Part I Shiitake

Chapter 4

Shiitake Bag Cultivation

SHIITAKE BAG CULTIVATION IN CHINA

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Shiitake has been cultivated for over 1,000 years in China. The first written record of shiitake log cultivation comes from the Sung Dynasty (960-1127 A.D.), but other documents recorded that shiitake had been consumed in 199 A.D. (Wang, 1993). Among many mushroom varieties, shiitake is the mushroom with the largest volume of production in China, accounting for 2 million tons per year (Gu, 2003), of which Zhejiang and Fujian produce half (Chang and chen, 2003). Shiitake grows naturally in a sub-tropical zone with an average annual temperature of 15.2-17.7℃ and average annual rainfall of over 1,000mm. The mountainous area of Qingyuan in Zhejiang province is regarded as the location of the first shiitake cultivation (Fig. 1B). The regions centered around the Qingyuan area produce half a million tons of fresh shiitake by the bag cultivation method. Shiitake producing areas have recently been appearing in other areas of northern China such as Henan, Shanxi, and Shandong, principally because of the lower price of substrates and higher profits than those in the south shiitake production region (Fig. 1A). Many shiitake farmers from Zhejiang and Fujian are moving to the suburbs of metropolitan cities in northern China and they are bringing with them money and growing knowledge.

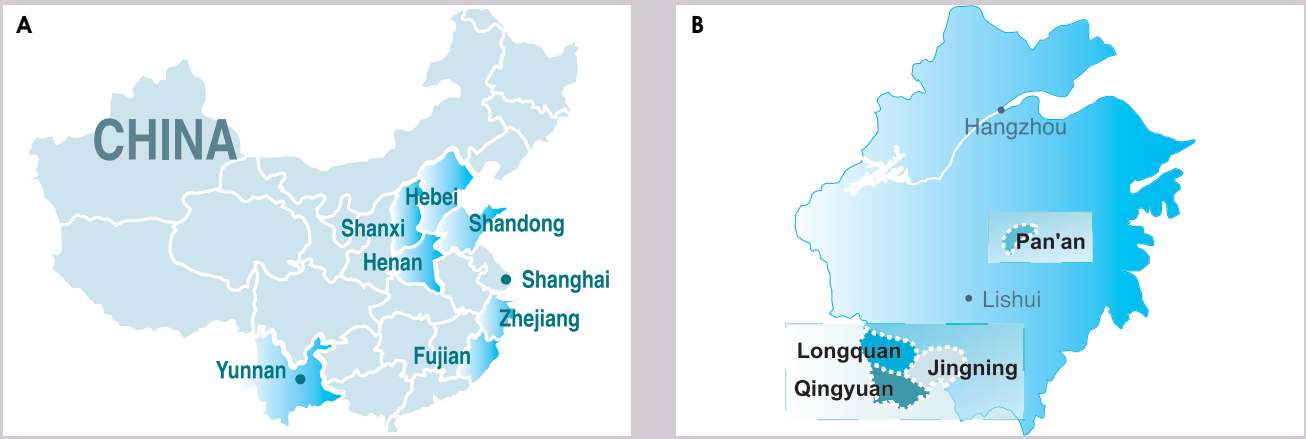

Figure 1. Maps of China **A**: Provinces in china **B**: Zhejiang Province

Development of Shiitake Bag Cultivation in China

The grower controlled parameters of shiitake cultivation include nutrition and environmental factors such as temperature, humidity, air, and light. Social conditions such as market stimulation programs and technical and financial support for farmers are as important as environmental conditions, especially those living in the remote and mountainous villages. The Chinese history of shiitake cultivation provides a very good example of the importance of social conditions.

Social conditions for shiitake cultivation: Zhejiang model

The demand for shiitake products is an important variable affected by social conditions. The Chinese shiitake industry was first developed to produce exportable materials. The shiitake enterprise started at the Zhejiang Academy of Agricultural Sciences (ZAAS) was the first shiitake export business and regularly sent fresh shiitake to Japan in the early 1980's. Initially, the suburbs of Hangzhou such as Xiaoshan, Fuyang and Lin'an were selected as shiitake production areas. Cultivation techniques were taught to farmers through training courses, and a standard shiitake production model was developed. As the suburbs of Hangzhou became more industrialized, however, shiitake production was transferred to the more rural regions. However, the farmers living in the remote and mountainous villages lacked both funds and cultivation knowledge. After opening to the outside in the 1980's, the Chinese government was seeking poverty alleviation methods that would assist the rural people in mountainous regions. Shiitake cultivation was determined to be a potentially effective means of poverty alleviation, due to low initial costs, high possible profits and relatively quick returns.

For these new programs the poor counties selected for the shiitake cultivation included Pan'an, Qingyuan, Longquan, and Jingning (Fig. 1B). Although shiitake had been traditionally cultivated in Qingyuan, the main method was log cultivation and the production was on a small scale. Thus, financial aid was provided to the farmers as the form of training program package. The government also supported shiitake cultivation here by establishing local markets that made trade more convenient and improved transportation. Initially, the mushroom researchers of ZAAS participated in training and planning, and then the specialists of Shanghai and Fujian joined and added their efforts in supporting the new shiitake production regions.

Increasing numbers of large export companies were founded, and competition increased. Some of these companies financed the farmers and others paid a good price to farmers, both of which increased shiitake production significantly. As a result of the new production, prices lowered to a reasonable level and local shiitake consumption rose. Knowledge of the nutritional and medicinal value of shiitake also spread by word of mouth. All these factors contributed toward creating domestic market with huge potential. Today, about 80% of the shiitake crop is sold in domestic markets.

Shiitake cultivation has become a model among poverty alleviation programs for rural people. Other provinces of China are now adopting and developing the model of Zhejiang, adjusting slightly depending on the local resources and environmental conditions. In some cases farmers have moved and brought knowledge of the cultivation techniques to other regions and in other cases farmers from distant areas have move to Zhejiang to learn about shiitake bag cultivation. Market demand, financial assistance, and technical training and exchange are the key factors in this large increase of shiitake production.

History of shiitake bag cultivation in China

Shiitake sawdust cultivation was developed in China in the 1960's using glass bottles as containers. Later, in the 1980's, shiitake was produced on molded bricks of sawdust (Fig. 2). Although effective, this method was very laborious. The sawdust mixed with supplements was placed in the bottles and then sterilized in an autoclave. After inoculation, the substrate in the bottles was incubated for 40-50 days. Upon full colonization, the substrate was removed from the bottle and then molded into a square wood frame of 30 ×20 ×5cm. Then the substrate was covered with plastic film and aerated for one week. Shiitake mycelium secreted brown water and the surface of the substrate was browned. Then the film was removed and fruiting was induced.

Figure 2. Shiitake fructified in the molded bricks of sawdust

Research on shiitake cultivation using plastic bag was inspired by the successful cultivation of *Tremella* in plastic bags in the late 1980's. This technique was quickly extended across the country and annual national shiitake production rose as a result. With bag culture the production cycle was shortened to 90-120 days' spawn run and 4-5 months' harvest. The biological efficiency of bag production is 50-60%. It has been reported that shiitake production in China increased 135 fold between 1983 and 2003 (Chang and Chen, 2003). The volume of shiitake production in China was perhaps 90% of world shiitake production in 2003 (Gu, 2003). It is estimated that 95% of the domestic production of shiitake is by bag cultivation with sawdust substrate (Gang, 2001). The percentage of the most desirable flower shiitake with white cracks on the caps is about 20% of domestic production (Yu, 2003).

Practices for Shiitake Bag Cultivation in China

Crop cycle and strains

There are many shiitake strains cultivated in China. Generally, shiitake can be cultivated for the whole year even in natural conditions if good protection from sunlight is provided and if high temperature strains are used in summer in the mountainous regions. The inoculation time varies according to the strains and regions. Usually one crop of shiitake is cultivated per year. Shiitake is mainly harvested in autumn and spring with a lesser amount harvested in winter. The production cycles and strains appropriate for each cycle are listed in Table 1. In the common 'Spring to Summer' cycle, high temperature strains are inoculated for summer fruiting.

Table 1. Production cycle and strains

Production cycle	Inoculation time	Spawn run period	Fructification time	Strains
Spring to fall and winter	February - April	More than 120 days	Fall and winter	241-4*, 9015, 939, Q20, 135*
Spring to summer	February -April	90-120 days	Summer fruiting	W-1*, Cr04, G47, 8001
Fall to next spring	Fall	90 days	Winter and spring	L82-2, 865, 9612, 33, 62, 66, 26, Cr02*

* Popularly used strain in China

Materials for substrate

Required nutrition for shiitake cultivation includes carbohydrates and nitrogen and a small quantity of mineral and vitamins. Theoretically, any agro-industrial organic materials which can provide the essential nutrition can be used as a substrate material for shiitake cultivation. This includes crop stalks, sawdust, sugarcane bagasse, cottonseed hulls, corncobs, and beanstalks. Some grasses[1] are also used for shiitake cultivation, including *Dicranopteris dicnotoma* Bernh, *Neyraudia reynaudiana* Keng, *Saccharum arundinaceum* Retz, *Phragmitas communis* Trin, *Miscanthus floridulus*, *Themeda gigantean* var., *Pennisetum ourpureum* Schumach, and *P. sinese* Roxb. All substrate materials should be ground prior to use lest spiky substances poke holes in the plastic bag. The main substrate requires supplementing with a rich nitrogen source such as rice bran, wheat bran, bean cake, rape cake, peanut cake, urea, or ammonium sulphate. These nitrogen sources are usually added at a rate of 10-20%. Minerals are also added such as gypsum, calcium carbonate, and calcium superphosphate.

Figure 3. Making sawdust with collected branches **A**: Collected branches stored in the corner of a farmer's house **B**: Sawdust making machine

Hardwood sawdust is the single best substrate material for the production of the highest quality shiitake. Many shiitake farmers in rural areas collect branches and twigs in the mountains in order to make sawdust by themselves (Figs. 3). The typical formula for shiitake cultivation in China is sawdust 78%, wheat bran 20%, gypsum 1%, and brown sugar 1%. These days

[1] For more information, *see* ALTERNATIVE SUBSTRATE: GRASS in Chapter 4.

cottonseed hulls are also widely used in shiitake bag cultivation. That typical formulation is cottonseed hull 50%, sawdust 28%, wheat bran 20%, gypsum 1%, and sugar 1%. These formulations have been developed by both experienced shiitake farmers and research organizations. The formulations can be changed each year according to the regional prices of the materials. For example, if cottonseed hull prices are high in a certain year, growers are likely to use less cottonseed hulls in order to reduce their production costs. Table 2 shows a substrate formulation for shiitake cultivation that has been adopted by many Chinese growers.

Table 2. Formulation of shiitake cultivation in China

Formulation	Main substance	Supplements
1	Hardwood sawdust 78%	Wheat or rice bran 20%, Red sugar 1%, Gypsum 1%
2	Hardwood sawdust 77%	Wheat or rice bran 20%, Red sugar 1%, Gypsum 1%, Calcium superphosphate 1%
3	Cottonseed hull 50%, Hardwood sawdust 28%	Wheat or rice bran 20%, Red sugar 1%, Gypsum 1%
4	Sugarcane baggasse 39%, Hardwood sawdust 39%	Wheat or rice bran 20%, Red sugar 1%, Gypsum 1%
5	Sugarcane baggasse 78%	Wheat or rice bran 20%, Red sugar 1%, Gypsum 1%

Note: The principal difference is the main substances, dependent on the local resources.

It is difficult to determine which formulation achieves higher productivity, and in most cases, growers choose the materials that are cheap and easy to obtain in their area.

Plastic bag and filling

The size of the plastic bags used differs depending on the mushroom species. In most cases, polyethylene or polypropylene bags that are 55-60cm long and 15-16cm wide are used for shiitake cultivation. The substrate materials are evenly mixed and clean water is added at a ratio of 1:1.2 (substrate/water) to achieve a water content of about 55%. Growers are advised to pile the substrate mixtures for 1-2 hours while the materials fully absorb the water. The mixture can be packed into the plastic bags either by hand or with a bagging machine (Fig. 4A). The bags are compacted during filling if a bagging machine is used. The ends of the filled bags are tied with string (Fig. 4B). Filled bags weigh about 2kg. The bags are arranged for sterilization. To stop the piles from collapsing growers tie the piles with string (Fig. 4C). When all the bags are ready, the pile is covered with a plastic sheet and steam is injected underneath the plastic cover.

Figure 4. Filling bags **A**: Filling with bagging machine **B**: Tying with string **C**: Bag arrangement with strings for sterilization

Sterilization

The bags are sterilized to remove the competitive microbes. Several different methods are used for sterilization. Injecting steam into the piled bags under plastic cover is a popular technique. The bags are sterilized at 100℃ for 8-10 hours. The temperature inside the plastic cover is checked, not the substrate temperature. It usually takes more than 10 hours to raise the air temperature inside plastic cover up to 100℃, and then bags are sterilized for an additional 8-10 hours. Figure 4C shows a boiler used to inject steam under a plastic cover.

Another common type of sterilizer in rural areas is a kiln. The filled bags are put into sacks for safe arrangement and the sacks are arranged in the kiln (Fig. 5A). The piled sacks are covered with cloth and tied, and then a fire is used to boil water beneath bags and the bags are then sterilized by the steam (Fig. 5B). Figure 5C shows the structure of fire holes and base of a kiln. Water is poured into the frame above the fire holes and the boiled water sterilizes the piled bags.

A steaming room is another method used for sterilization (Fig. 6A). In this system, the bags are stacked in layers in the steaming room and sterilized at 97℃ for 8-10 hours. This method uses stoves fired by charcoal or tree trunks. Figure 6B shows the structure of a steaming room very well. With this method, the substrate temperature can reach 97℃ in one hour and this temperature should be maintained for 8 hours.

In some regions, the bags are sterilized in an autoclave at 100℃ for 8 hours (Fig. 6C). On the following day, the bags are taken out when the temperature inside the autoclave drops to 60℃.

The bags are taken to the inoculation room and cooled to room temperature before inoculation. The inoculation room should be disinfected before the transfer of bags to prevent contamination during cooling and inoculation.

Figure 5. Sterilization kiln **A**: Arrangement of sacks with bags **B**: Sterilization with kiln **C**: The structure of kiln

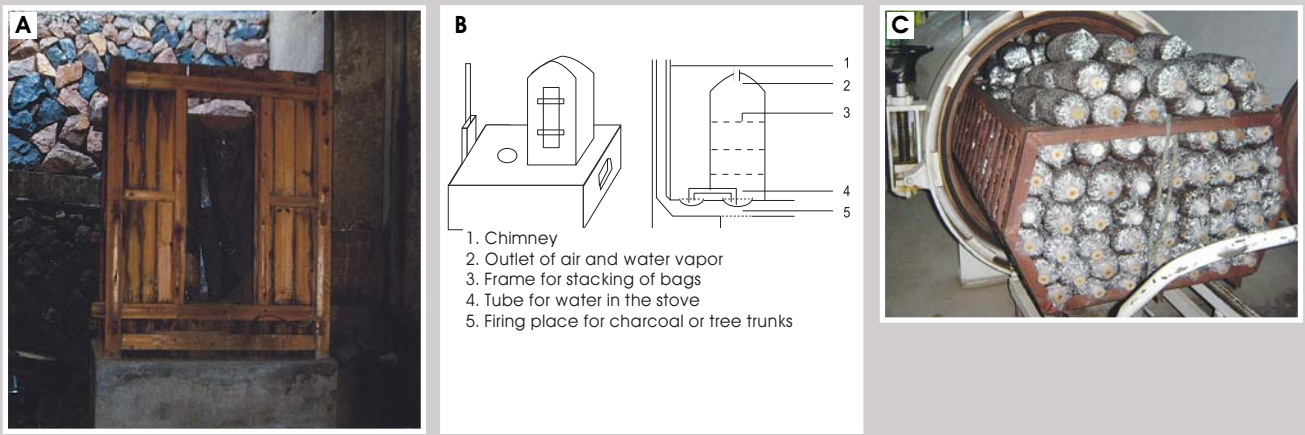

Figure 6. Steaming room and autoclave **A** and **B**: Steaming room and its structure **C**: Autoclave

Inoculation

Spawn is generally purchased from spawn production companies. Some farmers do produce their own spawn if they have mastered the techniques. Mother cultures can be obtained from research units. A farmer needs just one portable autoclave (50 liters) and an inoculation box equipped with a UV light in order to produce their own spawn. After some trials, they can get good results at a less than 5% contamination rate.

The bags are inoculated once they have cooled to below 25℃ inside the inoculation box (Fig. 7A). An inoculation box is relatively inexpensive to produce and is effective in preventing sterilized bags from coming in contact with outside air that contains many microorganisms. Both sides of the bags are punched with 3 holes, each 1.5cm in diameter and 2cm in depth,

and then sawdust spawn is inserted into the holes by hands. Plugs and liquid spawn are also used in some regions, but these spawn types are not very popular. The holes are sealed with adhesive tape, or the bags are put inside other bigger plastic bags to prevent contamination in the early stage of incubation (Fig. 7C). The thin outer bags are peeled off about 10 days later once mycelial growth appears around the inoculated parts. The ratio of spawn to substrate is 2-3% in general and the contamination rate is under the 5%, though this all varies depending on the individual farmers.

Figure 7. Inoculation **A**: Inoculation within inoculation box **B**: View inside the inoculation box **C**: Inoculated bags covered with thin bags

Management for mycelial growth

After inoculation, the bags are carried to the incubation room and stacked into pile (Fig. 8A). The duration of this phase depends upon the strains inoculated and environmental conditions. In general spawn run requires 90-120 days. It is recommended that growers re-stack the bags periodically in order to provide an equal amount of accumulated temperature and humidity for each bag. Changing the layers occasionally also prevents substrate temperature from becoming too high. The bags are also turned at regular intervals in order to provide a similar micro-environment to both sides of each bag.

Shiitake mycelia are aerobic, so they require oxygen for their growth. Because the plastic bags do not have any filter for air exchange, perforation is required. As the mycelia grow and cover more parts of bags, growers perforate the bags to provide more oxygen. Perforation is done around the edges of mycelial growth and will cover the whole bags by the time the bags are fully colonized (Fig. 8B).

Figure 8. Spawn run **A**: Stacked bags during spawn run **B**: Perforation for oxygen supply

The mycelia growth is basically completed when the bag surface is grown through with white mycelia. The bags are transferred to a growing house when there are some red spots or small warts on the surface of the bag. In some cases, the incubation room can be used as the fructification room, but this space does needs good protection from sunlight during the summer.

Primordia formation and fruiting

When the substrate bags are fully colonized by shiitake mycelia, they are moved into a growing house. In some cases, the plastic coverings are removed from bags and the substrates are placed on the ground of the growing house, leaned against a frame of wooden sticks or iron wires (Fig. 9A). Next, the substrates will go through a browning process. During browning, the temperature is kept at 20-25℃ for 3-5 days. When the mycelia on the substrate surface become dark white in color, the ventilation should be gradually increased. When the surface color of the substrates turns from light brown to dark brown and yellow water drops appear, it is time to spray water to induce primordia formation. The color change directly affects the yield of shiitake. A shiny brown color is usually an indicator of high quality and high productivity. Some growers peel off the plastic bags after browning. Coverage of a thin plastic film over the spawned blocks helps maintain appropriate humidity (Fig. 9B).

Figure 9. Browning and fruiting induction **A**: Arranged synthetic logs on the ground **B**: Browned synthetic logs and plastic cover

When the mycelial surface turns brown, temperature and humidity are controlled by watering the substrates and lifting up the plastic cover at night for 5-7 days. The change of temperature, humidity and light can stimulate primordia formation. About one week later, the primordia appear. No water is needed at this time, but humidity is maintained and minimal ventilation is used because primordia are very sensitive. After the fruiting bodies grow to 2cm in diameter, direct watering is possible again. During the development of fruiting bodies, the lower the temperature, the slower the shiitake develops and thicker caps and shorter stems produce a high quality shiitake mushroom.

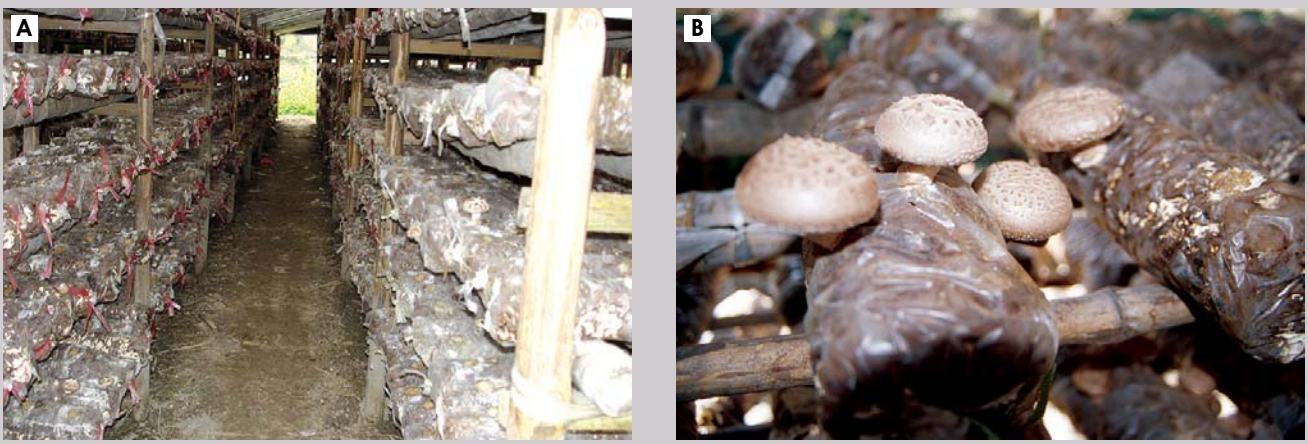

Figure 10. Fructification on shelves **A**: Substrate bags arranged on shelves **B**: Shiitake fruiting bodies

In other cases, the substrate bags are placed on the shelves in a growing house without removing the plastic coverings, and they are kept on until the harvest is finished (Fig. 10A). The plastic covering helps the substrate keep more moisture, so it is more likely to produce a higher quality of shiitake (Fig. 10B). When primordia form, growers need to cut the plastic at all the places where the primordia have formed, and this is a very time consuming and laborious process.

Flower shiitake cultivation

Flower shiitake with white cracks on its cap is considered the best quality of shiitake in many countries of Asia (Figs. 11). Cracking of mushroom cap occurs spontaneously in nature during cold and dry winter months. The flower pattern is not a characteristic of a particular genotype or genetically inherent trait, but rather a morphological flower-like cracking pattern on the upper surface of the cap. This white cracking pattern is produced by the different growth rates between the surface and the inner section of the cap due to drastic diurnal fluctuations of temperature and humidity. In most cases, flower shiitake is now produced on shelf systems with plastic coverings on the substrate. Flower shiitake production requires high humidity and temperature in daytime and lower humidity and temperature during nighttime. Sometimes, growers warm the growing houses with hot water steaming during the day and lift up the overhead plastic covering during the night to lower humidity and temperature. The techniques employed in an attempt to produce flower shiitake are applied when the caps of the fruiting body reach 2-3cm in diameter. Using the flower producing techniques too early may results in the death of the fruiting bodies because of their delicacy during the early stage of fruiting. On the other hand, too late an application may produce no results. When growers attempt flower producing, the number of fruiting bodies is reduced to fewer than 5 in one bag for each flush. The price of dried shiitake varies according to the quality, and the wholesale price of dried flower shiitake may be as high as USD10-20 per kg, while the price for regular air dried shiitake is USD5 per kg, and the low quality shiitake price is only USD3 per kg.

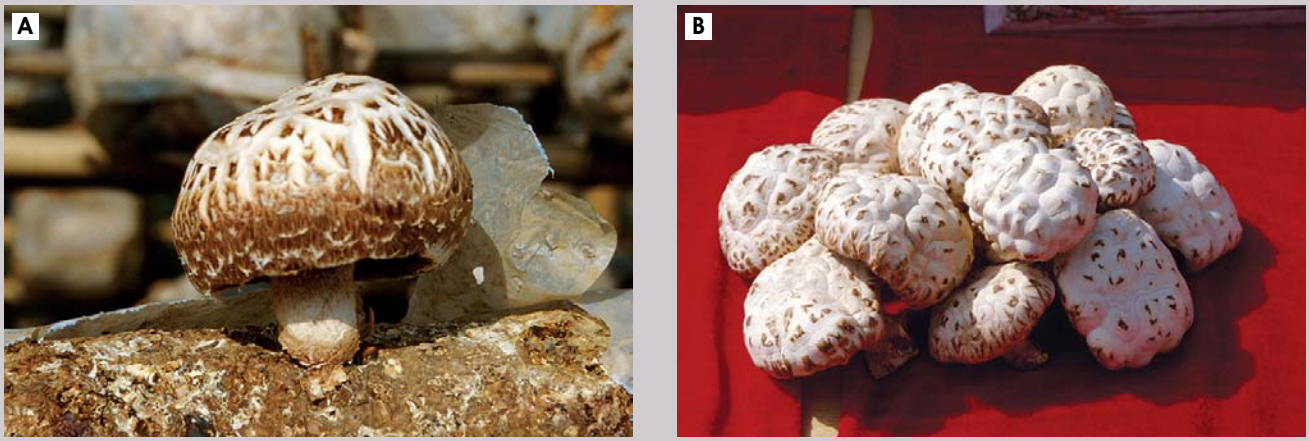

Figure 11. Flower shiitake **A**: A flower shiitake growing from bag **B**: Dried flower shiitake

Management for fruiting in each season

In China, one crop of shiitake is usually cultivated per year with family labor, and growing is mostly dependent on natural conditions. Therefore, it is highly recommended that Chinese growers inoculate with high temperature strains in order to produce fruit in summer, but fruiting of high temperature strains is most possible in mountainous regions during the hot summers. For summer fruiting, it is recommended to build the growing houses under trees and spray water 2-3 times a day in order to lower the temperature and increase humidity. For autumn fruiting, it is crucial to maintain the humidity at 90% by spraying water several times a day. Much attention should be paid to maintaining optimal temperatures during early fall when the ambient temperatures are high and during early winter when the outside temperatures are low. Usually, 4-5 flushes are harvested in fall. Winter is a period of dormancy, with very little harvest, so the substrate should be managed in such a way that it may recover vitality and prepare nutrients for the next fruiting in spring. It is essential to reduce air exchange and maintain the temperature and humidity of growing house in winter. In the spring, 2-4 flushes can be harvested if the management is proper. The substrates are immersed in water for 1-2 days so as to absorb enough water before fruiting induction. In general, 6-8 flushes are harvested for 10 months. Chinese growers harvest 0.5-0.6kg of shiitake from

substrate bags of 2kg. The dry weight of the substrate is about 1kg, so biological efficiency is about 50-60%.

Harvest and marketing

Shiitake mushrooms are harvested when the edges of caps are still curled in and before the caps are open. Care is required not to harm the substrate during harvest and not to damage harvested shiitake during handling and transportation. Growers might not want to harvest shiitake shortly after watering or raining, as shiitake quality will be lower due to more water content and the shelf life will be shorter. After harvest, it is recommended to deliver shiitake to markets as soon as trimming and grading are completed (Fig. 12A). If shiitake cannot be delivered to the market quickly, cold storage in refrigerator is recommended, but this type of facility is quite costly to growers in rural areas. Therefore, shiitake is often dried with hot air for longer preservation. There are specific companies that dry shiitake, but some growers have drying equipment in their own farms (Figs. 12B and C).

Figure 12. Trimming and drying shiitake **A**: Trimming and grading shiitake before market delivery **B** and **C**: Drying equipment using hot air and its fire place

Fresh shiitake is delivered to markets and sold to buyers or wholesalers (Figs. 13A, B and C). Fresh shiitake is exported to Japan, but most of the shiitake in domestic markets is dried. Therefore, most shiitake production bases sell dried shiitake. Qingyuan county is a good example, as it has very a big market that deals only in dried shiitake (Figs. 14).

Figure 13. Street vendors for fresh shiitake in rural area of Zhejiang **A**: Growers and wholesalers in street market **B**: Bargaining **C**: High quality fresh shiitake

Figure 14. Dried shiitake market in Qingyuan county **A** and **B**: A lot of people and dried shiitake in the market **C**: High quality dried shiitake **D**: Sieve grading dried shiitake according to cap size **E**: Stems are also dried and sold

Cost and Benefits of Shiitake Bag Cultivation in China

The basic investment required for shiitake bag cultivation by a family owned farm is shown in Table 3. A house (100m^2) for inoculation and spawn run costs USD1,500. The equipment costs USD280, which includes a bagging machine (USD80), a sterilizer with a steam generator (stove) (USD150), and an inoculation box equipped with a UV lamp (USD50). All of this equipment and house usually lasts for at least 10 years. A growing house (200m^2) made with bamboo and plastic film costs

Table 3. Cost and benefit of shiitake cultivation in China for one year in USD

Cost	Item	Cost	Depreciation cost
	House for inoculation and spawn run	1,500 (10 years)	150
	Equipments*	280 (10 years)	28
	Shiitake house	500 (3 years)	167
	Substrate and bags	800	800
	Total production cost	1,145	
Benefit	**Volume of production**	**Price per kg**	**Income**
	5,000-6,000 kg fresh shiitake	0.4	2,000-2,400
Net profit	Total income – Total production cost	minimum: USD855, maximum: USD1,255	

* Equipments include bagging machine (USD80), sterilizer with a steam generator (stove) (USD150), an inoculation box equipped with a UV lamp (USD50).

USD500, and last only for 3 years. If a farm makes substrate materials of 10,000kg dry weight every year, which can produce about 11,000 bags of 2kg, the cost of the substrate materials reaches USD800. The total production cost is USD1,145, figuring substrate material costs and the depreciation of equipment and houses (Table 3). Labor costs are not calculated because only family labor is utilized.

Substrate materials of 10,000kg dry weight can produce about 5,000-6,000kg fresh shiitake, which corresponds to 500-600kg of dried shiitake. The fresh shiitake price per kg varies with seasons and quality, but the average price is USD0.3-0.5 per kg. The average price of dried shiitake is USD3-5 per kg. If the yearly average price is USD0.4 per kg, a family can earn a minimum of USD2,000 by selling 5,000kg of fresh shiitake, and a maximum of USD2,400 by selling 6,000kg of fresh shiitake. The net profit of a family is a minimum of USD855 and a maximum of USD1,255 per year. Greater profit is possible if a greater amount of flower shiitake is produced. In most cases, shiitake cultivation is an additional income source, as most shiitake growers grow other plants such as rice, corn, sweet potato, and vegetables as their principal occupation.

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