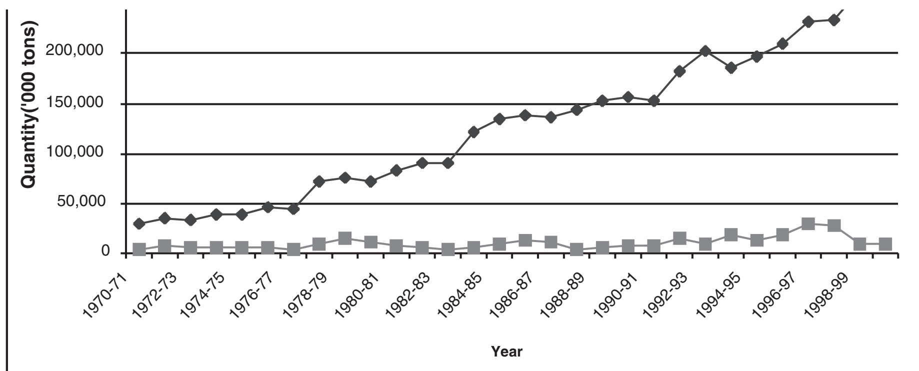


Figure 12.5 Trend in production and export of ginger from India.

- The physical volume of exports has increased by approximately 2.96% annually, whereas the annual growth in value terms works out to be approximately 10%. The annual growth in the unit price realization over this period works out to be around 6.9%.
- At a decadal disaggregated level, however, the performance of exports of ginger from India does not look encouraging. There is a steady decline in unit value realization from ginger exports. During the 1960s, the unit value realization grew at an annual rate of more than 19%, despite the fact that there was a negative growth in the physical volume of exports. The growth in the physical volume of exports picked up considerably during the 1970s, although at the

Table 12.11 Export of ginger from India (1970–2000)

Year	*Qty (tons)*	*Growth index*	*Value (Rs. in lakhs)*	*Growth index*	*Except as % to total production*
1970–71	3156	46.13	260.94	70.91	10.67
1971–72	6746	98.61	275.31	74.82	19.44
1972–73	6050	88.44	209.94	57.05	17.99
1973–74	5083	74.30	255.93	69.55	13.22
1974–75	4681	68.43	351.27	95.46	12.35
1975–76	4786	69.96	410.49	111.56	10.6
1976–77	4461	65.21	584.32	158.80	10.28
1977–78	9762	142.70	1368.99	372.04	13.62
1978–79	14515	212.18	1431.72	389.09	19.17
1979–80	11486	167.90	726.96	197.56	16.15
1980–81	6841	100.00	367.97	100.00	8.3
1981–82	5603	81.90	395.23	107.41	6.25
1982–83	4253	62.17	588.49	159.93	4.68
1983–84	6232	91.10	1190.16	323.44	5.14
1984–85	8857	129.47	1872.76	508.94	6.62
1985–86	13331	194.87	1089.35	296.04	9.66
1986–87	10361	151.45	571.16	155.22	7.62
1987–88	3926	57.39	488.99	132.89	2.75
1988–89	6368	93.09	940.82	255.68	4.15
1989–90	8135	118.92	1262.44	343.08	5.21
1990–91	6555	95.82	1175.79	319.53	4.27
1991–92	14259	208.43	2188.1	594.64	7.81
1992–93	9825	143.62	1687.37	458.56	4.87
1993–94	18442	269.58	2478.12	673.46	9.9
1994–95	12022	175.73	1673.03	454.66	6.08
1995–96	18483	270.18	3892.13	1057.73	8.81
1996–97	29737	434.69	5924.41	1610.03	12.79
1997–98	28268	413.21	7262.73	1973.73	12.1
1998–99	8683	126.93	4058.32	1102.89	3.3
1999–2000	8773	128.24	3060.15	831.63	3.33

cost of a decline in the growth in unit value realization. The 1980s witnessed a fall in the growth rate of both of these attributes. During the first half of the 1990s, however, we again observed a spurt in the growth of physical exports, accompanied by an almost stagnant unit value realization, in spite of considerable devaluation of the Indian rupee over this period (Table 12.12).

Export Instability: In order to estimate the observed instability in ginger exports in terms of quantity, value, and price, an instability analysis was done using the time series data, and the results are presented in Table 12.13. It can be observed from the table that there was instability in the case of volume, value and unit value of ginger exports and the instability was relatively higher in the case of volume (72.91%) compared to

Table 12.12 Average annual growth rates in Indian export performance in ginger (1960–1996)

Year	*Quantity*	*Value*	*Unit value*
1960–96	2.94	9.99	6.85
1960–70	−14.72	1.65	19.19
1970–80	12.40	21.97	8.51
1980–90	1.05	8.52	7.40
1990–96	16.09	16.96	0.75

Table 12.13 Instability indices (Coppock's instability index) of ginger exports (1970–2000)

SI No.	*Particulars*	*1970–71 to 1979–80*	*1980–81 to 1989–90*	*1990–91 to 1999–2000*	*1970–71 to 1999–2000*
1	Volume of ginger export	47.95	60.37	84.71	72.91
2	Value of ginger export	51.60	62.35	63.50	57.41
3	Unit value of ginger export	49.44	68.81	34.62	29.15

value (57.41%) and unit price (29.15%). The above instability index was a close approximation of the average year-to-year percentage variation adjusted for trend.

Composition of Indian Exports: As far as the itemwise export of ginger from India is concerned, there has been a marked improvement in recent years. More than half of the total export value is earned by dry ginger, which accounts for 30.16 percent in terms of quantity (Table 12.14). Fresh ginger, though, accounts for 66.65% of the total quantity exported; in terms of value, the percentage share is only 24.67. Ginger oil and oleoresin are the other products exported that have returned a high value. As in the case of reexporting countries, especially the EU countries, India has the potential to strengthen the processing industry to add more value-added products into its export basket

India exports a sizeable quantity of fresh ginger through the land custom stations in the northeastern states to Bangladesh. Although this export channel provides an opportunity to market the exportable surplus across the border at a reasonable price, whenever

Table 12.14 Contents of Indian Export basket (1990–91 to 1999–2000 Average)

Item	*Quantity (Mt)*	*Value (Rs. lakhs)*	*Unit price (Rs./kg)*	*% share in total* *Qty*	*Value*
Ginger, dry	4,587.80	2,182.58	48.92	30.16	51.76
Ginger, fresh	10,138.07	1,040.18	9.46	66.65	24.67
Ginger powder	418.32	209.46	48.08	2.75	4.97
Ginger oil	7.63	182.46	2,171.10	0.05	4.33
Ginger oleoresin	59.63	601.73	932.75	0.39	14.27
Total	15,211.45	4,216.41	30.12	100.00	100.00

Source: Spices Board, Cochin.

the price goes up, Bangladesh turns to a cheap supply from China and Indonesia. The same is the case with the other neighboring country, Pakistan (John, 2003).

Direction of Indian Exports: Until the end of 1980s, more than 30 percent of the Indian export of ginger was to Arabian countries, then from the 1990s onward, the share of Arabian countries in Indian exports, in general, has shown a decreasing trend, and India is finding a market in its neighboring countries of Pakistan and Bangladesh. However, these countries turn to other cheaper sources whenever the price goes up for Indian ginger. During 1991 to 1992, India exported more than 49% of its total ginger export to Pakistan. However, during 1999 to 2000, Pakistan's share in Indian exports of ginger declined to 33%, and during the same period, Bangladesh took an equal share with Pakistan (33%). During 1991 to 1992, Bangladesh imported hardly 7%, and its share increased to 33% by the end of the century. A sizeable quantity of ginger exported to Bangladesh is done so through major land custom stations in Mizoram (Table 12.15). Other main markets for Indian ginger are Saudi Arabia, the United Arab Emirates, Morocco, the United States, Yemen Republic, the United Kingdom, and the Netherlands. Figure 12.6A–C presents the direction of Indian ginger export in 1981 to 1982, 1991 to 1992, and 1999 to 2000, respectively.

To analyze the concentration of ginger exports to various countries both in terms of quantity and value of export markets, the Hirschman index was estimated and is presented in Table 12.16. Generally, the index number above 40% is considered to be high concentration. Here the estimated index for quantity is more than 40 during all the three periods indicating the higher concentration. In the case of value also, the index was more than 40% in the first period, and it was nearer to the 40% mark in the remaining two periods. This indicates that the country has a set of markets, which prefers Indian ginger.

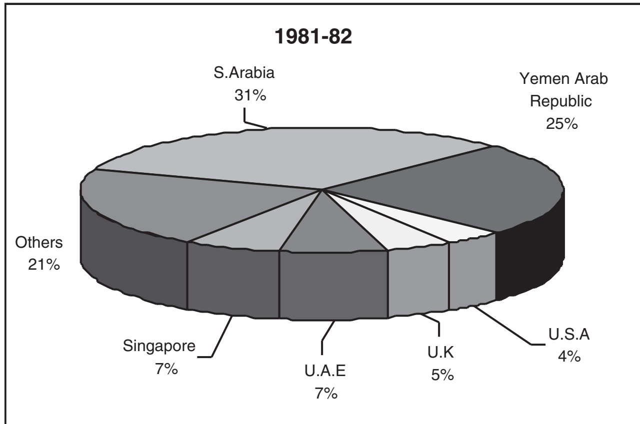
Export Promotion Programs: For export promotion of ginger, the Spices Board (Government of India) is implementing a number of programs (Spices Board, 2000). Some of them are:

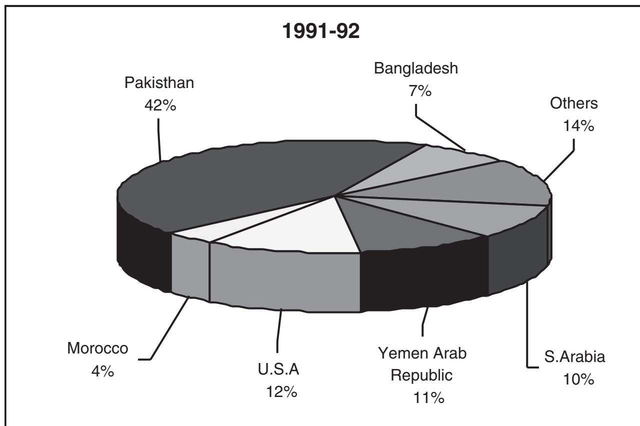
- Assistance for establishing improved cleaning and processing facilities
- Support for setting up of high-technological processing

Table 12.15 Ginger export through land custom stations to Bangladesh

SI No.	*Land custom station*	*Year*	*Quantity (Mt)*	*Value (Rs.)*	*Unit value (Rs./kg)*
1.	Karimganj	2001–02	1443.30	14128456	9.79
2.	Agartala	2001–02	258.60	2315528	8.95
Total			1701.90	15443984	9.37 (average)
1.	Karimganj	2002–03	3118.90	23558883	7.55
2.	Agartala	2002–03	505.00	4667019	9.24
Total			3623.90	28225900	8.40 (average)

Source: John (2003).





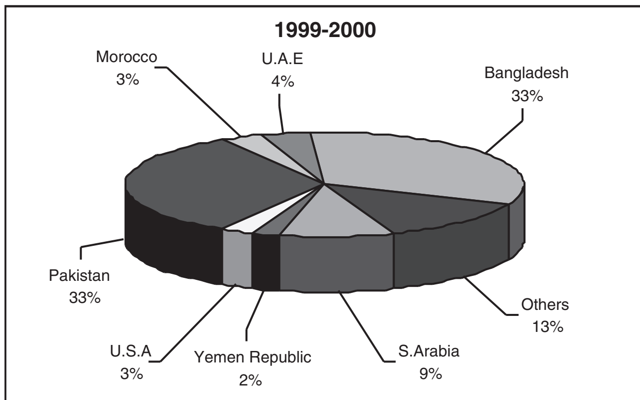


Figure 12.6 Direction of Indian exports of ginger

Table 12.16 Hirschman index—export

Period	*Particulars*	*Quantity*	*Value*
1981–82	Volume of ginger export	44.35	45.47
1991–92	Value of ginger export	48.52	38.63
1999–2000	Unit value of ginger export	48.42	36.87

- Assistance for establishing and strengthening in-house quality laboratories for testing various quality parameters
- Assistance for new product/end-use development
- Assistance for improved packaging
- Assistance for undertaking sale promotional tours and participation in international fairs
- Support for promoting branded consumer-packed ginger in identified markets abroad
- Support for organic certification for processing of ginger derivatives

Imports

In fact in the international market major importers of ginger are the United States, Japan, and the United Kingdom, where an increase in imports in terms of volume and value has been recorded over the years. These countries are importing mainly from China and Thailand (ITC, 1995).

Japan accounted for the major share (58.74%) of imported ginger during 1995, followed by the United States (9.93%), Hong Kong (7.62%), Singapore (5.16%), Saudi Arabia (4.37%), the United Kingdom (4.36%), Canada (2.39%), the Netherlands (1.93%), Germany (1.25), Malaysia (0.78%), and the rest by others including India (Table 12.17). The trend in import of ginger among the countries has remained the same with little change until 2000. During 2000, Japan accounted for a 57.68% share

Table 12.17 Ginger imports by major importing countries (1995 and 2000) (Q: tons, V: US $'000)

	1995			*2000*		
Country	*Qty*	*%*	*Value*	*Qty*	*%*	*Value*
Japan	83,274	58.74	76,985	104,342	57.68	76,938
United States	14,081	9.93	16,430	18,380	10.16	18,792
Saudi Arabia	6,189	4.37	4,449	8,106	4.48	4,566
United Kingdom	6,174	4.36	8,135	9,614	5.31	12,480
Malaysia	1,108	0.78	756	7,627	4.22	3,648
Canada	3,388	2.39	4,183	4,572	2.53	4,876
Netherlands	2,742	1.93	3,602	6,662	3.68	7,089
Singapore	7,314	5.16	4,850	7,564	4.18	4,237
Germany	1,769	1.25	3,075	2,172	1.20	3,696
Hong Kong	10,806	7.62	5,896	908	0.50	673
Others	4,915	3.47	5,492	1,0957	6.06	7,396
TOTAL	141,760	100	133,853	180,904	100.00	14,4391

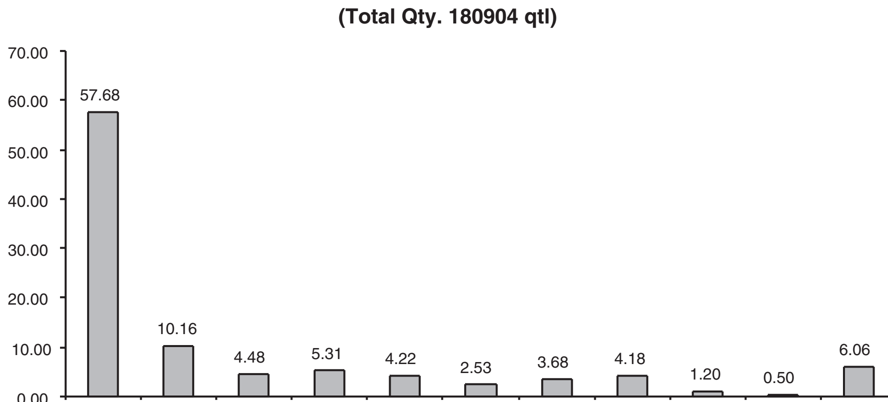


Figure 12.7 Share of importing countries in international ginger market (2000). Order of countries as in Table 12.17.

followed by the United States (10.16%), the United Kingdom (5.31%), Saudi Arabia (4.48%), Malaysia (4.22%), Singapore (4.18%), the Netherlands (3.68%), Canada (2.53%), Germany (1.20%), and Hong Kong (0.50%). In Figure 12.7, ginger imports by various countries are depicted in graphical form for the year 2000 indicating more or less the same situation after 5 years.

Japan, one of the major importers of ginger in the world, imports more than half of its requirement from China (Table 12.18). Thailand exports most preferred fresh ginger in large quantities to Japan. Japan's imports from India mainly constitute dry ginger. In recent years, the Spices Board has taken initiatives to study the Japanese market to increase India's share in that country's imports.

U.S. Imports of Ginger

In the United States, fresh ginger dominates the import market while dried ginger accounts for only a fraction of the government's unground total import. Ginger import increased over 50 percent in import tonnage in 1999 and gained another 14 percent in the year 2000. Since dried ginger is most heavily used in processed foods, its increasing

Table 12.18 Ginger imports by Japan (1994–1998) average, qty. = tons, value = US $'000

Country	*Qty*	*Value*	*Unit value*	*Qty*	*Value*
China	45,089.6	49,643.8	1.1068	56.5	55.9
Thailand	27,549.6	24,802.6	0.90244	34.5	27.9
Taiwan	3,753.6	11,308	3.06371	4.7	12.7
India	213.8	400.6	1.94193	0.3	0.5
Vietnam	1,114.4	827.4	0.71068	1.4	0.9
Indonesia	1,914.2	1,577.8	0.72868	2.4	1.8
Australia	79.8	120.6	1.51128	0.1	0.1
TOTAL	79,790.4	8,8851	1.10773	100.0	100.0

imports are undoubtedly a reflection of the growing numbers of Asian-inspired products being brought to the supermarket shelves today. Asian cooks have taught the rest of the world that ginger is not only for baking and beverages, it is also excellent with meats, poultry, fish, and vegetables. Mainland China, India, and Nigeria, in that order, are the main sources of dried ginger. Jamaican ginger also has its main market in the United States.

Although the available statistics (USDA/FAS, 1998, 1999) do not differentiate between fresh and dried ginger clearly, the figures in Table 12.19 give an indication about the quantity of imports and their origin. Value-added ginger products such as candied ginger

Table 12.19 Imports of ginger (itemwise) by the United States during 1998 (Qty in kg and value in US $)

	Ginger, unground		*Ginger, ground*		*Ginger, sweet*		*Ginger, candied*	
Countries	*Qty*	*Value*	*Qty*	*Value*	*Qty*	*Value*	*Qty*	*Value*
Australia	0	0	0	0	5675	21804	352315	1507713
Brazil	3520415	3424284	0	0	0	0	0	0
Canada	871	2400	0	0	75866	70594	0	0
China	2361380	2545324	35078	45827	96457	187628	56367	127079
Costa Rica	3091078	2044889	33771	52416	16680	16800	0	0
Dominican Republic	4121	3400	0	0	0	0	0	0
Ecuador	104746	65879	0	0	0	0	0	0
Germany	0	0	50	3294	0	0	0	0
Greece	0	0	0	00	0	0	0	0
Guatemala	388311	177426	0	0	0	0	0	0
Honduras	349023	229187	0	0	0	0	0	
Hong Kong	27575	34932	1531	4555	55444	152630	4563	8302
India	1150519	1639468	165732	379930	13678	19547	0	0
Indonesia	26833	41360	0	0	0	0	37061	117140
Italy	2896	21000						
Jamaica	6037	32047	0	0	0	0	0	0
Japan	14554	30463	10000	26563	20	2434	0	0
Korea Republic of	0	0	0	0	0	0	0	0
Leeward-Windward Islands	0	0	0	0	0	0	0	0
Malaysia	2813	10232	0	0	0	0	0	0
Nicaragua	119394	67278	0	0	0	0	0	0
Nigeria	664610	799444	0	0	0	0	0	0
Other Pacific Islands: NEC	393408	513229	0	0	0	0	0	0
Singapore	0	0	0	0	2139	6530	7749	21130
South Africa	2840	11806	0	0	0	0	0	
Taiwan	11874	26940	0	0	12791	60863	0	0
Thailand	1514935	1529921	3439	12184	483971	533908	222077	465148
United Kingdom	0	0	0	0	22570	72923	0	0
Vietnam	0	0	0	0	0	0	2828	3570
Western Samoa	0	0	0	0	0	0	0	0
Other	22500	79429	5658	21669	38400	91632	2932	9706
TOTAL	13777837	13309338	258155	567438	823691	1237293	685892	2259788

is only imported from a few countries, such as Australia, China, and Thailand, whereas the unground ginger, which includes fresh ginger, is being imported from more than 20 countries

Indian Import of Ginger

A sizeable quantity of ginger is imported into India, mainly in the green form. The major imports in the fresh form are from Nepal, whereas dried ginger is imported from China and Nigeria. The quantity imported and their values are given in Table 12.20.

Market Opportunities

According to an ITC market development paper (1995), consumption of spices is likely to increase due to an augmented production of high-flavored food by the food industry. In addition, an increasing interest in health food and, consequently, "natural" instead of "artificially" flavored food, will also increase the consumption of spices.

Dry Ginger: There is a place for newcomers in the market. A development noted in the trade of ginger has been the increasing use of oils and oleoresins and powdered and processed ginger in major importing countries, especially in Europe and the United States. Ginger exports for the manufacture of powdered ginger must be fiber free, whereas the products exported for the manufacture of ginger oil and oleoresins should have a high oil content. Export efforts should be based on increased productivity and improved postharvest technology.

Fresh Ginger: There may be some prospects for a moderate increase in international trade in fresh ginger, mainly for the ethnic market, especially Asian communities.

Preserved Ginger: Japan will continue to be the largest market, but some growth is also expected in other countries in Western Europe as well as in the United States. In general, however, the prospects for preserved ginger remain modest.

Competitiveness of Indian Ginger Industry

In order to understand the position and competitiveness of individual exporters in the world trade of ginger, market shares and unit value ratios were calculated and are presented in Table 12.21. In the absence of time series data on prices for individual products from various countries, the unit price was worked out from the value of the export and quantity exported. While calculating the unit price, individual items of

Table 12.20 Item-wise imports of ginger into India during 1995–2000 (Qty: Metric tons, Value: Rs. lakhs)

	1995–1996		*1996–1997*		*1997–1998*		*1998–1999*		*1999–2000*	
Item	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*
Ginger, dry	782.62	218.55	133.98	64.67	247.39	106.19	542.30	291.42	4695.01	1198.47
Ginger, fresh	6682.21	429.03	9277.76	580.71	11185.43	703.10	9727.21	614.76	7164.17	688.72
Ginger powder	—	—	—	—	—	—	neg	0.03	13.00	6.44

Table 12.21 Unit–price ratio for various exporting countries (1994–98)

Countries	*1994*	*1995*	*1996*	*1997*	*1998*	*1994–1998*
China	0.90	0.83	1.17	1.03	0.94	0.96
Thailand	0.87	1.06	0.91	0.82	0.73	0.86
Indonesia	0.54	0.51	0.43	0.62	0.48	0.53
Brazil	1.61	1.64	1.11	1.26	1.36	1.35
Taiwan	3.18	3.83	2.00	2.43	3.21	2.76
Costa Rica	1.19	1.33	0.89	1.01	1.10	1.10
India	1.23	2.07	1.06	1.20	1.80	1.40
Nigeria	0.74	0.97	0.85	1.16	1.36	1.06
Vietnam	0.50	0.67	0.57	0.89	0.56	0.66
Malaysia	0.35	0.43	0.32	0.37	0.38	0.36
United States	1.99	1.96	0.86	1.04	1.45	1.29
Others	1.77	1.53	0.96	1.12	1.65	1.33

export were not taken into account. So there is bound to be a slight variation depending upon the share of value-added products in the export basket of individual countries. However, the estimated unit value ratios help in comparing the prices of each exporting country with another and with the average of total imports. The ratio is computed by dividing the price received for a country's export by the world average price. When the unit–price ratio is less than 1, then it is considered that the country possesses competitiveness in the export market for its product. Accordingly, as it can be observed from Table 12.21, countries such as Indonesia, China, Thailand, Vietnam, and Malaysia with their unit–price ratio less than 1 are highly competitive, whereas India with an average unit–price ratio of 1.40 is considered to be less competitive in the world market.

Any country's competitive power in exporting a commodity depends crucially on its relative price and the quality of that commodity over the competing countries. India has a weak competitive position in the international market for ginger, which is mainly because of very low productivity of 3,357 kg/ha against 55,636 kg/ha in the United States and an average world productivity of 10,179 kg/ha (FAO, Rome). Moreover, the increased cost of production due to less productivity of Indian ginger compared to that of other producing countries makes it imperative for India to increase productivity, which alone can reduce the cost of production. The country has enough potential to increase its productivity, as it is shown in Figure 12.8. To be successful in the changing environment, it would be essential to be innovative and proactive. India, being the major producer of ginger in the world, stands seventh when we look toward the performance of other exporting countries.

The gross margin is a good measure for comparing the economic and productive efficiency of similar sized farms. More importantly, it represents the bare minimum that a farm must generate in order to stay in business. The cost–benefit ratio worked out for ginger production in the United States was 1.34. Productivity achieved on the ginger farms of Hawaii ranged from 50,000 lbs/acre to a low of 27,500. The reported average returns for the farm with a productivity of 46,200 pounds depends not only on the yield but also the price.

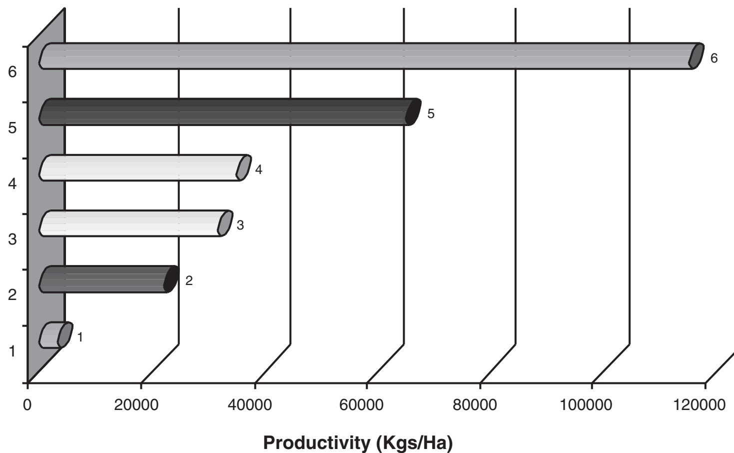


Figure 12.8 Productivity gap for ginger in India. 1. National average (3,391 kg/ha). 2. Productivity level of elite farmers (20,000 kg/ha). 3. Productivity reported from research farm (22,200 kg/ha). 4. State level highest productivity (35,000 kg/ha). 5. Highest productivity reported in farmer's field (65,000 kg/ha)—Shimoga, Karnataka. 6. Highest productivity achieved in the world (115,104 kg/ha)—China.

Risk and Uncertainty

Risk is inherent in all of agriculture, but the ginger industry appears to be more exposed to risk than many other agricultural endeavors (Fleming and Sato, 1998). A review by the Hawaii Agricultural Statistics Services (HASS) reveals considerable volatility in ginger price and yield, with relatively little correlation between the two variables. In addition to abruptly fluctuating prices, ginger is relatively susceptible to serious disease problems, providing an ever-present possibility for a disease problem sharply to reduce yields (Nishina et al. 1992). A sustainable ginger economy is possible only when these risks are minimized.

Along with price risk, cash flow implications are the perceived crop risk for a crop such as ginger. This is related to age to first bearing and longevity of the crop. Production and marketing risks are greater the longer the crop takes to bear and the greater the life of the crop. The length of the harvest period also has its risks; the longer the period, the greater the risk of failure. Vinning (1990), in an Australian Centre for International Agricultural Research (AICIAR) technical report for marketing perspectives on a "Potential Pacific Spice Industry," has given crop risk ratings for various spice crops based on the above points. It was found that ginger topped the list as a high-risk commodity, followed by vanilla.

The ginger industry is facing risk and uncertainty in different forms. Each country has to face considerable competition from other ginger-producing countries because many new countries have entered into the industry in recent years. Over the years, India has lost her market to China and Indonesia, mainly because of the price factor. From the Indian farmers' point of view, the prices have been generally good during the past 10 years, although there was a drastic fall in the 1996 to 1997 and 2001 to 2002 crop years. During 1999 to 2000, ginger farmers received an all-time high price, which was more than double the price in the previous crop year. The price was always above the breakeven point, with an average of Rs.8.80/kg for fresh ginger in the northeastern

states, where fresh ginger is marketed, thus leading to profitable ginger farming. The price for dry ginger was well below the breakeven point in the 1980s and in the early 1990s as well. During 1982 to 1984 and 1993 to 1995, the price almost doubled. In addition to this abrupt fluctuation in price, the ginger crop is also highly susceptible to serious disease problems leading to a reduction in yield and an unmarketable production. At times, the farmer may lose up to 80% of the crop toward the end of the crop cycle. Thus, the ginger crop industry is influenced by the risk factors of yield and price, although they are not related as per the analysis of long-term data. However, the analysis of variance indicates that the price variability of ginger is greater than the yield variability.

Prospects and Policy Measures

1. India, being the major producer of ginger, accounts for 33% of the total share in production but contributes hardly 1.17% to the world market with enough surplus to export.
2. There is a definite pattern of cyclical fluctuation in production, mainly due to the producers' response to price. Price stabilization measures can boost production further.
3. During the 1980s, Saudi Arabia was the major market for Indian ginger with an export of 31% of its total export. In the changed scenario of the 1990s and 2000, Pakistan and Bangladesh were the major markets.

While considering policy measures to strengthen the ginger economy of the country, it is imperative to undertake action plans at disaggregated levels—the regional level to begin with, followed by the handling of national issues. Following are the suggested policy measures to overcome the constraints faced by the ginger farming industry in India:

1. Healthy seed production through the "seed village concept" by regular field monitoring and development of seed certification procedures
2. Impose quarantine regulations to restrict seed transportation from one state to the other, especially where bacterial wilt is a major problem
3. An integrated approach to control a serious problem in ginger cultivation, rhizome rot; which is complicated by insect, bacterial, and fungal attack, is the need of the hour.

   The above measures can ensure disease-free seed material to the farming community and will reduce the crop risk due to disease and heavy postharvest losses at the farm level.
4. The higher fiber content in Indian ginger compared to that of its competing countries and the higher cost of production in India seem to act as deterrents in increasing our export trade. Hence, there is an urgent need to evolve high-yielding, disease-resistant cultivars with lower fiber but richer volatile oil and oleoresin contents.

   Varieties with the above quality parameters are already available from research organizations in India, and there is a need for adequate extension activities to allow the technology to reach farmers' fields.

5. Another aspect where a major thrust has been wanting is to develop cropping systems with ginger as a component, although it could be grown as a intercrop in coconut and arecanut plantations, we are yet to develop ideal systems with attention to a cost:benefit factor, soil disturbance, the shade and root effect, and other factors.
   An issue related to the above point is that treating ginger as an agricultural commodity while in its raw form and as a spice when dried is creating certain logistical problems in realizing the fullest potential of ginger in the world market. An effort should be made to solve this definitional ambiguity and due consideration should be given as in other spice commodities.
6. With sweeping changes occurring in the standard of life, life style, and consumption patterns in the buying countries, and with the focus being shifted toward value addition and branded consumer packs, the market development activities need to be geared up.
7. Since importing countries show a definite preference to an uncontaminated and clean product, there is a need for collective efforts on the part of the farmers, traders, and exporters to upgrade the quality of ginger through improved preharvesting practices, postharvest handling, processing and packaging, and storage to keep up with the grade specifications, pesticide residues, aflatoxin level, and microbial load.
8. Indian farmers need to be educated and trained to stand up effectively to the challenges. The need to adopt measures to be more competitive in terms of both quality and productivity assumes greater significance in view of the opening up of the agricultural sector and lowering of agricultural tariffs in accordance with World Trade Organization (WTO).
9. Since a high-value product line is emerging through organic farming, efforts should be made to popularize organic farming in ginger, so that it fetches a high demand in foreign markets.
10. One should not get the feeling that by value addition we just mean production of ginger derivatives alone. One EU document reveals that in the export market, "buyers are looking for clean, well flavored, artificially dried product with high hygiene levels, in contrast to the bulk of the materials which has been sun dried on the ground" (Commonwealth Secretariat, 1996, p. 45).

For the successful implementation of above the policy related-suggestions, there is a need to develop a special database regarding all aspects of ginger-based activities such as marketing, employment potential, production techniques, cost of cultivation, and value addition. This, in turn, will help in creating decision support systems to benefit the stakeholders.

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13 Pharmacology of Ginger

Ikuko Kimura, Leonara R. Pancho, and Hiroshi Tsuneki

Ginger rhizomes have been widely used as a cooking spice and herbal remedy to treat a variety of conditions. Fresh and dried gingers are used for different clinical purposes in traditional Chinese medicine (*Kampo*). Fresh ginger (*Zingiberis Recens Rhizoma*; *Sheng Jiang* in Chinese; *Shoga* in Japanese) is used as antiemetic, antitussive, or expectorant, and is used to induce perspiration and dispel cold, whereas dried ginger (*Zingiberis Rhizoma*; *Gan Jiang* in Chinese) is used for stomachache, vomiting, and diarrhea accompanied by cold extremities and faint pulse (Bensky and Gamble, 1986). Dried ginger, either simply dried in the shade (*Gan Sheng Jiang,* or simply *Gan Jiang* in Chinese; *Shokyo* in Japanese) or processed ones that are heated in pans or with hot sand (*Rhizoma Zingiberis Preparata: Pao Jiang* in Chinese) are often used in China. The simply dried ginger and the processed ginger are not clearly differentiated in clinical use. On the other hand, different types of dried gingers have been used in traditional Japanese medicine, such as dried ginger (*Shokyo* in Japanese, as shown above) and steamed and dried ginger (*Zingiberis Siccatum Rhizoma*; *Kankyo* in Japanese). Steamed and dried ginger is rarely used in traditional Chinese medicine. Here we describe the "simply dried ginger" as "dried ginger" (*Shokyo*), and the "steamed and dried ginger" as "steamed ginger" (*Kankyo*). Gingerols and shogaols are identified as the main components of dried ginger (*Shokyo*) and steamed ginger (*Kankyo*), respectively (Aburada, 1987). However, before we conducted this study, little was known about the scientific reasons why *Shokyo* and *Kankyo* are used for different clinical purposes.

The juice from freshly squeezed ginger (contains gingerols) has been reported to be hypoglycemic in diabetic rats (Sharma and Shukla, 1977). The diabetic state alters the microvascular function (Vandana and Brecher, 1987) and affects the synthesis of prostacyclin, thromboxane, and leukotrienes (Jeremey et al., 1983; Rosenblum and Hirsh, 1984). Similarly, the gingerols have been reported to inhibit both cyclooxygenase and lipoxygenase and to diminish the production of prostaglandins and leukotrienes (Kiuchi et al., 1992). The chemical structures of gingerols are similar in part to those of prostaglandins.

The therapeutic application of gingerol in the diabetic state (i.e., gingerol lowers the blood glucose level) is an area of interest. In this chapter the major focus is on the effects of gingerols on the eicosanoid-induced contraction in isolated mice mesenteric veins because the mesenteric veins control the blood flow from the liver to the digestive area. The study includes the investigations on the relation of the chemical structures of gingerol and related analogues in the modulation of prostaglandin (PG)$F_{2\alpha}$-induced contractions, the modulation of other eicosanoid-induced contractions by gingerols, and the possible mechanisms involved in the potentiation of $PGF_{2\alpha}$-induced contractions by gingerol in isolated blood vessels.

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The new insight into the role of gingerols as a modulator of eicosanoid responses in vascular smooth muscles will be useful in clinically evaluating the effects of ginger (or its active components) on vascular smooth muscles. The results of such studies will provide an area of investigation for the development of novel therapeutics.

Differences Between Dried Ginger (*Shokyo*) and Steamed Ginger (*Kankyo*)

Properties

Fresh ginger occurs in compressed tuberous pieces, 4 to 10 cm long and 1 to 2 cm thick, externally yellowish brown, with distinct nodes and internodes. The texture is fibrous with a juice extravasate when broken. The rhizomes have an aromatic odor and characteristic pungent taste (Lou et al., 1982).

Dried ginger (*Shokyo*) occurs in compressed tuberous pieces, 3 to 6 cm long, externally it is grayish yellow. The texture is rigid. The rhizomes have an aromatic odor and characteristic pungent taste (Lou et al., 1982). To prepare dried ginger, the skin from rhizomes of raw ginger are peeled off, sprinkled with lime water and the rhizomes are dried in the shade. Dried ginger is formulated in various traditional medicines in Japan, China, and India (Figure 13.1).

Steamed ginger (*Kankyo*) occurs in flattened pieces with finger-like branches, 3 to 6 cm long (see Figure 13.1). Externally it is grayish brown or pale grayish brown and rough with longitudinal wrinkles. The texture is compact. The rhizomes have an aromatic odor

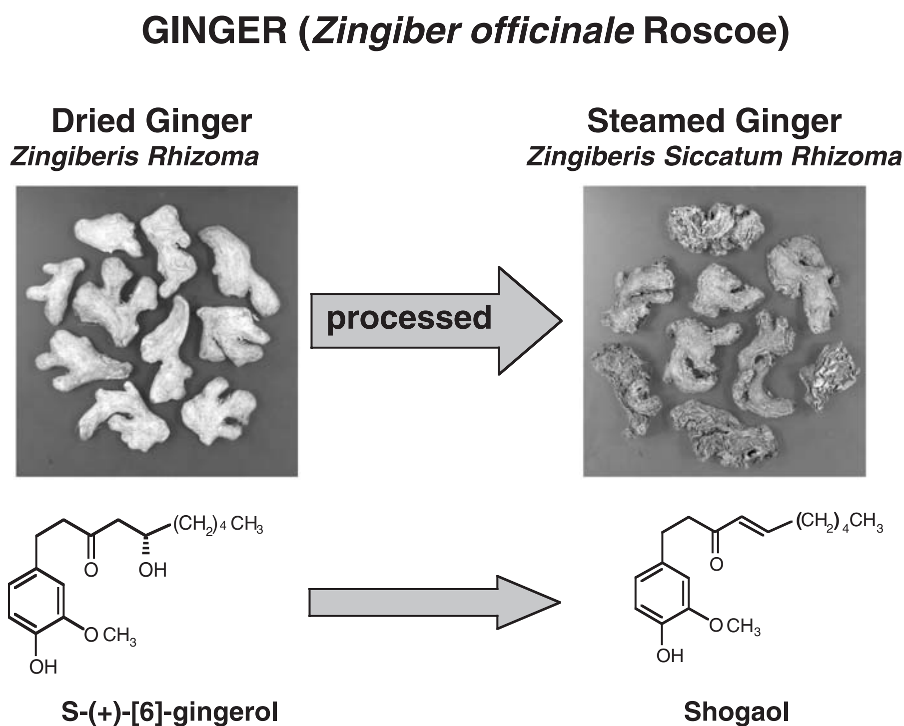

Figure 13.1 Components of dried ginger *(Shokyo)* and steamed ginger *(Kankyo)*.

and characteristic pungent taste. To prepare steamed ginger, the rhizomes of raw ginger are peeled off the skin, steamed, and then dried under heat.

Active Components

Besides starch, protein, and lipids, ginger contains active chemical constituents—volatile oil (zingeberene, curcumene, borneol, neral, geranial, geraniol, citronyl acetate, α-terpineol, and linalool), pungent compounds (gingerols and shogaols), and minor components related to gingerols (gingediols, gingediacetates, paradol, and hexahydrocurcumin) (Mustafa et al., 1993).

(6)-Gingerol and shogaol are the main pungent constituents of dried and steamed ginger, respectively (see Figure 13.1). Dried ginger contains 0.6 to 1.1 percent w/w *S*-(+)-(6)-gingerol and 0.05 to 0.1 percent w/w shogaol, whereas steamed ginger contains 0.2 to 0.7 percent w/w *S*-(+)-(6)-gingerol and 0.3 to 0.7 percent w/w shogaol. Gingerols are chemically unstable and heat sensitive. The amount of *S*-(+)-(6)-gingerol equalizes to that of shogaol when ginger has been processed (steamed and dried) for 12 hours (Kano, 1987). During the processing, the amount of shogaol increases, whereas that of (6)-gingerol decreases as a result of dehydration of gingerols (Aburada, 1987).

Use in Traditional Medicine

Fresh ginger is used to induce perspiration and dispel cold, to warm the stomach and stop vomiting, and to resolve phlegm and relieve cough with expectoration of whitish thin sputum (Tu, 1992). Dried ginger is used for epigastric pain with a cold feeling, for vomiting and diarrhea accompanied by cold extremities and faint pulse, to warm the lung and resolve phlegm retention, for cough and dyspnea with copious frothy expectoration, for abnormal uterine bleeding, for spitting blood, and to keep the blood circulating within the vessels (Tu, 1992).

Pharmacological Studies on Ginger Extract and Active Components

Fresh and Dried Ginger Extracts

In vitro studies have demonstrated that an aqueous extract of fresh ginger inhibits the activities of cyclooxygenase; as a result, it inhibits arachidonic acid metabolism and platelet aggregation (Srivastava, 1984). In vivo animal studies have demonstrated that an acetone extract of fresh ginger prevents vomiting in *Suncus murmunus*. Oral administration of the acetone extract of dried ginger also promotes gastrointestinal motility in rats (Mustafa et al., 1993). In addition, the juice of fresh ginger showed a hypoglycemic effect in diabetic rats (Sharma and Shukla, 1977). The pharmacological effect of ginger also has been reported in clinical studies: The powdered rhizome of dried ginger reduced the tendency of vomiting and cold sweating significantly better than placebo did in motion sickness (Grøntved et al., 1988). In a Danish study, blood thromboxane B_2 levels were lowered after consumption of fresh ginger, an effect which must be due to inhibition of cyclooxygenase by the active components of fresh ginger (Mustafa et al., 1993). Moreover, dried ginger is described to be useful in rheumatoid arthritis because more than 75 percent of the arthritis patients who consumed powder of ginger rhizome experienced relief of pain and reduction in joint swelling (Mustafa et al., 1993). One of the mechanisms by which the dried ginger elicits an ameliorative action against the inflammatory disease may be related to the inhibition of prostaglandin biosynthesis.

Active Components

Gingerols have been found to be potent inhibitors of prostaglandin biosynthesis (Kiuchi et al., 1992) and show potent positive inotropic effects on isolated atria of guinea pigs (Shoji et al., 1982). Shogaol inhibits carrageenin-induced paw edema in rats by inhibiting the cyclooxygenase activity (Suekawa et al., 1986). Gingerols and shogaols inhibit gastric contractions in situ (Suekawa et al., 1984), show significant antihepatotoxic actions in primary cultured rat hepatocytes (Hikino et al., 1985), and exert an antiemetic action through the central nervous system (Kawai et al., 1994).

Effects of Ginger Extracts and Active Components on $PGF_{2\alpha}$-Induced Contractions in Mice Mesenteric Veins

The methanol extract of dried ginger (10 μg/ml), *S*-(+)-(6)-gingerol (9 to 90 μg/ml and (±)-(6)-gingerol (30 to 90 μg/ml) significantly potentiated the contractile response to $PGF_{2\alpha}$ and decreased the EC_{50} (50 percent effective concentration) values. The ginger extract was more potent than the gingerol compounds on the percent maximal contraction induced by $PGF_{2\alpha}$. *S*-(+)-(6)-gingerol was more potent than (±)-(6)-gingerol. On the other hand, dried ginger extract (10 μg/ml) and shogaol (8 μg/ml) similarly inhibited the $PGF_{2\alpha}$-induced contraction (Table 13.1).

Table 13.1 Effects of ginger extracts and active components on the contractions induced by $PGF_{2\alpha}$ in mice mesenteric veins

		Prostaglandin $F_{2\alpha}$		
Compounds	*Concentration mM (μg/mL)*	*EC50[a] (95% confidence limits; μM)*		*Percent maximal contraction[b]*
	0	13 (11–14)		100
Dried ginger methanol extract	(10)	6.1 (4.9–7.4)		134 ± 2**[c]
S-(+)-[6]-Gingerol	0.01 (3)	8.5 (7.5–9.8)	d*	108 ± 2
	0.03 (9)	5.4 (4.5–6.4)		123 ± 4**
	0.1 (30)	5.1 (4.3–6.1)		125 ± 3**
	0.3 (90)	3.9 (3.3–4.7)	d*	135 ± 5**
(±)-[6]-Gingerol	0.1 (30)	6.8 (5.7–8.2)		112 ± 3**
	0.3 (90)	5.6 (4.9–6.2)		128 ± 3**
Steamed ginger extract	(10)	45 (27–75)		77 ± 6*[c]
Shogaol	0.03 (8)	59 (48–72)		81 ± 4**
	0.1 (40)	132 (97–177)		65 ± 5**

Note: EC50, fifty percent effective concentration
The contraction induced by $PGF_{2\alpha}$ (0.3 μM to 0.3 mM) without the above compounds was used as the control and the values are expressed as the concentrations inducing 50 percent response with confidence limits. All EC_{50} values were significantly different from the control at $P < .01$; determined by unpaired *t*-test.
[b]The contraction induced by $PGF_{2\alpha}$ (0.3 mM) without the above compounds was used as the control (100%). The values are expressed as mean percentages ± SEM.
(n = 3–5). Significant differences from the control were determined by two-tailed *t*-test ([c]paired, [d]unpaired) at $*P < .05$ and $**P < .01$.
Source: Pancho et al. (1989).

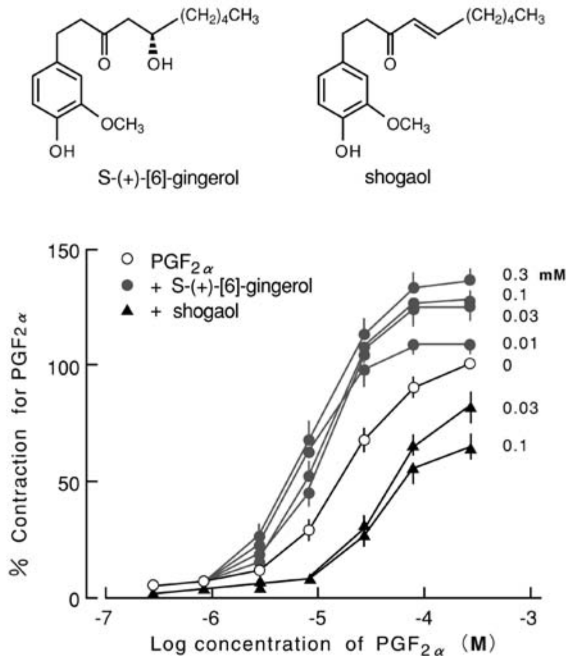

Figure 13.2 Chemical structures of *S*-(+)-(6)-gingerol and shogaol and cumulative concentration curves for $PGF_{2\alpha}$ before (◦) and after the addition of different concentrations of *S*-(+)-(6)-gingerol (•) or shogaol (▲).The values are the mean percentages ± SEM (n = 4 − 27). Significant differences from the control values (without gingerol or shogaol) were determined by *t*-test at $*P < .05$ and $**P < .01$. (From Pancho et al., 1989.)

Increasing concentrations of $PGF_{2\alpha}$ (0.3 μM to 0.3 mM) induced concentration-dependent contractions in mice mesenteric veins. The contractile response to $PGF_{2\alpha}$ was significantly enhanced by S-(+)-(6)-gingerol (0.01 to 0.3 mM) and inhibited by shogaol (0.03 to 0.1 mM) in a concentration-dependent manner (Figure 13.2).

(±)-(6)-Gingerol (0.3 mM), (±)-(8)-gingerol (0.1 mM) and (±)-hexahydrocurcumine (0.3 mM) significantly potentiated the $PGF_{2\alpha}$-induced contractions in mice mesenteric veins. In contrast, shogaol (0.1 mM) and (6)-gingerdione (0.3 mM) markedly inhibited the $PGF_{2\alpha}$ contractile response. Furthermore, (6)-dehydrogingerdione (0.3 mM) and *S*-(+)-(6)-gingerdiacetate (0.3 mM) had no significant effect. The potentiation effect recovered completely after 30 minutes, although it took 1.5 hours to recover the inhibitory action (Figure 13.3 and Table 13.2).

Different Effects of (6)-Gingerdione in Aqueous Solution on $PGF_{2\alpha}$-Induced Contractions

Among the gingerols tested, (6)-gingerdione showed different effects on $PGF_{2\alpha}$-induced contractions when its aqueous solution was allowed to stand for several hours at room temperature (27°C). As shown in Table 13.3, (6)-gingerdione just after preparation of the solution significantly inhibited the $PGF_{2\alpha}$-induced contraction, after 22 hours of

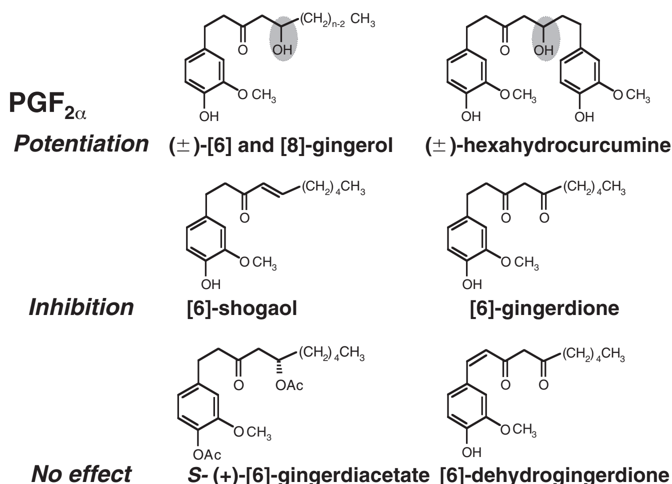

Figure 13.3 Chemical structures of gingerols and related compounds and their effects on $PGF_{2\alpha}$-induced contractions in mice mesenteric veins. n = 6 and 8 for (±)-(6)-gingerol and (±)-(8)-gingerol, respectively.

Table 13.2 Effects of gingerol analogues on $PGF_{2\alpha}$-induced contractions

Compounds (mM)	*$PGF_{2\alpha}$ (0.28 mM)% Contraction*
(±)-(6)-Gingerol (0.3)	128 ± 3**
(±)-(8)-Gingerol (0.1)	115 ± 2**
(±)-Hexahydrocurcumine (0.3)	109 ± 3*
Shogaol (0.1)	65 ± 5**
(6)-Gingerdione (0.3)	29 ± 3**
(6)-Dehydrogingerdione (0.3)	102 ± 3
S-(+)-(6)-Gingerdiacetate (0.3)	103 ± 1

Note: The contraction induced by $PGF_{2\alpha}$ in the absence of gingerol derivatives was taken as control = 100 percent. The values are the mean percentages ± SEM (n = 3–5). Significant differences from the control values were determined by paired *t*-test at $*P < .05$ and $**P < .01$.
Source: Kimura et al. (1989c).

Table 13.3 Different effects of (6)-gingerdione in aqueous solution on prostaglandin-induced contractions

	% Contraction		
Compounds (mM)	0	2 hours	5 hours
(6)-Gingerdione (0.3) + $PGF_{2\alpha}$ (0.28)	29 ± 3**	102 ± 2	124 ± 2**

Note: The contraction induced by $PGF_{2\alpha}$ without (6)-gingerdione was taken as control = 100 percent. The values are the mean percentages ± SEM (n = 5). Significant differences from the control values were determined by paired *t*-test at $**P < .01$.
Source: Kimura et al. (1989c).

incubation, it produced no marked effect, but after 5 hours of incubation, significant potentiation of $PGF_{2\alpha}$-induced contractions was observed.

To elucidate the correlations between the time-dependent effects and the change in the chemical structure of (6)-gingerdione, ferric chloride tests were performed, at first, to detect enol moiety. When the alcoholic solutions of benzoylacetone (0.15 μM), (±)-(6)-gingerol (1.5 μM), and (6)-gingerdione (1.5 μM) were treated with an aqueous solution of ferric chloride (0.19 μM), benzoylacetone and (6)-gingerdione showed positive results for the presence of enol as indicated by the change in color of the solution (i.e., from colorless to red), whereas (±)-(6)-gingerol was negative.

Next, the pattern of ultraviolet (UV) absorption of these compounds was studied. The spectra for benzoylacetone (75 nM) showed maximum absorption bands at 250 and 310 nm. Similarly with (6)-gingerdione (1.5 μM), the absorption maxima obtained were at 235 nm and 280 nm. The same intensity of absorption was observed. Only one spectral band was noted with (±)-(6)-gingerol (1.5 μM) at a maximum of 245 nm.

The UV absorption spectra of (6)-gingerdione (0.3 μM) in 10 percent ethanol under the same experimental conditions (i.e., incubation at 27°C) for different time intervals were compared (Figure 13.4). The measured absorbance at 235 μn decreased after several hours, whereas the absorbance at 280 nm increased.

Furthermore, the chemical structures of these compounds were studied using nuclear magnetic resonance (NMR). The ^{1}H-NMR spectra ($CDCl_3$, δ ppm) of (6)-gingerdione showed proton signals of 1,2,4-substituted benzene ring (6.6 to 6.9, 3H, multiplet: m), methoxy signal (3.9, 3H, singlet: s), benzyl proton signal (2.9, 2H, m), ketone α-proton signal (2.6, 2H, m), an olefinic proton signal (5.5, 1H, s), signals for methylene groups (2.3, 2H, m; 1.2 to 1.4, 4H, m; 1.6, 2H, m), and a methyl signal (0.9, 3H, triplet: t). A proton signal (15.5, 1H, s) in deuterium chloroform ($CDCl_3$), assigned to be an enol proton, disappeared by the addition of deuterium methanol (CD_3OD) or deuterium oxide (D_2O). The same was the case of a ketone α-proton signal to an olefinic proton signal. Several hours after solubilization, the ratio of the olefinic proton signal was increased.

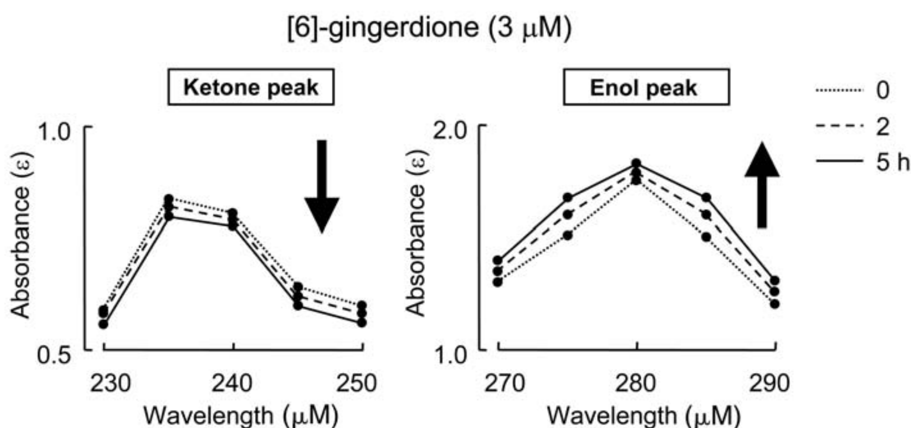

Figure 13.4 UV absorption spectrum for (6)-gingerdione (3 μM) just after preparation (0 hour) and after incubation for 2 and 5 hours at 27°C. (From Kimura et al., 1989c.)

Effects of (±)-(6)-Gingerol or Ethanol on Prostanoid-Induced Contractions in Mice Mesenteric Veins

Prostaglandin E_2 (0.28 mM), I_2-Na salt (0.27 mM), and a prostacyclin derivative TRK-100 (0.24 mM), also induced direct contraction of the mouse mesenteric vein, that is, 34 percent, 102 percent, and 25 percent of the maximal response to $PGF_{2\alpha}$ (0.28 mM), respectively. (±)-(6)-Gingerol (0.3 mM) caused a transient relaxation of the smooth muscle that gradually recovered and then significantly potentiated the contraction induced by the above prostanoids (Figure 13.5A).

On the other hand, low concentrations of ethanol had no direct effect on the tissue, but higher concentrations (1.7 mM) significantly potentiated the $PGF_{2\alpha}$-induced contractions. A tendency to augment the contractions induced by PGE_2 and TRK-100 was also observed, but was not significant (see Figure 13.5B). The potentiation effects of (±)-(6)-gingerol were reversible, but those induced by ethanol were irreversible.

The above result indicates that the extract contains other constituents that are more potent than *S*-(+)-(6)-gingerol in enhancing the contractile effects of $PGF_{2\alpha}$. The potency of *S*-(+)-(6)-gingerol was stronger than the synthetic compound, (±)-(6)-gingerol.

The potentiating effect of (±)-(8)-gingerol on $PGF_{2\alpha}$-induced contractions was greater than that of (±)-(6)-gingerol. The results showed that in gingerols shortening of the alkyl side chain decreases the activity (Hikino et al., 1985). The diarylheptanoid, (±)-hexahydrocurcumine (HHC), also potentiated the $PGF_{2\alpha}$-induced contractions but to a lesser extent compared to gingerols. Interestingly, shogaol produced significant inhibition of the $PGF_{2\alpha}$ contractile response in contrast to gingerols. (6)-Dehydrogingerdione (DHG) and *S*-(+)-(6)-gingerdiacetate (GDA) had no effect. Comparing the results and the chemical structures of the compounds tested, it shows that only those compounds containing the hydroxyl group at C-5 in the side chain potentiated the $PGF_{2\alpha}$-induced contractions. Further, alterations in the gingerol structure, such as elimination or substitution of the hydroxyl group at C-5 in the side chain (e.g., the presence of a double bond in shogaol or substitution of an acetate radical in *S*-(+)-(6)-GDA) either inhibits or produces no effect on the $PGF_{2\alpha}$ contractile response (see Figure 13.3).

Different effects of (6)-gingerdione on $PGF_{2\alpha}$-induced contraction were observed; that is, ranging from inhibition to potentiation after several hours of incubation at 27°C. The difference in responses of (6)-gingerdione is probably due to the diketones at C-3 and C-5 undergoing enolization.

Previous studies have shown that the activated hydrogen of the keto form migrates from the carbon by α, γ-shift to give an enol. The high enol content of 1,3 diketones such as acetylacetone and benzoylacetone showed that the activation by two carbonyl groups was more effective and favors enolization more readily than simple ketones such as acetone. Enols give a red color when treated with ferric chloride, forming colored ferric chloride complexes (Fieser, 1961).

Furthermore, absorption spectra determinations for benzoylacetone showed two absorption bands, with maximum near 247 and 310 nm, and their respective intensities differing from one solvent to another. These two maxima were associated with the ketonic and enolic forms. The intensity of the 247 nm peak in different solvents varies linearly with the total ketone content, and that at 310 nm with the enol content (Morton et al., 1934). The UV spectral data on benzoylacetone obtained in this study agree with the previous results.

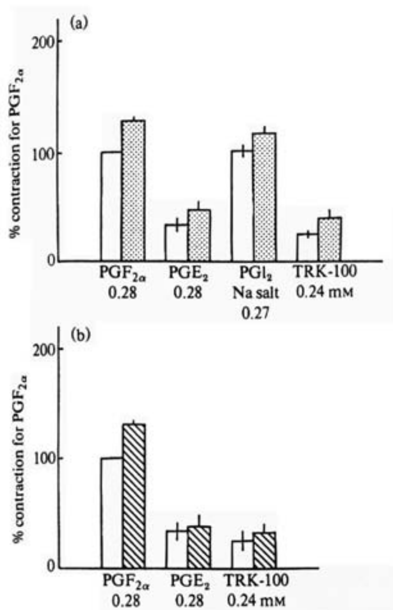

Figure 13.5 Potentiation effects of 0.3 mM (±)-(6)-gingerol on $PGF_{2\alpha}$, PGE_2, PGI_{2-Na} salt, and TRK-100 (A) and 1.7 mM ethanol on $PGF_{2\alpha}$, PGE_2, and TRK-100 (B)-induced contractions in mice mesenteric veins. The contraction in response to $PGF_{2\alpha}$ without (±)-(6)-gingerol or ethanol was taken as control = 100 percent. The values are the mean percentages ± SEM (n = 3–4). Significant differences were determined by paired t-test at $*P < .05$ and $**P < .01$. (From Kimura et al., 1989c.)

(A) without; ▭ with (±)-(6)-gingerol; ▭

(b) without; ▭ with ethanol; ▭

The absorption maxima that occur with (6)-gingerdione at 235 and 280 nm may be associated with its ketone and enol contents, respectively. The ^{1}H-NMR spectrum of (6)-gingerdione solution also showed a time-dependent increase of an enol type configuration. It is, therefore, presumed that in aqueous solution (6)-gingerdione changed its chemical structure after several hours of incubation forming enols, although the extent of conversion to enol and the resulting chemical structure need further elucidation. Figure 13.6 suggests one possible chemical structure of (6)-gingerdione in solution.

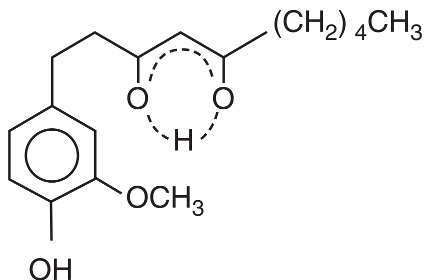

Figure 13.6 Possible chemical structure of (6)-gingerdione in solution. (From Kimura et al., 1989a.)

The intensity of absorption at 235 nm decreased after 5 hours, whereas the intensity at 280 nm increased. The shift in the intensity of absorption spectrum was only slight because of its extremely low concentrations. It is possible that the conversion of diketone to enol might have increased during incubation, thus causing the observed transfer of effect from inhibition to potentiation of $PGF_{2\alpha}$-induced contractions.

Previous investigations (Collier et al., 1975, Landolfi and Steiner, 1984) have shown that ethanol can differentially affect the contractile responses to a variety of prostaglandin compounds in vascular smooth muscles. Low concentrations of ethanol can enhance prostaglandin-induced contractions in isolated blood vessels. The gingerol derivatives containing the hydroxyl group in the alkyl part of the chemical structure potentiated the $PGF_{2\alpha}$-induced contractions in the same manner as ethanol. In addition, a significant potentiating effect of (±)-(6)-gingerol was also observed upon other types of prostanoid-induced contractions.

Modulation of Eicosanoid-Induced Contractions by (±)-(6)-Gingerol in Isolated Blood Vessels

Eicosanoids are lipid mediators containing 20 carbon fatty acid derivatives. They are derived from phospholipase-released arachidonic acid. In the membrane, the arachidonic acid released by phospholipase A_2 from phospholipids is metabolized by cyclooxygenase to prostaglandins and thromboxanes or by lipoxygenase to leukotrienes. The eicosanoids are involved in numerous biological functions such as pain, fever, and inflammation (Rang et al., 1999).

Physiologically active eicosanoids such as the prostaglandins, thromboxane (TX), and leukotrienes (LTs) either dilate or constrict the vasculatures. PGI_2, $PGF_{2\alpha}$, PGD_2, and TXA_2 are synthesized in the blood vessels (Fostermann et al. 1984) and are involved in the modulation of contractions in vascular smooth muscles. Similarly, LTC_4 and LTD_4 induce contractions of mesenteric vascular tissues (Feigen, 1983).

The gingerols have been reported to inhibit the synthesis of prostaglandins and leukotrienes in vascular smooth muscles (Kiuchi et al. 1992). Subsequently Kimura et al. (1989a) investigated the effects of gingerols on the contractions induced by various eicosanoids on isolated blood vessels. Such studies will provide new insights into the pharmacological action of gingerols as a modulator of eicosanoid responses in vascular smooth muscles.

Effects of (±)-(6)-Gingerol on $PGF_{2\alpha}$-Induced Contractions in Isolated Mice and Rat Blood Vessels

The effects of gingerol were compared between species (mouse and rat), between veins (mesenteric vein and vena cava), and arteries (mesenteric artery and aorta) and between longitudinal and circular segments (Table 13.4). (±)-(6)-Gingerol potentiated $PGF_{2\alpha}$-induced contractions in longitudinal segments of mouse and rat veins and decreased $PGF_{2\alpha}$-induced relaxation in longitudinal segments of rat artery. In contrast, (±)-(6)-gingerol inhibited $PGF_{2\alpha}$-induced contractions in circular segments of rat aorta and longitudinal segments of mouse mesenteric artery.

Table 13.4 Effects of (±)-(6)-gingerol on $PGF_{2\alpha}$-induced contractions in isolated blood vessels of mice and rats

Blood vessel (muscle segment)	*0.3 mM $PGF_{2\alpha}$*	*+ (±)-(6)-gingerol % (mM)*
Mouse mesenteric vein (L)	C	128 ± 4** (0.3)
Rat mesenteric vein (L)	C	132 ± 8* (0.3)
Rat vena cava (L)	C	129 ± 7* (0.03)
Rat mesenteric artery (L)	R	90 ± 1** (0.3)
Rat aorta (L)	R	78 ± 4** (0.3)
Rat aorta (C)	C	69 ± 4** (0.3)
Mouse mesenteric artery (L)	C	54 ± 8** (0.4)

Note: (L): longitudinal; (C): circular; C: contraction; R: relaxation.
The contraction to $PGF_{2\alpha}$ (0.3 mM) without gingerol was used as the control = 100 percent. The values are expressed as mean percentage ± S.E.M. (n = 4).
Significant difference from the control value without gingerol were determined by paired *t*-test at $^{*}P < .05$ and $^{**}P < .01$.
Source: Kimura et al. (1989a).

Effects of (±)-(6)-Gingerol on Eicosanoid-Induced Contractions in Mice Mesenteric Veins

Cumulative additions of prostaglandins ($F_{2\alpha}$, E_2, and D_2), prostacyclin stable derivatives (PGI_2 -Na and TRK-100), a stable TXA_2 (U-46619), and leukotrienes (C_4 and D_4) induced concentration-dependent contractions of mice mesenteric veins. The maximal contraction for $PGF_{2\alpha}$ was obtained at a 0.28 mM concentration. PGE_2 and PGD_2 (0.28 mM) caused 48 percent and 12 percent of the maximal response to $PGF_{2\alpha}$, respectively. PGI_2-Na (0.27 mM) produced the same maximal contraction as $PGF_{2\alpha}$. The other prostacyclin derivative, TRK-100 (0.24 mM), induced a contraction that was 27 percent of the maximal response for $PGF_{2\alpha}$. The muscle segments were more sensitive to U-46619, LTC_4, and LTD_4. Higher amplitudes of contractions were obtained at low concentrations; that is, 152 percent for U-46619 (29 μM), 179 percent for LTC_4 (1μM), and 163 percent for LTD_4 (1μM). Arachidonic acid and PGD_1 failed to cause contractions even at high concentrations (0.3 mM).

Figure 13.7 shows typical recordings of the mesenteric vein contraction response to maximum concentrations of $PGF_{2\alpha}$, PGE_2, and TRK-100 in the absence and presence of (±)-(6)-gingerol. The gingerol alone caused a transient relaxation of the smooth muscle that immediately recovered to baseline tension, then after 5 minutes, it significantly potentiated the prostanoid-induced contraction. The response to TRK-100 was the most markedly potentiated.

The contractions induced by prostanoids except PGD_2 were significantly enhanced by gingerols. In contrast, the contractions induced by PGD_2, U-46619, LTC_4, and LTD_4 were significantly inhibited by gingerols (Table 13.5). The effects of the gingerols disappeared completely after a washout of 30 minutes to 1 hour.

The prostaglandins, thromboxane, and leukotrienes induce concentration-dependent contractions of various blood vessels. In rabbit and rat aorta (Borda et al., 1983), human coronary artery (Davis et al., 1980), and canine basilar artery (Chapleau et al., 1979),

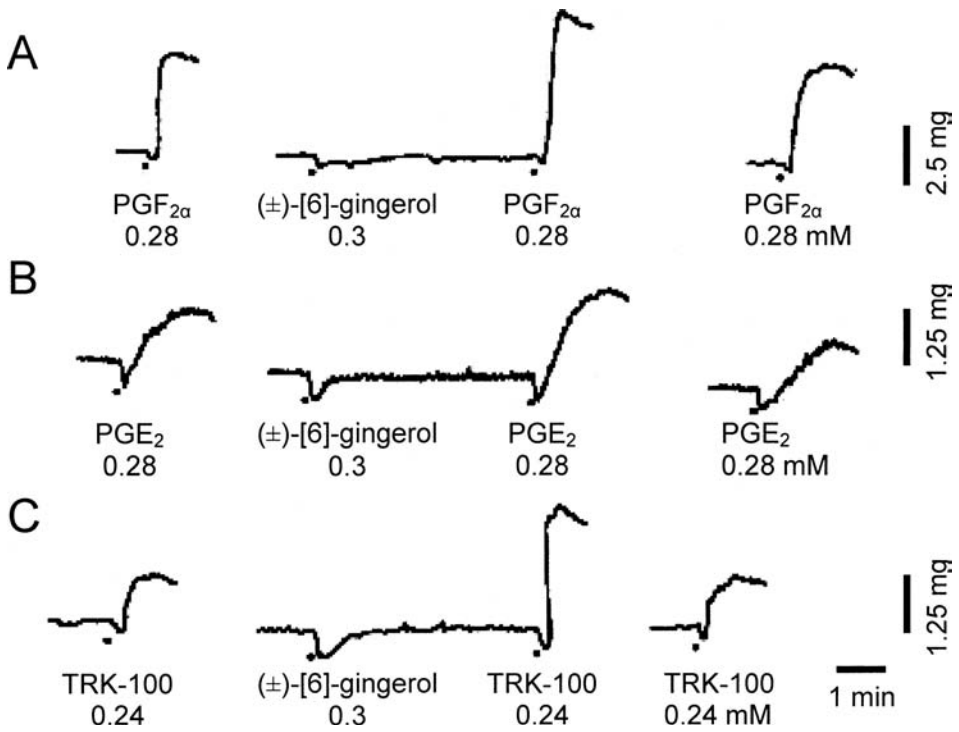

Figure 13.7 Typical recordings of the contractile responses to maximum concentrations of $PGF_{2\alpha}$ (A), PGE_2 (B), and TRK-100 (C) with or without (±)-(6)-gingerol (0.3 mM). Each response was observed at 30-minute intervals in separate experiments for each prostanoid. (From Kimura et al., 1989a.)

Table 13.5 Effects of (±)-(6)-gingerol on eicosaoid-induced contractions in mice mesenteric veins

		(±)-(6)-Gingerol % Contraction		
Action pattern	*Compounds (mM)*	*0.03*	*0.1*	*0.3*
Potentiation	$PGF_{2\alpha}$ (0.28)	103 ± 1	112 ± 3*	128 ± 3**
	PGE_2 (0.28)			135 ± 5**
	PGI_2-Na (0.27)			117 ± 0.3**
	TRK-100 (0.24)		101 ± 4	162 ± 9**
Inhibition	PGD_2 (0.28)			69 ± 8*
	U-46619 (0.029)			91 ± 1**
	LTC_4 (0.001)			86 ± 2*
	LTD_4 (0.001)			95 ± 3

Note: The contraction induced by the above compounds without gingerol was taken as the control = 100 percent. The values are expressed as mean percentages ± SEM (n = 3–5). Significant differences from the control value without gingerol were determined by *t*-test at $*P < .05$ and $**P < .01$.
Source: Kimura et al. (1989a).

low doses of PGI_2 relax the vascular smooth muscle, but higher doses elicit concentration-dependent contractile responses. In this study, the prostanoids and leukotrienes induced concentration-dependent contractions in mice mesenteric veins. The longitudinal segments of mice mesenteric artery, rat mesenteric vein, and rat vena cava and the circular segments of the rat aorta also contracted in response to $PGF_{2\alpha}$. On the other hand, $PGF_{2\alpha}$ relaxed the longitudinal segments of rat aorta and mesenteric artery.

(±)-(6)-Gingerol exhibited different actions on veins (longitudinal) and arteries (longitudinal and circular). It augmented the $PGF_{2\alpha}$-induced contractions in veins and decreased the $PGF_{2\alpha}$-induced relaxation or inhibition of $PGF_{2\alpha}$-induced contraction in arteries. The stimulation of the cyclooxygenase pathway induced opposite responses in rat isolated blood vessels; that is, relaxation in arteries and contraction in veins (Vanhoutte et al., 1986). The potentiation of $PGF_{2\alpha}$-induced contraction in veins and inhibition of the $PGF_{2\alpha}$ contractile response in arteries by (±)-(6)-gingerol suggest that the effects of (±)-(6)-gingerol involve the cyclooxygenase system.

Both the leukotrienes and thromboxane A_2 (TXA_2) derivative produced a response of higher sensitivity and greater maximal response than the other prostaglandins in mice mesenteric veins. The order of potency of the prostanoids and leukotrienes was estimated to be LTs > TXA_2 > $PGF_{2\alpha}$ > PGI_2-Na > PGE_2 > TRK-100 > PGD_2 for mice mesenteric vein. The responses were similar to those obtained for guinea pig lung (Coleman and Kennedy, 1985) and isolated bronchus (Black et al., 1986). The results suggest that the mice mesenteric veins contain more than one type of eicosanoid receptor mediating the contraction. The receptors for prostanoids (Coleman and Humphrey, 1993) with lower potency may not be so abundant in the mesenteric veins or these agents may be partial agonists.

(±)-(6)-Gingerol alone induced transient relaxation of the mice mesenteric veins which then recovered to baseline force, but did not induce direct contractile effect. However, (±)-(6)-gingerol potentiated the contraction induced by $PGF_{2\alpha}$, PGI_2, and PGE_2, but inhibited the contractions induced by LT, TXA_2 and PGD_2. The inhibition of TXA_2 synthesis (Uotila and Matintalo, 1984) and the LT receptors (Mong et al., 1986) has been reported to convert arachidonic acid to $PGF_{2\alpha}$, PGI_2, and PGE_2 via the cycloxygenase system. The results of this study further suggest that gingerol-induced potentiation of prostanoid contractions (except PGD_2) involves the cyclooxygenase.

Mechanism Involved in Potentiation of $PGF_{2\alpha}$-Induced Contractions by (±)-(6)-Gingerol in Mice Mesenteric Veins

The vascular endothelium releases various chemical mediators (including PGs, TX and LTs) that control the contraction of the underlying smooth muscles (Rang et al., 1999). The influence of the endothelial cells and the involvement of the cyclooxygenases in the potentiation of $PGF_{2\alpha}$-induced contraction by (±)-(6)-gingerol in mice mesenteric veins were investigated by Hata et al. (1998) and Kimura et al. (1989b).

Influence of Endothelial Cells on (±)-(6)-Gingerol Potentiation of $PGF_{2\alpha}$-Induced Contractions in Mice Mesenteric Veins

To determine whether the endothelial cells are involved in the potentiation mechanism, the effects of (±)-(6)-gingerol on $PGF_{2\alpha}$-induced contractions were compared in isolated

Table 13.6 Influence of endothelial cells on (±)-(6)-gingerol potentiation of $PGF_{2\alpha}$-induced contraction in mice mesenteric veins

(±)-(6)-Gingerol	mg tension (% contraction) by $PGF_{2\alpha}$	
	With endothelium	Without endothelium
−	6.6 ± 0.1 (100)	7.1 ± 1.4 (100)
	*	NS
+	8.4 ± 0.3 (128 ± 4)	7.3 ± 1.5 (102 ± 1)

Note: The values are the means ± SEM (n = 3–12). Significant differences at $*P < .05$ by paired t-test. NS, not significant.
Source: Hata et al. (1998).

mice mesenteric veins with or without endothelium (Table 13.6). Removal of the endothelium was confirmed by the lack of relaxation response to acetylcholine (60 μM). The maximum contraction elicited by $PGF_{2\alpha}$ (0.28 mM) was significantly potentiated up to 28 percent by (±)-(6)-gingerol in intact mesenteric veins (with endothelium). In mesenteric veins without endothelium, the contractile responses to $PGF_{2\alpha}$ tended to increase slightly, but did not significantly change from those in intact veins. The potentiating effect of (±)-(6)-gingerol on the $PGF_{2\alpha}$ contractile response disappeared completely in veins without endothelium.

Effects of Cyclooxygenase and Lipoxygenase Inhibitors on the Potentiation of $PGF_{2\alpha}$-Induced Contractions by (±)-(6)-Gingerol in Mice Mesenteric Veins

The cyclooxygenase inhibitors aspirin (0.2 mM) and indomethacin (0.2 mM) markedly reduced the potentiation of $PGF_{2\alpha}$-induced contractions by (±)-(6)-gingerol, whereas a lipoxygenase inhibitor, nordihydroguaiaretic acid (NDGA, 0.03 mM), and a TXA_2 antagonist, ONO-3708 (3 nM, data not shown), had no effect (Table 13.7).

Table 13.7 Effects of cyclooxygenase and lipoxygenase inhibitors on the potentiation of $PGF_{2\alpha}$-induced contractions by (±)-(6)-gingerol in mice mesenteric veins

Compounds	Concentration mM	Potentiation %
(±)-(6)-Gingerol	0.3	35 ± 10
+ Aspirin	0.2	5 ± 2*
+ Indomethacin	0.2	−1± 3*
+ NDGA	0.03	29 ± 3

Note: The maximal contraction elicited by $PGF_{2\alpha}$ alone (0.28 mM) was taken as 100 percent response. The inhibitors were applied for 1 hour. The values are the means ± SEM (n = 4–5). Significant differences from the response with (±)-(6)-gingerol alone were determined by unpaired *t*-test at $*P < .05$.
Source: Hata et al. (1998).

Effects of (±)-(6)-Gingerol on $PGF_{2\alpha}$-Induced Contractions in Normal and Streptozotocin-Diabetic Mice Mesenteric Veins

The $PGF_{2\alpha}$-induced contractions were two times greater in the veins of streptozotocin (STZ)–diabetic mice than in normal mice (Table 13.8). Removal of the endothelial cells significantly reduced the responses to $PGF_{2\alpha}$ in the diabetic mesenteric veins. The diabetic enhancement of $PGF_{2\alpha}$ contractile responses was not suppressed by cyclooxygenase inhibitors, aspirin (0.2 mM) and indomethacin (0.2 mM) and a TXA_2 antagonist, ONO-3708 (0.003 μM), but were significantly suppressed by lipoxygenase inhibitors, NDGA (0.03 mM), and phenidone (0.05 mM) (data not shown).

The potentiating effects of (±)-(6)-gingerol (0.3 mM) on $PGF_{2\alpha}$ (0.28 mM)-induced contractions were compared in the mesenteric veins of STZ-induced diabetic (10 weeks old) and of normal age-matched mice. (±)-(6)-Gingerol significantly potentiated the contractile responses to $PGF_{2\alpha}$ in both normal and diabetic mice mesenteric veins. However, the potentiation percentages by (±)-(6)-gingerol were not significantly different between STZ-diabetic (26 ± 6 percent) and normal (30 ± 3 percent) veins (see Table 13.8).

It is known that the endothelial cells release potent chemical mediators (Rang et al., 1999) and modulate the contraction of vascular smooth muscles (Hickey et al., 1985; Vanhoutte et al., 1986). The potentiation of $PGF_{2\alpha}$-induced contractions by (±)-(6)-gingerol disappeared completely in mesenteric veins without endothelium. The results suggest that gingerol stimulates the release of a vasoconstrictor substance from the endothelial cells inducing potentiation of $PGF_{2\alpha}$-induced contractions in mice mesenteric veins.

The endothelium-dependent potentiation of $PGF_{2\alpha}$-induced contractions by (±)-(6)-gingerol were inhibited by cyclooxygenase inhibitors but not affected by the thromboxane antagonist and the lipoxygenase inhibitors. This indicates that the vasoconstrictors released by cyclooxygenase from the endothelial cells, except thromboxane, contribute to the potentiation of $PGF_{2\alpha}$-induced contractions by gingerol in mice mesenteric veins.

(±)-(6)-Gingerol significantly potentiated the $PGF_{2\alpha}$-induced contraction in mesenteric veins of both normal and diabetic mice to a similar extent. These results suggest that the mechanism involved in the potentiation of the $PGF_{2\alpha}$ contractile response by (±)-(6)-gingerol is the same in normal and diabetic mesenteric veins; that is, via the cyclooxygenase pathway.

Table 13.8 Effect of (±)-(6)-Gingerol on $PGF_{2\alpha}$-induced contractions in normal and STZ-diabetic mice mesenteric veins

	ms tension (% contraction) by $PGF_{2\alpha}$	
(±)-(6)-Gingerol	*Normal*	*STZ-diabetic*
−	5.6 ± 0.5 (100)	12.4 ± 2.3 (100)
	**	*
+	7.4 ± 0.9 (130 ± 3)	15.3 ± 2.4 (126 ± 6)

Note: The values are the means ± SEM (n = 3–5). Significant differences were determined by paired *t*-test at $*P < .05$ and $**P < .01$.
Source: Hata et al. (1998).

Hypothesis on the Mechanisms Involved in the Enhancement of $PGF_{2\alpha}$-Induced Contractions by Gingerol

The hypothesis on the mechanism involved in the potentiation or enhancement of $PGF_{2\alpha}$-induced contraction by gingerol or diabetic state in mice mesenteric veins is illustrated in Figure 13.8. In normal mesenteric veins, the exogenous prostaglandin (i.e., $PGF_{2\alpha}$) acts on the prostaglandin receptors and induces contraction of the vascular smooth muscle. Gingerol activates the cyclooxygenase in the endothelial cells, increasing the synthesis of prostaglandins, thus causing potentiation of prostaglandin-induced contraction. On the other hand, leukotriene acts on the leukotriene receptors and induces contraction of the smooth muscle. Gingerol inhibits the leukotriene-induced contraction, and this may be due to the inhibition of the leukotriene receptors but is not due to the inhibition of lipoxygenase in the endothelial cells. Similar results were observed in the guinea lung wherein the inhibition of leukotriene receptors converts the synthesis of arachidonic acid to the production of prostaglandins (PGE_2, PGI_2, and $PGF_{2\alpha}$) via the cyclooxygenase pathway (Mong et al., 1986).

The diabetic state damages the endothelial cells and disturbs the microvascular function. This may be related to the alterations in the synthesis of prostanoids and leukotrienes in the diabetic state (Harrison et al., 1978; Silberbauer et al., 1979; Roth et al., 1984). In the diabetic mesenteric vein (Figure 13.8), the prostaglandin-induced con-

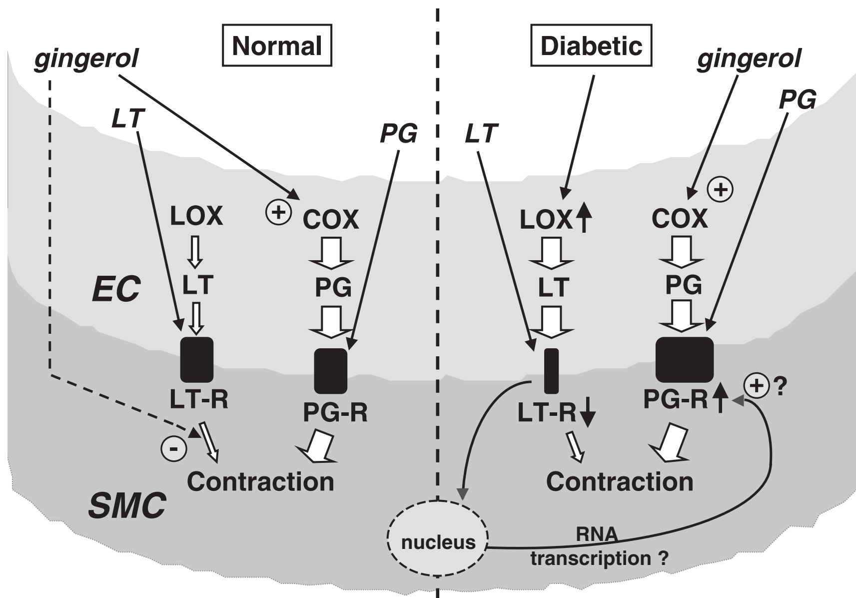

Figure 13.8 Potentiation or enhancement of $PGF_{2\alpha}$-induced contraction by gingerol or diabetic state in mice mesenteric veins. EC, endothelial cells; SMC, smooth muscle cells; PG, prostaglandin; LT, leukotriene; PG-R, prostaglandin receptor; LT-R, leukotriene receptor; COX, cyclooxygenase; LOX, lipoxygenase.

traction was significantly enhanced compared to that in the normal vein. The enhancement of the prostaglandin contractile response was significantly suppressed by lipoxygenase inhibitors but not by cycloxygenase inhibitors, suggesting the activation of the lipoxygenase in the diabetic state. The downregulation of the leukotriene receptors may, in turn, cause the upregulation of the prostaglandin receptors and the enhancement of the PG contractile response. It is assumed that the diabetic state induces an imbalance in the regulation of eicosanoid receptors in the vascular smooth muscle; however, this requires further investigation.

(±)-(6)-Gingerol also potentiated the contractile response to $PGF_{2\alpha}$ in diabetic mice mesenteric vein (see Figure 13.8). The extent of potentiation was not significantly different from that in the normal vein. The results suggest that the mechanism involved in the potentiation of the $PGF_{2\alpha}$ contractile response by (±)-(6)-gingerol is the same in normal and diabetic mesenteric veins; that is, via the cyclooxygenase pathway.

Relation to Current Findings

The main source of the eicosanoids is arachidonic acid. Arachidonic acid is metabolized by cyclooxygenase (COX), which initiates the synthesis of prostaglandins and thromboxanes or by lipoxygenase (LOX), which initiates the synthesis of leukotrienes (Rang et al., 1999). COX exists in two forms—COX-1 and COX-2. The structures of COX-1 and COX-2 are similar, with one amino acid difference that leads to a larger substrate access for COX-2 (Funk, 2002). COX-1 is found in most cells as a constitutive enzyme, and it is thought that the prostanoids, which it produces, are involved in normal homeostasis, for example, regulation of vascular responses. COX-2 is induced in inflammatory cells by inflammatory stimuli. On the other hand, (LOX) is present in tissues in inflammatory conditions (Rang et al., 1999).

Gingerols have been shown to inhibit arachidonic acid–induced platelet release and aggregation via an effect on the cyclooxygenase activity in platelets (Koo et al., 2001). Further, gingerols were found to have an effect on both COX-1 and COX-2 (Crowe, 2001). Ginger constituents, (8)-paradol and shogaol, showed strong inhibitory effects on COX-2 enzyme activity (Tjendraputra, 2001). Steamed ginger increases the intestinal blood flow in normal rat (Hashimoto et al., 2002). These results support the findings of the inhibitory effect on mouse mesenteric veins by steamed ginger extracts and by shogaol.

The potentiation of $PGF_{2\alpha}$-induced contraction by (±)-(6)-gingerol is present in both the normal and diabetic state to the same extent, suggesting the activation of COX-1 by gingerol. The inhibition of cyclooxygenase activity by gingerols in platelets (Koo et al., 2001) and in arthritic conditions (Sharma et al., 1994) may be related to its inhibition of COX-2. Increased vascular permeability in the diabetic state reflects the effects of COX-2–derived PGs and LTs (Funk, 2002). The stimulatory effect of gingerol on COX-1 and the increase in production of prostanoids that will regulate the vascular function may counteract the effects of COX-2– and LOX-derived mediators in inflammatory conditions and in diabetes. However, the specific effect of gingerol on COX-1 and COX-2 requires further investigation using selective COX-2 inhibitors; for example, Coxibs (Funk, 2002).

On the other hand, shogaol has been reported to have strong inhibitory effects on COX-2. When the structure of (8)-shogaol is compared to (8)-paradol, as well as two synthetic analogues, 3-hydroxy-1-(4-hydroxy-3-methoxyphenyl) decane and 5-hydroxy-1-(4-hydroxy-3-methoxyphenyl) dodecane, three important structural features that affect COX-2 inhibition are revealed: (1) lipophilicity of the alkyl side chain, (2) substitution pattern of hydroxy and carbonyl groups on the side chain, and (3) substitution pattern of hydroxy and methoxy groups on the aromatic moiety (Tjendraputra et al., 2001).

The chemical structures of gingerols and shogaols have a different moiety in the side chain. The aliphatic hydroxyl group in gingerol is necessary for the potentiation of $PGF_{2\alpha}$-induced contractions in mice mesenteric veins (Kimura et al., 1989c). Elimination of the hydroxyl group (e.g., in the shogaol structure) inhibited the contractile response to $PGF_{2\alpha}$.These findings suggest that the hydroxyl group in gingerol affects the activation of the cyclooxygenase in mice mesenteric vein (Kimura et al., 1989c; Pancho et al., 1989). The different effects of gingerol (a main component of fresh ginger) and shogaol (a main component of steamed ginger) on COX-1 and COX-2 suggest that the combination of the two drugs may be used as an effective treatment for diabetes mellitus and other inflammatory conditions. See Chapter 14 for other pharmacological effects and medicinal uses of ginger.

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14 Properties and Medicinal Uses of Ginger

R. Remadevi, E. Surendran, and P. N. Ravindran

The past decade has witnessed a considerable enhancement of interest in the use of various traditional herbs and plant extracts in primary healthcare and conventional medicine. They form part of traditional medicine systems, and a vast body of anecdotal evidence exists supporting their use and efficiency. Some of these traditional medicines (especially in the Chinese system of medicine) have stood up well to modern clinical investigations, whereas the so-called miracle cure of others have been either disproved or not substantiated. There is evidently a lack of scientific data from well-planned clinical trials, and the situation is further complicated by the fact that the herbs are almost always used as complex polyherbal mixtures. Among the herbal drugs, one raw drug that has undergone considerable study is ginger. This is perhaps most widely used in the Indian system of medicine known as Ayurveda. Ginger is also a very important drug in both the Chinese and Japanese systems of medicine.

Ginger in Indian System of Medicine

In the Ayurvedic system of medicine, both fresh and dry ginger are used. Ginger has been widely used as a common household remedy for various illnesses from ancient times. The properties and uses of ginger in Ayurvedic medicine are available from authentic ancient treatises like *Charaka Samhitha* and *Susrutha Samhitha,* which are the basics for this system. Descriptions of ginger are available from similar documents of Chinese and Sanskrit literature written in the subsequent centuries. Dry ginger seems to be an essential ingredient in several Ayurvedic recipes, and hence ginger is called *Mahaoushadha*, the great cure. This emphasizes the extensive usage of ginger in Ayurveda.

Fresh ginger and dry ginger are used in Ayurveda in different ways:

1. As a single medicine for internal use
2. As an ingredient in compound medicines
3. For external use
4. As an adjuvant
5. As an antidote
6. For the purification of some mineral drugs

In Sanskrit literature, ginger has several synonymous words, which are indicative of its properties, and in Ayurveda different terms are used to denote the usage of ginger in different contexts. Aiyer and Kolammal (1966) quotes the following synonyms:

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Ardrika, Ardraka—that which waters the tongue and also shows the relation to the star *Ardra*
Sringivera, Sringa, Sringika—that which resembles the shape of the horns of animals
Chatra, Rahuchatra—that which dispels diseases
Sunti, Kaphahari, Soshana—that which overcomes diseases due to kapha (phlegm)
Mahaushadha—the great cure
Viswa, Viswabeshaja—universal remedy
Nagara—that which is commonly found in towns
Katubhadra—drug that has a pungent taste, which is capable of bringing goodness
Katootkata, Katuka, Katu, Ushna, Katigranthi—drug having a very pungent taste
Gulma moola—rhizome (root), which is generally spongy in nature
Saikatesta—that which grows generally in sandy places
Anoopaja—plant that requires plenty of water for its growth

Properties

Fresh and dry ginger are similar in their properties. The only difference is that fresh ginger is not so easily digested as the dried type (Aiyer and Kolammal, 1966). All the Ayurvedic classics like *Charaka samhitha, Susrutha samhitha, Ashtanga hridaya,* and *Nighantus* give the same properties for ginger

Rasa (taste)—*Katu* (pungent)
Guna (property)—*Laghu, Snigdha* (light and unctuous)
Veerya (potency)—*Ushna* (hot)
Vipaka (metabolic property)—*Madhura* (sweet)

Ginger rhizome has pungent taste and is considered to be converted to sweet products after metabolic changes. Being hot and light, ginger is easily digestible. It has an unctuous quality. In *Bhavaprakasa* (a famous ancient text in Ayurveda, by Bhavamisra) fresh ginger is called *rooksha*, meaning dry. It acts as an appetizer, carminative, and stomachic. Ginger is acrid, anodyne, antirheumatic, antiphlegmatic, diuretic, aphrodisiac, and cordial. It has anti-inflammatory or anti-edematous action according to *Dhanwantary nighantu* (another ancient gospel of Ayurveda attributed to the legendary Rishi Dhanwanthari). It cleanses the throat, is good for the voice (corrective of larynx affections), subsides vomiting, relieves flatulence and constipation, and relieves neck pain (*Saligrama nighantu*; yet another ancient text). Due to its hot property, ginger is capable of causing dryness and thus is antidiarrheal in effect. *Bhavaprakasa* specifically emphasizes the antiarthritic and antifilarial effects of dry ginger. It is also good in asthma, bronchitis, piles, eructation, and ascitis.

Kirtikar and Basu (1935) mentioned a remedy for cough in which fresh ginger is made into pills along with honey and ghee, and taken in a dose of four pills a day. It is applied externally to boils and enlarged glands, and internally as a tonic in Cambodia (Kirtikar and Basu, 1935). The outer skin of ginger is used as a carminative and is said to be a remedy for opacity of cornea. In acute Ascitis with dropsy arising from liver cirrhosis, complete subsidence by the use of fresh ginger juice is reported. The juice also acts as a strong diuretic (Kirtikar and Basu, 1935).

Ginger strengthens memory according to Nadkarni (1954) and removes obstruction in the vessels, incontinence of urine, and nervous diseases. Dry ginger paste with water is effective in recovering from fainting as an external application to the eyelids, or the ginger powder can be used as a snuff.

Bhaishajya ratnavali (another ancient Ayurvedic text) gives an important combination of dry ginger, rock salt, long pepper and black pepper, powdered and mixed with fresh ginger juice, to be gargled after warming, as a specific drug for phlegmatic affections of the heart, head, neck, and thoracic region. It is very good for all types of severe fevers and their associated symptoms. Ginger is made use of in veterinary science as a stimulant and carminative, in indigestion in horses and cattle, in spasmodic colic of horses, and to prevent gripping by purgatives (Pruthi, 1979). The ginger sprouts and shoots do not have any conspicuous taste and are said to aggravate *Vata* and *Kapha* (*Saligrama nighantu*) (Aiyer and Kolammal, 1966).

Note: According to the Ayurveda system of medicine, all the physiological functions of the human body are governed by three basic biological parameters—the *thridoshas,* or the three basic qualities: *vata, pitta,* and *kapha* (*kafa*). *Vata* is responsible for all voluntary and involuntary movements in the human body, *pitta* is responsible for all digestive and metabolic activities, and *kapha* provides the static energy (strength) for holding tissues together, and also provides lubrications at various joints of friction. When these three qualities (*doshas*) are in a normal state of equilibrium, the human body is healthy and sound, but when they lose equilibrium and become vitiated by varying internal and external factors, they produce varied diseases. Ayurveda treatment of any disease is aimed at restoring the equilibrium of the three *doshas,* or qualities.

Indications

Apart from its extensive use as a spice, ginger plays an important and unavoidable role in traditional medicine with a wide range of indications. Because of its carminative, stimulant, and digestive properties, ginger, wet or dry, is commonly used in fever, anorexia, cough, dyspnea, vomiting, cardiac complaints, constipation, flatulence, colic, swelling, elephantiasis, disuria, diarrhea, cholera, dyspepsia, diabetes, tympanitis, neurological disorders, rheumatism, arthritis, and inflammation of liver. It is also indicated in all phlegmatic conditions and respiratory problems such as asthma and cough.

Contraindications

In diseases like leprosy, anemia, leukoderma, painful micturition, hematemesis, ulcers, and fevers of *Pitha* predominance and in hot seasons, wet or dry ginger is not indicated (*Bhavaprakasa* and *Saligrama nighantu*).

Experimental and Clinical Investigations

Effect on Digestive System

Goso et al. (1996) investigated the effect of ginger on gastric mucin against ethanol-induced gastric injury in rats and found that the oral administration of ginger significantly prevented gastric mucosal damage. Patel et al. (1996) and Patel and Srinivasan (2000) investigated the influence of dietary spice on digestive enzymes experimentally.

Dietary ginger prominently enhanced the secretion of saliva and intestinal lipase activity by chymotripsin and pancraetic amylase as well as the disaccharides sucrose and maltose. The positive influence on this terminal enzyme of the digestive process could be an additional feature of this spice to stimulate digestion. Ginger contains proteolytic enzymes that promote the digestive process and also enhance the action of the gall bladder and protects the liver against toxins (Yamahara et al., 1990).

Yoshikawa et al. (1994) analyzed ginger for its stomachic principles. An antiulcer constituent (6-gingesulfonic acid), three monoacyl digalactosyl glycerols (gingeroglycolipids A, B, C), and (+)-angelicoidenol (2-0-beta-D-glucopyranoside) were isolated.

Cardiovascular and Related Actions

Suekawa et al. (1984) reported that gingerol and shogaol present in ginger juice cause vagal stimulation leading to a decrease in both the blood pressure and heart rate. Ahmed and Sharma (1997) found that male rats fed with 0.5 percent ginger for 4 weeks had a significant decrease in blood glucose, in total serum cholesterol with an increase in high-density lipoprotein (HDL) cholesterol. Additionally, these workers also found that compared to other treatment groups (control, 5 percent garlic, and ginger plus garlic), the animals consuming ginger failed to show an increase in body weight during the study. The hypoglycemic activity of ginger was also reported by Mascolo et al. (1989). They found that ethanolic ginger extract (100 to 300 mg/kg) contains compounds that inhibit prostaglandin release by leukcocytes. The inhibition of prostaglandin release is related to the antipyretic and anti-inflammatory properties of ginger.

Stimulation of the sarcoplasmic reticulam Ca_2^+ ATPase by gingerol and its analogues was investigated by Ohizumi et al. (1996). They studied the effects of 6-gingerol, (8)-gingerol, and (10)-gingerol isolated from rhizomes of ginger and the synthetic analogues (AP-004, AP-005, and AP-015). Ca_2^+ ATPase activity and Ca_2^+ pumping activity were increased by these compounds in a concentration-dependent manner. It was suggested that both the O-methoxyphenol and hydrocarbon chain of compounds were necessary for the activation of Ca_2^+ pumping ATPase activity of SR.

Jih Hwa et al. (1995) showed that gingerol at a 0.5 to 20 μM concentration dependently inhibited the aggregation and release reaction of arachidonic acid and collagen-induced rabbit platelets—activating factor (PAF) u-4661 and thrombin. Gingerol (0.5 − 10μM) also concentration dependently inhibited thromboxane B_2 and prostaglandin D_2 formation caused by arachidonic acid and completely inhibited phosphoinositide breakdown induced by arachidonic acid, but had no effect on that of collagen, PAF or thrombin even at concentrations as high as 300 μM. In human platelet-rich plasma, gingerol and indomethacin (indometacin) prevented the secondary aggregation and blocked ATP release from platelets induced by ADP (5 μM) and adrenaline (epinephrine) (5 μM), but had no effect on primary aggregation. The highest antiplatelet effect was obtained when platelets were incubated with gingerol for 30 minutes and this inhibition was reversible. It has been concluded that the antiplatelet action of gingerol is mainly due to the inhibition of thromboxane formation.

Janssen et al. (1996) studied the effect of the dietary consumption of ginger on platelet thromboxane production in humans. The result of the clinical assay of the raw and cooked ginger does not support the hypothesis on the antithrombolic activity of ginger in humans.

Lumb et al. (1994) investigated the effect of dried ginger on human platelet function, thrombogin, and hemostasis. The use of ginger as an antiemetic in the preoperative period has been criticized because of its effect on thrombaxane synthetase activity and platelet aggregation. When administrated to the healthy volunteer, ginger had no dose-dependent effect on thromboxane synthetase activity or such an effect only occurs in fresh state.

However, in a previous investigation by Verma et al. (1993) on 10 male healthy volunteers, it was shown that 5 g of ginger taken with a high-fat meal for 7 days was able to inhibit significantly the enhanced tendency to platelet aggregation normally seen after a high-fat intake. Earlier studies (Srivastava 1986, 1989) indicated that ginger, in addition to inhibiting platelet aggregation, also reduces platelet thromboxane synthesis both in vivo and in vitro. However, this effect in vivo was seen after consumption of 5 g/day for 7 days. It is unknown whether the effect would also be seen under normal patterns of consumption. It is unlikely that 5 g of ginger per day would be part of a normal consumption pattern, and this amount is far in excess of what is currently available in ginger-containing preparations.

Bordia et al. (1997) showed that the dose of 10 g of powdered ginger administered to patients suffering from coronary artery disease produced a significant reduction in ADP- and epinephrine-induced platelet aggregation. An aqueous extract of ginger has strong anticlotting activity. Some components present in ginger have been shown to prevent blood clotting through physiological changes exerted on the arachidonic acid metabolism and cicosanoid metabolism (Srivastava, 1984; 1986).

Antiemetic and Antinauseant Properties

One of the best-known and best-studied areas is the use of ginger for the treatment of various forms of nausea. Many animal and clinical trials have been conducted to investigate the use of ginger in preventing nausea of various types. Arfeen et al. (1995) carried out a double-blind randomized clinical trial to investigate the effect of ginger on the nausea and vomiting following gynecological laparoscopic surgery. Both 0.5 and 1.0 g of ginger were effective in reducing nausea, with only the higher dose being effective at reducing vomiting. Phillips et al. (1993) and Bone et al. (1990) reported that ginger was as effective as metoclopromide in reducing postoperative nausea and vomiting. In both of the above studies treatment with ginger reduced the need for other antiemetics during the postoperative period. In a later study Visalyputra et al. (1996) found that 2 g of ginger was ineffective in preventing the postoperative nausea and vomiting associated with diagnostic gynecological laparoscopy.

Suekawa et al. (1984) reported that 6-gingerol and 6-shogaol suppressed gastric contraction but increased gastrointestinal motility and spontaneous peristaltic activity in laboratory animals. However, these effects were observed only when ginger was administered orally and not when given intravenously. This suggests that direct contact with the intestinal mucosa and not delivery by the blood is required for the action of ginger; possibly the hepatic metabolism is involved in the action.

Treatment of morning sickness using ginger is an area in which many studies have been carried out. Fischer–Rasmussan et al. (1991), in a double-blind randomized cross-over trial, found that 1 g/day of ginger was effective in reducing the symptoms of morning sickness and did not appear to have any side effect or adverse effect on pregnancy.

Murphy (1998), in her analysis of the published data on randomized clinical trials, concluded that although there was some evidence for the beneficial effects of ginger in alleviating the symptoms of morning sickness, there was so little information that definite conclusions were impossible. Nevertheless, of the various alternative therapies suggested, ginger holds the most promise as a safe, effective treatment. Similar opinions were also expressed by Jewell and Young (1998) in their Cochrane-Cochrane report on treatments of nausea and vomiting in early pregnancy.

Backon (1991) reported that ginger may affect binding of testosterone to its receptor, and when this occurs in the uterus, may alter steroid dependent differentiation. No supporting evidence is available for this conclusion. However, several sources (McGuffin et al., 1997) advise against the use of therapeutic doses of ginger during pregnancy. A survey has found that whereas 55 percent of sources recommended ginger as being safe and effective in pregnancy, 16 percent stated that ginger should not be used in pregnancy due to its potential to cause miscarriage (Wilkinson, 2003).

Recently, Keating and Chez (2003) administered ginger syrup in water to study the ameliorating effect of ginger on nausea in early pregnancy. This double-blind study showed a positive improvement in 77 percent of the cases tested. They concluded that 1 g of ginger in syrup form in a divided dose daily is useful in some patients experiencing nausea and vomiting during the first trimester of pregnancy. On the other hand, Vutyavanich et al. (2001) concluded, from another double-blind study, that ginger effectively treats the symptoms of pregnancy-associated nausea and vomiting and that there is no evidence of any adverse effect. Fulder and Tenne (1996) reported that ginger is an over-the-counter medicine recommended for managing pregnancy-related nausea in many western countries.

Sontakke et al. (2003) studied the antiemetic effect of ginger in preventing nausea and vomoting induced by cyclophosphamide. The results indicated that in 62 percent of patients complete control of nausea was achieved; metoclopromide controlled nausea in 58 percent of patients, whereas with odansetron 86 percent control resulted. The authors recommended that the use of powdered ginger is useful in preventing nausea and vomiting induced by cyclophosphamide. The antiemetic efficacy of ginger was equal to that of metaclopromide.

Ernst and Pittler (2000) carried out a systematic review of the evidence that have accumulated from randomized clinical trials on the effect of ginger in checking nausea and vomiting. They found only six studies that satisfied all the experimental conditions. Three studies on postoperative nausea and vomiting indicated that in two cases ginger was superior to placebo and equally effective as metoclopromide. The pooled information indicated only a nonsignificant difference between the ginger and placebo groups for ginger 1 g taken before operation. One study was found for each of the following conditions: seasickness, morning sickness, and chemotherapy-induced nausea. These studies collectively favored ginger over placebo.

Ginger is also reported to be an effective remedy for travel and motion sickness. Mowrey and Clayson (1981) has done one of the best-known experiments in this area. In this clinical trial 39 men and women who reported a very high susceptibility to motion sickness were tested. Motion sickness was induced by being subjected to a rotating chair while blindfolded under controlled conditions. It was found that ginger was significantly more effective in reducing motion sickness than the antihistaminic dimenhydrinate and a placebo.

A Danish controlled trial on seasickness involved 80 naval cadets who were unaccustomed to sailing in rough seas. The subjects reported that ginger consumption reduced the tendency to vomiting and cold sweating significantly better than the placebo did.

Han Chung et al. (2003) analyzed the effect of ginger on motion sickness and gastric slow-wave dysrhythmias induced by circular vection. Volunteers subjected to circular vection were studied for nausea induction, electrogastrographic recordings, plasma vasopressin levels, both with and without ginger pretreatment, in a crossover design, double-blind, randomized placebo-controlled study. Pretreatment with ginger reduced the nausea, tachygastria, and plasma vasopressin. Ginger also prolonged the latency before nausea onset and shortened the recovery time after vection cessation. Intravenous vasopressin infusion at 0.1 and 0.2 U/min induced nausea and increased bradygastric activity; ginger pretreatment (2000 mg) affected neither. Ginger effectively reduced nausea, trachygastric activity, and vasopressin release induced by circular vection. The authors suggest that ginger may act as a novel agent in the prevention and treatment of motion sickness.

The general hypothesis of the mode of action is that ginger ameliorates the nausea associated with motion sickness by preventing the development of gastric dysrhythmias and the elevation of plasma vasopressin. Ginger also prolonged the latency before nausea onset and shortened the recovery time. So ginger is recommended as a novel agent in the prevention and treatment of motion sickness (Holtmann et al., 1989).

Anti-Inflammatory Properties; Effect on Rheumatoid Arthritis and Musculoskeletal Disorders

In the Indian system of medicine (Ayurveda) ginger is used as an anti-inflammatory drug. It has been suggested that ginger may be useful as a treatment for arthritis, and a number of commercial preparations are available for this use. For example, Bio-organics Arthri-Eze Forte (Bullivants, Australia) and Extralife Artri-care (Felton grimwade & Brickford, Ltd., Australia) are marketed as arthritis treatments and contain 500 mg dried, powdered ginger rhizome. Srivastava and Mustafa (1989, 1992) reported more than 75 percent of patients receiving 3 to 7 g of powdered ginger daily for 56 days had a significant reduction in pain and swelling associated with either rheumatoid or osteoarthritis. Adverse effects have not been so far reported. The results indicate that ginger has anti-inflammatory properties. Follow-up studies carried out (from 3 months to 2.5 years) in patients using 0.5 to 1 g powder/day exhibited a significant reduction in pain and swelling in 75 and 100 percent, respectively, of arthritis (rheumatoid and osteoarthritis) and muscular discomfort. The World Health Organization (WHO) document (2000) reports that 5 to 10 percent ginger extract administration brought about full or partial pain relief, or recovery of joint function and a decrease of swelling in patients with chronic rheumatic pain and lower back pain.

Kishore et al. (1980) clinically evaluated the effects of a ginger and *Tinospora cordifolia* combination in rheumatoid arthritis. The combination showed better results compared to other traditional medicines. The antiarthritic effect of ginger and eugenol was studied by Sharma et al. (1997a), who reported that ginger significantly suppressed the development of adjuvant arthritis.

Rebild et al. (2002) evaluated a biocomplex, Zinaxin, derived from a highly concentrated extract of ginger for its efficacy and safety in relieving knee osteoarthritis in 247 patients. The extract significantly reduced the knee pain after standing and walking. However, the extract increased the incidence of gastrointestinal pain in treated patients.

Jana et al. (1999) demonstrated that ginger at a dose of 100 mg/kg body weight was as effective as acetylsalicylic acid (100 mg/kg) in reducing carrageenin-induced edema in rats. Although this dose also reduced inflammation, it was not as effective as phenylbutazone. Similar results for the anti-inflammatory and analgesic activities of ginger were reported by Mascolo et al. (1989). It is thought that these anti-inflammatory actions are a result of inhibition of prostaglandin release, and hence ginger may act in a similar fashion to other nonsteroidal anti-inflammatory drugs that interfere with prostaglandin release or biosynthesis. Bliddal et al. (2000) carried out a randomized, placebo-controlled, crossover study on the effects of ginger extract and ibuprofen in patients suffering from osteoarthritis. The workers obtained a significant effect from ginger administration. More intensive and wider study on the beneficial effect of ginger in reducing pain due to osteoarthritis and rheumatoid arthritis have been advocated (Reginster et al., 2000).

A common side effect of treating inflammation with modern drugs is that they can lead to ulcer formation in the digestive system. Ginger not only prevents the symptoms of inflammation, but it also prevents ulcers in the digestive tract (Anonymous, 2003b).

Ginger is also shown to be effective in preventing gastric mucosal damage induced by ethanol (administered 30 minutes later). In ethanol-treated rats the mucin content of the deep mucosa was reduced. This reduction of the deep corpus mucin content was significantly inhibited by treatment with ginger rhizome (Goso et al., 1996).

Chemoprotective Properties

There is considerable emphasis on identifying potential chemoprotective agents present in foods consumed by the human population. In prior in vitro studies, the water or organic solvent extract of ginger was shown to possess antioxidative and anti-inflammatory properties. Ethanolic extract of ginger (GE) rhizome was investigated for anti-tumor–promoting effects in a mouse skin tumerogenesis model (Katyar et al., 1996). Skin tumor promotes induced epidermal ornithine decarboxylase (ODC), cyclooxygenase, and lipoxygenase activities, and hence edema and hyperplasia are conventionally used markers of skin tumor promotion. So the effect of GE on these parameters was assessed initially. Preapplication of GE onto the skin of SENCAR mice resulted in significant inhibition of 12-0-tetradecanoylphorbol-13-acetate (TPA) induction of epidermal ODC-cyclooxygenase and lipoxygenase activities and ODC m-RNA expression in a dose-dependent manner. Preapplication of GE to mouse skin also afforded significant inhibition of TPA-induced epidermal edema (56 percent) and hyperplasia (44 percent). In long-term tumor studies, topical application of GE, 30 minutes prior to each TPA application of 7,12-dimethyl-benz(a)-anthracene–initiated SENCAR mice, resulted in a highly significant protection against skin tumor incidence and its subsequent multiplicity. The animals pretreated with GE showed substantially lower tumor body burdens compared with non–GE-treated controls. The results provide clear evidence that GE possesses anti-skin-tumor–promoting effects, and that the mechanism of such effects may involve inhibition of tumor promoter-caused cellular, biochemical, and molecular changes in mouse skin.

Sharma and Gupta (1998) investigated the effect of ginger in reversing the delay in gastric emptying caused by the anticancer drug cisplatin. Cisplatin causes nausea, vomiting, and inhibition of gastro-emptying. Acetone and 50 percent ethanolic extracts of ginger (100, 200, and 500 mg/kg, p.o) and ginger juice (2 and 4 ml/kg) were investigated against cisplatin effects on gastric emptying in rats. Ginger administration significantly reversed cisplatin-induced delay in gastric emptying. The ginger juice and acetone

extracts were more effective than the 50 percent ethanolic extract. The reversal produced by the ginger acetone extract was similar to that caused by the 5-HT_3 receptor antagonist ondansteron; however, ginger produced better reversal than ondansteron. These authors suggested that ginger, used as an antiemetic in cancer therapy, may also be useful in improving the gastrointestinal side effects of cancer chemotherapy.

Chih Peng et al. (1995) showed that the extract of dried ginger rhizome exhibited biphasic effects on the secretion of cytokines by human peripheral blood mononuclear cells in vitro. The stimulatory effect of the extract on cytokine secretion was shown to be time dependent; a significant increase in the secretion of cytokines was noted in the presence of low doses of ginger extract (10 to 30 mg/ml) 18 to 24 hours after administration. At a higher concentration of the extract, cytokine production was suppressed.

Kim et al. (2002) found that the four types of shogaols from ginger protect IMR32 neuroblastoma and normal human umbilical vein endothelial cells from beta-amyloid at EC50 = 4.5 to 8.0 $\mu M\ l^{-1}$. The efficacy of cell protection from beta-amyloid insult by the shogaols was shown to improve as the length of the side chain increases.

Sharma et al. (1997) investigated the effect of ginger extract (50 percent ethanolic and aqueous) for activity against emesis induced by 3 mg/kg cisplatin (iv) in healthy mongrel dogs. The acetone and 50 percent ethanolic extract at doses of 25, 50, 100, and 200 mg/kg, p.o. exhibited significant protection, whereas the aqueous extract was ineffective at these doses. The acetone extract was more effective than the ethanolic extract. However, both were less effective when compared with the 5-HT receptor antogonist granisetron. Ginger extract was not effective against apomorphine-induced emesis, ruling out mediation at the level of dopaminergic transmission. The findings suggest that ginger could be an effective and cheap antiemetic adjunct to cancer therapy.

Hypolipidemic Effect

Sharma et al. (1996) studied hypolipidemic and antiatherosclerotic effects of *Z. officinale* in cholesterol-fed rabbits. The administration of GE increased the fecal excretion of cholesterol, thus suggesting a modulation of absorption; the treatment reduced total serum cholesterol and low density cholesterol (LDC) levels. The atherogenic induct was reduced from 4.7 to 1.12.

An herbal medicine containing ginger was investigated for vaso-relaxant action on isolated vessels from rat, guinea pigs and rabbits by Calixto and Cabrini (1997) and the extract produced partial relaxation. Inoue et al. (1996) subjected for study a kampo medicine containing ginger for its restorating effect, and the drug prevented the modification of the macrophage function induced by atherogenic factors.

Wijaya et al. (1995) Investigated a Chinese medicine, Slimax, containing ginger for its effect on lipid metabolism in obese experimental animals. The major pharmacological action of Slimax appeared to be on the regulation of glucose utilization and mobilization.

Lumb (1994) investigated the effect of dried ginger on human platelet function, thrombogin, and hemostasis. The use of ginger as an antiemetic in the preoperative period has been criticized because of its effect on thromboxane synthetase activity and platelet aggregation. Bordia et al. (1997) studied the effect of ginger and fenugreek on blood lipids, blood sugar, and platelet aggregation in patients with coronary artery disease (CAD). A single dose of ginger powder (10 g) administered to CAD patients significantly reduced platelet aggregation induced by ADP or epinephrine and found no effect on blood lipid or blood sugar.

Bhandari et al. (1998) studied the protective action of ginger on cholesterol-fed rabbits. The animals receiving GE showed a lower degree of atherosclerosis.

Antimicrobial and Insecticidal Properties

Hiserodd et al. (1998) successfully isolated 6-, 8-, and 10-gingerol and evaluated their activity to inhibit *Mycobacterium avium* and *M. tuberculoses.* 10-Gingerol was identified as an active inhibitor of these two microbes in vitro.

The protective effect of a traditional Chinese medicine, *Shigyakuto* (containing 50 percent ginger), against infection of herpes T virus infection was investigated by Ikemoto et al. (1994) and the drug was found to be protective through the activation of CD8 + T cells. No virucidal or virostatic activity was observed.

Sandeson et al. (2002) studied the bioactivity of ginger extract on adult *Schistosoma mansoni* worms and their egg production under in vitro and in vivo conditions in laboratory mice. Ethyl acetate extract of ginger at a concentration of 200 mgL^{-1} of extract killed almost all worms within 24 hours. Male worms are more susceptible than females. The cumulative egg output of surviving worm pairs in vitro was considerably reduced when exposed to the extract. After 4 days of exposure to 50 mgL^{-1}, the cumulative egg output was only 0.38 eggs per worm pair compared with 36.35 for untreated worms. However, in vivo GE did not show any significant effect on worms or on their egg-laying capacity. Extract of the rhizome of *Zingiber corallium* was shown to be effective in killing the larvae of *S. japonicum cercaria* (Shuxuan et al., 2001)

Anxiolytic-Like Effect

A combination of ginger and *Ginkgo biloba* was studied experimentally in elevated plus maze by Hasenohrl et al. (1996). The investigation evidently proved the anxiolytic effect of ginger is comparable to diazepam. But the action is biphasic; in high dosage it may also have an anxiogenic effect. The known antiserotonergic action of ginger and *G. biloba* is considered to be the responsible factor for the anxiolytic-like action.

Effect on Liver

Yamaoka et al. (1996) investigated a kampo medicine for its action in augmenting natural killer (NK) cell activity. This medicine isused in Japan to treat chronic hepatitis, distress, and fullness in the chest and ribs. Ginger is one of its seven ingredients, and studies showed that extracts of ginger and *Zizyphus jujube* and the other three components augmented NK cell activity.

Sohni and Bhatt (1996) studied the activity of a formulation in hepatic amebiasis and in immunomodulation studies. The ingredients in the formulation were *Boerhaavia diffusa*, *Tinospora cordifolia, Berberis aristata, Terminalia chebula,* and *Z. officinale*. The formulation showed a maximum cure rate of 73 percent. Humoral immunity was enhanced. The cell-mediated immune response was stimulated as observed in the leukocyte migration inhibition test. Bhandari et al. (2003) studied the effect of an ethanolic extract of ginger on country-made liquor (CML)-induced liver injury in rats. Hepatotoxicity was induced by administering CML (3 ml/100 g/day in two divided doses) and corn oil (1 mL/100g/day in a single dose) orally for 21 days. The administration of ginger ethanolic extract (200 mg/kg) orally from day 15 to 21 along with CML produced significant lowering of serum AST, ALT, ALP, gamma-GTP, and tissue lipid peroxide

levels. The results were comparable to silymarin (25 mg/kg orally). The study thus showed that several mechanisms are involved in the reduction of liver damage by ethanolic GE.

Other Properties

Dedov et al. (2002) showed that gingerol functions as an agonist of the capsaicin-activated vanilloid receptor (VR1). (6)-Gingerol and (8)-gingerol evoked capsaicin-like intracellular $Ca2+$ transients and ion currents in cultured dorsal root ganglion neurons. These effects of gingerols were blocked by capsazepine, the VR1 receptor antagonist. The potency of gingerols increased with the increasing size of the side chain. The authors concluded that gingerol represents a novel class of naturally occurring VR1 receptor agonists that may contribute to the medicinal properties of ginger.

Kamtchouing et al. (2002) evaluated the androgenic activity of ginger in male rats. The aqueous extract significantly increased the relative weight of the testis, serum testosterone level, testicular cholesterol level, and epididymal alpha-alpha-glucosidase activity. The effects indicate the androgenic activity of ginger.

Ginger has also been shown to have an antivertigo activity similar to dramamine (Tyler, 1996). A significant decrease in induced vertigo indicated a possible inhibitory action of ginger on the vestibular impulses to the brain (Grotved and Hentzer, 1986),

Ginger has a strong antitussive effect, and helps to dispel bronchial congestion. A cup of hot ginger tea containing one-quarter tablespoon of ginger mixed with honey relieves congestion and has been reported to be more effective, when a cough mixture proved to be ineffective (McCaleb, 1996). Both gingerol and shogaol possess an antitussive property; shogaol is more potent (Miller and Murray, 1998).

Toxicity

Normally, ginger is a safe drug without any adverse reactions and has a wide range of utility. Paradoxically, it is included in the list of plants containing poisonous principles (Chopra et al., 1958) because of its oxalic acid content.

Ahmad et al. (2002) tested ginger oleoresin on adult Swiss mice. The oleoresin exhibited a marked action on the central nervous system. A single dose up to 0.5 g/kg resulted in vasodilatation, activeness, and alertness in animals. A dose up to 3 g/Kg was nonlethal, whereas doses above that resulted in mortalities, an abnormal gait associated with abdominal cramps, and gastric irritation. The LD50 is 6.284 g/kg. Death may be due to the direct action on the CNS resulting in respiratory failure as well as circulatory arrest.

Purification

Fresh and dry ginger are used as such and are generally not subjected to any purification methods. Yet there are some references to purification in Ayurvedic descriptions. Methods of purification for dry ginger and fresh juice are available from *Arogyakalpadruma* (an Ayurvedic text that concentrates on pediatrics). Purification of ginger may therefore be intended only for pediatric use, that is, to reduce the potency and pungency for infant use.

The method of purification of ginger involves immersing it in limewater for 1-1/2 hour, washing with sour gruel (or sour rice washings), and drying in bright sunlight.

The expressed fresh juice is to be kept undisturbed until the particles settle down. The supernatant alone is then poured into a red-hot iron vessel and thus becomes purified.

Ginger in Home Remedies (Primary Health Care)

1. Decoction of dry ginger together with jaggery (a form of crude sugar) relieves dropsy (an excessive accumulation of watery fluid in any of the tissues or cavities of the body.
2. Hot decoction of dry ginger is stomachic and digestive and relieves cough, asthma, colic, and angina pectoris.
3. Ginger juice with an equal quantity of milk is indicated in ascitis (abnormal accumulation of fluid in the peritoneal cavity). The ghee prepared with 10 times the ginger juice also has the similar effect.
4. Warm juice of ginger mixed with gingelly oil, honey, and rock salt is a good eardrop in otalgia (pain in the ear).
5. Paste of ginger made with *Ricinus* root decoctions is cooked over red-hot coals after covering with mud, and the juice is collected with this special method (*Pudapaka swarasa*). This juice, if taken along with honey, cures the symptoms of rheumatic fever.
6. Juice of ginger with old jaggery cures urticaria (nettle rash) and is digestive.
7. Ghee prepared with ginger juice, ginger paste, and milk relieves edema, sneezing, ascitis, and indigestion.
8. Ginger juice along with lemon juice and mixed with little rock salt powder is effective in flatulence (presence of excessive gas in the stomach and intestine), indigestion, and anorexia (having no appetite for food).
9. Dry ginger is effective in all symptoms due to the ingestion of jackfruit.
10. Ginger immersed in lime water (calcium hydroxide) and applied to the skin can remove warts.
11. Ginger juice and clear lime water mixed and applied cures corn (a small painful horny growth on the sole of the foot or the toes).
12. Ginger juice and honey (from *Apis indica*) in equal quantities is hypotensive in action, and of course is excellent for relieving cough.
13. Application of ginger juice around the umbilical region is good for curing diarrhea.
14. Purified ginger juice, onion juice, and honey in equal parts if taken at bedtime is anthelmintic in action.
15. Dry ginger pounded in milk and then the expressed juice used as a nasal drop relieves headache and associated symptoms.
16. Dry ginger powder, tied in a small piece of cloth, if massaged after heating will cure alopecia (loss of hair, a condition in which the hair falls from one or more round or oval areas leaving the skin smooth and white) and promote hair growth.
17. Dry ginger paste, taken along with milk is indicated in jaundice, and when applied to the forehead relieves headache.
18. Dry ginger boiled in buttermilk is antipoisonous and is given for internal use.
19. Dry ginger paste taken internally with hot water and applied over the whole body is the antidote for the toxic effects of *Gloriosa* (spider lily).

20. In snake poisoning, the external application with ginger over the bite wound and cold body parts and the drinking of ginger decoction is said to be effective.
21. Ginger juice is an excellent adjuvant for the medicinal preparation *Vettumaran* (an ayurvedie preparation), which is indicated in such conditions as fever, chickenpox, and mumps.
22. Ginger juice is used in the purification of cinnabar (HgS) before incinerating it to lessen its toxicity and to make it biologically acceptable.

Ginger forms a component of a large variety of Ayurvedic preparations. However, the following cautions are indicated. Ginger has *ushna* (hot) and *tikshna* (intense-pungent) attributes, and hence is contraindicated in anemia, burning sensation, calculus (a concretion formed in any part of the body, usually by compounds of salts of organic or inorganic acids), hemorrhage of liver, leprosy, and blood diseases. Its consumption should be reduced or avoided in the hot summer season. Green ginger should not be used for medicinal purposes according to Nadkarni (1976). Ginger is also used in homeopathy and the Unani systems of medicine. In the former it is used to treat albuminemia (the presence of serum albumin and serum globulin in the urine), bad breath, dropsy, and retension of urine. In the Unani system, ginger is used for its anthelmintic, aphrodisiac, carminative, digestive, and sedative properties; in headache, lumbago, nervous diseases, pains, and rheumatism; and for strengthening of memory (Nadkarni, 1976).

Ginger is also used in veterinary medicine in horses and cattle for rheumatic complaints, and as an antispasmodic, and a carminative in atonic indigestion (Blumenthal, 1998; Pakrashi and Pakrashi, 2003).

Ginger in Chinese and Japanese Systems of Medicine

Ginger rhizome is an important drug in the Chinese and Japanese systems medicine (known as *sheng jiang* in Chinese [Mandarin] and *shokyoin* in Japanese). In fact, in Chinese medicine fresh and dry ginger are used for different clinical purposes. Generally, fresh ginger (*Zingiberis Recens rhizoma-Sheng Jiang*) is used as an antiematic, antitussive, or expectorant, and is used to induce perspiration and dispel cold. Dried ginger (*Zingiber Rhizoma, gan Jiang* in China) is used for stomachache, vomiting, and diarrhea accompanied by cold extremities and faint pulse (Benskey and Gamble, 1986). In China ginger dried in the sun as well as heated and dried in pans with or without hot sand is used. In Japanese medicine ginger dried in the sun (*shokyo* in Japanese) as well as steamed dried (*kankyo* in Japanese) are used differently.

In Chinese Materia Medica (Benskey and Gamble, 1986) ginger is indicated to have the following functions and clinical uses:

- Releases the exterior and disperses cold; used for exterior cold patterns.
- Warms the middle burner and alleviates vomiting—used for cold in the stomach, especially when there is vomiting.
- Disperses cold and alleviates coughing, used for coughing from acute wind, cold cough patterns, and chronic lung disorders with phlegms.
- Reduces the poisonous effects of other herbs—used to detoxify or treat overdoses of other herbs such as *radix, aconity carmichaeli praeparata (Fuzi)* or *Rhizoma Pinelliae Ternate (Banxia).*

- Adjusts the nutritive and protective *Qi*—used for exterior deficient patients who sweat without an improvement in their condition.

In the *Divine Husbandman's classic of the Materia Medica* of China, ginger rhizome is indicated to have the following functions and chemical uses: "Vomiting, diarrhea, light-headedness, blurred vision, and numbness in the mouth and extremities. In advanced cases, there can be premature atrial contractions, dyspnea, tremors, incontinence, stupor, and a decrease in temperature and blood pressure."

Functions and Clinical Uses

- Warms the middle body (stomach region) and expels cold: used to warm the spleen and stomach, especially in deficiency cold patterns with such manifestations as pallor, poor appetite, cold limbs, vomiting, diarrhea, cold painful abdomen and chest, a deep, slow pulse, and a pale tongue with a moist, white coating.
- Rescues devastated *Yang* and expels interior cold: used in patterns of devastated or deficient *Yang* with such signs as a very weak pulse and cold limbs.
- Warms the lungs and transforms phlegm: used in cold lung patterns with expectoration of thin, watery, or white sputum.
- Warms the channels and stops bleeding: used for deficiency cold patterns that may present with hemorrhages of various types, especially uterine bleeding. Ginger is used in hemorrhage only if the bleeding is chronic and pale in color and is accompanied by cold limbs, ashen white face, and a soggy, thin pulse.

Major Combinations

- With *Radix Glycyrrhizae Uralensis* (*Gan Cao*) for epigastric pain and vomiting due to cold deficient stomach and spleen.
- With *Rhizoma Alpiniae Officinari* (*Gao Liang Jiang*) for abdominal pain and vomiting due to cold stomach.
- With *Rhizoma Pinelliae Ternate* (*Ban Xia*) for vomiting due to cold-induced congested fluids. Add radix ginseng (*Ren Shen*) for vomiting due to deficiency cold.
- With *Rhizoma Coptidis* (*Huang Lian*) for epigastric pain and distension, dysentery-like disorders, and indeterminate gnawing hunger. The latter is a syndrome characterized by a feeling of hunger, vague abdominal pain, or discomfort sometimes accompanied by belching, distension, and nausea, which gradually culminates in pain.
- With *Cortex Magnoliae Officinalis* (*Hou Po*) for epigastric distension and pain due to cold-induced congealed fluids.
- With *Rhizoma Atractyloids Macrocephalae* (*Bai Zhu*) for deficient spleen and diarrhea. If both herbs are charred, they can be used for bloody stool and excessive uterine hemorrhage.
- With *Fructus Schisandrae Chinensis* (*Wu Wei Zi*) for coughing and wheezing from cold congested fluids preventing the normal descent of lung *Qi.*
- Compared to *Rhizoma Zingiberis Officinalis Recens (Sheng Jiang), Rhizoma Zingiberis officinalis (Gan Jiang)* is more effective in warming the middle burner and expelling interior cold, whereas *Rhizoma Zingiberis Officinalis Recens (Sheng Jiang)* promotes sweating and disperses exterior cold.

Cautions and Contraindications

- Contraindicated in deficient *Yin* patterns with heat signs.
- Contraindicated in reckless marauding of hot blood.
- Use cautiously during pregnancy.

Chinese Healing with Muxibustion: The Ginger Moxa

Moxibustion is a Chinese treatment practice used along with acupuncture for conditions ranging form bronchial asthma to arthritis with amazing success. In moxibustion the leaves of the herb (*Artemesiae vulgaris,* Chinese mugwort) are dried, rolled into pencil-like sticks and burned, and this burning stick is used for the treatment. The ginger moxa is one type of treatment that combines the therapeutic properties of muxibustion with those of ginger. A slice of ginger, 1 to 2 cm thick, is cut and pierced with tiny holes. Dried mugwort leaves are then rolled into a short cone. The ginger disk is placed on the umbilicus of a patient suffering from diarrhea or abdominal pains. The moxa cone is placed on the ginger disk and then carefully lit with a small flame. The burning nugget of moxa and ginger remain on the umbilicus until the patient perspires and the area turns red. New cones are added as the original cones burn down and this continues until 4 to 5 cones are consumed. Ginger moxa also has been proven to be beneficial in the treatment of painful joints (Balfour, 2003).

Ginger in Traditional Medical Care in Other Countries

Ginger is used in primary health care in almost all ginger-producing countries. The most important use to which it is put is to cure indigestion and stomachache. The expressed juice of fresh ginger mixed with sugar or honey is used widely for these purposes.

Conclusion

It may be difficult to believe that a plant has so many diverse properties and medicinal values combined with the properties of a spice. Next to black pepper, ginger is the most widely cultivated and used spice around the globe. Ginger is also the only spice that is extensively used in the manufacture of a variety of sweetmeats and soft drinks. For the Indians it is the *Mahaoushadha* and *Vishwa Bheshaja*—the great cure and the universal medicine, respectively. For the Chinese, it is invaluable as a cure for a variety of illnesses and maladies. Ginger also forms part of the traditional local medical practices of all the ginger-growing countries. Further studies are needed for the validation of the uses to which ginger is currently put, and perhaps new products and new usages may emerge in the years to come.

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15 Ginger as a Spice and Flavorant

K. S. Premavalli

Spices are added to contribute flavor to the bulk foods, which are generally insipid, to increase their acceptability and intake. Flavor is usually used to mean a combination of taste and aroma, but a comprehensive definition is the total effect provided in the mouth when a prepared food is eaten. This includes besides aroma and taste, other perceptions such as pungency, astringency, warmth, and cold. It is essentially these sensations that produce the physiological reactions leading to humeral, hormonal secretions, which in turn give the cues to acceptance or rejection reactions.

Apart from salt (sodium chloride), spices are the most important taste and flavor enhancers. Spices are often used in association with the term *condiments*; both are used indiscriminately and interchangeably. However, for the chef, food technologist, and connoisseur of food, spices and condiments mean different things. Spices are fragrant, aromatic or pungent edible plant products, which contribute flavor and relish or piquancy to foods or beverages. Condiments, on the other hand, are prepared food compounds containing one or more spices or spice extractives, which when added to a food, after it has been served, enhances the flavor of the food (Farrell, 1985). So condiments are compound food additives and they are added after the food has been served. *Seasoning* is another term that is related to both spices and condiments. Seasonings are compound preparations containing one or more spices or spice extractives, which when added to a food, either during its manufacture or in its preparation, before it is served, enhances the natural flavor of the food and thereby increases its acceptance by the consumer (Farrell, 1985). Seasonings are added before or during the preparation of a food, whereas condiments are added after the preparation of the food or after it has been served.

Spices have various effects: they do impart flavor, pungency, and color, and they also have antioxidant, antimicrobial, nutritional, and medicinal functions. In addition to these direct effects, spices have complex or secondary effects when used in cooking, such as salt reduction and improvement of texture of certain foods.

Forms of Ginger Used in Cooking

Ginger is more or less a universal spice, although its use is more predominant in certain countries such as China. Ginger is used in cooking in various forms (Figure 15.1): immature ginger, mature fresh ginger, dry ginger, ginger oil, ginger oleoresin, dry soluble ginger, ginger paste, and ginger emulsion. Essential oil, oleoresin, and other extractives are standardized by the manufacturers to yield the same aromatic and flavorant characteristics of the specific spice. Manufacturers usually determine the ground spice equivalency of the extract before marketing. Spice equivalency of extract is defined as the number of pounds of oleoresin required to equal 100 lb of freshly ground spice in aromatic and

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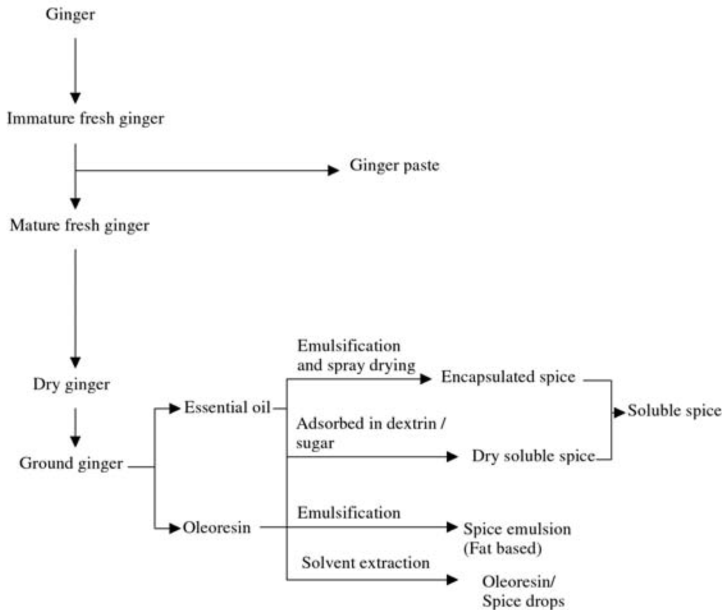

Figure 15.1 Different forms of ginger used in cooking and flavoring.

Table 15.1 Spice extractive equivalencies of ginger

					Federal specifications	
Extractive	*Type*	*g/type equivalent to 1 oz ground spice*	*% extractives on soluble dry edible carrier*	*Minimum % volatile oil in extractive vol./wt.*	*Extract on dry carrier (%)*	*Volatile oil in extract vol/wt*
Ginger (African)	OS	1.134	4	28	4	25
Ginger (Cochin)	SR	1.134	4	28	4	25
Ginger (commercial)	SR	1.134	4	28	4	25

OR, Oleoresin; SR, Superesin (a blend of oleoresin and essential oil).
Source: Farrell (1985).

flavorant characteristics (Farrell, 1985). This weight of oleoresin is added to sufficient salt, sugar, dextrose, or other edible dry material as a carrier to total 100 lb of dry, soluble spice. One pound of such dry, soluble spice is equivalent to 1 lb of the corresponding freshly ground spice. The spice extractive equivalencies of ginger are given in Table 15.1 (Farrell, 1985).

Spices have little value as nutrients, as they are used only in very small quantities. However, when ginger is consumed as ginger beer or ale, the intake also may be significant nutritionally. The nutritional composition of ginger is given in Table 15.2.

Table 15.2 Nutritional composition of ginger

Composition	*USDA Handbook 8-2*[a] *(Ground)*	*ASTA*[b]
Water (g)	9.38	7.0
Food energy (kcal)	347.00	380.00
Protein (g)	9.12	8.5
Fat (g)	5.95	6.4
Carbohydrates (g)	70.79	72.4
Ash (g)	4.77	5.7
Calcium (g)	0.116	0.1
Phosphorus (mg)	148.00	150.00
Sodium (mg)	32.00	30.00
Potassium (mg)	1,342	1,400.00
Iron (mg)	11.52	11.3
Thiamine (mg)	0.046	0.050
Riboflavin (mg)	0.185	0.130
Niacin (mg)	5.155	1.90
Asorbic acid (mg)	—	ND
Vitamin A activity (RE)	15	15

[a]Composition of Foods: Spices and Herbs, USDA Agricultural Handbook 8-2, January 1977.
[b]The Nutritional Composition of Spices, ASTA Research Committee, February 1977.
ND, not detected.
Source: Tainter and Grenis (2001).

Ginger as a Flavorant

Spices are used in food for four basic purposes: (1) for flavoring, (2) for masking or deodorizing, (3) for imparting pungency, and (4) for adding color. In addition, they have ancillary properties such as antimicrobial, antioxidant, and nutritional. However, when spices are used in cooking, complex secondary effects often result, leading to changes such as salt reduction, sugar reduction and improved texture for certain foods. Each spice has one of the basic functions as mentioned previously; in addition, it may perform one or more secondary functions (Hirasa and Takemasa, 1998).

When a spice is used in cooking, its overall quality has to be evaluated. Heating can lead to the loss of essential oil, and hence reductions in overall flavor quality. Because of this adverse effect of heat, the timing of adding a spice is a very important aspect. In addition, the taste of a food often changes in combination with another food or beverage. When one food component enhances the taste of another component, a synergistic effect results. On the other hand, certain tastes are decreased in intensity by combining with certain other food components resulting in a suppressive effect, or "offset effect." The synergistic effect is said to involve a "taste illusion"; the best-known example being the taste enhancement caused by the addition of sodium glutamate. In fact, ginger has a remarkable synergistic effect when it is used in soft drinks. Ginger has a typical earthy smell, but has a refreshing flavor and imparts a "freshness stimulus." Such qualities enhance the freshness of some soft drinks when ginger is added to them (Hirasa and Takemasa, 1998).

The functionally significant components of ginger are primarily its aroma and secondarily its pungency. Many studies have been published on the component chemicals that contribute to its functional qualities. Salzer (1975) has suggested the following determinants of ginger quality:

1. Citral and citronellyl acetate are important co-determinants of odor.
2. Zingiberene and β-sesquiphellandrine are the main components of the freshly prepared oil.
3. These components are converted to ar-curcumene with storage.
4. The ratio of zingiberene +β-sesquiphellandrine to ar-curcumine is indicative of the age of the oil.

However, the sensory evaluation studies conducted subsequently, mainly by Govindarajan and his group (Govindarajan, 1982a,b; Narasimhan and Govindarajan, 1978; Bhagya and Govindarajan, 1979), have given us a much greater insight into the flavor characters of ginger. They have developed the thin-layer chromatographic (TLC) aromagram technique to evaluate the flavor quality of individual components of ginger oil. Such studies have highlighted the importance of compounds such as borneol, α-terpineol, citral, and nerolidol to the total ginger aroma. The ginger aroma should have the proper blend of lemony, camphory, stale coconut (sweet rooty), and flavory aromatic notes; and the full flavor requires the impact of the pungency as well.

Ginger as a Deodorizing Agent

Spices do perform a deodorizing function in food. According to the Weber-Fecher law, the strength of an odor perceived by the sense of smell is proportional to the logarithm of the concentration of the smelled compounds. In other words, the sensational strength perceived with the five senses is proportional to the logarithm of the actual strength of these stimuli. So even if 99 percent of the total smelled compound is eliminated chemically, the sensational strength is perceived as reduced only 66 percent (Hirasa and Takemasa, 1998). In food items spices are employed for masking or deodorizing the remaining 1 percent. Spices differ much in their masking ability. Ginger is, in fact, very weak in this property, having the deodorizing rate of only 4 percent (Table 15.3).

Frequency Patterning Analysis of Ginger

Food technologists have analyzed the use of spices in various countries and in various preparations and developed a frequency patterning analysis of each spice. This analysis gives information on natural trends and the suitability of a spice for a particular type of preparation. The information on ginger is summarized below (Hirasa and Takemasa, 1998).

1. Ginger is more suitable for dishes in Japan and China, Southeast Asia, India, and the United Kingdom, and is less suitable or seldom used in the cuisines of other nations; however, it is most suited for Chinese dishes.
2. Ginger is suitable for meat, seafood, milk, egg, grains, vegetables, fruit, bean seeds and beverages.

Table 15.3 Deodorizing rate of ginger in comparison with other common spices[a]

Spice	*Deodorizing rate (%)*
Ginger	4
Turmeric	5
Cardamom	9
Pepper	30
Star anise	39
Allspice	61
Clove	79
Coriander	3
Fennel	0
Cumin	11
Anise	27
Celery	44
Mint	90
Rosemary	97
Thyme	99

[a]Deodorizing rate—percent of methyl mercaptan (500 mg) captured by methanol extract of each spice.
Source: Tokita et al. (1984).

3. Ginger is suitable for boiled, baked, fried, deep fried, steamed, food dressed with sauce, pickled, and fresh food; however, more suitable for fried and steamed dishes.
4. Ginger is used for imparting pungency to food in Japan, China, Southeast Asia, India, and the United Kingdom; most commonly used in Chinese cooking.

Analysis of the ethnic foods in the United States has indicated that ginger is an important spice in dishes in the following ethnic groups: Armenian, Cambodian, Chinese, Cuban, Danish, Egyptian. Finnish, French, German, Hungarian, Indonesian, Iranian, Korean, Lebanese, Norwegian, Polynesian, Puerto Rican, Russian, Spanish, Swedish, Syrian, Turkish, and Vietnamese (Farrell, 1985).

However, compared to the other major spices (black pepper, cinnamon), ginger is not usually found in seasoning formulations except in Caribbean, Indian, and Chinese seasonings (including spice blends). The spices usually used in Asian cooking formulations are ginger, cumin, coriander, cassia, star anise, galangal, chili pepper, turmeric, clove, and garlic and the leaves of coriander, basil, mint, and celery. Special seasoning masalas often create an almost magical effect on fish and meat dishes. In most such blends, ginger is essential, and in certain dishes ginger is a predominant component (e.g., in ginger chicken, ginger fish, ginger vegetables).

Ginger is an ingredient in many curry powder formulations. The compositions of some typical curry powder blends are provided in Table 15.4 and Table 15.5. The federal specification of curry powder (Sp. No. EES-631 J) contains ginger not less than 3 percent.

Table 15.4 Typical curry powder formulation containing ginger

Ingredients	*Typical range (%)*
Coriander	10–50
Cumin	5–20
Turmeric	10–35
Fenugreek	5–20
Ginger	5–20
Celery	0–15
Black pepper	0–10
Red pepper	0–10
Cinnamon	0–15
Nutmeg	0–15
Cloves	0–15
Caraway	0–15
Fennel	0–15
Cardamom	0–15
Salt	0–10

Source: Tainter and Grenis (1993).

Table 15.5 Curry powder blends as per U.S. specifications

		General-purpose curry formulas			
Freshly ground spice	*U.S. standard formula No. 1%*	*No. 2%*	*No. 3%*	*No. 4%*	*No. 5%*
Coriander	32	37	40	35	25
Turmeric	38	10	10	25	25
Fenugreek	10	0	0	7	5
Cinnamon	7	2	10	0	0
Cumin	5	2	0	15	25
Cardamom	2	4	5	0	5
Ginger (Cochin)	3	2	5	5	5
Pepper (white)	3	5	15	5	0
Poppy seed	0	35	0	0	0
Cloves	0	2	3	0	0
Cayenne pepper	0	1	1	5	0
Bay leaf	0	0	5	0	0
Chili peppers	0	0	0	0	5
Allspice	0	0	3	0	0
Mustard seed	0	0	0	3	5
Lemon peel (dried)	0	0	3	0	0

Source: Farrell (1985). Formula 1 is the U.S. Military specification Mil-C-35042 A. Formula 2 is considered a mild curry. Formula 3 is sweet curry. Formula 4 is a hot curry type. Formula 5 is a very hot pungent Indian-style curry.

Table 15.6 Pumpkin pie spice formulation

Ingredient	*Typical range (%)*
Ground cinnamon	40–80
Ground nutmeg	10–20
Ground ginger	10–20
Ground cloves	10–20
Ground black pepper	0–5

Ginger also forms part of a typical pickling spice combination, ranging from 0 to 5 percent in various brands. Ginger is a component of the popular pumpkin pie spice formulation (Table 15.6). A selection of curry flavor formulations in vogue in various countries is given in Table 15.7.

In many other cases, ginger may not form a complement in the formulation itself, but is added while cooking with, for example, fresh ginger, ginger paste, or ginger powder.

Flavor Properties of Ginger

The aromatic compounds present in ginger contribute to the flavor properties. The pungency and hotness are the principal sensations, which makes it more palatable. Although, generally, volatile compounds contribute to flavor, in ginger, both volatile and nonvolatile constituents are important for imparting the totality of flavor properties such as taste, odor, and pungency. The flavor quality depends on factors such as variety, geographical origin, processing methods, and storage conditions. African ginger has a harsh, strong flavor as compared to the mild, sweet flavor of Jamaican ginger. Peeling of green ginger for drying should be carried out carefully to avoid the loss of volatile oil due to damage of oil cells present below the epidermal layer. Cochin ginger has a softer, richer flavor than African ginger. Flavorant properties of ginger depend both on volatile oil and its nonvolatile fraction. Volatile oil is composed mainly of sesquiterpene hydrocarbons, of which α-zingiberene, β-bisabolene, and ar-curcumene are the major compounds. The major flavor constituents for the pungent principle of ginger have been reported to be 6-, 8-, or 10-gingerol and 6-, 8-, or 10-shogaol. The type of ginger plays a prominent role in the flavor; the method adopted for extraction influences the type of compounds and quality. Bartley and Foley (1994) have reported neral, geranial, zingiberene, alphabisabolene and beta-sesquiphellandrene as major flavoring compounds of Australian ginger, and reported that 6-gingerol is the major contributor to the pungency (Bartley, 1995). Nishimura (1995) studied the volatile compounds responsible for the aroma of fresh rhizomes of ginger, and the compounds with high dilution factor were linalool, geraniol, geranial, neral, isoborneol, borneol, 18-cineol, 2-pinenol, geranyl acetate, 2-octenal, 2-decenal, and 2-dodecenal. Nishimura also reported that linalool, 4-terpineol, borneol and isoborneol contribute to the characteristic aromatic flavors of Japanese fresh ginger. The pungent principle of ginger, 6-gingerol, has been reported to be a potential antioxidant among 10 phenolic compounds separated by TLC.

Ginger as an Antioxidant

Ginger has a high content of antioxidants and has been grouped as one of the spices with good antioxidant activity, with 1.8 index rating (Chipault et al., 1952). This makes

***Table** 15.7* Curry blends and masala mixes having ginger as a component

Spice	*Ingredients*
Japanese seven spice blend	Ginger, red pepper, orange/tangerine peel, dried nori/seaweed flakes, white and black pepper, sesame seed, white poppy seed.
Teriyaki blend and sauce	Soy sauce, sugar, vinegar, sweet wine, ginger, chives, sesame, and fish stock.
Indian curry blends	Basic curry blend consists of coriander, cumin, red pepper, and turmeric. Special blends (e.g., for fish or meat) contain, in addition to the above, ginger, cardamom, clove, cinnamon, mustard, fenugreek, curry leaf, mint, coriander leaf, and celery seed, depending upon the particular blend.
Chat masala	A specific north Indian curry masala blend consisting of green chilies, coriander leaf, coriander, cumin, ajwain, black pepper, ginger, asafetida, and dried mango powder (*amchoor*).
Tandoori masala	It is an aromatic, spicy masala blend used for marinating meat before baking in a tandoor (a type of clay oven). The blend consists of ginger, chilies, cumin, coriander, clove, cinnamon, nutmeg, mace, cardamom, pepper, and bay leaves.
Pickling masala blends	Many different types of pickling blends are in vogue. The important ingredients are mango or lime pieces, chili pepper, ginger, garlic, mustard oil, mustard seed paste, turmeric, sesame seeds, mint, and cilantro. Mango, lime, and mixed fruit pickles are the common ones.
Burmese curry blend	Onion, garlic, ginger, turmeric, fish sauce, chilies, and tamarind.
Malaysian curry blend	Lemongrass, star anise, ginger, galangal, pandan leaf, tamarind, mint, coriander, turmeric, and shallot.
Javanese curry blend	Hot and fiery curry blend consisting of ginger, galangal, black pepper, red pepper, and cassia cinnamon. Apart from these spices, meat and fish stocks and a variety of other ingredients are also used.
Mediterranean spice blend	Cardamom, ginger, cassia cinnamon, black pepper, cumin, fenugreek, lovage, mace, cubeb, long pepper, allspice, nutmeg, rose petals, lavender blossoms, orange blossoms, grains of paradise, chilies, nigella, onion, thyme, rosemary, and turmeric.
French spice blend	White/black pepper, ginger, nutmeg, cloves, mace, cinnamon, allspice, bay leaf, sage, marjoram, and rosemary.
Mozambique (*piri-piri*)	Hot and fiery curry blend consisting of birds-eye-chilies, garlic, ginger, onion, hot paprika, black pepper, olive oil, and lemon juice.
West African spice blend.	Black pepper, red chilies, pink pepper, ginger, cubebs, grains of paradise.
Global spice blend (green)	Leafy spices (basil, cilantro, parsley, mint), green pepper, ginger, garlic and lemon.

Source: Compiled from various sources

it a free radical scavenger (Lee and Ahn, 1985). Sethi and Aggarwal (1957) reported that dried ginger has weak antioxidant properties. The antioxidant property of ginger in comparison with other common spices is given in Table 15.8.

Fugio et al. (1969) studied the antioxidant properties of the chemical components of many spices and found that the shogaol and zingiberene found in ginger exhibited strong antioxidant activities. The antioxidant activity of ginger is dependent on the side-chain structures and substitution patterns on the benzene ring. Twelve compounds showed higher activity than α-tocopherol. Mainly, the antioxidant activity is exerted by gingerol

Table 15.8 Antioxidative activity of ginger in comparison with other common spices against lard

Spice	*Ground Spice POV (mEq/kg)*	*Petroleum ether–soluble fractions POV (mEq/kg)*	*Petroleum ether–insoluble fraction POV (mEq/kg)*
Ginger	40.9	24.5	35.5
Turmeric	399.3	430.6	293.7
Black pepper	364.5	31.3	486.5
Chilies	108.3	369.1	46.2
Cardamom	423.8	711.8	458.6
Cinnamon	324.0	36.4	448.9
Clove	22.6	33.8	12.8
Mace	13.7	29.0	11.3
Nutmeg	205.6	31.1	66.7
Rosemary	3.4	6.2	6.2
Sage	2.9	5.0	5.0

Note: Concentration added was 0.02%.
Source: Saito et al. (1976).
POV: Peroxidation value

and hexahydrocurcumen (Tsushida et al., 1994). Ginger added at a 1 to 5 percent level to soybean oil and cottonseed oil exerted the antioxidant activity during storage and the activity was equivalent to butylated hydroxy toluene (BHT). In general, the increase in concentration of crude gingerol increases the antioxidant activity. However, the thermal stability studies by heating the gingerol component at 165°C for 30 minutes indicated the retention of the antioxidant activity only to 10 percent. Shogaol has been shown to be a compound with high antioxidant activity when a methanolic extract of the spices was further fractionated by ethyl acetate and the activity potency was similar to tocopherol. In animal experiments (Ahmed et al., 2001), the diet containing ginger showed a highly protective effect, against the malathion-induced oxidative damage exhibiting the antioxidant activity. Incorporation of salt and ginger extract to precooked lean beef retarded rancidity during storage, increased the tenderness, and extended shelf life (Kim and Lee, 1995).

Antimicrobial Activity

Although used in food preservation, ginger is not very effective in preventing spoilage of food due to microbial contamination and oxidative degradation. Ginger has only mild antimicrobial activity. The MIC (minimum inhibitory concentration) of ginger against *Clostridium botulinum* (the bacterium that causes severe food poisoning) was shown to be about 2,000 μg/ml. The ginger essential oil was shown to inhibit both cholera and typhoid bacteria. The components of oil responsible for this antimicrobial effect were shown to be gingerone and gingerol (Hirasa and Takemasa, 1998). Other studies reporting the antimicrobial properties of gingerols are in relation to *Bacillus subtilis* and *Escherichia coli* (Yamada et al., 1992) and *Mycobacterium* (Galal, 1996; Hiseradt et al., 1998).

Ginger stimulates appetite, acts as an antioxidant, antimicrobial, and antiflatulant, and hence has a tremendous use in processed food products. Ginger has occupied the

pride of place in many food products such as, for example, masala powders, curry mixes, ready-to-eat foods, and pastes.

Lists of processed foods, processed foods with specific actions, manufactured products, and a selection of dishes with ginger are provided in Appendix 15.1.

Appendix 15.1

Processed foods containing ginger

	Processed foods	*Concentration*	*Reference*
1.	Plum appetizer	1.5% ginger extract	Barwal and Sharma (2001)
2.	Cake	ginger	Donovan (2001)
3.	Chicken feet Jokpyun	0.1% ginger	
4.	Apple-ginger–based squash	10% ginger	Lal et al. (1999)
5.	Baby food	ginger	Theuer (2000)
6.	Beverage	ginger	Edjeme and Stapanka (1999)
7.	Bread	ginger	Ludewig et al. (1999)
8.	Fragrant beef	Ginger	Feng and Cai (1998)
9.	Wooung kimchi	1.3% ginger	
10.	Chicken patties	Ginger	Nath et al. (1996)
11.	Semidry fish sausage	0.1% ginger	Joshi and Rudhrashetty (1994)
12.	Meat pickle	10% ginger	Dhanapal et al. (1994)
13.	Pickle	ginger	Sachdev et al. (1994)

Processed foods containing ginger with specific actions

Food Products	*Action*	*Reference*
Meat and meat products	Tenderizing	Naveena and Mandiratta (2001a)
	Antioxidant	
	Antimicrobial	
Chicken meat	Antioxidant	Naveena et al. (2001)
	Antimicrobial	
Chicken meat	Tenderizing	Naveena and Mandiratta (2001b)
Sheep meat	Tenderizing	Mandiratta et al. (2000)
	Antioxidant	
Rape seed oil	Antioxidant	Takacsova et al. (1999)
Infant food	Reduce gastrointestinal reflux	Theuer (2000)
Beef patties	Antioxidant	Mansour & Khalil (2000)
Meat patties	Antioxidant	Abd-El-alim et al. (1999)
Ready-to-serve (RTS) tomato juice	Increased flavor and taste	Manimegalai et al. (1996)
Meat products	Superior sensory quality	Syed-Ziauddin et al. (1996)
Lean beef cooked	Antioxidant	Kim & Lee (1995)
Korean cereal product	Antioxidant	Lee and Park (1995)
Buffalo meat	Antimicrobial	Syed Ziauddin et al. (1995)
Soybean oil, cottonseed oil	Antioxidant	Eun and Myung (1993)

Manufactured products containing ginger

Masalas

Meat
Tandoori chicken
Chicken
Garam
Channa
Instant khara bath
Kitchen king
Chat
Tea
Gobi manchurian
Pav bhajhi
Fish
Kabab
Chole
Biryani/pulav
Rajmar
Stuffed vegetable
Rajmar

Pickle and Chutneys

Ginger pickle
Mango-ginger pickle
Ginger thokku
Spice-up-tomato chutney
Red chilli chutney
Onion chutney
Mango-ginger pickle

Sauces

Chinese chili sauce
Stromy sauce—chill tomato
Manchurian
Schezuan hot

Powder and Paste

Dry ginger powder
Ginger garlic paste
Ginger paste

Mixes/Ready-To-Eat Products

Butter chicken mix
Tikka gravy
Paneer makanwala
Veg jawa mix
Shahi gravy
Channa gravy
Chicken kolapuri mix
Yellow curry paste

Manufactured products containing ginger

Chicken moghlai mix
Chole gravy mix
Gobi Manchurian mix
Navaratna kurma ready-to-eat (RTE)
Mixed vegetable curry (RTE)
Pavbhaji mix
Veg pulav
Instant kara bath

Others

Ginger biscuits
Ginger and mint
Ginger fresh (mouth freshener)
Oriental stir fry

Sources: Compiled from various sources.

Selection of dishes where ginger is used as a spice and flavorant

Nonvegetarian

Ginger chicken
Ginger fried chicken
Chicken pulao
Mutanjan
Tash kabab
Mutton vindaloo
Mutton chops with curd
Mutton curry
Mince pie
Masala liver
Minced fish
Mallai curry
Fish kababs
Fish roast

Vegetables

Spicy vegetable pie
End of the month pie
Cauliflower in ginger
Cauliflower-ginger Manchurian
Potatoes and aubergines with ginger
Mushroom-ginger Manchurian
Sweet and sour ginger curry
Spicy besan pakories
Ginger pachadi
Sindhi channa
Ginger pakories
Ginger dip

Selection of dishes where ginger is used as a spice and flavorant

Ginger sweets and desserts

Ginger preserve
Ginger candy
Crystallized ginger
Potato-ginger halwa
Quick ginger pudding
Ginger-custard pudding
Gingerbread pudding
Crisp fruit pudding
Ginger refrigerated cake
Oriental sundae
Ginger snow
Gingersnaps
Brandysnaps
Gingered pears
Baked semolina pudding with ginger sauce
Pumpkin pie
Creamy custard flan
Carrot fruit custard
Ginger muffins
Apple ginger tarts
Ginger crispies
Ginger sugar puffs
Ginger cake doughnuts

Ginger cakes, breads, biscuits

American hot cheese cakes
Ginger Dundee cake
Ginger pastry
Ginger cake (eggless)
Ginger preserve cake
Ginger sponge with treacle
Date-ginger cake
Fruit and nut bars
Ginger dessert cake
Ginger fruit cake
Ginger nuts
Simple ginger biscuits
Frosted ginger cake
Fruit gingerbread
Lemon gingerbread
Grantham gingerbread
Grasmore gingerbread
Spice loaf
Sindhi masala bread
Ginger bread nuts

Selection of dishes where ginger is used as a spice and flavorant

- Ginger rock bun
- Canadian gingerbread

Ginger jams, pickles, chutneys

- Apple ginger jam
- Tomato marmalade
- Beetroot jam with ginger
- Parvel preserve with ginger
- Hot chili pickle
- Ginger-prawn pickle
- Lime-ginger pickle
- Ginger mango pickle
- Ginger-garlic pickle
- Ginger-onion pickle
- Apple pickle
- Mixed fruit pickle
- Ceylonese mixed pickle
- Mustard-mango pickle
- Mutton pickle
- Dry fruit pickle
- Plantain stem pickle
- Prawn belches
- Sour lime pickle
- Beetroot pickle in water
- Tomato chutney
- Ginger chutney
- Ginger pineapple chutney
- Plum chutney
- Ripe tomato chutney
- Mango bud chutney
- Sweet pumpkin chutney
- Hot mango chutney
- Sweet mango chutney

Ginger soft drinks, beverages

- Melon-ginger cocktail
- Ginger wine
- Rich ginger wine
- Lemon-ginger punch
- Orange-ginger punch
- Raspberry-ginger punch
- Cool ginger mint
- Hot lemon ginger
- Ginger pop
- Ginger beer
- Gingerade
- Ginger tonic

Ginger-orange milkshake
Pineapple-ginger cocktail
Ginger punch
Ginger-vegetable soup
Ginger-Chinese soup
Ginger-mutton soup
Ginger-chicken soup
Ginger-seafood chowder soup
Marwari tea
Kothamalli (coriander) tea

Source: Compiled from various sources.

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16 Yield Gaps and Constraints in Ginger

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Ginger is an essential requisite of the cuisines of most countries, and it has also played an important role in traditional medicine from very early times. Over the years, ginger registered a positive growth rate in area, production, and productivity of 260, 760, and 140 percent, respectively, from 1970–1971 to 1998–1999. The export demand continues to be high, registering a 4.05 percent growth in export quantity and 10.15 percent in export value (Rajesh et al., 2002). In spite of the increased production and productivity, Indian ginger is costly (US $1600 to $1700 per ton) as compared to the Chinese and Nigerian product (US $1300 and $1050 to $1100 per ton, respectively), demanding cost effectiveness to be competitive in the international trade. An analysis of the realizable productivity and the constraints for achieving potential productivity is an essential step to bridge the gap.

Yield Gaps

The yield of ginger has been reported to vary greatly depending on cultivars, climate, soil factors, planting time, and maturity at harvest. Prentice (1959) reported that the average yield in Jamaica was 1,570 to 2,250 kg/ha of dry ginger. Maistre (1964) found that on the southwestern coast of India, the yield ranged from 9 to 11 tons of green ginger per hectare, which gave 1.3 to 1.8 tons of dry ginger per hectare. On an all India basis, the average yield of green rhizomes varied from 7 to 10 t/ha, although yield up to a maximum of 40 t/ha has been reported. Comparative evaluation of 20 cultivars of Indian and exotic ginger at the Central Horticultural Research Station, Ambalavayal, India, revealed that most of the cultivars gave yields considerably higher than reported earlier. The green rhizome yield varied from 7.6 t/ha in the cultivar Thodupuzha to 36.5 t/ha in cultivar Rio de Janeiro (CSIR, 1976). Bendall and Daly (1966) stated that the normal yield in Queensland for an early harvest crop for preserved ginger was approximately 10,000 kg/ha green rhizomes. They opined that there was ample scope for increasing the average yield since experimental yields of 37,000 kg/ha of green ginger for early harvest and 59,000 kg/ha for a late crop had been reported. Nybe (1978) observed a significant difference among 25 cultivars of ginger in green rhizome yield that ranged from 2.74 t/ha (Arippa) to 28.56 t/ha (Nadia) and the dry rhizome yield that ranged from 1.13 t/ha (Uttar Pradesh) to 6.45 t/ha (Nadia). The productivity is much lower in other countries compared to that in China. The average productivity in some of the ginger-producing countries is given in Table 16.1. The present productivity figures indicate the wide gap existing between national productivity vis-à-vis the yield achieved in experimental yield trials and by high tech farmers. An assessment of the potential for a productivity increase

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Table 16.1 Average production and productivity of ginger (2001)

Country	*Area (ha)*	*Production (tons)*	*Productivity (t/ha)*
China	20,700	240,000	11.6
Bangladesh	7,290	42,000	5.8
India	80,000	275,000	3.4
Indonesia	10,600	77,500	7.3
Jamaica	180	620	3.4
Korea (Republic of)	4,255	7,950	1.9
Nepal	1,400	4,200	3.0
Nigeria	174,000	90,000	0.5
Philippines	5,000	29,000	5.8
Sri Lanka	2,000	8,000	4.0
Thailand	12,000	30,000	2.5
United States	150	7,350	49.0

at the national level revealed that the national average productivity remains at 2,421 kg/ha of dry rhizome; progressive farmers have produced a yield up to 5,500 kg/ha, whereas in research stations it is 8,250 kg/ha. The average productivity reported from the Philippines is 7,470 kg/ha (Sivaraman and Peter, 1999). In China reports indicated a fresh ginger yield of 60 to 70 tons in well-maintained fields. Xianchang et al. (1995) reported a yield level of 70.7 tons of fresh ginger under black film mulch. Under the recommended fertilizer levels, Chinese reports indicated a yield level of over 48 t/ha. A combination of fertilizer, irrigation, black film mulch, plant protection, and cultural operations can surely push up the yield level to 75 t/ha or more.

Constraints

Although Indian ginger is well known for its intrinsic qualities, high productivity is not being realized in commercial cultivation due to severe constraints, which can be broadly classified as:

- Technological factors
- Socioeconomic factors

Technological Constraints

Ecological Specification

With the environment being a major factor influencing productivity in ginger, demarcating areas having ideal soil and climatic factors to achieve high productivity should be considered before undertaking large-scale cultivation. Considering the growing demand, there is a potential for area expansion in Arunachal Pradesh and Andaman and Nicobar Islands in India, which is to be undertaken, based on soil suitability studies. Ginger cultivation in unsuitable land and unfavorable ecological situations is a major reason for low yield and low productivity.

Nutrition and Crop Management

Cultivation of ginger is popular in high ranges, plains, and in reclaimed paddy fields in varied soil types and in cropping systems such as an intercrop in plantations. Information is lacking on the nutritional requirement for the major production areas or soil types and cropping systems.

Ginger is a soil-exhaustive crop, which demands a high amount of humus and shows good response to added nutrients. Standardizing the nutritional requirement of the crop based on uptake studies and soil test data will make the recommendations meaningful and cost effective. The present fertilizer schedules are blanket recommendations without taking into consideration the inherent fertility status of the soils.

A variable response to added manures was observed depending on the region and variety. Application of 30 t/ha of farmyard manure (FYM) has been the standard practice to maintain the optimum organic matter status. Under virgin soils, 10 tons of FYM and 7.2 tons of green leaf mulch per hectare produced an economic crop of ginger. Application of FYM alone at 48 t/h resulted in highest returns, profit, and benefit:cost ratio, indicating the suitability of ginger for investing in organic farming (Chengat, 1997). The Kerala Agricultural University recommends 75 kg N (nitrogen), 50 kg P_2O_5 (phosphorous), and 50 kg K_2O (potassium)/ha as split applications. The response to higher doses of 150 kg N, 75 kg P_2O_5, and 150 kg K_2O/ha have been reported that corroborates the need for location-specific fertilizer recommendations. Studies on the influence of micronutrients such as boron at 50 kg/ha increased the vigor of plants, yield and reduced the incidence of soft rot disease. This indicates the need for micronutrient studies in understanding their role in augmenting yield and imparting resistance.

The inherent productivity potential of ginger cultivars varies and to realize maximum productivity, a matching fertilizer application is needed. For the cultivar Rio de Janeiro, a highly productive cultivar, application of 100 kg N, 100 kg P_2O_5, and 200 kg K_2O/ha was reported to produce a bumper crop.

Shade-response studies have proven that ginger is a shade-loving plant giving higher yield at 25 percent shade. Cultivation of ginger as an intercrop among plantations such as coconut, arecanut, and the early stages of rubber are in vogue. Uptake studies showed that the fertilizer requirement of intercropped ginger will be 10 to 50 percent higher than that of a pure crop (Bai, 1981). The need for an increased fertilizer requirement has been confirmed wherein application of 150 kg N, 100 kg P_2O_5, and 100 kg K_2O/ha gave a maximum net profit for ginger raised as an intercrop in coconut (Joseph, 1992). But in actual practice, farmers apply much higher rates of fertilizers, opting for the dose for highest productivity rather than the economic optimum.

Heavy mulching with green leaves immediately after planting repeated twice after top dressing and earthing up is an essential practice in ginger to step up yield. Due to the paucity of green leafy material, this practice is often neglected, restricting it to the first mulching alone. Raising green manure crops such as daincha and cowpea in the interspace of ginger beds will provide green leaves for a second mulching, which needs to be popularized. When ginger is intercropped in a coconut garden, the mulch requirement can be reduced substantially from 30 to 15.0 t/ha without affecting yield (Babu, 1993). These experimental findings have not found their way into actual practice, resulting in unwanted expenditure on the production side.

Although ginger is mainly raised as rain-fed crop from May to February, off-season production during the summer months is also practiced. Under such systems, proper

irrigation together with nutrition is a critical factor deciding productivity, and as such scheduling of irrigation and nutrition needs to be prioritized.

Varieties

Exclusive vegetative propagation in ginger limits the variability in the germplasm. The cultivated types are mainly land races, and a few high-yielding varieties released are not popular with farmers due to inadequate multiplication and distribution of seed material. In cultivation, it is found that the inherent yield potential of cultivars is often suppressed by the incidence of diseases like soft rot and bacterial wilt, which result in heavy crop losses. None of the varieties is resistant to these diseases. A lack of seed set under natural conditions is a limitation for outbreeding strategies. Hence developing resistant/tolerant varieties has to depend upon biotechnological approaches such as in vitro creation of a somaclonal variability or through genetic engineering.

Screening of ginger cultivars for shade tolerance indicated that the responses vary, and the cultivar Himachal Pradesh adapted well to all situations (0 to 75 percent shade) (Varghese, 1989). The performances of varieties are reported to vary depending on the locations and cropping systems, and choosing ideal varieties for each situation can boost the yield. Crop physiological studies reported from China (see Chapter 2 of this volume) indicated that yield declines when ginger is grown in full sunlight. For yield maximization ginger needs about 30 to 40 percent shade. Shade also reduces the incidence of leaf spot disease. Ginger grown in low-lying areas such as paddy fields are subjected to intense light flux, which results in decline in the photosynthetic rate and subsequently rhizome development and final yield; moreover, leaf spot disease is also aggravated.

Pests and Diseases

Soft rot and bacterial wilt are major diseases affecting ginger, causing huge crop losses. *Phyllosticta* leaf spot and pests such as the shoot-borer cause minor damages. An analysis of the production constraints in the high range zone of Wynad, India, indicated that bacterial wilt is a major problem affecting 91 percent of the ginger crop, causing a loss of Rs. 9,029 per hectare, which comes to 69 million rupees from an area of 7,648 ha (Babu et al., 2003). The soil-borne and seed-borne nature of soft rot and bacterial wilt makes effective control difficult. A lack of resistant varieties makes the farmers opt for chemical control, which often becomes futile after initiation of symptoms in the field and leaves considerable chemical residues in the rhizome. The increasing demand for organic spices and spices with a zero residue level underscores the need to evolve an IPM strategy to ensure the sustainability of "clean spice" production. Soil solarization, healthy seed selection, seed treatment with *Trichoderma* spp. and its soil application along with organics were found to be effective in controlling soft rot disease. Spraying *Dipel* (0.3 percent), a formulation based on *Bacillus thuringiensis*, against the shoot-borer deserves attention and needs popularization.

Socioeconomic factors

Social and economic backwardness, poverty and illiteracy among farmers and price fluctuations are major impediments in achieving high productivity of ginger. Since more than 80 percent of the farmers are in small and marginal groups, any production technology must be scale neutral or skewed towards this sector. Calculation of the

inputwise cost of cultivation of ginger in the high ranges of Wynad, India, indicated that human labor accounted for 37 percent of the operational expenses. Cultivation was found to be labor intensive as well as capital intensive with an operational expense of Rs. 54,200/ha. An assessment of the acreage ratio of ginger in Kerala, India, revealed that it has been declining continuously, which is truly indicative of the relative profitability. The wage rate has increased by about 400 percent in Kerala between 1980 and 1995 (Babu et al., 2003). The fact that Kerala has a high wage rate structure coupled with a highly trade-unionized labor force is compelling farmers to switch over to less labor intensive perennial crops. This may be a reason for the present reduction in the relative share of area (21 percent) and production (23 percent) in Kerala against 90 percent of the Indian production during post-independent years.

The problem of price fluctuations is evident in ginger. One kilogram of dry ginger fetched Rs. 22/kg during 1990–1991, it soared up to Rs. 52.50/kg in 1994–1995 and was Rs. 64/kg in 1999–2000. But the farm-gate price during 2000–2001 crashed to Rs. 8.33/kg. Losses due to falling prices have affected 36 percent of the growers, and the economic loss worked out to 19 million rupees from an area of 7,648 ha in the high ranges of Wynad, India (Babu et al., 2003).

Negligible processing of harvested ginger rhizomes at the producers' level has added to such price fluctuations. There is not even large-scale drying even though dried rhizomes fetch a better and more stable price. Strong postharvest research on product development and diversification is inevitable. The market for value-added products like volatile oil, oleoresin, and its encapsulated forms has been steadily increasing over the years due to microbial problems associated with whole dried ginger. In Sri Lanka, farm-level extraction of ginger oil is widespread. Production and sale of freshly harvested green ginger in an oligopsony market dominated by a few private traders cannot protect the interest of farmers, necessitating product development that can be easily adopted at the producers' level. Different types of ginger preserves such as ginger in brine, ginger in syrup, and ginger candy are products that can be tried at the producers' level. The export potential for these items has to be taken advantage of, since ginger in brine is a major item imported by Japan (Sreekumar, 2001). The Buderim ginger company in Queensland, Australia, makes more than 100 products from fresh ginger. In China, Thailand, and Taiwan, for example, a wide variety of fresh ginger products are produced, mostly as home-level industries, whereas product development and diversification are neglected areas in countries such as India, Bangladesh, Nepal, Bhutan, and Nigeria. The philosophy of value addition and product development should be utmost in the minds of planners, developmentalists, and scientists to save the cultivation of ginger from a devastating decline.

The trade names Cochin ginger and Calicut ginger, produced and exported from Kerala, India, are marks of intrinsic quality named after the two ginger trading centers on the Malabar coast of India, which are to be protected under geographical indications rights and developing a brand name can help in trade promotion.

Strategies to Bridge the Gap

- Enhancement of potential and realizable productivity through an integrated system of cultivation using high-yielding and resistant varieties, plant nutrient management, production technology suited to different agroecological situations

and cropping systems, and need-based plant protection measures are future areas of increasing relevance in boosting ginger production.

- Resistance breeding against devastating diseases such as soft rot and bacterial wilt incorporating genes from wild relatives using biotechnological tools or through the exploitation of somaclonal variations.
- Enhancement of quality and evolving and popularizing very efficient post-harvest handling techniques including product diversification.
- Tailoring production to meet export needs and international requirements such as clean ginger.
- Organic ginger production is to be promoted as a large quantity of immature ginger and fresh ginger are being used for the production of fresh ginger products. Popularization of products such as ginger beer, ginger ale, ginger squash, and ginger tea among consumers can help to create demand for ginger, which in turn will boost the ginger economy.

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17 Other Economically Important *Zingiber* Species

M. Sabu and Dave Skinner

The genus *Zingiber*, the type genus of the family Zingiberaceae, forms an important group of the order Zingiberales. The word ginger refers to the edible ginger of commerce, *Zingiber officinale*. Ginger is also the common term for the members of the ginger family, Zingiberaceae, which includes the many other species of *Zingiber* besides *Z. officinale,* worth growing as ornamentals, while some are valuable medicines. Many species are grown in the garden as ornamentals. They bear showy, long-lasting inflorescences and often brightly colored bracts and floral parts; they are widely used as cut flowers in floral arrangements. The gradual changing of the inflorescence bracts from green to yellow to various shades of red and finally to deep red adds to the beauty of the inflorescence. Many wild species have great ornamental potential. Some of them are good foliage plants due to their arching form and shining leaves. Leaves exhibit shades of light green to dark green, variegated with yellow and white, or with deep purple undersurfaces. Many of the inflorescence bracts, when squeezed, release a thick juice with the form of mucilage, or a shampoo-like substance. Hence, those gingers having this mucilage in their bracts are called shampoo gingers. The following is a brief description of the *Zingiber* species having economic importance as local medicine, as spice, or as ornamental plants.

General Features

The plants are perennial, medium-sized herbs with stout rhizomes. Most of the species produce the inflorescence on a separate shoot directly from the rhizome, at the tips of a short or long peduncle. In a few species, the inflorescence develops at the tips of the leafy shoots (*Z. capitatum*). The inflorescence possesses a number of closely overlapping bracts, each bearing a single flower. The flowers are peculiar in that the lateral staminodes are fused with the labellum, whereas in other genera they are free, highly reduced, or absent. The anther is unique in having a curved beak or horn-like appendage. This genus resembles other genera such as *Alpinia, Amomum, Hedychium,* etc., and so on in the vegetative stage, but it can be distinguished from others because it has a pulvinus at the base of the petiole. The rhizome and pseudostem of *Zingiber* spp. are fleshier when compared with *Alpinia*, *Amomum,* and so on. The duration of the flowers in the genus is very short and differs from one species to another, but it is constant for each species. In *Z. zerumbet*, the flowers open from morning until evening in an inflorescence.

The flowers are usually cross-pollinated. The pollination in the species of *Zingiber* is rather simple because of the specially modified anther structure and nature of staminodes. An insect visiting a flower first lands on the labellum and moves to the throat of the corolla tube. When the insect's front portion pushes the base of the anther, the anther bends forward and dusts the pollen grains on the backside of the insect. As it bends

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forward, the stigma protrudes and arches through the long anther crest and presses against the proboscis of the insect. Thus, pollen grains from other flowers deposited on the back of the insect stick to the stigma, and pollination is effected.

Zingiber mioga Roscoe

Z. mioga (myoga ginger or Japanese ginger) is a perennial woodland species, endemic to Japan, where it is most popular. It is grown for its edible flowers and young shoots, both of which are used extensively as vegetables. The flowers are mostly sterile, and the propagation of this species is through rhizome division, as in the case of true ginger. The species is unique in having a pentaploid chromosome number of $2n = 55$. In Japan, it is widely grown as a seasonal crop, and the flower bud-producing season is summer. Forced production in glass houses and heated polyhouses occurs during the winter months, and the product attracts a premium price (Sterling et al., 2003). From Japan, myoga cultivation has spread to China, Vietnam, Taiwan, Thailand, Australia (Queensland), and New Zealand.

The myoga plant needs well-drained and fertile soil to grow well. Under poor drainage, plant growth is retarded, and rhizome rotting can occur. Myoga shoots emerge in the spring and produce dense foliage on robust stalks. The sterile flowers are produced at ground level from the underground stems during summer and autumn. The aerial shoot dies out during winter, and the underground stem sprouts in spring and growth continues. The crop is propagated by planting 25 cm-long rhizome pieces, planted about 10 cm deep, 40 cm apart, in rows. Harvesting the flower buds begins in the second year. An annual fertilizer application of 200 to 300 kg/ha of nitrogen–phosphorous–potassium (NPK) fertilizer is suggested (Paghat, 2003).

Myoga flower buds are picked before they emerge above surface from the underground shoots. To facilitate harvesting, a 10 to 15 cm layer of sawdust is used to mulch the plant bases. The buds are located in the sawdust and are harvested individually at the appropriate stage two to three times each week. Export-grade buds need to be above 6 g and be plum or pink in color. The harvested flower buds can be kept in cold storage, and the production is around 8 to 13 t/ha in a second-year crop (see Figure 17.1). Sterling et al. (2003) showed that flower bud production is influenced by photoperiod.

Myoga cultivation has recently become popular in Australia and New Zealand. In Australia, a superior type of myoga plant has been identified and multiplied through tissue culture on a large scale for distribution to farmers. The myoga industry in Australia and New Zealand depends on this superior line, and cultural conditions have been standardized for growing this type of ginger (Clark and Warner, 2000).

A dwarf variegated variety, known as *dancing crane,* is an ornamental plant, growing to about 45 cm in height and producing yellow flowers. This variant has leaves with white stripes on a green background (see Figure 17.2).

Myoga ginger is used in Japan as a spice and as a substitute for true ginger. Two compounds—galanal A and galanal B—were isolated from myoga rhizomes. These are known to contribute to the characteristic flavor of the myoga rhizomes. The pungent principle in myoga was identified as (E)-8beta(17)-epoxylated-12-ene-15,16-diel, commonly known as myogadial. When isolated, this compound, and also Galanal A and B and reduced, myogadinol are tasteless. The pungency of myogadial depends on the presence of the alpha-beta-unsaturated -1,4-dialdehyde group (Abe et al., 2002). In Chinese Pharmacopoeia, myoga ginger is used to treat fever and also as a vermifuge.

Figure 17.1 Harvested flower buds of *Zingiber mioga*, a delicious vegetable.

Figure 17.2 Ornamental *Z. mioga var.* dancing crane.

*Z. montanum (*Koenig) Link ex Dietr. *(= Z. cassumunar* Roxb.*)*

Z. montanum is a native of India and is present throughout the Malaya Peninsula, Sri Lanka, and Java. It is also cultivated in tropical Asia. Its rhizome is an ingredient in many traditional medicines. It is usually used together with the rhizomes of *Z. amaricanum, Z. aromaticum,*

Z. officinale, and *Kaempferia galanga*. In the Philippines, the decoction prepared from these rhizomes is used to relieve cough and asthma (Quisumbing, 1978). The rhizome is also used as an antidiarrheal medicine in its powdered version or it is made into a paste with rice water (Saxena et al., 1981). As a paste, it can also be given twice daily for three days as an antidote to snakebite. Olivers and Bruce (1991) have proven that the oil of *Z. montanum* has antibacterial and antifungal properties. The rhizome is also considered a good tonic and appetizer. It is given with black pepper for cholera and also as vermifuge (Barghava, 1981).

Z. montanum is cultivated in the United States as a garden ginger and is often called "chocolate pinecone ginger." The stems are tall and thin, and the bracts are brown, thus the common name.

Z. casusmunar is propagated vegetatively through the division of suckers. The rhizomes on storage get easily affected by fungi, causing rotting. Rhizome pieces with one or two emerging shoots are used for planting immediately after separation from the mother stock. Poonsapaya and Kraisintu (2003) came out with a tissue culture multiplication protocol. Shoot tips cultured in Linsmaier and Skoog (LS) medium, supplemented with $4 mgl^{-1}$ benzyl amino purine (BAP), produce an average of 13 shoots within 8 weeks. The incorporation of antibiotics is essential to suppress microbial contamination. The rooting of shoots was achieved in a medium with a low concentration of α-naphthane acetic acid (NAA) or with the addition of activated charcoal.

Many studies have been made on the medicinal properties, especially of the anti-inflammatory effect, of *Z. casumunnar*. Ozaki et al. (1991) isolated three compounds identified as (E)-1-(3, 4-dimethoxyphenyl) but-1-ene, (E)-1-(3, 4-dimethoxyphenyl) butadiene, and zerumbone. The methanol extract was found to possess the anti-inflammatory and analgesic activities, which come from the first compound, (E)-1-(3,4-dimethoxyphenyl)but-1-ene.

Masuda et al. (1995) isolated cassumunarins A, B, and C, three anti-inflammatory antioxidants, and determined their structures. Cassumunarins are complex curcuminoids. Their antioxidant efficiency was determined by the inhibition of linoleic acid's antioxidation in a buffer–ethanol system. The anti-inflammatory effect was measured by the inhibition of an edema formation on a mouse ear, induced by 12-o-tetradecanoyl-phorbol-13-acetate. The cassumunarins showed greater activity than curcumin in both assays.

Masuda and Jitoe (1995) isolated four phenyl butanoid monomers from the fresh rhizomes of *Z. cassumunar* from Indonesia:

- (E)-4-(4-hydroxy-3-methoxyphenyl)but-2-en-1-ylacetate
- (E)-4-(4-hydroxy-3-methoxyphenyl)but-2-en-1-ol
- (E)-2-hydroxy-4-(3,4-dimethoxyphenyl)but-3-en-1-ol
- (E)-2-methoxy-4-(3,4-dimethoxyphenyl)but-3-en-1-ol

In addition, Masuda and Jitoe also isolated three phenylbutenoid monomers that are already known.

Nugroho et al. (1996) screened the rhizomes of 18 species for insecticidal activity, and the rhizomes of *Kaempferia rotunda* and *Z. cassumunar* exhibited a marked insecticidal activity in chronic feeding bioassays at concentrations of 2,500 and 1,250 ppm, respectively. Bioassay-guided isolation led to two phenylbutanoids from the rhizomes of *Z. cassumunar* (an LC_{50} value of 121 and 127 ppm). Both compounds were active in the residue-contact bioassay (LC_{50} values of 0.5 and 0.36 $\mu g/cm^2$). The presence of oxygenated substitutes in the side chain nullified the insecticidal activity.

Panthong et al. (1997) assayed the anti-inflammatory activity of compound D ((E)-4-(3',4'-dimethoxy-phenyl)but-3-en-2-ol) isolated from the hexane extract of *Z. cassumunar* rhizome using various inflammatory models in comparison with Aspirin, indomethacin (indimetacin), and prednisolone. The results showed that the anti-inflammatory effect of compound D mediated prominently on the acute phase of inflammation. It exerted a marked inhibition of carrageenin-induced rat paw edema, exudate formation, leukocyte accumulation, and prostaglandin biosynthesis in carrageenin-induced rat pleurisy. Compound D possessed only a slight inhibition of both the primary and secondary lesions of adjuvant-induced arthritis and had no effect on cotton-pellet–induced granuloma in rats. Compound D elicited analgesic activity when tested on the acetic acid-induced writhing response in mice but had weak inhibitory activity on the tail flick responding to radiant heat. Compound D possessed marked anti-pyretic effect when tested on yeast-induced hyperthermia in rats.

Nagano et al. (1997) studied the effect of cassumunarins A and B, isolated from *Z. cassumunar*, in dissociated rat thymocytes suffering from oxidative stress induced by 3mM H_2O_2 (hydrogen peroxide) by using a flow cytometer and ethidium bromide. The effects were then compared with those of curcumin. The pretreatment of rat thymocytes with cassumunarins (100 nM to 3μM) dose dependently prevented H_2O_2-induced decrease in cell viability. Cassumunarins were also more effective when administered before the start of the oxidative stress. The respective potencies of cassumunarins A and B in protecting cells suffering from H_2O_2-induced oxidative stress were greater than that of curcumin.

Bordoloi et al. (1999) investigated the essential oil composition of *Z. cassumunar* from the northeast of India using gas chromatography-mass spectrometry (GC-MS), analyzing oil hydrodistilled from rhizomes and leaves. The rhizome essential oil contained terpenen-4-ol (50.5 percent), E-1-(3,4-dimethoxyphenyl)buta-1,3-diene (19.9 percent), E-1-(3,4-dimethoxyphenyl)but-1-ene (6.0 percent), and β-sesquiphellandrene (5.9 percent) as major constituents out of the 21 compounds identified. In the leaf essential oil, 39 compounds were identified. The main components were 1(10),4-furanodien-6-one (27.3 percent), curzerenone (25.7 percent), and β-sesquiphellandrene (5.7 percent).

Z. zerumbet (L.) Smith

This is a native of tropical Asia, occurring up to an altitude of 1200 m. It is commonly known as shampoo ginger; also known as pinecone ginger in the southern United States (see Figure 17.3). The inflorescence resembles a tight pinecone and releases a thick juice when squeezed. This juice is used to make the Paul Mitchel and Freemans' Shampoo.

Pseudostems grow to 0.6 to 2 m, the leaves are sessile or petiolate, and the rhizomes are light yellow inside. The inflorescence, produced at the tip of a long peduncle, is green when young. The flowers are white in color, and three to four are produced at a time. The color of the inflorescence changes from green to red on aging and lasts for many weeks. Hence, it is widely used as a cut flower. Capsule is ellipsoid, seeds are black.

Some variegated forms of this species are also grown in gardens. The variegated form, called *Darceyi*, is very popular in the United States. Another form, called *Twice as Nice*, produces both basal inflorescences and occasional terminal spikes on a very compact plant.

Srivastava (2003) studied the pharmacognosy of this species on which the following discussion is based. The rhizome is 7 to 15 cm long, 1 to 2.5 cm broad, and is irregularly branched. In commerce, the rhizome is found in pieces 4 to 7 cm long, which are

Figure 17.3 *Z. zerumbet*, the shampoo ginger, an ornamental variety in flowers.

irregular, wrinkled, brown, and showing a large central pith. The dried rhizome is hard, brittle, with a fragrant odor and an aromatic, spicy taste. A transverse section of the rhizome shows a single, layered epidermis, below which are 7 to 10 layers of thin-walled cork cells. The cortex consists of several layers of parenchymatous cells, with intercellular air spaces, and oil cells are present. The endodermis is made of a single layer of cells. The stele consists of a broad central zone of ordinary parenchyma cells. Closed collateral vascular bundles are found in a circle just inside the endodermis. Throughout the remaining region of the stele, closed collateral bundles, partially covered by sclerenchymatous fibers, are scattered. The tracheids are nonlignified and have reticulate, spiral, or scalariform thickening on the wall. The very tender rhizomes are eaten. The decoction of the rhizomes is used to cure various kinds of diseases.

Tewtraki et al. (1997) analyzed the water-distilled volatile oil composition of *Z. zerumbet* by gas chromatography and MS. The main component of the volatile oil was found to be zerumbone (8-oxohumulene) (56.48 percent). Other components in significant amounts were 1,8-cineole (1.07 percent), o-caryophyllene (2.07 percent), α-humulene (25.70 percent), caryophyllene oxide (1.41 percent), humulene epoxide (3.62 percent), humulene epoxide 11 (2.45 percent). Also, 3,4-o-diacetylafzelin and zerumbone epoxide were isolated from rhizomes (Rastogi and Mehrotra, 1993).

The most studied chemical compound is the sesquiterpene zerumbone, which is reported to be a potent inhibitor of a tumor promoter, the 12-o-tetradecanoylphorbol-13-acetate-induced Epstein-Barr virus activation. The IC_{50} value of zerumbone (0.14 μM) was noticeably lower than those of the antitumor promoters hitherto obtained (Murakami et al., 1999). Murakami et al. (2002) reported that zerumbone has potent anti-inflammatory and chemopreventive qualities. They found that zerumbone effectively suppressed tetradecanoyl-phorbol-13-acetate (TPA)-induced superoxide anion generation from both nicotinamide adenine dinucleotide (reduced) (NADH)-oxidase in dimethyl sulfoxide-differentiated HL-60 human acute promyelocytic leukemia cells and xanthine oxidase in AS 52 Chinese hamster ovary cells. The combined lipopolysaccharide and interferon-gamma-stimulated protein expressions of inducible nitric oxide synthase and cyclooxygenase (Cox)-2, together with the release of tumor necrosis factor (alpha) in

RAW 264.7 mouse macrophages, were also markedly diminished. These suppressive effects were accompanied with a combined decrease in the medium concentrations of nitrite and prostaglandin E_2, whereas the expression level of Cox-1 was unchanged.

Zerumbone inhibited the proliferation of human colonic adenocarcinoma cell lines in a dose-dependent manner, whereas the growth of the normal human dermal (2FO-C25) and colon (CCD-18CO) fibrobasts was less affected. It also induced apoptosis in COLO205 cells, as detected by the dysfunction of the mitochondria transmembrane, the Annexin N-detected translocation of phosphatidyl serine, and the chromatin condensation. Alpha-humulene, a structural analogue lacking only the carbonyl group in zerumbone, was virtually inactive in all experiments, indicating that the alpha, beta-unsaturated carbonyl group in zerumbone may play some pivotal role in interactions with an unidentified target molecule. The results strongly support the claim that zerumbone in a food phytochemical (neutraceutical), has a potential use in anti-inflammation, chemoprevention, and chemotherapy strategies. Dai et al. (1997) reported that zerumbone has a potent HIV-inhibitory action.

Z. amaricanus Bl.

Z. amaricanus is a medicinally important species. The rhizome is small, yellow, hard, weakly fragrant, and bitter. The propagation is done through rhizome cuttings. It prefers shady, humid soils rich in humus. It grows wild in teak forests in Southeast Asia, where it has several medicinal uses. The old rhizomes are used as an ingredient in various traditional medicines. The pounded rhizome is usually used as a poultice for women after delivery. It has also gained importance as an attractive garden plant and is grown widely in the USA. The young rhizomes are eaten as a vegetable in Java (Prance and Sarket, 1977).

Z. aromaticum Val.

This plant grows up to 1.5 m. The yellow flowers come from a striking red cone produced from the base of the plant. The rhizome is strongly aromatic and fibrous, resembling *Z. amaricanus* in taste and aroma. The specific epithet is derived from the strong aroma of the rhizome. It is considered to be native of tropical Asia and is called *puyang* in Indonesia. *Z. aromaticum* is also widely cultivated in kitchen gardens and as an ornamental plant.

Its fresh and tender shoots and flowers are eaten and used to flavor foods. The rhizomes are used as an ingredient in folk medicines as well as for poultice (Prance and Sarket, 1977). From the rhizome of this species, zerumbone and 3",4'"-o-diacetylafzelin were isolated. Zerumbone exhibited HIV-inhibitory and cytotoxic activities (Dai et al., 1997).

Z. argenteum J. Mood and I. Theilade

This species is endemic to the Sarawak Malaysia. *Z. argenteum* is a small plant, the pseudostem reaching about 75 cm. Its leaves grow to 15 to 18 cm long, with an upper surface that is silvery green with a dark green cloud along the midrib, while the lower surface is green. It produces cream-colored flowers and spikes 8 to 9 cm long that are broadly elliptic. Its bracts are bright orange, with the lower ones turning red. This species is related to *Z. coloratum* and *Z. lambi*. It is a very attractive plant and is valued much by the ginger lovers. Under cultivation, the plant is highly floriferous (Theilade and Mood, 1997).

Z. bradleyanum Craib.

This plant is now cultivated in the United States, mainly grown as a foliage plant for the beautiful silvery stripe on the midrib of the leaves. The plant has a natural dormancy and therefore may be winter-hardy in subtropical climates.

Z. chrysanthum Rosc.

This is a medium-sized *Zingiber* with stems about 1 to 1.5 m tall. It produces a typical basal inflorescence, but the individual flowers are long lasting and colorful, with a spotted lip. The seed capsules are also ornamental bright red and remain until the stalks die in winter.

Z. citriodorum J. Mood & I. Theilade

This species is from Thailand and has been under cultivation for several years in the United States as an ornamental plant under the name *Chiang Mai Princess*. It was recently described as a new species, *Z. citriodorum*. It is a beautiful plant, with sharply pointed bracts starting out green and maturing to bright red. The flowers are white. The pseudostems and foliage have a silvery gray color. This species can be difficult to grow in cool climates as the rhizomes are subject to rotting during dormancy if kept too wet. This is a valuable ornamental plant used both as a pot plant and as cut flower.

Z. clarkii King ex Benth.

Z. clarkii is a native of the Sikkim Himalayas of India and has been adopted as a valuable ornamental plant in the subtropical and temperate countries. The plants are tall with a foot-long inflorescence appearing from the main stem rather than from the ground. The bracts form a tight, cone-shaped spike, and the individual flowers are dull yellow in color with a dotted lip. Among the *Zingiber* species, this is unique because the spike is produced laterally and not radially as in other species.

Z. collinsii J. Mood & I. Theilade

A recently described beautiful *Zingiber* species, *Z. collinsii* was discovered and introduced by Mark Collins. This one has silvery stripes across the leaves, somewhat similar to *Alpinia pumila*, but much taller. This species has become a favorite of plant lovers in United States and Europe.

Z. corallinum Hance

This *Zingiber* species is a medium-sized plant producing long, pointed, red-bracted inflorescences near the ground. The foliage is medium green in color. This species has been proven winter-hardy down to 20°F. The rhizome is used in traditional Chinese medicine. The effect of this species in preventing skin invasions by *Schistosma japonicum cercaria* was investigated in mice. A worm reduction rate of 91 percent was found at 5 percent concentration of the rhizome extract (Shuxuan et al., 2001). *Z. corallinum* is valued as an ornamental and a medicinal plant of great promise.

Z. eborium J. Mood & I. Theilade

This species is endemic to Borneo in Indonesia and is the unique white ginger, ivory ginger, or ivory spike ginger, in the parlance of nurserymen. It grows to about 0.75 to 1 m in height, with dark green, ovate leaves, glabrous above and with fine silky hairs below. It has a pale reddish scape sheath, with an inflorescence about 7 to 8 cm. Its bracts are ivory white and the flowers orange. The white spike and the orange flower make this a very attractive garden plant and a favorite among the ginger lovers in the Western world. Under cultivation, the plant flowers profusely, making it a valuable pot plant (Theilade and Mood, 1997). It is also tolerant to freezing.

Z. griffithii Baker

This is a Malaysian species, having oblong, glabrous leaves, a shortly peduncled cylindrical spike, and bright red, obovate, obtuse bracts. The tip of the bract is yellowish white and three lobed. It is a common ornamental plant. Zakaria and Ibrahim (1986) reported four phenolic compounds of the catechol and pyrogallol type, three flavanoids and terpenols in the volatile oil.

Z. gramineum Noronha

This plant is cultivated in United States gardens under the common name *palm ginger*. It is a thin-stemmed and narrow-leafed plant.

Z. junceum Gagnepain

This species is being sold in the United States under the name *Yellow Delight*. This plant has symmetrical silvery stems and leaves, and produces yellow basal cones. It can produce either basal or terminal inflorescences. The spikes are yellow and long lasting, and it is used as a cut flower also. It has only recently come into cultivation in the United States and is a favorite of ginger lovers.

Z. lambi J. Mood & I. Theilade

This is a Malaysian ginger endemic to East Malaysia. It is a small plant, with a leafy stem about 60 cm in height. Its leaves are glabrous, with a silvery green upper surface, ribbed side nerves, and a green lower surface. Its fusiform spike grows up to 10 to 12 cm long. The bracts are orange, greenish towards the apex, and they turn pink with age. This species produces yellow flowers and a light yellow labellum. *Z. lambi* is unusual for its beautiful silvery green leaves, orange spikes, and yellow flowers. It has become a valuable garden plant within a short span of time. The species is related to *Z. argenteum*.

Z. longipedunculatum Ridley

Reportedly in cultivation in Australia for many years and has been a valuable garden plant used for cut flower purposes. The spikes are often used in floral arrangements.

Z. malaysianum C.K. Lim

This garden ginger plant has become extremely popular and is widely sold in the United States under the name *Midnight Beauty* . It has shiny dark brown—almost black—leaves and produces bright red inflorescences at its base. It is an evergreen species and must

be protected in winter from frost. It is a very attractive ornamental plant and is much sought after by plant lovers as a pot or as a bed plant. Its spikes are used as cut flowers and in floral arrangements.

Z. neglectum Valet.

This is another popular plant in cultivation in the United States, one of the most sought after by ginger collectors. It has very long inflorescences with beautiful cup-shaped bracts similar to *Z. spectabile,* with purple flowers.

Z. niveum J. Mood and I. Theilade

Z. niveum is an ornamental ginger sold in the United States for several years under the name *Milky Way.* It produces milky white, rounded spikes that are very unusual looking, and yellow flowers. The stems and leaves are silvery gray, and this attractive ornamental plant only grows about 3 ft tall.

Z. ottensii Valet.

This is a native of Southeast Asia. The stem is reddish and attractive, hence widely cultivated as an ornamental. The inflorescence is more or less similar to *Z. zerumbet,* but the color is red from the beginning and persists for a long time. The perodixase isozyme studies have proven that this is very close to *Z. zerumbet* and *Z. montanum*. The rhizome is used as a poultice in postnatal treatment and also as an appetizer. Three sesquiterpenes—humulene, humulene epoxide, and zerumbone—and a diterpene, (E)-landa-8(17),12-diene-15,16-diel-, were isolated from dried rhizome (Sirat, 1994). It is a valuable ornamental plant, both as a pot plant and as a cut flower.

Z. pachysiphon B.L. Burtt & R.M. Sm.

This is in cultivation in Australia. The plant has a beautiful purplish-colored inflorescence with white edges to the bracts. The species is rather rare and valued much by the ginger lovers as a very attractive pot plant.

Z. rubens Roxb.

This species is from the Indo-Malaysian region and has been introduced to the United States' gardens as a pot plant where it has become very popular. The plant is 6 to 8 ft. tall, leaves 4 to 5 inches long that are pubescent beneath. Its spike is dense, and globose, with a small peduncle, bright red bracts, red corolla segments, with an oblong lip, that is much spotted and streaked with red. The paste of the rhizome (10 gm) is given after heating and is also applied to the head for giddiness (Saxena et al., 1981).

Z. spectabile Griff.

This is also known as beehive ginger, due to the peculiar shape of the spike. The plants are large, growing up to 8 feet, and the inflorescence is large and very attractive. The spike turns from yellow to red on aging. Because it has a shelf life of a few weeks, it is widely used as a cut flower. It is also used as a flavoring agent and an ornamental plant (Holttum, 1950). This species is widely used in Malay traditional medicine (Brukhill and Haniff, 1930) and is very popular in cultivation in the United States. It comes in

two varieties, one having the red bracts and the other with golden yellow bracts. The latter is often sold as "golden shampoo ginger." Both are very much valued as pot plants and for cut flower production.

Ibrahim and Zakaria (1987) analyzed the rhizome using thin layer chromatography (TLC) and gas chromatography (GC) and reported 18 compounds, the major ones being trans-d-bergamontene, β-elemene, isobutyl benzoate, β-copaene and β-terpenol.

Z. vinosum J. Mood and I. Theilade

This species of ginger is a native of Sabah, East Malaysia, and its cultivation as an ornamental plant has spread rapidly in the United States. It is a short-statured plant with dark green upper foliage that is deep maroon on the undersides. Its leafy shoot grows to 1 to 1.25 m and is dark burgundy at the base. Its spike can be from 15 to 30 cm long, and its bracts are burgundy. Its flowers are white, with a snow-white labellum. The attractive foliage and red inflorescence make it a very valuable garden plant. The rhizome is moderately aromatic.

In addition to the above listed species, there are also others that can be groomed into attractive garden plants.

Wild Ginger

In the United States and Europe, the name wild ginger is commonly used for the plant *Asarum canadense* (Aristolochiaceae), which is not related to ginger in any way. It is an inconspicuous, herbaceous perennial, about 30 cm in height, found growing in rich soil on roadsides and in the woods. The plant is almost stemless, usually possessing two heart-shaped leaves and carrying a solitary bell-shaped flower between the two petioles at the base. The root stock is yellowish and creeping, and is sold in pieces 10 to 12 cm long. The plant has brownish ends that are wrinkled on the outside, whitish inside, fragrant, aromatic, spicy, and slightly bitter (Grieve, 2003).

It is called wild ginger because it gives a ginger-like smell. Native Americans have used the root to flavor foods, just like the true ginger. They have also used the root to treat digestive disorders, especially gas, and as a poultice on sores. It is often used to promote sweating, reduce fever, and to counteract coughs and sore throats. The plant extract has also been shown to have antimicrobial properties (Reed, 2003).

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