Part I Shiitake

Chapter 4

Shiitake Bag Cultivation

FARM DIARY FOR SHIITAKE BAG CULTIVATION

Chan-Kyu Choi
Han Jung Nong San, 26-4 Go-po, Song-san, Hwa-sung, Kyung-gi, Korea (kumung1@hanmail.net)
Reported by Song Baek Cho, MushWorld, Korea
Translated by Kyung Wha Choi, MushWorld, Korea

My Personal History as a Shiitake Grower

Figure 1. The author taking care of shiitake bags

I was born in Song-san, a village that is famous for grape production in Korea and my family cultivated grapes. I used to grow grapes, but decided to choose another produce which could provide greater profits. While searching for an appropriate produce, I chanced to attend SIEMSTA (Seoul International Exhibition of Machinery, Science and Technology for Agriculture) in 1998. There I encountered shiitake bags imported from China and these attracted me very much. As one of the traditional products in Korea, shiitake has been considered a relatively luxurious food so its price is quite high if the quality is good. At that time, almost all shiitake in Korea were cultivated from logs because people believed that high quality shiitake could not be obtained from bag cultivation. After pilot trials with some sample bags imported from China, however, I found that the quality of shiitake cultivated from sawdust bags was good and I was convinced that I could produce high quality shiitake from bag cultivation.

I began to research the possibility of my cultivating shiitake in bag cultivation here in Korea. It was not an easy task because I had very little knowledge concerning shiitake cultivation on either logs or in sawdust, and very little information on shiitake bag cultivation was available in Korea at that time. I started my own shiitake bag cultivation but the results of early days were terrible failures. It is very important to emphasize that I experienced a lot of failures and performed numerous trials before I finally became able to realize a profit from shiitake bag cultivation. The numerous failures taught me what to do and finally I became one of the pioneers of shiitake bag cultivation in Korea.

Farm diary and my success

I began to write my farm diary when I first started shiitake cultivation. My wife and I checked the temperature, humidity, bag condition, and fruiting body condition of each growing house every three hour by turns. I also examined and studied what happened to bags and shiitake quality under certain temperatures and humidity as well as under different amounts of watering. Finally, I accumulated enough experience and understanding concerning appropriate temperatures, humidity, ventilation, and watering for each step of shiitake bag cultivation. Actually, I am not writing such a laborious farm diary any more because I established my own cultivation methods which, I think, fit best for the Korean natural environment and market characteristics. However, I am still applying what I learned from my farm diary in striving for better shiitake quality. I recommend that all new growers keep a farm diary because this activity helps you learn about shiitake growing.

I wrote this particular farm diary not for my own reference, but rather to share my experience and knowledge with other

shiitake growers. I have visited various regions in China to see how they cultivate shiitake on sawdust bags, so many parts of my growing methods are modeled after activites I saw in China. I have applied these methods to fit the environment and shiitake market of Korea. A grower may find my methods inappropriate for their own situation, and such differences are natural. We live in countries or regions with different temperatures, humidity, social customs, available equipment, distribution systems, and market demand. I just hope all growers can learn from my experiences and apply this knowledge to their own situations. Good luck to all!

Why I chose bag cultivation

Shiitake can be produced throughout the year if cultivated on sawdust bags because the environment is much more controlled than with log cultivation. This method produces a stable income to growers all year round. In addition, bag cultivation enables planned production of shiitake by controlling production cycles, which prevents a fall in the price of shiitake caused by over production. However, absolute control of the environment is sometimes so expensive that shiitake production can be less profitable. Therefore, I am trying to achieve a maximum of efficiency at a minimum of cost by making the utmost use of the natural environment of each season.

The name of my shiitake farm is Han-Jung, which means 'cold well' in Korean. I have three growing houses (total 792m^2), one incubation room (198m^2), a small cooling room and a spawning room and cold storage (66m^2) and a work area (132m^2) with a mixer and a bagging machine. I also have a ribbon mixer, a sterilizer, and a clean bench for inoculation. The full capacity of my growing houses is 9,000 bags at the same time, and I can cultivate 2.5 crops a year. Therefore, I estimate that I can cultivate 22,500 bags per year.

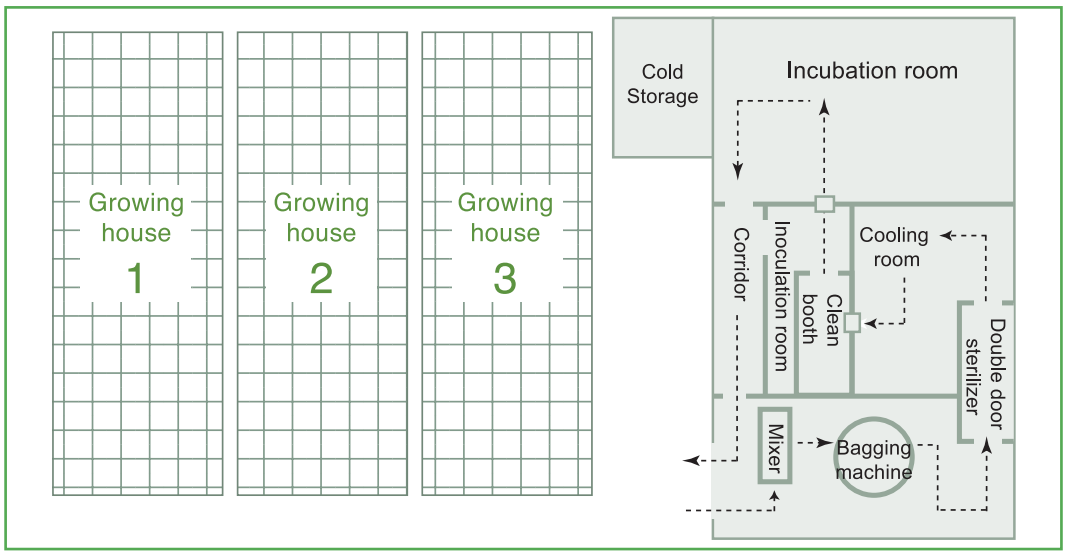

Figure 2. Schematic drawing of Han-Jung ("cold well" in Korean)

<Shiitake cultivation cycle written in this farm diary>

Location \ Month	April	May	June	July	August	September	October	November
Incubation room								
Growing house #1								
Growing house #2								

Lot #1: Group 1 Group 2

Lot #2:

Bag Preparation and Inoculation

April 9, 2004

Temp. : 3.8/20.5℃ R.H.: 47.0% Rainfall : 0mm Sunny

All the substrate materials have been delivered. In March and April, I prepare bags with formulation for high temperature strains. Though these bags are made in spring, the shiitake will start to fruit 2 months later when the bags are fully incubated by the shiitake mycelia, which will be hot summer. Shiitake strains are classified by its optimum temperature range for fruiting induction (appropriate temperature for spawn run is uniform for every strain), so one should choose a strain suitable for the temperature when it fruits, not when it is inoculated. This can be confusing for beginners.

Preparation of materials and its formulation

For high temperature strains, I use the substrate formulation as shown in Table 1 while I use a different formulation for the low temperature strain as shown in Table 2.

Table 1. Substrate formulation for high temperature strain

Material	Sawdust	Wheat bran	Rice bran	Gypsum	Brown sugar	Lime	Calcium carbonate	Total
Quantity (kg)	700	60	60	7	7	4	6	844
Ratio (%)	83	7.1	7.1	0.8	0.8	0.5	0.7	100

Table 2. Substrate formulation for low temperature strain

Material	Sawdust	Wheat bran	Rice bran	Gypsum	Brown sugar	Calcium carbonate	Urea	Potassium carbonate	Total
Quantity (kg)	700	63	63	9.8	9.8	2.1	2.1	1.98	851.78
Ratio (%)	82.2	7.4	7.4	1.2	1.2	0.2	0.2	0.2	100

Supplements such as wheat and rice bran, brown sugar provide nutrients that are lacking in sawdust, but the high nutrients within the supplements are more likely to cause contamination, especially in summer. Therefore, they are less used for the high temperature strain and urea and potassium carbonate are not added. I concluded from my experience that the formulation in Table 1 is so far the best for the high temperature strain because of the minimized contamination rate, though I may change my mind later. The current contamination rate is lower than 1%.

Lime is added only for the high temperature strain. If lime is added, the substrate temperature increases up to 60℃ during mixing, so this functions as pasteurization and the contamination risk decreases as a result. Gypsum adjusts the acidity of the substrate. The initial acidity of the substrate is about pH7, but becomes pH3-4 after sterilization. Rice bran is easy to obtain, but also decomposes easily. It has a high nutrient content and thus increases contamination risk. When the time between mixing and sterilization is long, rice bran is more likely to decompose. Therefore, I mix wheat bran with rice bran at the rate of 5:5. It is recommended to use fresh rice bran.

Figure 3. Oak sawdust and chip (5:5)

I currently use both oak chip of 3-5mm and sawdust of 2-3mm in diameter at the rate of 5:5 (Fig. 3). But, the porosity is quite high, so I am planning to change the rate to 4:6. The appropriate porosity or solidity of substrate bags can be tested by pressing them with a finger. If the bag recovers soon after pressing, it is appropriately compacted.

The difference caused by sawdust particle size is worthy of explaining. If 3-5mm chips are used for more than 50% of the mix, it takes longer for the shiitake mycelium to penetrate the particles and absorb the nutrients. Though the white mycelia cover the particles, it takes more time to digest and absorb the nutrients inside the particles. 3-5mm chips give a steady and good quality shiitake for up to 10 flushes, while 2-3mm sawdust produces only a very small amount of fruiting bodies after the second or third flush. When 3-5mm chips and 2-3mm sawdust are used half and half, the first flush could be of low quality, but high quality shiitake will be harvested from the second flush.

April 10, 2004

Temp. : 5.3/21.7 ℃ R.H.: 42.1% Rainfall : 0mm Party cloudy

Today, I mixed substrate materials and filled 1,200 bags and put them into the sterilizer. They are being sterilized tonight for 6 hours.

Mixing substrate materials

All the substrate materials are mixed for one and one-half hours. At first, sawdust and wheat bran and rice bran are poured into ribbon mixer and mixed for 30 minutes. Water (more than 50% of the substrate weight) is added and this is thoroughly mixed for another 30 minutes. Gypsum, brown sugar, lime, and calcium carbonate are dissolved respectively and added to the mixture and mixed for last 30 minutes (Fig. 4). Finally, the moisture content is adjusted to 50-55%, which is the optimal water content for the growth of shiitake mycelia. The water content of delivered substrate materials varies according to the supplier, so the added water amount is also varied. I used to use measuring instruments to calculate water content, but now I estimate with my hands. Usually, the substrate mixture contains the appropriate amount of water if the mix ture sticks together for a while when a handful is grabbed.

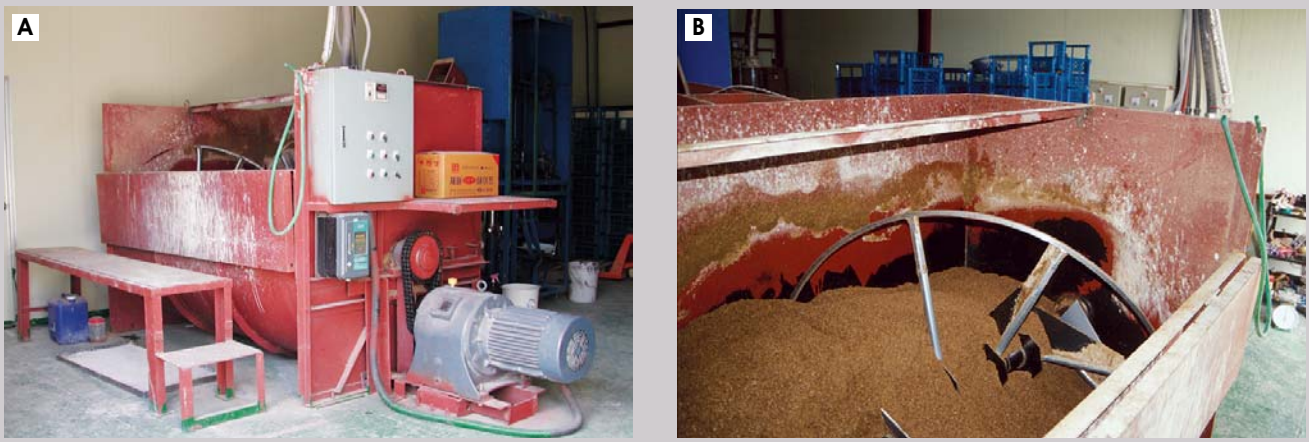

Figure 4. Mixing substrate materials **A**: Ribbon mixer with watering hose and motor attached **B**: Mixing substrate materials thoroughly

Bagging

The mixer is connected to a bagging machine, so the substrate mixture is moved to the bagging machine which fills the substrate into plastic bags (Figs. 5). My mixer can produce about 400 pieces of 3kg bags with one operation. 700kg sawdust and 144kg supplements make the total substrate material weigh 844kg. In most cases, water is added for 50% of the total weight of materials to make the water content be 50-55%. The total weight of the substrate mixture is about 1,266kg and this amount can fill about 400 bags. A filled bag is 12cm in diameter and 38-40cm in length. It is recommended that bagging be done within two hours. The shorter the bagging time, the better. It usually takes about 40 minutes for 4 persons to fill 400 bags; one fits plastic bags in bagging machine, another two tie the filled bags and the last carrys them to sterilizer.

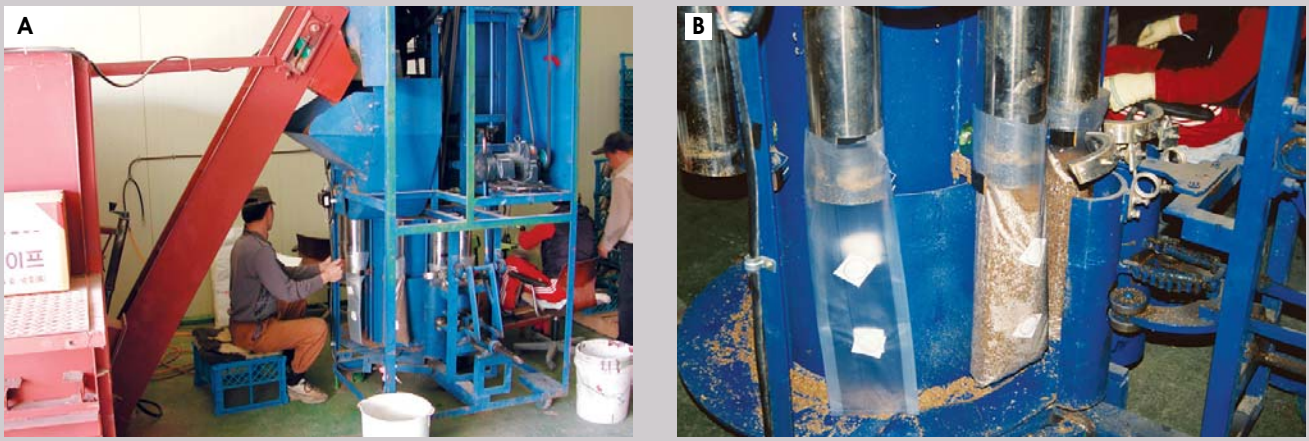

Figure 5. Bagging **A**: Substrate mixture is carried from mixer to bagging machine through conveyer **B**: Filling bags with substrate mixture

Filled and compacted bags are closed with iron staples (Figs. 6A and B). Iron staples are much better than nylon cable tie because they are much stronger and durable during the high pressure sterilization. Nylon cable ties can become untied during high pressure sterilization. The person who staples also cuts away the extra plastic above the staple (Fig. 6C).

Stapled bags are placed into heat resistant nests and stacks. Four bags fit into one nest and stack. The nest and stacks are moved to the sterilizer by hand pallet truck and they are arranged in the sterilizer (Figs. 7A and B). I have a double door sterilizer; one door is open to the work area where the mixer and bagging machine are located, and the other door leads to the cooling room (Fig. 7C).

Figure 6. Tying with staple **A**: Stapler **B**: Bags tied with iron staple **C**: Cutting above the staple

Figure 7. Sterilization **A**: Nest and stacks filled with bags on hand pallet truck **B**: Bags arranged in sterilizer **C**: The other side door opens towards the cooling room

Sterilization

The sterilizer can sterilize 1,200 bags at one time, so the mixer should be operated three times to fill the sterilizer full. It usually takes about 2.5-3 hours for mixing and bagging 400 bags for each operation. Therefore, a 9 hour gap occurs between the first mixed substrate batch and the last one. Lime is used in summer to prevent the substrate from decomposing during the interval.

I am planning to utilize two mixers at the same time which can fill 600 bags each. Then, I will be able to fill the sterilizer with 1,200 bags within 3 hours. I have three growing houses and each of them can be filled by about 3,000 bags. Therefore, I need to operate the sterilizer at least twice to fill one growing house.

The bags are sterilized at 110℃ under 0.5kg/cm for 6 hours. I used to sterilize bags at 100℃ for 10 hours including 8 hours to increase temperature up to 100 ℃. By sterilizing at 110 ℃ for 6 hours I have lowered the contamination rate. Moreover, I save fuel costs by reducing the sterilization time.

April 11, 2004

Temp. : 9.8/22.2℃ R.H.: 45.3% Rainfall : 0mm Mostly sunny

The sterilized bags were transferred to the cooling room. They will be cooled there all day long because the cooling room is small. They will be inoculated tomorrow after having cooled.

My farm structure

My farm is designed to minimize the movement of bags from mixing to incubation (Fig. 8). The contamination rate is also minimized by this design. The substrate mixture is moved to the bagging machine and the filled bags are moved into the sterilizer through one door. After sterilization, the bags are moved into the cooling room through the other door. When one door of the sterilizer is open, the other is always closed in order to prevent contamination. After cooling, the bags are inoculated in the inoculation room and then moved to the incubation room and kept there for 2 months. Upon the completion of incubation, the bags are moved to a growing house.

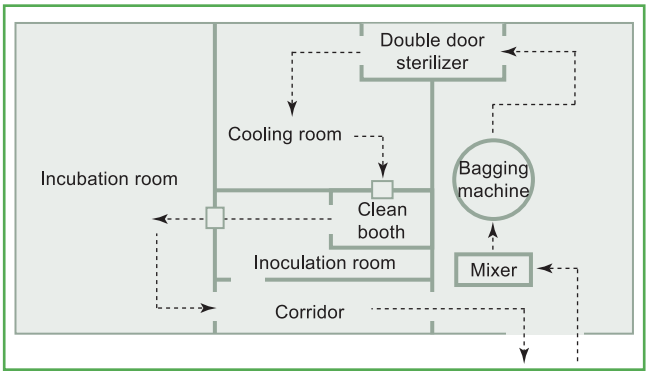

Figure 8. One way voyage of bags from mixing to incubation

Cooling bags

After sterilization, the chamber is depressurized and then the bags are moved to the cooling room that is equipped with a 10-horsepower cooler (Figs. 9). It takes a relatively long time to cool the bags to 18-20 ℃ in the current size cooling room, so I am planning to expand it to shorten cooling time. The cooling room and inoculation room are the places where the highest degree of cleanliness is required. The sterilized bags are moved into the cooling room without any contact with outside air, thanks to the double door sterilizer, and then to the inoculation room after cooling. The sterilized bags are empty of microorganisms. If any fungi or bacteria do contact the substrate before shiitake spawn is inoculated, the microorganism will occupy the substrate very easily because it will not need to compete with any other microorganisms. That is why I pay careful attention to maintaining hygiene and sanitation in the cooling room and the inoculation room.

Figure 9. Cooling room **A**: The other side door of the sterilizer and sterilized bags being cooled **B**: Cooler with a 10-horsepower engine

April 12, 2004

Temp. : 8.0/22.4 ℃ R.H.: 66.3% Rainfall : 0mm Partly cloudy

The 1,200 cooled bags were inoculated today and transferred to the incubation room.

Inoculation

I use sawdust plug spawn[1] for inoculation. After purchasing sawdust spawn, I make sawdust plug spawn by myself with a plug spawn production machine and it is not a complicated process[1]. I use an ozone generator in the inoculation room and in the incubation room to lower the contamination rate. The inoculation room is disinfected with strong ozone (3ppm) from the ozone generator one day before inoculation for 3-5 hours (Fig. 10). A high concentration of ozone can be dangerous enough to kill workers. Therefore, no one should enter the inoculation room during this disinfection and entry should be allowed only after at least 10 hours later than the finish of the disinfection. The inoculation process requires the highest degree of cleanliness, so we wear special suits, masks and hats during inoculation (Fig. 11).

[1] For detailed process of making plug spawn, *see* SHIITAKE SPAWN PREPARATION CHIEFLY WITH SAWDUST in Chapter 2.

Figure 10. Ozone generator attached to the outside wall of the inoculation room

Figure 11. My wife and I, wearing suits for inoculation, are holding a plate of plug spawn

There is a pathway equipped with ultraviolet in between the cooling room and the clean booth within the inoculation room (Fig. 12A). The bags are disinfected under the ultraviolet lamp and brought into the clean booth of the inoculation room (Fig. 12B). The temperature within the inoculation room is maintained at 17-20℃. The ambient temperature should be lower than that of the cooled bags because a higher ambient temperature could increase the bag temperatures and this could cause contamination of the bags.

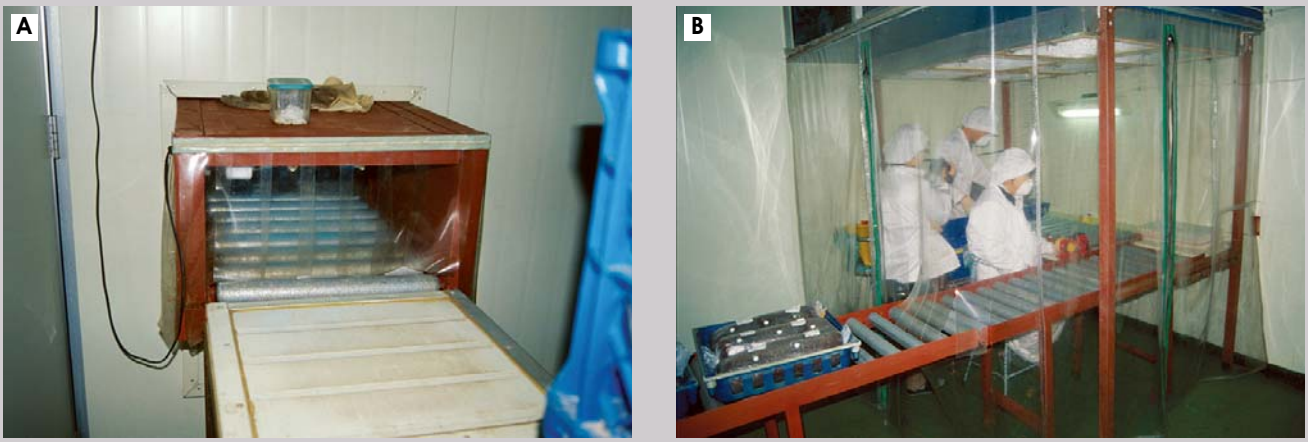

Figure 12. From cooling room to clean booth in inoculation room **A**: Pathway to inoculation room equipped with ultraviolet lamp (the photo is taken from cooling room) **B**: Clean booth in inoculation room

I disinfect the inoculation spots on the bag surface with 70% alcohol and then punch holes in a bag with 5 holes on each side (Fig. 13A). And the plug spawn inserted holes are taped to prevent contamination (Fig. 13B). The inoculated bags are loaded on the rolling conveyer to the incubation room and stacked on shelves with 15 levels in the incubation room (Figs. 14).

Temp. : 9.9/22.4℃ R.H.: 53.3% Rainfall : 0mm Partly cloudy

April 13, 2004

I filled another 1,200 bags after mixing substrate materials. They are being sterilized tonight for 6 hours.

Temp. : 8.0/23.0℃ R.H.: 52.4% Rainfall : 0mm Mostly sunny

April 14, 2004

The sterilized bags were moved to cooling room and they will be cooled until tomorrow.

Temp. : 5.3/21.6℃ R.H.: 49.4% Rainfall : 0mm Partly cloudy

April 15, 2004

The 1,200 cooled bags were inoculated today and transferred to the incubation room. Now about 2,400 bags are in the incubation room and they can fill a growing house. I will call these 2,400 bags Lot #1, though there was a 3-day gap between the

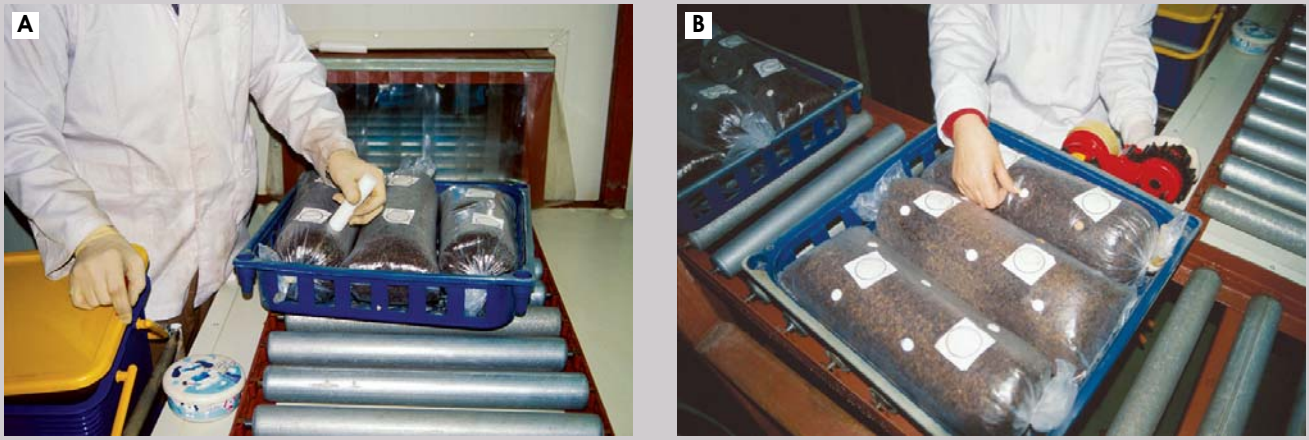

Figure 13. Inoculation within clean booth **A**: Plug spawns are inoculated after punching holes **B**: The inoculated spots are taped to prevent contamination

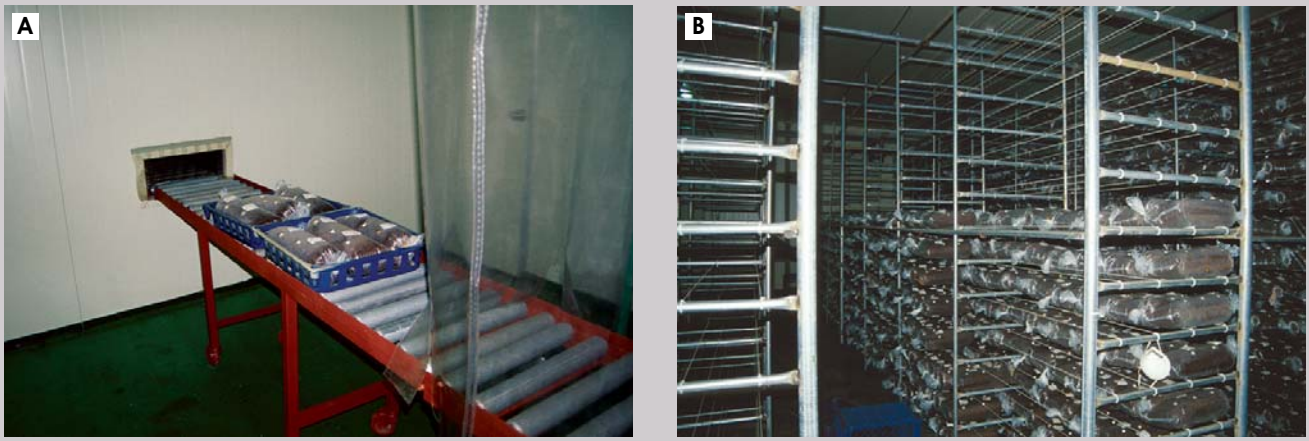

Figure 14. From inoculation room to incubation room **A**: Inoculated bags being moved into incubation room through the outlet **B**: Stacked bags in incubation room

first 1,200 bags and the second 1,200 bags. I can not make 2,400 bags at one time because of the small cooling room. After I expand the cooling room, I could place 2,400 bags in the cooling room and inoculate them all in one day. I will assume that I had started incubating 2,400 bags from today.

Spawn Run

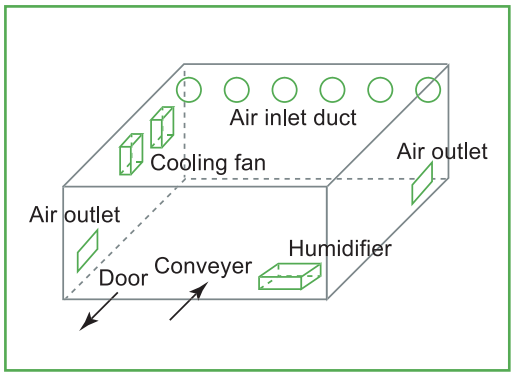

Figure 15. Structure of incubation room

Proper incubation for the spawn running is essential to achieving a successful yield. Once the bags are well incubated, the fruiting process gets much easier. The incubation room has air-inlet ducts, two air-outlet holes with a fan, two unit coolers and a humidifier (Fig. 15). The temperature, humidity and CO_2 concentration are controlled during incubation with this equipment. I also use an ozone humidifier that vaporizes ozonized water to lower the contamination rate (Fig. 16C). The ceiling is also equipped with ozone nozzles connected to the ozonizer. 0.2ppm ozone is diffused to incubation room for 10 minutes per hour and controlled by a timer. This concentration of ozone doesn't harm the shiitake mycelia but does prevent contamination.

Ventilation is achieved by inhalation through inlet ducts and exhaust through the fan in my incubation room (Figs. 16A and B). The room doesn't have any windows and all the air comes through a HEPA filter within the inlet and is then distributed into the room through

ducts. I keep a higher pressure inside incubation room, to provoke the natural exhaust of inside air. In this way the air enters the room mainly through the inlet with the HEPA filter.

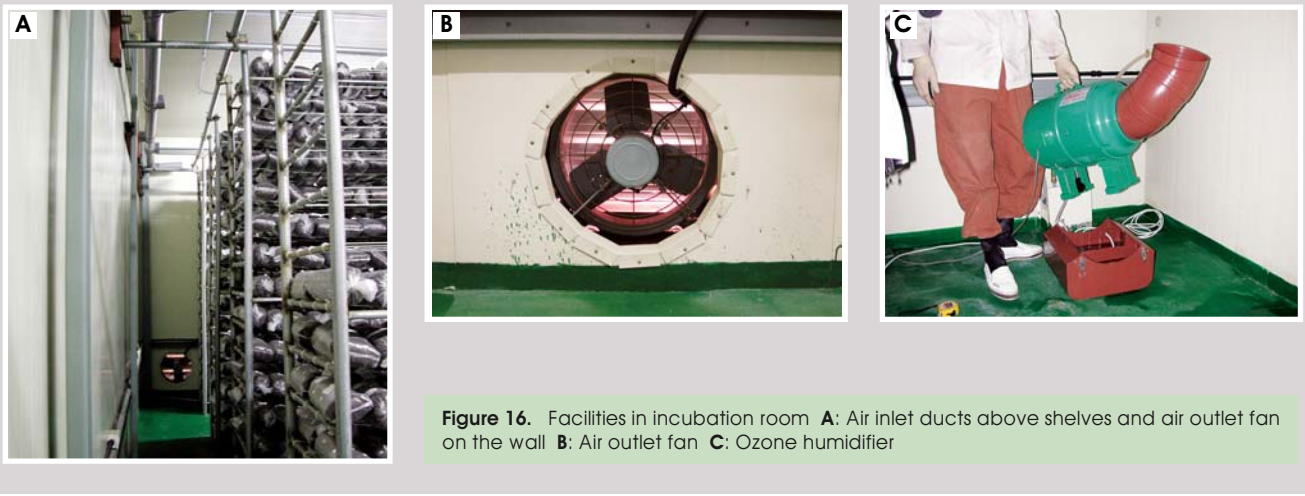

Figure 16. Facilities in incubation room **A**: Air inlet ducts above shelves and air outlet fan on the wall **B**: Air outlet fan **C**: Ozone humidifier

Chinese shiitake growers prefer strains with a longer spawn run period (4-5 months). However, strains with longer than 60 days' spawn run period are not a good economic choice in Korea because it is very costly to incubate bags for 4-5 months under these controlled environments. I used to incubate the bags for 60 days, but I learned how to shorten the period to 50 days after I had gained a bit of experience.

However, I will incubate the bags for 60 days in this case for the reader's reference. After mastering 60 days' incubation growers might themselves want to find a way to shorten the timeframe. My incubation room is very tightly controlled and this facility has required a large investment. Though the investment is reasonable in Korea due to the high prices and large market for shiitake, another farmer's situation might be different. If the environment for incubation is not controlled, it might take more time for full spawn running.

The stages of the 60-day spawn run period are shown below.

Table 3. Each stage of 60-day spawn run period

Stage		Duration(days)	Temperature (℃)	Ventilation	Light	Humidity (%)
Early stage		7	18	no	darkness	70
Middle stage	1st half	15	23-25	no	darkness	70
	2nd half	15	20-23	a little	darkness	70
Late stage	Maturity period	10	below 20	a lot	light	70
	Browning period	13	23	a lot	light	70

April 16, 2004

Temp. : 8.9/21.8℃ R.H.: 49.6% Rainfall : 0mm Sunny

All the bags were arranged on the shelves in the incubation room yesterday and they will be incubated there for about 60 days. During the 'Early stage,' the temperature in the incubation room will be adjusted at 18℃. This temperature is not favorable for the growth of green mold or bacteria, thus giving the shiitake mycelia the chance of stable colonization again other weed molds. The relative humidity is maintained at 70% without any controls. No ventilation or light is provided. The same conditions will be provided for 7 days and the shiitake mycelia will grow from the inoculated spots.

April 22, 2004

Temp. : 12.7/18.2℃ R.H.: 69.3% Rainfall : 0.5mm Shower

Shiitake mycelia keep growing white from the inoculated spots (Fig. 17B). The first half of the 'Middle stage' has started today. The temperature is being maintained a bit higher at 23-25℃. No ventilation or light is provided and the humidity is about 70% without any control. The same environment will be provided for 15 days.

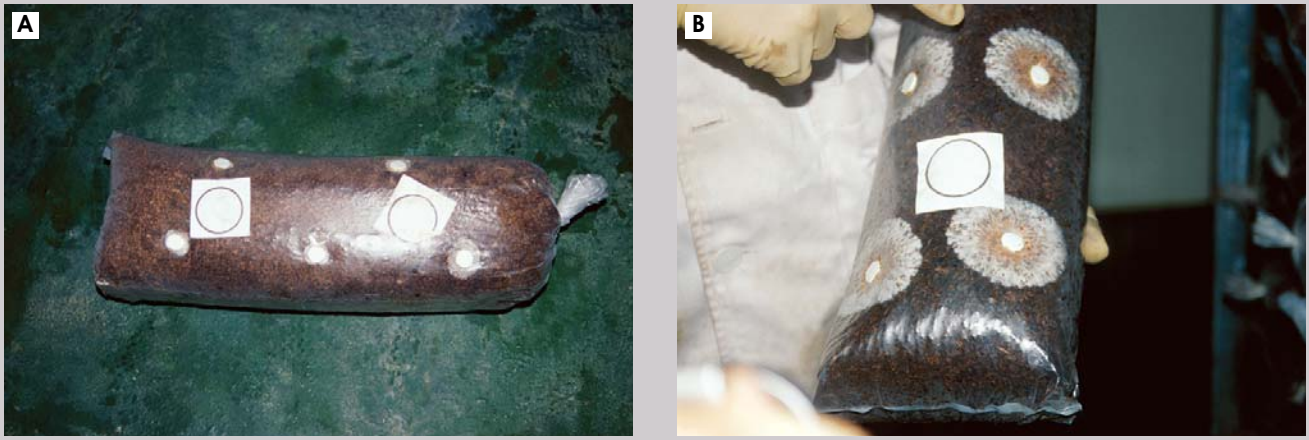

Figure 17. Early stage of spawn run **A**: White mycelia are visible around the plug spawn after 3 days' spawn run **B**: The bags after 7 days' spawn run

Turning of bags

The bags are turned in each stage of incubation. This turning aims at uniform incubation of each bag. The micro environments between the upper and lower part of bag are different in temperature and light intensity. More even temperature and light can be provided to both sides by turning the bags. In addition, the slight percussion by turning promotes the growth of the shiitake mycelia. Chinese shiitake growers change stacking shapes in each incubation stage, which provides the slight percussion to bags that promotes growth.

I turned the bags today because the 'Middle Stage' has started today (Fig. 18). It is not a difficult job, but quite tricky because the shelves are quite high with 15 levels. I use a ladder for turning bags on the upper parts of the shelves.

Figure 18. My wife turning bags during incubation

Exchange of O_2 and CO_2 through filter on the bag

Shiitake mycelia are aerobic, so I use bags with filters of 3cm in diameter on both sides to provide oxygen for the mycelia growth. If the plastic bag has no filter, it is recommended to perforate the parts covered with white mycelium with small punch holes to provide air. Chinese growers using bags without filters usually perforate the bags 3-4 times in concentric circles until the bags are fully colonized, but the filters save me the labor of doing this work. During mycelial growth gas should be allowed to escape from inside the bags through a filter or perforations. Un-ventilated gases inside the bags can damage the shiitake mycelia.

May 7, 2004

Temp. : 7.3/24.8℃ R.H.: 41.9% Rainfall : 0mm Partly cloudy

The first half of the 'Middle stage' finished yesterday and the second half started today, so I turned the bags. About 70% of each bag has been colonized by the white shiitake mycelia. As mycelial activity becomes more active, the emitted heat increases the temperature in the room. Therefore, the temperature is maintained a bit lower, at 20-23℃. The humidity has also begun to be controlled at 70% (Fig. 19). Ventilation started today: one hour in the morning and one hour in the evening. Light is not provided yet. This environment will be continued for 15 days. The ventilation time will be increased little by little, up to two hours both in the morning and evening, within the next 15 days.

Figure 19. Digital thermo-hygrometer

May 22, 2004

Temp. : 10.8/23.6℃ R.H.: 52.8% Rainfall : 0mm Mostly sunny

The 'Late stage' incubation starts today, so I turned the bags again. The first half of the 'Late stage' is called the 'Maturity

period' (10 days) and the rest is the 'Browning period' (13 days). More than 90% of each bag has been colonized by white shiitake mycelia. The bags will be fully colonized soon, so the temperature should be maintained as low as 20℃. The room is ventilated for 2 hours in the morning and evening. These conditions will be continued for 10 days. In addition, lighting will be provided day and night starting today to provoke the alteration from the vegetative stage into the reproductive stage. Browning starts in the 'Maturity period' (the first half of 'Late stage') of 10 days and is completed during the 'Browning period' (the second half of 'Late stage'). Primordia are also formed within the substrate during the 'Maturity period'.

May 28, 2004

Temp. : 16.5/21.7℃ R.H.: 88.0% Rainfall : 42.5mm Rain

It rained today. During the first half of the 'Late stage' (Maturity period) the temperature is maintained below 20℃, the humidity is at 70%, and there is a 2 hour ventilation in the morning and evening. On rainy days the room does not require the 2 hour ventilation. Exhaust is performed with the fan whenever the air is felt not fresh and when the humidity should be lowered.

June 1, 2004

Temp. : 12.1/27.8℃ R.H.: 51.4% Rainfall : 0mm Mostly sunny

The first half of the 'Late stage' finished yesterday. The bags are already fully colonized by shiitake mycelia and browning has started during the 1st half of the 'Late stage'. The second half, the 'Browning period', has started today, so I turned the bags. Browning will be completed during this period of 13 days. The temperature is adjusted at 23℃, the humidity at 70%, and lighting and much ventilation are provided.

I took 200 bags (I will call them Group #1) randomly and transferred them to growing house #1 where shiitake fruiting bodies from previously transferred bags are being produced. The group #1 bags will be browned in the growing house while the others (I will call them Group #2) will be browned in the incubation room. I will later compare the Group #1 bags to the Group #2 bags in the incubation room.

The browning period is critical in producing high quality shiitake. Though the shiitake mycelia moved into the reproductive stage during the 'Maturity period', it is recommended to also have a 'Late maturity' period in order to produce higher quality for a longer period.

Based on my own experience, I recommend completing the full incubation period even though the bags look fully incubated before the incubation period ends. When fruting is induced without having completed the incubation period, the shiitake quality was not high. This seems to be because the shiitake mycelia are not yet mature enough to produce high quality fruiting bodies. Of course, the substrate formulation also has some effect on the incubation period and the quality of fruiting bodies.

Figure 20. Browned bags in incubation room

June 4, 2004

Temp. : 17.8/30.4℃ R.H.: 54.5% Rainfall : 0mm Partly cloudy

Browning is going on both in the incubation room and in the growing house. The bags in the growing house are shrinking as browning goes on, so there is a gap between the plastic bags and the substrate.

June 7, 2004

Temp. : 18.6/24.7℃ R.H.: 49.8% Rainfall : 0mm Cloudy

I found green mold growing on some bags in the growing house because of the very high relative humidity and the gap between the plastic bags and the substrate. I always keep the plastic bags on during the browning in the incubation room, but I decided to peel off the bags now to minimize the contamination rate. The group #1 bags in the growing house are all peeled off while the Group #2 bags in the incubation room are still wearing the plastic bags.

Shiitake Growing House

I estimate that the sapwn running of the bags will be complete by June 13th and expect to transfer them to the growing house. Growing house management[2] is very important, especially during the hot summers. The outside temperatures are very high for shiitake fruiting, so the inside temperature and humidity must be controlled properly to achieve high yield.

[2] For detailed information on growing house management, *see* SHIITAKE GROWING HOUSE-KOREAN CASES in Chapter 6.

June 12, 2004

Temp. : 17.7/30.5℃ R.H.: 43.9% Rainfall : 0mm Mostly sunny

Today I checked the growing houses to see whether there were any problems. I have three growing houses and previously incubated bags are fruiting shiitake in the houses. I haven't previously written about my working with the already incubated bags lest it confuse the reader. Old substrates from which the eighth flushes have been harvested were removed from growing house #1 in order to make room for the newly incubated bags which are being incubated in the incubation room. Now, only the Group #1 bags remain in growing house #1.

I am paying a lot of attention to the growing house management now because it is summer. Because shiitake prefers temperate climates, special care is required to grow shiitake in hot summers. Therefore, I have built the growing house with an open roof that allows me to meet the picky requirements for fruiting shiitake in the summers. The temperature inside the growing house with the open roof is lower than the temperatures inside the typical growing houses without the open roof by 10℃ on sunny days and by 5℃ on cloudy days in summer. The open roof growing house also costs less to build than the ordinary panel growing houses. My open roof growing house has a triple structure; the inner plastic covers the shelves and the outer structure covers the inner structure. Shade net covers the outer structure (Figs. 21A, B and C). This growing house is characterized by an open roof. This partly opened and overlapped roof enables abundant ventilation to lower the temperature while it still prevents rain or snow from coming inside the building. The ground inside the growing house is covered with gravels or yellow soil to prevent contamination. The ground under the shelves is a bit lower than the aisles to let water drain away.

Figure 21. Growing house **A**: Triple structure of growing house **B**: The outer structure with partly open roof and the inner structure with plastic rolled up **C**: The outer structure made by two sheets of plastic cover and chemical cashmilon within

Induction and Fruiting

June 13, 2004

Temp. : 16.4/26.5℃ R.H.: 48.9% Rainfall : 0mm Sunny

The Group #2 bags which had been matured in incubation room were transferred to the growing house #1 today. The 2,200 bags were transferred by truck from incubation room to the growing house (Fig. 22A). The bags were carried into growing house by handcart (Figs. 22B and C). I arranged the group #2 bags on the shelves with two rows of 6 bags on each level (Fig. 22D). My shelves have 6 layers in total.

As soon as all the bags of Group #2 were arranged on the shelves, I peeled off the plastic bags to induce fruiting (Fig. 23A). I usually keep the plastic bags on the synthetic log during fruiting and harvesting, but I peel them off when I am growing high temperature strains. This is because the high temperature strain forms a lot of pins in the first flush and it is very laborious to make holes for the numerous pins. From the second flush, however, much reduced number of fruiting bodies are formed. The high number of pins in the first flush doesn't affect the life span of the bag. The physical shocks caused by the transfer are enough to induce the first flush. The high temperature strain is induced to fruit when the temperature is at around 20℃. Fruiting induction is the most crucial step in shiitake bag cultivation because the induction stage decides much of shiitake quality. Therefore, optimal temperature and humidity should be provided for fruiting induction. The temperature is maintained at 23-25℃ and the humidity at 70-90%. When the surface of the bags is dry, it is very hard to get pins.

Therefore, water should be sprayed in the growing house in the morning and evening. Ventilation is not essential for fruiting induction, but the side wall is opened and closed to control the temperature.

Figure 22. Transferring bags from incubation room to growing house **A**: The bags are transferred by truck **B** and **C**: The bags are carried into growing house by handcart **D**: Bags arranged on shelves

After the plastic is peeled off, the bags are watered enough to provide enough moisture to the surface of substrate (Fig. 23B). Though the relative humidity is quite high in summer, wind dries the moisture from the surface of the substrate. Therefore, enough watering is required to maintain the humidity and soften the peeled substrate blocks. For one day after filling the shelves, I keep the growing house closed to maintain stability.

Figure 23. Fruiting induction **A**: Peeled bags on shelves **B**: Watering

June 14, 2004

Temp. : 15.8/29.3℃ R.H.: 46.0% Rainfall : 0mm Partly cloudy

I started ventilation today. I rolled up the inner plastic to the end and opened the plastic of the outer structure to 80cm above the ground. The bags are more likely to be attacked by green mold if sufficient ventilation is not provided. I should see pins in the substrate soon. It takes about 3-4 days for fruiting induction and 7-10 days for fruiting development, so it takes a total of 10-14 days from induction to harvest for the high temperature strains.

June 15, 2004

Temp. : 16.3/30.8℃ R.H.: 43.8% Rainfall : 0mm Partly cloudy

Two days have passed since I transferred the bags into the growing house. I have compared the Group #1 bags as they browned and matured in the growing house with the Group #2 bags that were browned in the incubation room. Thick brown bark has formed for the Group #1 bags. I think this is mainly due to the strong light as well as the fluctuation of temperature between daytime and nighttime. The thick bark of the substrate hinders the pinning of fruiting bodies and the wider fluctuation of temperature than that of the incubation room provoked an excessive amount of primordia. However, it is very hard for these primordia to penetrate the thick bark, so many of them will die within the substrate. On the other hand, it seems to be because the fluorescent lighting within the incubation room is much weaker than the indirect sunlight in growing house, so the bark of the Group #2 substrate bags that were browned in the incubation room is soft and thin, which makes pinning much easier.

I performed this test to see whether I could incubate more bags in the incubation room by incubating a batch of bags for shorter period of 47 days in the room in order to be able to produce more shiitake bags. If the bags could be successfully browned in a growing house, I would brown them in the growing houses after incubating for only 47 days in the incubation room This would have made the operation of the incubation room more efficient. However, as a result of this test I have concluded that I had better not make this change.

June 19, 2004

Temp. : 20.0/22.6℃ R.H.: 87.3% Rainfall : 89.5mm Rain

It has been raining for three days. The weather forecast said the rainy season will be over next week. Korea, as well as Japan and China, has a rainy season in early summer and then the hot and humid summer continues for 1-2 months.

When the relative humidity is very high, as it is today, the shiitake bags are easily contaminated by green molds. The optimal relative humidity for high quality shiitake is 65-70%, but the actual humidity here is as high as 70-80% even in the hot summer which comes after rainy season. Therefore, I need to lower the humidity by ventilation in order to harvest high quality shiitake. Small pins are now visible on the substrate. High temperature strains have a reliable fruiting schedule, and it takes 3-4 days for fruiting induction, 7-10 days for fruiting and harvesting, and 5-7 days for rest. A total of 15-21 days are required for one flush. On the other hand, the harvest of a low temperature strain cannot be divided by flush. Though the quality is lower, the high temperature strain is more appropriate for yields planned according to market price. If the price is low I can keep the shiitake substrate resting. If the price goes higher, I can induce the next flush and supply shiitake at the higher price. Shiitake sells at twice the susual price on special occasions including Korean Thanksgiving Day. Therefore, I can control my cropping day to meet these peak days by cultivating a high temperature strain.

June 20, 2004

Temp. : 20.1/24.1℃ R.H.: 86.9% Rainfall : 6.5mm Rain

It keeps raining. Some of the fruiting bodies have grown large enough to be harvested. I harvested about 20kg today. The harvest will go on for 7-10 days as fruiting bodies develop asynchronously. When the harvest ends, the bags will rest for a week.

The Korean summers are very humid and hot. Therefore, the most difficult problem is lowering the relative humidity. Humidity can be easily controlled by running a humidifier when the relative humidity is low.

June 24, 2004

Temp. : 20.4/29.5℃ R.H.: 71.7% Rainfall : 0mm Cloudy

The shiitake is growing very well and We have harvested about 14kg per day. The first flush of a high temperature strain has many fruiting bodies (Figs. 24A and B). This year I have for the first time myself grown a high temperature strain. I used to cultivate low temperature strains even in summer by controlling the temperature with an air conditioner, but I was not successful in growing a low temperature strain in summer when the outside temperature was over 30℃. The high temperature strain is now fruiting without any difficulties in my growing house, but the quality of the fruiting bodies is much lower than that of the low temperature strain. The rate of flower shiitake (the highest quality of shiitake) is up to 40% when a low temperature strain is cultivated. However, this is my first trial with a high temperature strain. I believe the quality of the high temperature strain will be improved by repeating cultivation every summer as my experience with it will increase.

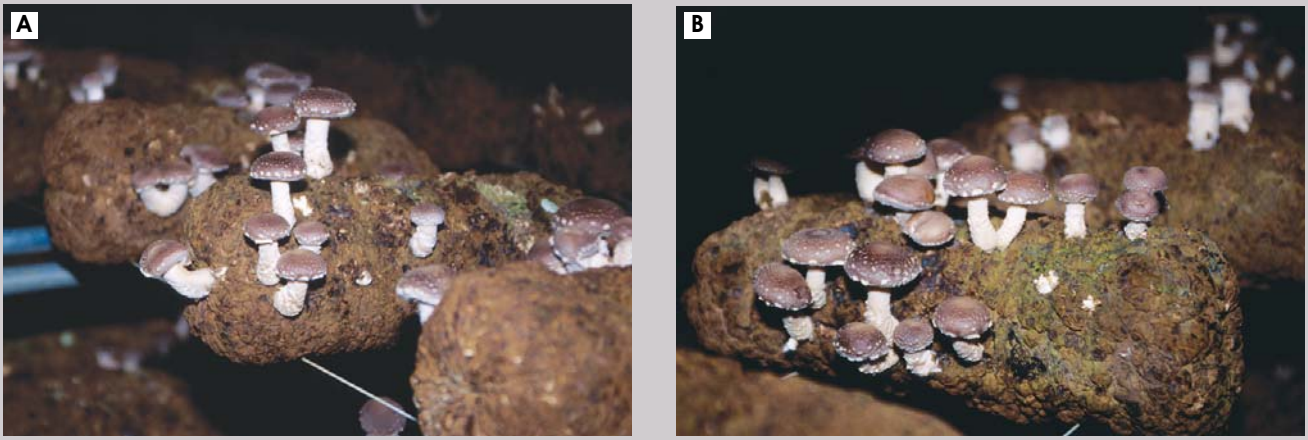

Figure 24. The first flush with many fruiting bodies

It is hot summer with high humidity, so I cannot find flower shiitake and the currently produced shiitake is fair to average in quality. Shiitake is harvested everyday and stored in the refrigerator. They are supplied after trimmed every other day because I use the collecting car that comes every second day to minimize transportation costs (Fig. 25). I supply my shiitake to the Suwon Agricultural Wholesale Market. They are sold by auction, so the price fluctuates according to supply and demand. The price goes up in the hot summer and cold winter when enough shiitake is not produced from logs. In addition, it also increases around Korean Thanksgiving day (September or October) and Korean New Year's Day (January or February) due to the temporary surge of demand.

Figure 25. Trimming and packing

June 26, 2004

Temp. : 21.1/28.7℃ R.H.: 71.3% Rainfall : 1.0mm Shower

Harvest of the first flush in Growing House #1 (both from Group #1 and 2) has almost finished. I harvested 300kg shiitake from 2,400 bags during the 1st flush. The quality is medium and I got an average of KRW[3]5,200 (USD5.2) per kg. The substrates are resting after harvesting the first flush. Usually, they rest for 7 days after cropping, but I will let them rest a little more before inducing a second flush because they produced more fruiting bodies than usual in the first flush. A lot of fruiting bodies does not guarantee high productivity. The first flush has a lot of pins, so many of them, mostly the smaller ones, are thinned out.

July 5, 2004

Temp. : 19.3/27.3℃ R.H.: 79.5% Rainfall : 7.0mm Rain

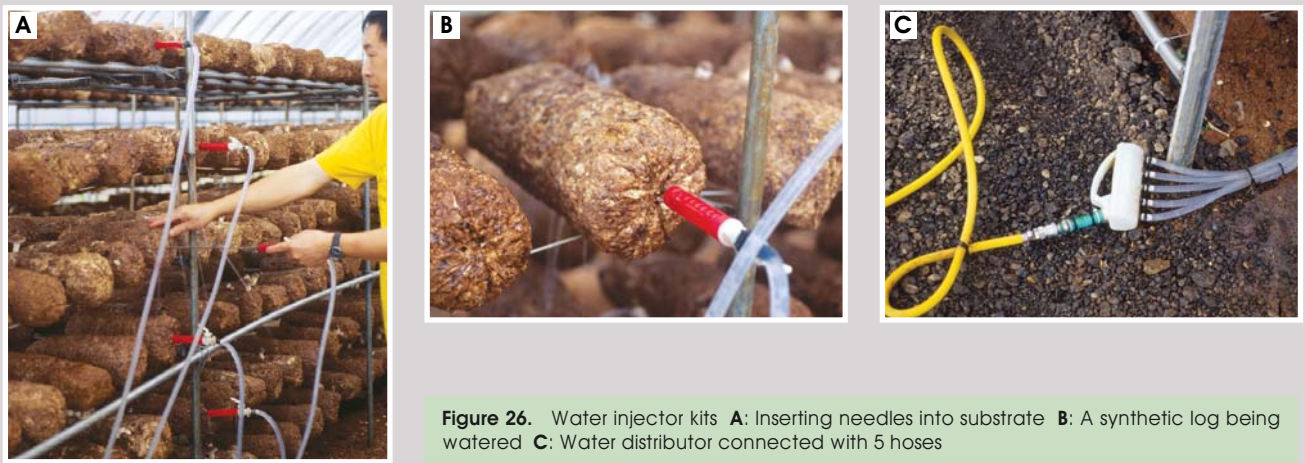

Figure 26. Water injector kits **A**: Inserting needles into substrate **B**: A synthetic log being watered **C**: Water distributor connected with 5 hoses

[3] KRW(Korean Won, USD1 ≒ KRW1,000 in March, 2005)

The substrates have rested for 10 days since the harvest of the first flush. I induced the second flush by watering. A low temperature shock is not required because the daytime temperature and nighttime temperature differ by more than 10℃ nowadays.

I use a water injector for watering. This injector is very effective and easy to use. It consists of needles, hoses, and a water distributor. The water is divided into five thin hoses through the distributor and each hose is connected to a each needle (Fig. 26C). Needles are inserted into the center of bags (Figs. 26A and B). Each needle has many holes on its body and water comes out through the holes into the substrate. Regular watering with a hose cannot penetrate the brown bark, but this injector forces water inside the substrate.

July 10, 2004

Temp. : 19.1/28.6℃ R.H.: 75.3% Rainfall : 0mm Partly cloudy

I started to harvest the second flush. A smaller number of shiitake is fruiting per bag than the first flush and the quality is better than the first flush (Figs. 27). So, I am getting a higher price per kg for the second flush.

Figure 27. Smaller number of shiitake per bag in the second flush

July 18, 2004

Temp. : 23.0/29.3℃ R.H.: 79.9% Rainfall : 0mm Cloudy

The harvest of the second flush has almost finished. I harvested about 320kg from 2,400 bags in the second flush. Most of the harvested shiitake are medium high quality (Figs. 28). It is very hot nowadays; the highest temperature is up to 30℃. It should be reminded of that shiitake harvest from logs in this season has been known impossible due to the high temperature. The price is quite high perhaps because of the low supply; I got an average of KRW7,000 (USD7) per kg for the second flush. The bags will rest starting today.

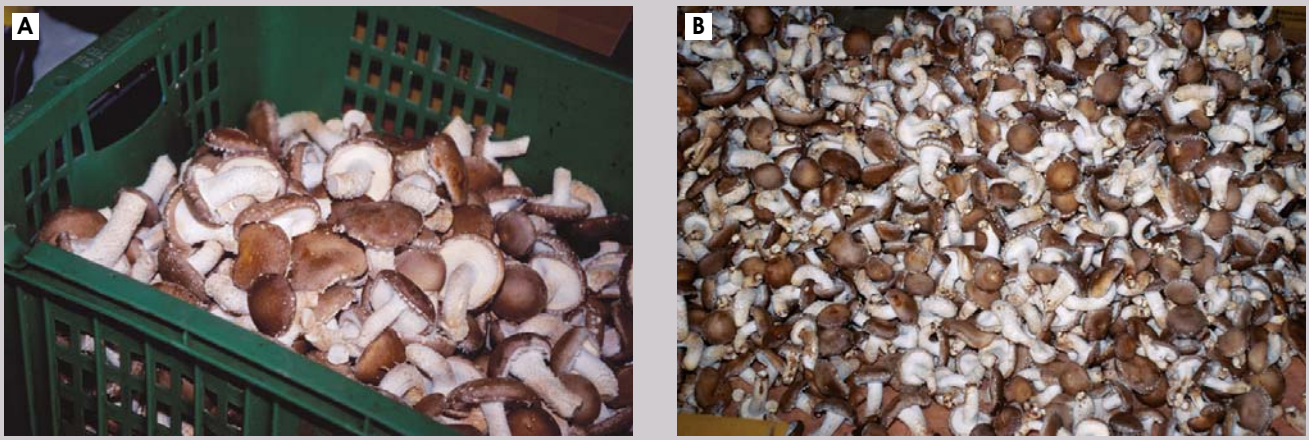

Figure 28. Harvested shiitake (the second flush)

July 26, 2004

Temp. : 23.7/30.4℃ R.H.: 75.9% Rainfall : 0mm Cloudy

Growing house #1

I started inducing the third flush by watering. Shiitake pins will show up within several days.

Growing house #2

Today, I also transferred 1,980 fully colonized (browned and matured) bags in the incubation room into Growing House #2. I will call these 1,980 bags Lot #2. These bags were inoculated with a high temperature strain in late April and have been incubated for 100 days in the incubation room. I was planning to build a new growing house after 60 days' spawn run and these bags were supposed to fruit the new one. However, the construction was delayed and these bags have been incubated 40 more days than the other bags. Though the transfer was delayed due to a lack of space in the growing house, I can harvest a second flush from these bags right before Korean Thanksgiving Day when shiitake prices are the highest, thanks to this delay. I peeled off the bags, but didn't water because the substrate contained much moisture. These bags have a high water content because they have absorbed much exudate generated from browning during the extended late maturity period. The mycelia have deactivated due to excessive water content, so they need to be dried to activate the mycelia. If not dried, it would be possible to get nothing from the bags. They could be dried enough within 5 days, I think.

July 30, 2004

Temp. : 23.7/33.2℃ R.H.: 67.0% Rainfall : 0mm Sunny

Growing house #1 - Lot #1

After inducing the third flush 4 days ago, the shiitake is growing well. I could harvest some shiitake starting tomorrow.

Growing house #2 - Lot #2

The bags are being dried. During the extended late maturity period, fully matured primordia were not able to fruit because the temperature in the incubation room was not appropriate and a physical shock was not provided. Stressed by the inappropriate environment, the shiitake primordia were on standby for fruiting. Once they got a physical shock during the transfer and an appropriate temperature for fruiting and enough oxygen after the bags were peeled off, however, all the standby primordia were matured into pins. High temperature strains are very sensitive to physical shock, so the number of pins reached above 40-50. Therefore, I am getting rid of most of them, leaving only 5-7 fruiting bodies to get better quality shiitake.

August 2, 2004

Temp. : 23.7/33.0℃ R.H.: 67.5% Rainfall : 0mm Partly cloudy

Growing house #1 - Lot #1

Fruiting bodies of shiitake keep growing, and I harvest some of them everyday.

Growing house #2 - Lot #2

The bags are dried enough. I expected that they would be dried enough within 5 days, but it took a week, a bit longer than I expected. I watered today to induce the first flush.

August 11, 2004

Temp. : 24.7/35.1℃ R.H.: 57.6% Rainfall : 0mm Sunny

Growing house #1 - Lot #1

I have harvested the third flush for 11 days. The harvest of the third flush has finished today and the bags will rest for several days.

Growing house #2 - Lot #2

The harvest of the first flush has finished today. I have harvested 358kg from 1,980 bags in 9 days. It means that I harvested about 180g per bag for the first flush. The highest price in August was KRW9,230 (USD9.2) per kg. I have been getting an average of KRW7,000 (USD7) since July and this price is much higher than the average annual price of KRW5,198 (USD5.2). Therefore, I can make much more money if I can produce high quality shiitake in summer. I need more trials and investment to produce higher quality in summer.

August 12, 2004

Temp. : 24.2/37.3℃ R.H.: 60.9% Rainfall : 0mm Sunny

This summer is really hot. However, the open roof growing house is very effective at keeping a lower temperature. The high daytime temperatures have been 35-37℃ for a week, but the temperature inside the growing house is maintained at about 28 ℃ by opening and closing the side plastic covers. I also water the growing house with underground water at 15℃ when the

inside temperature increases up to 30℃ and I can thereby lower the temperature by 3℃.

--------- 45 days later ---------

September 27, 2004

Temp. : 14.8/26.1℃ R.H.: 71.8% Rainfall : 0mm Mostly sunny

This year Korean Thanksgiving holiday started on September 26. Thanksgiving Day is very special for shiitake growers in many aspects. I have managed to get shiitake from all the bags in the growing houses in order to supply shiitake at the high price before the Thanksgiving holiday. I have supplied most of them by direct transaction.

I found that I could get a much higher price than usual by providing shiitake directly to consumers by telephone orders. I can get as much as KRW15,000 (USD15) per kg in these sales. This price is much higher than that for direct transactions at ordinary times it is about 3 times the average annual wholesale price. Direct transactions are beneficial to both the consumer and me because consumers can thereby get fresh shiitake. On the other hand, the auction price in the wholesale market was not better than that in summer because I sold the higher quality mushrooms directly to the consumers and the rest to the wholesale market.

Conclusion

Cost and benefit

I have harvested 2,793kg from 2,400 bags, so a bag of 3kg has produced average of 1.164kg through 8 flushes. I sold 85% of them to wholesale market and 15% directly to consumers. I supplied 2,374kg to the wholesale market at an average price of KRW5,198 (USD5.2) per kg, from which I earned KRW12,318,686 (USD12,318.7). I also sold 419kg directly to consumers at an average price of KRW10,000 (USD10), from which I earned KRW4,190,000 (USD4,190). For the 2,400 bags which I have written about, the average shiitake price per kg was KRW6,878 (USD6.9) and the total value of sale was KRW16,508,686 (USD16,508.7).

Cost of production includes labor costs, material costs, packing costs, electricity, fuel costs, management costs, and depreciation costs of fixed property such as land, spawn production facilities, incubation facilities, and growing houses.

The depreciation costs for the machines are calculated with a 5 year's duration and that for a building with 10 year's duration. In my case, the production cost per bag is KRW1,100 (USD1.1), so the production cost for 2,400 bags is KRW2,640,000 (USD2,640). (My own labor cost is not included.) In addition, I have paid KRW1,096,800 (USD1,096.8) for 2,400 bags as market fees such as handling fees, transportation costs, auction fees, and so on. This corresponds to KRW457 (USD0.46) per bag. This cost is really high, so I do prefer direct transactions. In total the net profit from 2,400 bags is KRW12,771,886 (USD12,771.9) and net profit from a bag is KRW5,321 (USD 5.3).

Table 4. Value of sale from 2,400 bags

	Volume of sale (kg)	Price per kg in KRW	Value of sale in KRW
Wholesale market	2,374	5,198	12,318,686
Direct transaction	419	10,000	4,190,000
Total	2,793	6,878 (USD6.9)	16,508,686 (USD16,508.7)

Production cost: 2,400 bags ×KRW1,100=KRW2,640,000 (USD2,640)

Market charge: 2,400 bags ×KRW457=KRW1,096,800 (USD1,097)

Net profit = Value of sale - Production cost - Market charge

= KRW16,508,686 - KRW2,640,000 - KRW1,096,800

= KRW12,771,886 (USD12,771.9)

Epilogue

The weather is getting cold and winter has already come. I am harvesting low temperature strains nowadays. The quality is much better than the high temperature strain (Fig. 29). Before concluding this farm diary, I would like to briefly introduce shiitake cultivation in winter and my future plans.

Figure 29. High quality shiitake (low temperature strain)

As I wrote before, I don't peel off plastic bags for low temperature strains. The plastic bag helps the substrate to retain moisture content in the substrate and it is one of the important factors in getting high quality shiitake. When pinning starts, therefore, I have to make the cuts at the pinning spots on the plastic bag to help the fruiting bodies come out (Figs. 30). This is a very laborious job as I grow shiitake at a large scale. One day I got a phone call from my friend in China. He introduced to me a newly released plastic bag which didn't require cutting plastic bag for the pinning to grow. It was a very thin plastic flim in which young fruiting bodies can manage to go through as they grow out. I was very happy about the new bags and imported some as samples. However, the result was not satisfactory. Though the fruiting bodies penetrated the plastic bags, they were somewhat distorted during penetration (Fig. 31A). This decreased the shiitake price, so I tore the plastic bags for each fruiting body again.

Figure 30. Cutting plastic bags for fruiting bodies to grow

I also tried coating synthetic logs with liquid paraffin (white oil) as a drying retarding agent after peeling off the plastic bags after browning (Fig. 31B). It was very effective at keeping the enough moisture within the substrate, and I didn't need to cut the plastic bags. However, I was not quite sure whether liquid paraffin is okay for human health, so I stopped using it.

During my travel in Zhejiang, China, I found other alternative methods to plastic bags. A government organization was testing with various possible drying retarding agents. One was mainly starch and the other was vegetable oils (Figs. 31C and D). The detailed composition of these coating agents was not disclosed. Once I had tried a with starch-based coating by myself, but it was easily watered aways. This was found to be fatal flaw because the substrates are supposed to be watered many times until fruiting stops. The vegetable oil-based coating looked very good, but I could not find the detailed composition. I am trying various compositions to identify the solution by myself.

I am also planning to use another type of shiitake spawn, the wood dowel (Figs. 32). Once colonized by shiitake mycelia, the wood dowels can be a very good spawn media that are easy to inoculate substrate bags. They are long enough that I don't have to inoculate both sides of the bag. I am planning to inoculate a bag with only 3-5 dowels per bag. Punching is not required for inoculation because the dowel itself can punch the bag with a conical point.

My facilities for bag production and spawn run are much bigger than those for the growing houses. I am therefore planning to operate a bag distribution center where colonized shiitake bags are delivered to shiitake growers who only fruit and harvest shiitake. Actually, quite a few people are waiting for my fully colonized shiitake bags, encouraged by my success. The operation of a "Bag Distribution Center" may be a challenge for me.

I believe a new challenge can always produce fruit. Though one might fail in these kinds of trials, a farmer should remember that he got an important lesson at least and that will be a step forward towards the future success.

Figure 31. Alternative methods for plastic bags **A**: Thin plastic bags **B**: Liquid paraffin-based coating **C**: Starch-based coating **D**: Vegetable oil-based coating

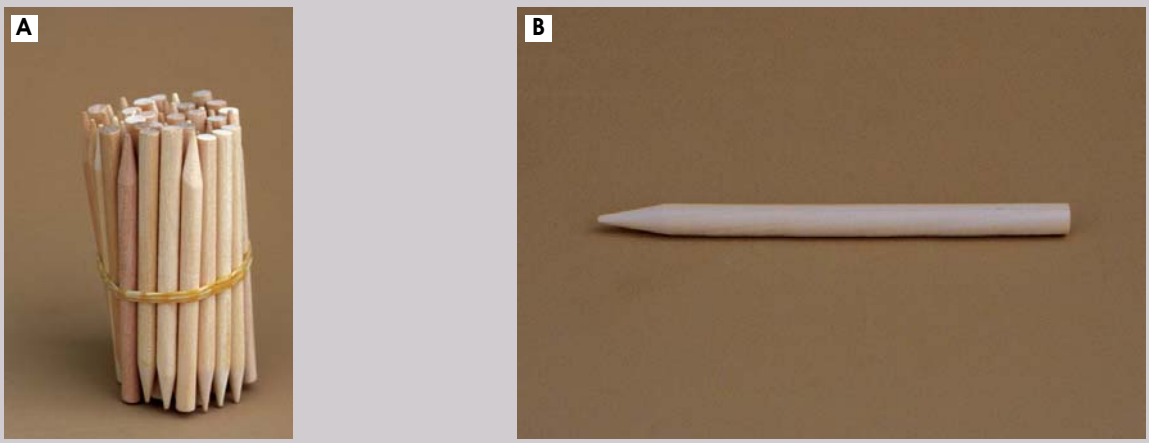

Figure 32. Wood dowel before shiitake mycelia is inoculated **A**: A batch of the dowels **B**: A piece of the dowel