Part I Shiitake

Chapter 3

Shiitake Log Cultivation

SHIITAKE LOG CULTIVATION

Keisuke Tokimoto
The Tottori Mycological Institute, Kokoge-211 Tottori, 689-1125, Japan (kin-tkmt@infosakyu.ne.jp)

Introduction

Figure 1. Fruiting bodies of shiitake, Lentinula edodes (Berk.) Pegler, on a log

Shiitake is a wood-decaying fungus that lives on dead broadleaf trees, particularly of the oak family (Fig. 1). Since shiitake was first cultivated on logs about 1,000 years ago, log cultivation has been the most common cultivation method, but this has changed recently. Bag cultivation of shiitake using sawdust packed into plastic bags was developed in the early twentieth century, and many shiitake growers have converted to bag cultivation due to the short production cycle and quick return of capital. However, log cultivation that uses a forest environment still has some advantages over artificial sawdust cultivation. Shiitake log cultivation requires less care and labor because it accepts natural conditions rather than requiring controlled conditions. The bark of the logs provides protection for shiitake mycelia and logs attract fewer microorganisms due to their low water content (Przybylowicz and Donoghue, 1990). Though it takes a longer time for the inoculated logs to be fully colonized and produce fruiting bodies, shiitake cultivated on logs are usually of a high quality with thick caps and fragrant odor. Log cultivation also causes less environmental pollution. In general, shiitake produced by log cultivation contained much more of polysaccharide than those cultivated by sawdust cultivation (Brauer *et al*., 2002), and lentinan, an anti-tumor polysaccharide of shiitake, shows similar relations (Tokimoto *et al*., unpublished).

Table 1. Annual production of shiitake in Japan (ton)

Year	Dried shiitake			Fresh shiitake			
	Production on logs	Import	Export	Production on logs	Production on sawdust	Import	Export
1975	11,356	93	2,695	58,560	-*	0	0
1985	12,065	140	3,330	74,706	-*	0	0
1999	5,582	9,146	156	36,069	34,442	31,628	0
2000	5,236	9,144	115	32,567	34,657	42,057	0
2001	4,964	9,253	151	28,542	37,586	36,301	0
2002	4,449	8,633	118	25,400	39,042	28,148	0

* Volumes of production from sawdust in 1975 and 1985 were not calculated, but actually zero.

Source: Forestry Agency, Japan, 2003

Japan has been one of the main producers of shiitake on logs. For the Japanese market, the thickest and largest shiitake are dried and the rest are usually consumed fresh. Dried shiitake is usually produced from logs and fresh shiitake is produced both from logs and sawdust (Table 1). Shiitake cultivation increased from 1950 to 1984 in Japan, but, production declined after 1985 mainly because of the exchange rate in favor of the yen. Most shiitake used to be produced from logs, but now about 36%[1] of the Japanese shiitake, both dried and fresh, is produced from sawdust.

South Korea produced 1,937 tons of dried shiitake and 22,374 tons of fresh shiitake in 2003 (Korea Forest Service, 2003). Separate statistics on production with logs and sawdust are not available, but it is mostly accepted that more than 95% of the Korean shiitake is produced from logs. On the other hand, most of the shiitake production in China is from sawdust bags.

The process of log cultivation involves three stages: 1. The log preparation and the growth of the vegetative mycelium, 2. The formation of fruiting body primordia, and 3. The development of fruiting bodies (Fig. 2).

Log Preparation and Mycelial Growth

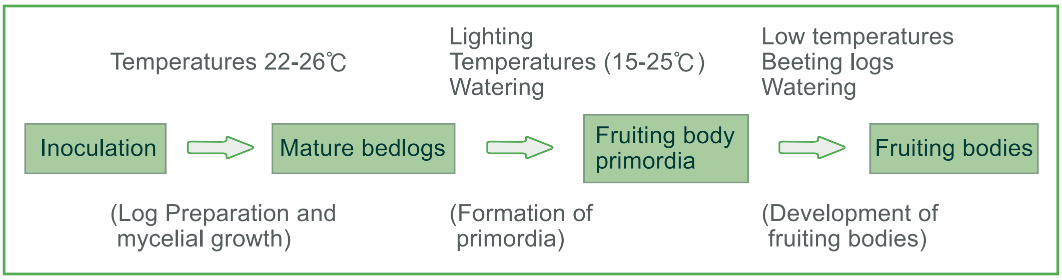

Figure 2. Process of shiitake cultivation on logs

Preparation of well-colonized logs is one of the most important requirements for fruiting body formation. This stage consists of the selection of host trees, felling and cutting, inoculation, and spawn run.

Selection of host trees

Logs are mainly composed of polysaccharides, cellulose and hemicellulose, and lignin, which are all decomposed by shiitake mycelia and used as their energy source. Sugars play important roles in the initial mycelial growth. Logs have a relatively low amount of nutrients compared with other agricultural wastes. This low nutritional availability also makes logs unattractive to other microorganisms. The bark on a log also provides very efficient protection from the attacks of other fungi and molds and it also prohibits moisture evaporation from the log. Once shiitake spawn is inoculated beneath the protective bark, it has essentially an exclusive access to nutrients in the wood, a fact that makes logs quite attractive as locations for cultured shiitake (Przybylowicz and Donoghue, 1990).

The main structures of a log are bark, sapwood, and heartwood (Fig. 3A). The bark is divided into inner bark and outer bark, and the former is the area where fruiting body primordia are formed. Sapwood is distinguished from heartwood by its color, as sapwood is lighter than heartwood. Shiitake mycelia colonize sapwood, which contains available polysaccharides, but do not grow easily into heartwood (Fig. 3B). Therefore, it is recommended that growers choose logs with a wide sapwood section.

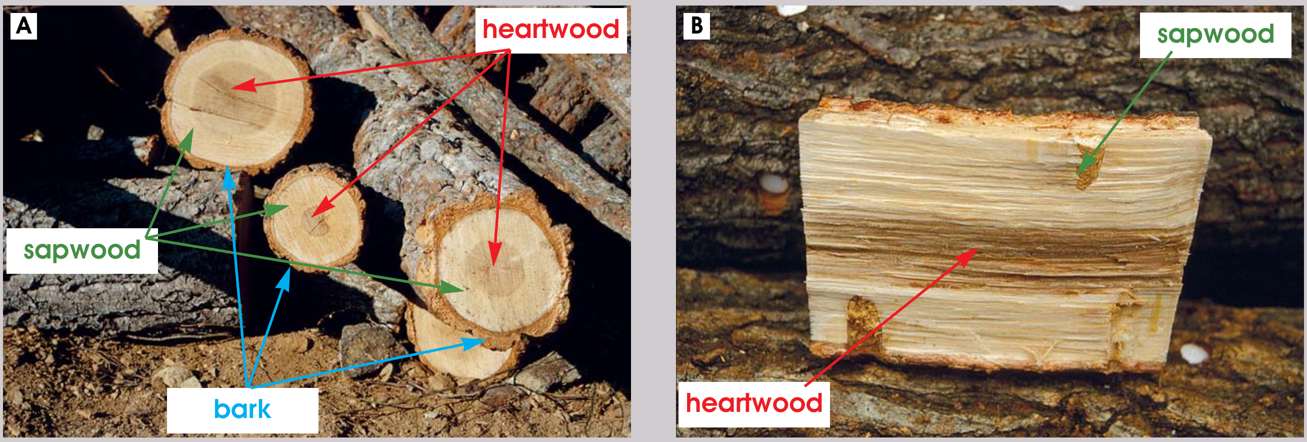

Figure 2. Consumer preference **A**: Light-colored shiitake **B**: Dried flower shiitake with white cracks on the cap (Jang-heung, Korea)

[1] Productions of fresh shiitake with logs and sawdust are estimated about 2,600 and 3,900 tons in dry weight, respectively.

In China, Korea, and Japan, many growers choose primarily oak (*Quercus*) trees. Although many factors affect the suitability of logs for shiitake cultivation, bark is one of the most important factors. Oak logs have strong bark that keeps its forms for many years, and is thus able to fruit for a long period of time, perhaps as long as four to five years (Fig. 3A). In tropical countries, oak trees inhabit the highlands. Cultivation using logs from oak trees has been tried in India (Lee, 1978), Thailand (Triratana, 1993), and other countries.

Though oak is preferred for shiitake log cultivation, shiitake can be and has been cultivated on other various hard and soft woods around the world. Each log species produces different amounts of shiitake with various qualities for various periods. Logs from softwood trees, which are also capable of cultivation, tend to start fruiting earlier than those of hardwood trees but exhaust their fruiting capacity more quickly.

Tree species tested for suitability of shiitake cultivation are listed according to Przybylowicz and Donoghue (1990), (Table 2).

Table 2. Tree species tested for suitability for shiitake production

Common name	Family	Genus	Species
High suitability			
Oak	Fagaceae	*Quercus*	*acutissima, alba, brandisiana, crispula, dentata, garryanna, kelloggii, kerii, kingiana, mongolica, muehlenbergii, prinus, rubra, semiserrata, serrata, variabilis*
Chinkapin	Fagaceae	*Castanopsis*	*accuminatissima, argentea, chrysophylla, cuspidata, indica*
Tanoak	Fagaceae	*Lithocarpus*	*auriculatus, densiflorus, lanceafolia, lindleyanus, polystachyus*
Hornbeams	Fagaceae	*Carpinus*	*betula, caroliniana, japonica, laxiflora, tschonoski*
Medium suitability			
Alder	Betulaceae	*Alnus*	*glutinosa, japonica, rubra, serrulata, tinctoria*
Aspen,Poplar, Cottonwood	Betulaceae	*Populus*	*balsamifera, deltoides, grandidentata, nigra, trichocarpa*
Beech	Fagaceae	*Fagus*	species
Birch	Betulaceae	*Betula*	*nigra, pendula*
Chestnut	Fagaceae	*Castanea,*	*crenata*
		Cyclobalanopsis	*acuta, glauca, salicina, myrsinfolia*
Hickory	Juglandaceae	*Carya*	species
Maple	Aceraceae	*Acer*	*rubrum, macrophyllum*
Sweetgum	Hamamelidaceae	*Liquidambar*	*styraciflua*
Tupelo	Nyssaceae	*Nyssa*	*silvatica*
Willow	Salicaceae	*Salix*	*nigra*
Low suitability			
Cucumbertree	Magnoliaceae	*Magnolia*	*accuminata*
Tulip poplar	Magnoliaceae	*Liriodendron*	*tulipifera*
Dogwood	Cornaceae	*Cornus*	*florida*
Apple	Rosaceae	*Malus*	*sylvestris*
Sycamore	Platanaceae	*Plantanus*	*occidentalis*
Virginia pine	Pinaceae	*Pinus*	*virginiana*

Note: Trees considered highly suitable are widely used, while medium suitability trees require careful management. Trees with low suitability are not recommended for commercial shiitake production.
Source: Przybylowicz and Donoghue, 1990

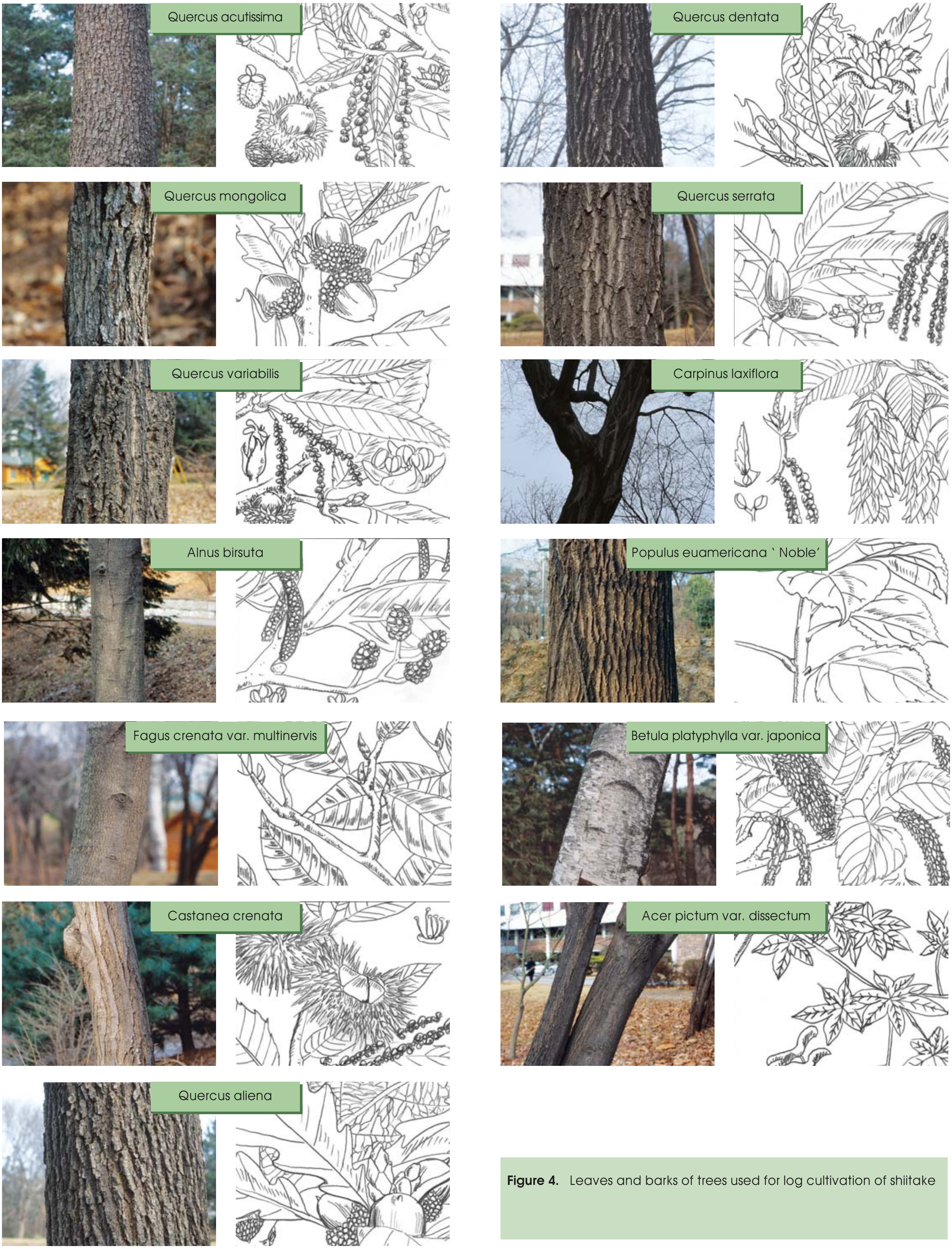

Figure 4. Leaves and barks of trees used for log cultivation of shiitake

Tree felling, cutting and storage

Once most appropriate trees are selected, it is recommended that growers fell them during the dormant season of trees, although the stage of "leaf-reddening" is the best for *Quercus* trees. Trees 5-15cm in diameter are appropriate for shiitake logs. The felled trunks are usually cut into logs about 100cm in length and dried slightly. If the felled trees still have green leaves, they are dried for a period less than 10 days. This water reduction weakens the resistance of the logs to the shiitake mycelia and enables better mycelial growth. On the other hand, shiitake mycelium itself requires water for its growth. Therefore, excessive drying should be avoided. Drying may be excessive if logs are stored for a long period before spawning. To control the water content of logs and keep it within a suitable ranges (30-35% in wet base for *Quercus* trees), logs are generally piled up less than 50cm high and sheltered from direct sunlight. Long storage under warm conditions (more than 10 ℃) also involves some risk of the contamination with other microorganisms.

Figure 5. Preparation of logs **A**: Cutting **B**: Conveying **C**: Storage before inoculation

Choice of log and felling time for better mycelial growth

Death of woody cells

The speed of colonization of shiitake in logs is closely correlated to the viability of the woody cells (Komatsu *et al*., 1980; Shimomura and Hasebe, 2004). Less viable cells are preferred for colonization by shiitake mycelia. In countries with four distinct seasons such as Japan and Korea, *Quercus* trees are felled in late autumn when the leaves remain partially green. The logs are left on the felling site for more than 10 days with the leaves attached. By this treatment, an excess of water is gradually and evenly lost from the wood tissues, mainly through the green leaves. This process promotes the death of living cells in the inner bark, cambium, and sapwood regions.

If trees are felled too early, the bark strips off easily, perhaps due to the condition of the formative layer of the logs. The formative layer is wide and shows physiological activity before autumn, but later it stops the physiological activity and becomes thin. This change in the autumn probably fastens the bark to the sapwood. In contrast, when trees are felled after all the leaves have turned red, water evaporation through the leaves is prevented, and the natural resistance to shiitake remains and the growth of shiitake mycelia is inhibited.

Nutriment amount

The nutritional content of the wood is important for mycelial growth, wood decay, and fruiting. In general, thin logs contain much more nutrition per volume than those of fat logs. Thus thin logs produce fruiting bodies earlier, but with logs less than 5cm in diameter it is difficult to control the water content (Fukuda *et al*., 1987).

Felling time affects the amount of nutriments of the wood. Logs felled in late autumn have much more nutrition than those felled in early autumn. In general, the nitrogen in green leaves moves to the trunks before the leaves turn red (Tokimoto *et al*., unpublished). In addition, it is thought that the sugar contents of logs increase as the temperature drops, a process trees initiate to avoid freezing.

In *Quercus* logs, the degree of wood decay and fruiting body yield per 10,000cm^3 in volume negatively correlates with both the diameter and outer bark thickness, but positively correlates with the contents of nitrogen, phosphorus and others (Fukuda *et al*., 1987; Matsuomoto *et al*., 1990). In other words, thinner logs and bark are preferred for more wood decay and higher yield, and more nutrition promotes wood decay and shiitake production.

Strain selection

Table 3. Summarized properties of shiitake strains

	Strain types			
	Low temp.	**Low to medium temp.**	**Medium temp.**	**High temp.**
Maximum temperature for fruiting induction	about 5℃	about 10℃	about 15℃	20-25℃
Incubation period for full colonization	Long	Medium or long	Medium	Short
Size and quality of fruiting bodies	Big sized, mainly dried		Medium or big sized, mainly dried	Small or medium sized, consumed fresh

Note: Typical properties are shown, although there are some exceptions.

Shiitake strains are classified according to fruiting temperatures into four types: low, low to medium, medium, and high temperature types (Table 3). Low, low to medium and medium temperature types fruit at lower than about 5, 10 and 15℃, respectively. Many high temperature strains are able to fruit at 20-25℃, but in many cases require soaking the logs in cold water lower than 20℃. For fruiting in summer or warm places, high temperature strains are recommended. Generally, the incubation period of high temperature strains tends to be shorter but their fruiting life ends earlier.

In Japanese and Korean markets, high quality shiitake with larger and thicker caps are dried. Therefore, low or medium temperature types are selected for dried shiitake products because these strains generally produce larger and thicker fruiting bodies than high temperature strains.

Inoculation

Just prior to the inoculation, thirty to sixty holes, about 2cm in depth, are drilled in a log of average size (Fig. 6A). In many cases, the inoculation holes are spaced at 15-20cm intervals along the longitudinal direction with rows 3-4cm apart. This is because mycelial expansion in the longitudinal direction is almost five times faster than in the circumferential direction (Fig. 6B).

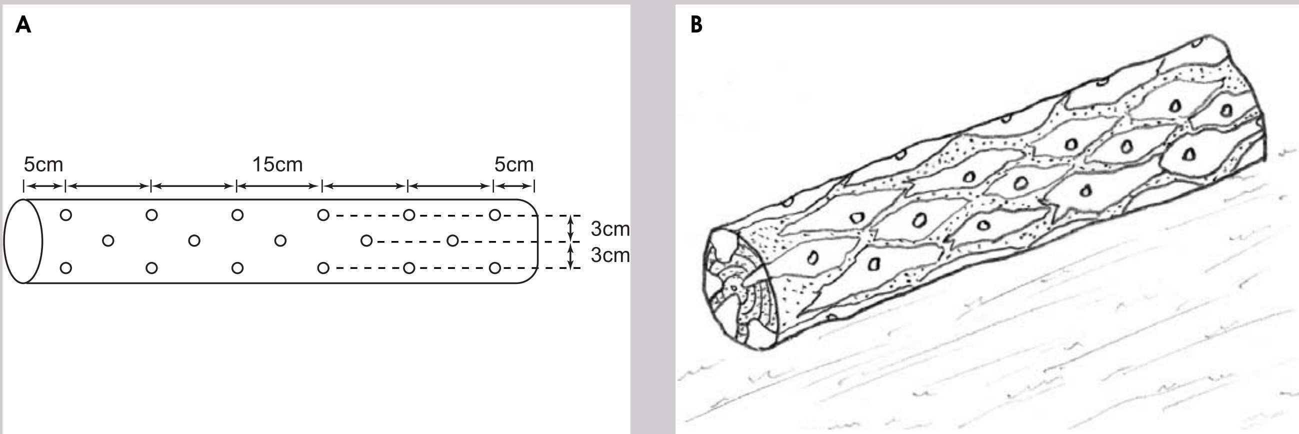

Figure 6. Patterns of drilling and mycelial growth **A**: A typical way of inoculation (inoculation holes and their arrangement) **B**: Growth pattern of shiitake in a log

Either sawdust or wooden plug spawn that carries the shiitake mycelium is inserted into the holes. Images of the two types of inoculation of sawdust spawn, a spawning gun and a sawdust plug spawn are shown in Figures 7. A spawning gun is an effective tool for inoculating sawdust spawn into the holes and sealing them. After drilling holes on logs in the suggested patterns, the spawning gun is loaded with sawdust spawn, which is then shot into the holes (Figs. 7A, B, and D). The gun inserts sawdust spawn using compressed air and covers the spawned hole with a styrofoam seal at the same time (Fig.

7C). Sawdust plugs are pre-made for spawning and inoculation is performed by inserting them into the holes in the logs (Fig. 7F). Figure 7E shows the structure of a sawdust plug spawn[2].

Figure 7. Inoculation and equipment **A**: Drill **B**: Drilling holes **C** and **D**: Spawning gun and spawning with it **E** and **F**: Plug spawn and spawning with it

Spawn run

Inoculated logs are arranged in places where suitable humidity, good drainage, and indirect sunlight are available. Tree shade or shading nets can provide such an environment. Inoculated logs can also be incubated in a growing house. The optimal temperature for mycelial growth is 22-26℃, while the wood-decay process is stronger at 25-30℃ (Tokimoto *et al*., unpublished). Direct sunlight to logs must be avoided, because this can raise the log temperature to over 35℃, which causes

[2] For detailed process of sawdust plug production, *see* SPAWN PRODUCTION PREPARATION CHIEFLY WITH SAWDUST in chapter 2.

heat damage to the shiitake mycelium. When the temperature is below 15℃ during spawn run, covering of log pile with a plastic film is an effective way to raise the temperature. However, these films must be removed when the outdoor temperature rises above 15℃.

The optimal water content of logs during spawn run is around 35% in wet base, which represents a 5-10% loss from the weight of living fresh logs. In the dry season, watering is effective. Mycelial growth tends to slow in the rainy season because of the excessive supply of water. Occasional screening that protects the logs from rain is used for controlling the water content of logs during the rainy season.

Log stacking methods

Inoculated logs are re-stacked several times during the spawn run according to the environmental requirements of each growing stage. Several stacking methods such as bulk stack, crib stack, lean-to stack and A-frame stack are used. Each serves in different micro-environments to aid in ventilation and humidity control. Growers should consider their own conditions when choosing a stacking method. In general, well ventilated stacking is recommended for wet logs while low or close stacking is better for dry logs. The main focus of log management should be on the mycelial protection for one or two months after inoculation, on pest and disease control during the spawn run period, and on easy working during the pinning and fruiting periods.

Figure 8. Various ways of stacking during spawn run **A**: Bulks **B**: Crib stacks **C**: Lean-to stacks **D**: A-frame stacks

In Korea, with four distinct seasons, growers are advised to stack the logs three times. The stacking methods mentioned here are standard in Korea, but may not be appropriate for another country. As logs are inoculated when it is still cold and dry outside, they are stacked for 1-2 months in such a way as to help the shiitake mycelia start growing. A bulk stack is common for mycelial growth, and this is a very dense stacking (Fig. 8A). The object is to keep the temperature at 10-20℃, and the humidity at 80-90%. When the shiitake mycelia have grown about 20mm along the wood fiber after one or two months, restacking is required. Once the initial shiitake mycelia have grown sufficiently, the logs are stacked to aid in spawn run. Either a crib stack or a lean-to stack is usually used for spawn run (Figs. 8B and C). The logs go through the long spawn run period over six months that includes both a rainy season and a hot summer. During this spawn run period, pests and diseases, and drainage should be well controlled. When spawn run is almost completed, they are arranged in an A-frame stack and kept in this shape during fruiting and harvesting (Fig. 8D). It is recommended that growers should not arrange logs so closely as to ruin the shiitake's shape. The slant of log stacking affects mycelial growth. In general, a different degree of slant is recommended for log stacking according to the different log species, thickness, weather, drainage, ventilation, and amount of logs (Table 4). The required period for full colonization of logs by shiitake mycelia depends on the spawn run temperature, humidity, strains, the type of spawns, and log properties. For example, some strains of sawdust spawn produce fruiting bodies directly from the spawn holes after about six months' spawn run, but many strains of plug type spawn require more than one year.

Table 4. Slant of logs stacking

	Steep	Gentle
Wood species	*Quercus acutissima, Q. serrata, Q. mongolica, Q. variabilis*	*Carpinus laxiflora, Q. myrsinaefolia*
Log thickness	Thick	Thin
Weather	Rainy	Dry
Drainage	Bad	Good
Ventilation	Bad	Good
Amount of logs	More	Less

Source: Teaching Material for Shiitake Cultivation in 2002, National Forestry Cooperatives Federation

What makes a good log?

Importance of mycelial amount in logs

The development of fruiting bodies requires nutrition which is supplied by the vegetative mycelium to the fruiting body. During the development of fruiting bodies, sugars, amino acids, and other chemicals accumulate beneath the young fruiting bodies then move into the fruiting bodies (Tokimoto *et al.*, 1977, 1984). Colonized logs with higher measured chitin content[3] produce greater fruit body yields, because high chitin content indicates abundant mycelial growth (Tokimoto and Fukuda, 1981) (Fig. 10). The logs with well developed mycelia also possess a strong resistance against antagonistic fungi due to their production of antifungal substances (Tokimoto and Komatsu, 1995). However, there is no guaranteed method to encourage mycelial growth. Control of the log water content is important in many cases, and every step in the preparation of the logs affects the subsequent mycelial growth.

Figure 9. Well incubated logs seen from above (Lean-to stacks)

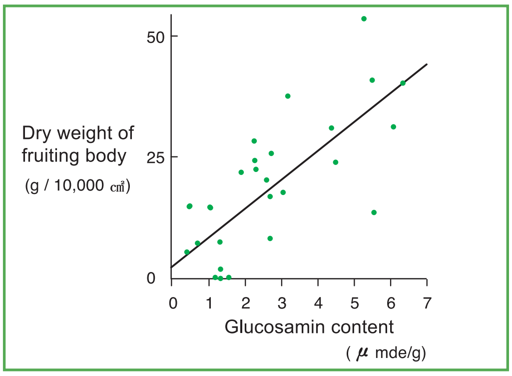

Figure 10. Relation of glucosamine content to fruiting body yield in shiitake bedlogs (Tokimoto and Fukuda 1981).
Glucosamine, an acid hydrolysate of chitin, was used for the estimation of mycelial amounts in bedlogs. One- to six-year-old bedlogs, 31 samples in total, were employed. Y = 5.92**X + 2.59 (**P < 0.001)

[3] As shiitake mycelium contains fixed amount of chitin, chitin content is useful for the estimation of the mycelial amount. Logs do not have their own chitin.

Degree of wood-decay

Wood-decay of logs is accompanied by mycelial growth. During cultivation, there is a suitable point of wood-decay which sustains good fruiting. The degree of wood decay is measured by the dry weight of wood, which is calculated by the specific gravity of a log dried in oven. In the case of *Quercus* logs, the specific gravity changes during cultivation from around 0.75, uninoculated logs, to around 0.30, five-year-old logs. A *Quercus* log dried in an oven to a specific gravity of about 0.4 is capable of the best fruiting (Tokimoto *et al*., 1984). When the fresh weight of a log has decreased by more than 30% before inoculation, the time is generally considered the optimal point of wood-decay. Therefore, it is recommended that fruiting be induced when the logs have lost 30% of their weight.

Formation of Fruiting Body Primordia

Figure 11. Exposed fruiting body primordia beneath the outer bark of a log

A fully incubated shiitake mycelium is ready to change from the vegetative stage (mycelial growth) to the reproductive stage (fruiting). A sudden change of environment is required to trigger the reproductive stage. Lower temperature, higher humidity, and light are the key points of this environmental change. The first step of the reproductive stage is primordia formation. A fruiting body primordium is a tiny mycelial mass, around 2-5mm in diameter, which is formed at the inner bark of logs (Fig. 11). To check the primordium number in logs, the outer barks of several logs are removed as samples. While a sawdust culture fully incubated in darkness requires lighting of 2-3 weeks for primordium formation (Tokimoto and Komatsu, 1982), at least 30 days' lighting is required to produce fruiting body primordia in logs (Komatsu and Tokimoto, 1982).

Conditions for primordia formation

Fully incubated logs are transferred to a raising yard or growing house where lower temperature, higher humidity and light are provided for primordia formation and fruiting. Primordia formation is an important step because the number of fruiting bodies tends to be equal to the number of primordia. Basically, good logs having well grown mycelia and a proper degree of wood-decay will produce many fruiting body primordia (Tokimoto and Fukuda, 1981).

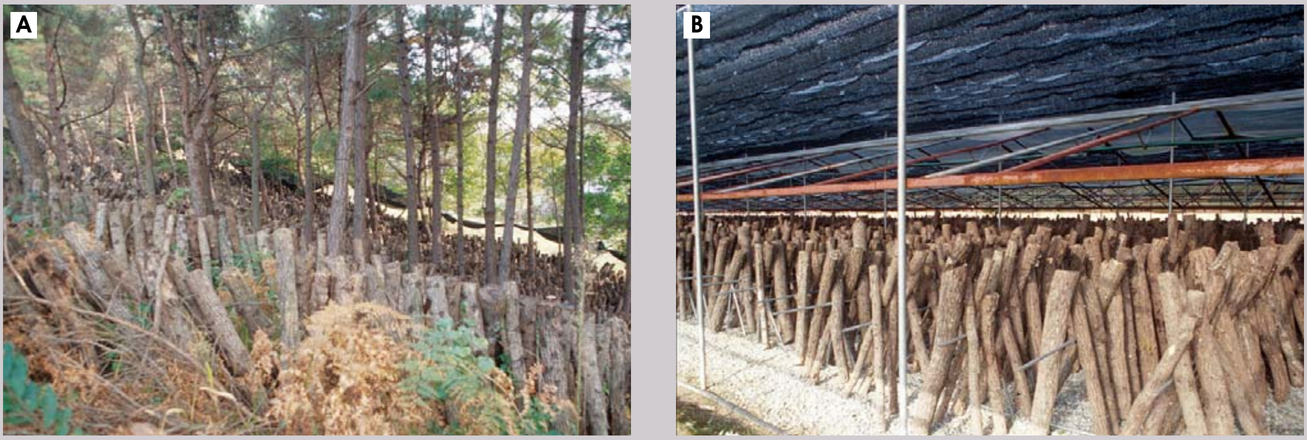

Figure 12. Fruiting area **A**: Raising yard under trees **B**: Simple structure under shading nets

Temperature

The appropriate temperature for the formation of fruiting body primordia ranges from 15-25℃, although each strain has its own optimum temperature (Komatsu and Tokimoto, 1982; Tokimoto and Komatsu, 1982). Watering or rain lowers the temperature and also increases the moisture content of logs.

Moisture content

The water within logs is divided into free water and bound water that is bound to woody cells. Free water plays its part in the mycelial growth and fruiting, while bound water does not. Therefore, free water should be increased within logs to encourage primordia induction. The formation of primordia requires a log water content in which more than 10% (v/v) is free water (Tokimoto, unpublished). Unfortunately it is difficult for growers to determine the amount of free water. However, the weight of logs is an important measure by which farmers can estimate the rough amount of free water. In general, the logs weighing 7kg/10,000cm^3 (equals to logs of 100cm-long and 12cm-diameter) contain more than 10% free water.

Lighting

Figure 13. Fruiting bodies from the holes of sawdust spawn

Sunlight reaching the mycelium beneath the outer bark of logs triggers the formation of primordia. An abundant amount of primordia results in a good shiitake crop.

The minimum luminous intensity for the formation of fruiting body primordia is estimated to be about 0.01-0.001 lux. The inner bark where primordia are formed needs to recieve this quantity of light (Ishikawa, 1967). The thickness of the outer bark is important because it prevents light transmission into the mycelium of the inner bark. In the case of *Quercus serrata* logs, the outer bark of more than 2mm in thickness completely prevents both the light transmission and formation of fruiting body primordium (Komatsu and Tokimoto, 1982).

Logs with thick outer bark are not capable of fruiting through the outer bark, but they can fruit directly from the inoculation holes (Fig. 13). The period of light exposure necessary for fruiting may be very short, and may be less than one hour under certain circumstances (Leatham and Stahmann, 1987).

However, it is not always necessary to control the light intensity to induce primordia formation. When 3,000 lux of light is given to logs, even the mycelium beneath the outer bark generally receives several lux of illumination, which is enough to initiate fruiting. In the open air, more than 3,000 lux of illumination is available under trees in most cases.

Development of Fruiting Bodies

Once primordia are formed, they should develop into fruiting bodies that are large enough to harvest. Fruiting body development is stimulated by low temperatures from 5 to 20℃, depending on the strains and watering. When the temperature is appropriate for the strain, fruiting occurs naturally in autumn and spring. Log beating, which is a physical shock, is also known to be effective in fruiting induction. Many growers soak the logs in cold water at 15-20℃ to promote fruiting body development. Soaking process gives logs water and physical shock.

In intensive cultivation, logs of high temperature strains are commonly used. This is because high temperature strains tend to be more sensitive to stimuli and thus more suitable for forced fruiting. These days the majority of shiitake growers cultivate high temperature strains indoors in order to be able to regulate the environmental factors and timing of the mushroom production more easily.

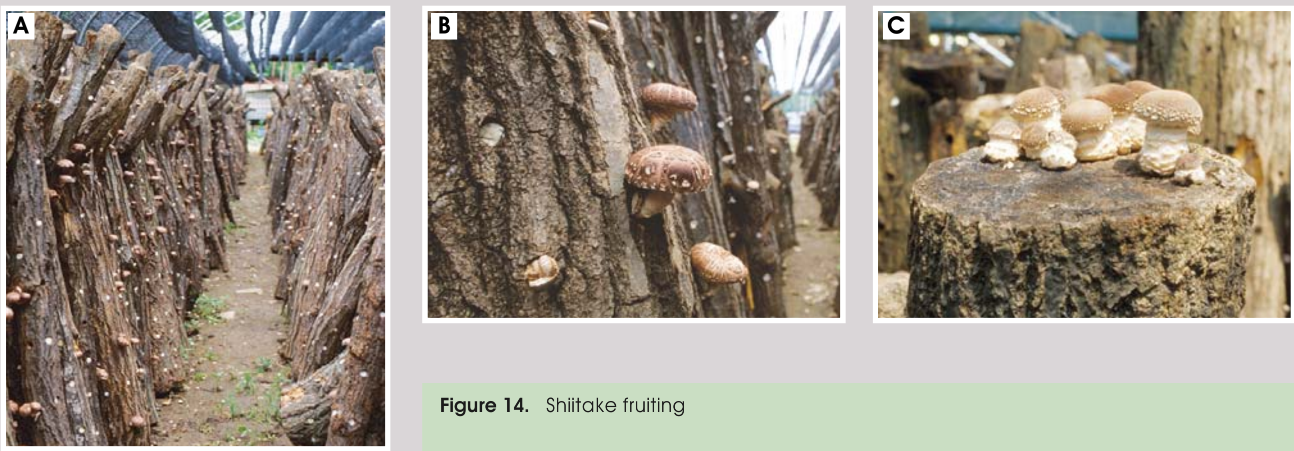

Figure 14. Shiitake fruiting

Conditions for fruiting body development

Low temperature

Low temperatures induce fruiting body development which accompanies the enhancement of enzyme activities such as acid protease and the accumulation of nutriments around a developing fruiting body (Tokimoto *et al*., 1984; Tokimoto and Fukuda, 1997). Temperature during fruiting body development also affects the shape and yield of fruiting bodies and each strain has its own optimum temperature (Kawai and Kashiwagi, 1968; Ohira *et al*., 1982). When the temperature is lower or higher than optimum for the strain, smaller fruiting bodies are produced. High temperature strains are induced to produce fruiting bodies with a shorter exposure of low temperature, and may need only several hours of cold. However, low or medium temperature strains require much longer exposure to low temperature to induce fruiting by exposure to a brief low temperature.

Generally, old and light logs require much more water but young and heavy logs also need a small amount of water. Watering is the most practical way of lowering temperature in summer. Water temperature is also important as is the amount of absorbed water.

Water content in logs

A relative humidity more than 65% is essential for the normal growth of fruiting bodies (Kawai and Tokimoto, unpublished). Logs consist of wood substance, water (bound water and free water), and air. In *Quercus* wood, the maximum amount of the bound water is around 28% (w/w) of the wood substance, and the remaining amount is free water. In many cases, the free water is about 10-20%, but occasionally it may reach more than 20% after the logs have been soaked in water. The amount of free water depends on the amount of total water which varies with log conditions. The progress of wood-decay reduces wood substance and increases the capacity of free water and air.

Each log has its own optimum water content for fruiting, depending on the degree of wood-decay. In the case of *Quercus* logs, a high content of free water, more than 20%, together with a high content of air volume, more than 30%, results in a good fruiting (Tokimoto *et al*., 1998) (Table 5). As less decayed young logs have high levels of wood substance, it is difficult to hold high contents of free water and air. That is why less decayed logs produce fewer fruiting bodies. In contrast, old logs easily get much more free water and air but have insufficient nutriments.

Table 5. Physical properties in sapwood after soaking and mean yield of 10 logs

Log age (month)	Treatment before soaking*	Volume (%) in sapwood after soaking**			
		Wood substance and bound water	Free water	Air	Fruiting body yield (g)***
21	Cut ends	40.5	20.5	39.0	111
	Notched bark	40.9	23.9	35.5	122
	None	40.1	17.3	42.3	151
45	Cut ends	29.7	32.8	37.7	242
	Notched bark	29.4	32.0	38.6	190
	None	29.4	17.8	52.8	68

* To promote water absorbance, the both ends of logs were cut off or the outer bark was notched six places per log.
** Per 10,000cm^3 of wood, after 16 hours soaking
*** Fresh weight, mean of 10 logs
Note: A strain of low to medium temperature type was used.

Physical shock

Log beating as well as watering promotes fruiting body production. Generally, beating synchronized with watering induces much more fruiting bodies. However, logs soaked in water 24 hours after the beating fruit poorly. When farmers try a second beating after the first beating, the interval of the two beatings is important. The second beating on the day following the first beating shows no effect, but those on the fourth and the eighth days' treatment result in good fruiting. In general, the negative effect of the first beating will remain through the second day and disappear on the fourth and eighth days, although such an interval is changeable with strains and log conditions (Table 6, Tokimoto, unpublished). The mechanism of the effect of physical shock remains unclear.

Table 6. Effect of beating and soaking the bedlogs on fruiting body yield

Treatment	Number of fruiting bodies per log
Soaking only	38
Beating and soaking	55
The 1st day's beating, and the 2nd day's beating with soaking	30
The 1st day's beating, and 2nd day's soaking without beating	31
The 1st day's beating without soaking, and the 4th day's soaking with beating	56
The 1st day's beating without soaking, and the 4th day's soaking without beating	32
The 1st day's beating without soaking, and the 8th day's soaking with beating	58
The 1st day's beating without soaking, and the 8th day's soaking without beating	36

Note: Treatments of beating and soaking in the same day were carried out without intervals between them. The period of soaking logs in water was 16 hours.

Maximum yield from a log

Shiitake cultivation is thought to be a conversion of wood components into fruiting bodies. Comparison of the amounts of elements between *Quercus serrata* wood and the fruiting bodies revealed that the amounts of N, P, and K in the logs limit the fruiting yield. As most of the shiitake growers do not utilize the nutriments of logs sufficiently, an increase in these nutriments may be not important. Addition of these elements to the soaking water promotes fruiting, but it sometimes causes the invasion of antagonistic fungi after fruiting. In addition, shiitake is assumed to always be cultivated without chemicals in Japan. Thus, addition of extra elements is not recommended. On the supposition that spent logs contain these elements at the amount of 20-30% of the un-inoculated logs, a log of 10,000cm^3 in volume could produces about 2.5kg of fresh fruiting bodies in the course of its whole life (Tokimoto *et al*., 1982; Matsumoto *et al*., 1990).

Harvest and Management

Cropping and fruiting cycle

Figure 15. Joy of shiitake harvest

Shiitake is harvested when the fruiting bodies grow large enough to harvest. Cropping time depends on which type of shiitake the market prefers. Shiitake is harvested early if closed cap is preferred and late if open cap is preferred by the consumers. From the point of nourishment, the most desirable cropping time of fruiting bodies is in the middle or later stage of development. The quantities of many components including sugars and polysaccharides are constant or increase slightly during development (Yoshida *et al*., 1986). Lentinan, an anti-tumor substance of shiitake, is present in higher quantities during the middle stage of development (Minato *et al*., 2001). Fruiting bodies harvested in the middle stage of development are able to be preserved for longer than those harvested during the later stages. As fruiting body production uses a great deal of energy, the mycelia in the logs require a rest of more than one month between one flush and the next flush. A temperature of 15-25 ℃ and watering may shorten the recovery period.

Storage of fresh shiitake

The quality of harvested shiitake drops quickly at room temperature as brownish pigmentation increases in bad smell and decreases in the amount of sugar, polysaccharides, and others (Minamida *et al*., 1980a; Yoshida *et al*., 1986). To escape this deterioration, a low temperature treatment is the most applicative. The shelf life of fresh shiitake is about 3 days at 20 ℃ but can be 14 days at 6 ℃ (Minamide *et al*., 1980b). In addition, storage in a controlled atmosphere (CA) is effective. Forty percent CO_2 with 1-2% O_2 is shown to be a good condition for maintaining shiitake freshness. The shelf life of shiitake could be extended 4 times in kept at 20 ℃ as compared to non CA-treated shiitake (Minamide *et al*., 1980a). Cold treatment and CA treatment slow down the decrease of useful substances such as lentinan within shiitake (Minato *et al*., 2001; Kawakami *et al*., 2004).

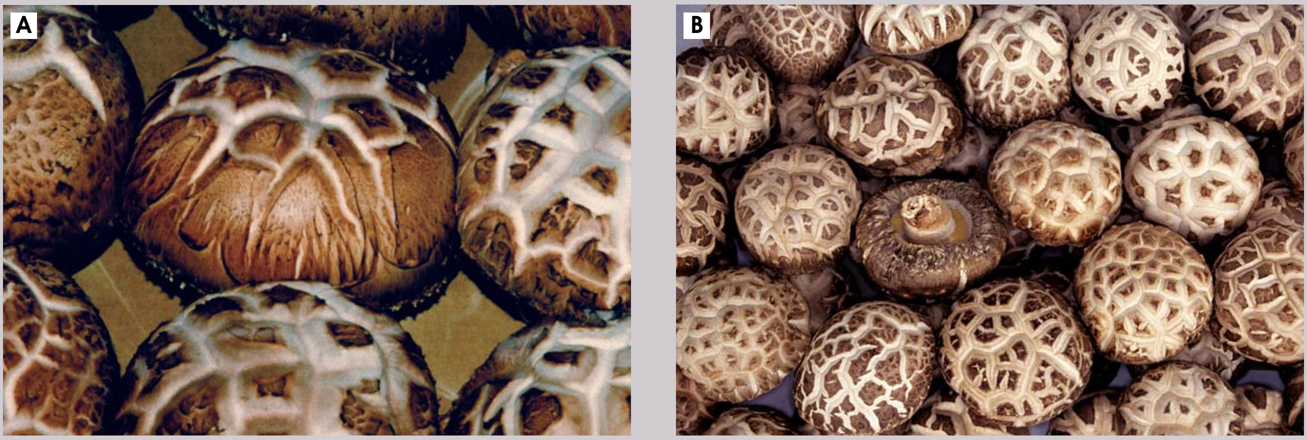

Figure 16. Harvested shiitake **A**: Fresh shiitake **B**: Dried shiitake

Drying shiitake

One of the most commonly used preserving methods for shiitake is drying. The manner in which they are dried can affect the quality of dried shiitake. The fundamental principle of drying is using "a short period with the temperature not too high." This is achieved by using a current of dry air at 30-50℃. The temperature to be given to shiitake depends on the water content of the fruiting bodies being treated. Lower air temperatures are used for wetter fruiting bodies. Faster drying produces less shrunken shiitake (Kawai, 1962). However, when the surface temperature of the fruiting bodies rises over 30-35℃ in the first five hours of drying, the dry shiitake turn black and become very small (Kawai and Kawai, 1961).

Conclusion

Log cultivation of shiitake can be described as a process whereby the log components are converted to edible shiitake under natural environmental conditions. The methods of shiitake cultivation have improved according to the variable environmental conditions, and each country or region tends to have its own best methods. It is essential to understand the biological nature of shiitake and observe the logs carefully in order to adopt the suitable management measures as well as the appropriate cultivation method.

REFERENCES

- Brauer, D., T. Kimmons, and M. Phillips. 2002. Effects of management on the yield and high-molecular-weight polysaccharide content of shiitake (*Lentinula edodes*) mushrooms. *J. Agric. Food Chem.* 50: 5333-5337.
- Fukuda, M., K. Tokimoto, M. Tsuboi, and Y. Nishio. 1987. Relation of properties of logs to the rate of wood decay and fruitbody yield in cultivation of *Lentinus edodes. Rept. Tottori Mycol. Inst*. 25: 68-74.
- Ishikawa, H. 1967. Physiological and ecological studies on *Lentinus edodes* (Berk.) Sing. *J. Agr. Lab*. 8: 1-57.
- Kawai, A. 1962. On the relation between the drying speed and the shrinkage during the drying of fruit-bodies of *Lentinus edodes* (Berk.) Sing. *Rept. Tottori Mycol. Inst*. 2: 27-30. (In Japanese)
- Kawai, A., and J. Kashiwagi. 1989. Relation of temperature to yield of fruitbodies of shiitake, *Lentinus edodes* (Berk.)Sing. *Rept. Tottori Myc. Inst*. 6: 43-48.
- Kawai, W., and A. Kawai. 1961. Studies on Nietsuki production during the drying of fruit-bodies of *Lentinus edodes* (Berk.) Sing. *Rept. Tottori Mycol. Inst*. 1: 29-34.
- Kawakami, S., K. Minato, K. Tokimoto, N. Fujita, M. Mizuno. 2004. Changes of lentinan contents and glucanase activity in *Lentinus edodes* (Berk.) Singer (Agaricomycetideae) stored under controlled atmosphere. *Intern. J. Med. Mushrooms* 6: 57-62.
- Komatsu, M., Y. Nozaki, A. Inoue, and M. Miyauchi. 1980. Correlation between temporal changes in moisture contents of the wood after felling and mycelial growth of *Lentinus edodes* (Berk.) Sing. *Rept. Tottori Mycol. Inst*. 18: 169-187.
- Komatsu, M., and K. Tokimoto. 1982. Effect of incubation temperature and moisture content of bed-logs on primordium formation of *Lentinus edodes* (Berk.) Sing. *Rept. Tottori Mycol. Inst*. 20: 104-112.
- Korea Forest Service. 2003. *Statistics on Forest Products in 2003*.
- Leatham, G., and M. Stahmann. 1987. Effect of light and aeration on fruiting of *Lentinula edodes*. *Trans. Br. mycol. Soc.* 88: 9-20.
- Lee, E.R. 1978. Studies on the possibility of oak mushroom (shiitake) cultivation on Ban Oak (*Quercus incans*) of India. *Korean J. Mycol*. 6: 31-35.
- Matsumono, T., K.Tokimoto, M. Fukuda, and M. Tsuboi. 1990. Contents of mineral elements in *Quercus serrata* logs: variation with the felling time and

their effects on the fruitbody yield of *Lentinus edodes. Rept. Tottori Mycol Inst.* 28: 325-332.

- Minato, K., M. Mizuno, S. Kawakami, S. Tatsuoka, Y. Denpo, K. Tokimoto, and H. Tsuchida. 2001. Changes in immunomodulating activities and content of antitumor polysaccharides during the growth of two medicinal mushrooms, *Lentinus edodes* (Berk.) Sing., and *Grifola frondosa* (Dicks.:Fr.) S. F. Gray. *Intern. J. Medic. Mushrooms* 3: 1-7.
- Minamide, T., T. Nishikawa, and K. Ogata. 1980a. Influences of CO_2 and O_2 on the keeping freshness of shiitake (Lentinus edodes (Berk.) Sing.) after harvest. *Nippon Shokuhin Kogyo Gakkaishi* 27: 505-510.
- Minamide, T., Tsuruta, M., and Ogata, K. 1980b. Studies on keeping freshness of shii-take (*Lentinus edodes* (Berk.) Sing.) after harvest. *Nippon Shokuhin Kogyo Gakkaishi* 27: 498-504.
- National Forestry Cooperatives Federation. 2002. *Teaching Material for Shiitake Cultivation in 2002*. 32 pp.
- Ohira, I., Matsumoto, T., Okubo, M., Maeda, T., and Yamane, K. 1982. Effects of temperatures on the yield and shape of *Lentinus edodes* fruitbodies. *Rept. Tottori Mycol. Inst*. 20: 123-139.
- Przybylowicz, P., and J. Donoghue. 1990. *Shiitake Growers Handbook*. Dubuque, Iowa: Kendall/Hunt Publishing Company. pp. 217.
- Shimomura, N., and K. Hasebe. 2004. Estimation of viability o f inner bark tissue of *Quercus serrata*, a substrate for log cultivation of *Lentinula edodes*, using the TTC assay method. *Mycoscience* 45: 362-365.
- Tokimoto, K., and M. Fukuda. 1981. Relation between mycelium quantity and fruit-body yield in *Lentinus edodes* bed-logs. *Taiwan Mushrooms* 5: 1-5.
- Tokimoto, K., and M. Fukuda. 1997. Changes in enzyme activities in bedlogs of *Lentinula edodes* accompanying fruit body development. *Mokuzai Gakkaishi* 43: 444-449.
- Tokimoto, K., and M. Komatsu. 1982. Influence of temperature on mycelium growth and primordium formation in *Lentinus edodes. Trans. Mycol. Soc. Japan* 23: 385-390.
- Tokimoto, K., and M. Komatsu. 1995. Selection and breeding of shiitake strains resistant to *Trichoderma* spp. *Can. J. Bot*. 73: S962-S966.
- Tokimoto, K., A. Kawai, and M. Komatsu. 1977. Nutritional aspects of bed-logs of *Lentinus edodes* (Berk.) Sing. during fruit-body development. *Rep. Tottori Mycol. Inst.* 15: 65-69.
- Tokimoto, K., T. Hiroi, A. Nishida, A. Tamai, and M. Fukuda. 1982. Changes of bed-log components and fruit-body yield during *Lentinus edodes* cultivation. *Rept. Tottori Mycol. Inst*. 20: 117-122.
- Tokimoto, K., M. Fukuda, and M. Tsuboi. 1984. Physiological studies of fruitbody formation in bedlogs of *Lentinus edodes. Rept. Tottori Mycol. Inst*. 22: 78-79.
- Tokimoto, K., M. Fukuda, and M. Tsuboi. 1998. Effect of the physical properties of *Lentinula edodes* bedlogs on fruiting body production. *Mycoscience* 39: 217-219.
- Triratana, S. 1993. Shiitake production in tropical Thailand. In: *Proc. Intern. Shiitake Mushroom Symposium in Oita* pp. 157-165.
- Yoshida, H., T. Sugahara, and J. Hayashi. 1986. Changes in the contents of carbohydrates and organic acids in fruit-bodies of shiitake-mushroom (*Lentinus edodes* (Berk.) Sing.) during development and post-harvest storage. *Nippon Shokuhin Kogyo Gakkaishi* 33: 414-425.