Cultivation of Shiitake on Natural and Synthetic Logs

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An introduction to shiitake

When most Americans hear the word "mushroom," they picture just one variety: the cultivated white mushroom, fruit of the fungus *Agaricus bisporus*. But other varieties are appearing in local markets, including shiitake (pronounced she-TAH-key), a darker and stronger-flavored cousin of the common button mushroom.

The shiitake, *Lentinula edodes*, begins life as an invisible network of pale, spidery threads, which burrow through the dead tissue of various hardwoods—oak, beech, chestnut, or the shii tree (from which the mushroom derives its name). The threads, or mycelia, digest the wood and convert it into fungal tissue. When the wood has deteriorated sufficiently, the fungus produces fruit. In the wild, the mushrooms that pop out of the wood form spores, which the wind blows to new logs, starting a new life cycle.

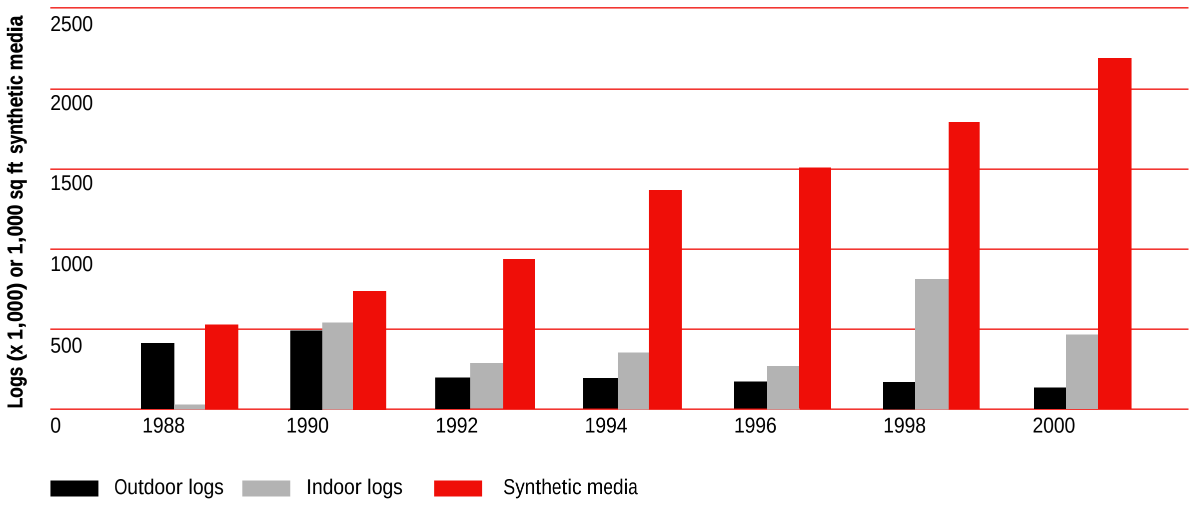
In China, shiitake have been cultivated on notched logs stacked in evergreen forests since as early as A.D. 1100. It is believed that Chinese growers introduced shiitake cultivation techniques to Japanese farmers, who named the mushroom and were later responsible for its spread eastward. Centuries later, in 1972, the U.S. Department of Agriculture lifted a ban on importing live shiitake cultures, and the U.S. shiitake industry took off. Between 1986 and 2000, total U.S. production of shiitake increased from less than 1 to 8.6 million pounds, while the price dropped from $5.42 to $3.29 per pound.

Shiitake can be grown on synthetic as well as natural logs. Composed of sawdust and supplemented with millet and wheat bran, synthetic logs may produce three to four times as many mushrooms as natural logs—in one-tenth of the time. Also, environmentally controlled houses allow for the manipulation of temperature, humidity, light, and the moisture content of the logs to produce the highest possible yields. These advances in cultivation technology, in conjunction with heightened consumer demand, account for shiitake's decline in price and increased availability.

Recent trends suggest that in the future most shiitake will be cultivated on synthetic logs. This trend seems to be especially likely for the United States (see figure 1). The major advantages of producing shiitake on synthetic logs rather than natural ones are a consistent market supply through year-round production, increased yields, and decreased time required to complete a crop cycle. These advantages far outweigh the major disadvantage of a relatively high initial investment cost to start a synthetic log manufacturing and production facility.

Natural log and synthetic log production of shiitake are described below in their normally occurring sequences. The explanations emphasize the salient features within each production step. First, let's examine natural log cultivation to see how shiitake have been grown for nearly a thousand years. Then let's look at synthetic log production, or how shiitake can (and probably will) be grown in the future.

Figure 1. Area in production for shiitake produced in the United States from 1988 to 2000. Data are for natural wood outdoor logs (x 1,000), natural wood undercover and indoor logs (x 1,000), and synthetic logs (x 1,000 square feet).



Total commercial mushroom production worldwide has increased more than 21-fold in the last 30 years, from about 350,000 tons (1 ton = 2,205 pounds) in 1965 to about 7.5 million tons in 2000. Most of this increase has occurred during the last 15 years. A considerable shift has occurred in the variety of genera, or types, of mushrooms that constitute the mushroom supply. During the 1979 production year, the button mushroom, *Agaricus bisporus* (*A. brunnescens* Peck), accounted for over 70 percent of the world's supply. By 1997, only 32 percent of world production was *A. bisporus* (see table 1). The People's Republic of China is the major producer of edible mushrooms (3.9 million tons, about 64 percent of the world supply). In 1997, China produced 1,397,000 tons of shiitake, which is about 89 percent of the total worldwide production (see table 2). Much of China's crop yield is exported either fresh or dried. The United States produced 3,707 tons (about 0.3 percent of the world supply) of shiitake in 2000. Annual increases in shiitake production in the United States have averaged over 20 percent since 1987.

Table 1. World production of cultivated edible mushrooms in 1986 and 1997.

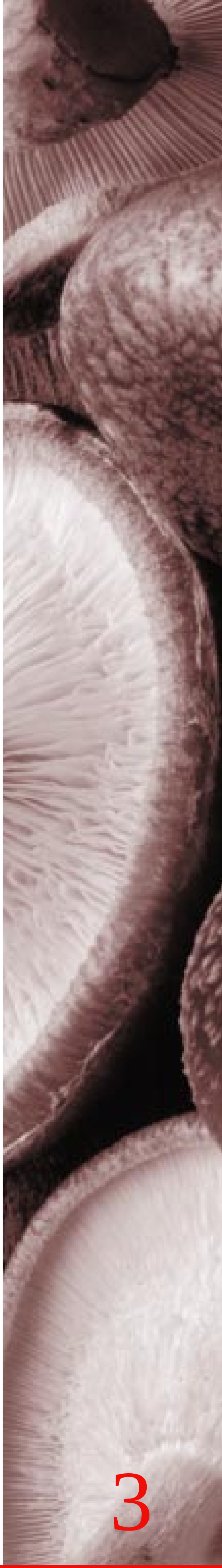
	Fresh weight (x 1,000 t)				Increase
Species	**1986**		**1997**		**(%)**
Agaricus bisporus	1,227	(56.2%)	1,956	(31.8%)	59.4
Lentinula edodes	314	(14.4%)	1,564	(25.4%)	398.1
Pleurotus spp.	169	(7.7%)	876	(14.2%)	418.3
Auricularia spp.	119	(5.5%)	485	(7.9%)	307.6
Volvariella volvacea	178	(8.2%)	181	(3.0%)	1.7
Flammulina velutipes	100	(4.6%)	285	(4.6%)	130.0
Tremella fuciformis	40	(1.8%)	130	(2.1%)	225.0
Hypsizygus marmoreus	—	—	74	(1.2%)	—
Pholiota nameko	25	(1.1%)	56	(0.9%)	124.0
Grifola frondosa	—	—	33	(0.5%)	—
Others	10	(0.5%)	518	(8.4%)	5,080.0
Total	**2,182**	**(100.0%)**	**6,158**	**(100.0%)**	**182.2**

Source: Chang (1999)

Table 2. Estimated production (fresh weight) of shiitake (*Lentinula edodes*) in some countries in 1997.

	Production		
Country	**1,000 mt**	**1,000 lbs**	**%**
China	1,397.0	3,080,385	89.3
Japan	115.3	254,237	7.4
Rest of Asia	47.4	104,517	3.0
North America	3.6	7,938	0.3
Latin America	0.3	661	—
EU	0.5	1,103	—
Rest of Europe	0.3	661	—
Total	**1,564.4**	**3,449,502**	**100.0**

Source: Chang (1999)



Natural log cultivation

Traditionally, shiitake have been cultivated on various species of hardwood trees (figure 2). In past years, the primary species used for cultivation in one area of Japan was the shii tree (*Castanopsis cuspidata*)—thus the derivation of the name *shii-take* (*take* = "fungus of"). However, most natural-log production of shiitake in the United States is not on the shii tree, but on various species of oak (*Quercus*), chinkapin (*Castanopsis*), tan oak (*Lithocarpus*), or hornbeam (*Carpinus*).

Figure 2. Oak logs inoculated with shiitake and stacked under shade cloth to prevent excessive drying caused by direct sunlight.

Natural logs are usually cut in the fall (after leaf drop) and may be inoculated with shiitake *spawn* within 15 to 30 days of felling. Trees that are cut in the fall may also be left intact through the winter and, just before inoculation, cut into lengths of about 1 meter. Trees that are cut in the summer are less suitable for shiitake production because their bark is often more loosely bound, and because sugar content is usually lowest during this time. Also, because it is loose, the bark may strip off more easily from these trees, increasing the chance of the wood's contamination by competitive organisms and further reducing the chance of a good yield. The most efficient log diameter appears to be in the 7- to 15-centimeter range. (Since 2.5 centimeters is equal to about 1 inch, the logs are 2.5 to 7 inches thick.) Logs greater than 25 centimeters (10 inches) in diameter are often cut in half lengthwise prior to inoculation.

Once the logs are cut to the desired length, they are ready for *inoculation*, or *spawning*. Spawn is supplied in the form of wooden plugs or sawdust. Growers drill holes in the logs with high-speed drills, the holes corresponding to the diameter and length of the wood-plug spawn. One row of holes is drilled for each 2.5 centimeters of log diameter, and the holes are evenly spaced lengthwise every 15 centimeters along the row. Because shiitake *mycelium* grows much faster along the grain than across it, the holes are usually spaced in a diamond pattern to facilitate growth. Plug spawn is then driven into the holes with a hammer and is usually covered with hot wax to prevent excessive drying of the spawn. If sawdust spawn is used instead of plug spawn, the drilled holes are usually made wider to facilitate the spawning process. Instead of the hammering required for placing a spawn plug, sawdust spawn is pressed into the drilled holes with an inoculation tool and is then covered with hot wax or a plastic foam plug.

Plug spawn has several advantages over sawdust spawn. Plug spawn is easier to use than sawdust spawn because one end of the plug is usually tapered or chamfered to facilitate its insertion into the log. Furthermore, plugs do not require specialized tools and, once inserted, better resist drying because they have less exposed surface. In addition, in moist conditions, sealing of plug spawn holes with wax may not be needed, reducing the time required to complete spawning.

Spawn run, or vegetative mycelial growth, may last from 6 to 18 months, depending on the tree species, log size, spawn cultivar, moisture content and temperature of the environment, and other variables. After the spawn run period, logs are transferred to a "raising" yard. Raising yards are usually cooler and moister than spawn run areas. The change of conditions provides an optimum environment for the growth and development of shiitake. Also, in a form of shock treatment intended to stimulate primordial formation, logs may be banged with a hammer or dropped on end. (No one is certain precisely why this stimulation benefits shiitake growth, but the shock treatment increases yields and facilitates more consistent fruiting on each log.) In the raising yard, the logs are arranged to allow convenient harvesting of the mushrooms (figure 3). Most production occurs in the spring and fall, when growing conditions are most favorable; thus, prices are usually lowest during these seasons.

Figure 3. Inoculated logs in a raising yard used for production of mushrooms.

Growers may use greenhouses for the winter production of shiitake. While this practice makes more mushroom production possible, prices for fresh mushrooms are still considerably higher in winter than during the rest of the year due to an increased demand for the mushrooms during late fall and early winter. In the greenhouse method, logs are usually soaked in water (normally less than 48 hours) and vibrated mechanically for various periods prior to placement in the greenhouse. Soaking the logs allows the water to displace the carbon dioxide (CO_2) contained in any air spaces and provides enough moisture (55 to 60 percent being an optimum amount) for one *flush* of mushrooms. After the mushrooms are harvested, the logs are further incubated (up to 3 months) and the process is repeated as many as five times. Once the logs are no longer productive, they may be cut up and used as firewood to provide heat for the greenhouse during the winter.

Yields of shiitake with as much as 33 percent *biological efficiency* have reportedly been produced from natural logs. Most logs yield their best production during the second and third years. Up to 75 percent of the total yield for the life of the log may come during these production periods.

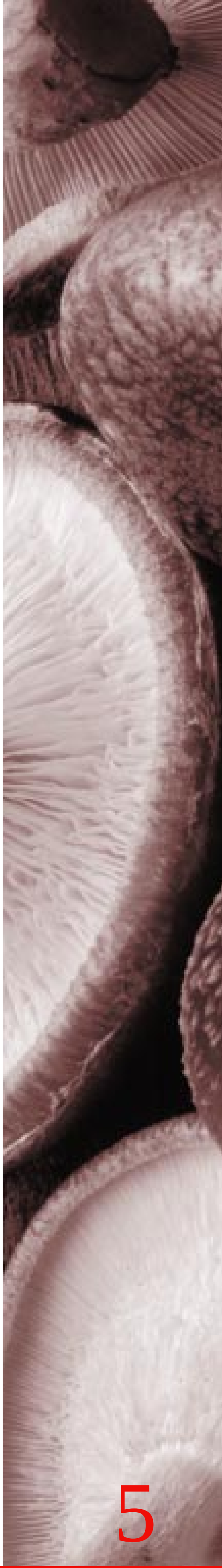
As the logs age, the bark begins to loosen and shiitake production stops in any area where the bark has detached from the underlying wood tissues. Competitive fungi may also begin to colonize a log when the bark begins to slough off, reducing the life of the log. Shiitake production is no longer possible when the bark is lost.

Synthetic log production

Sawdust is the most popular basal ingredient used in synthetic formulations of *substrate* for producing shiitake in the United States, but other basal ingredients may include straw, corncobs, or both. Regardless of the main ingredient used, starch-based supplements (10 to 60 percent dry weight) such as wheat bran, rice bran, millet, rye, and maize are always added to the mix. These supplements serve as nutrients to create an optimum growing medium. Other supplements, added in lesser quantities, include calcium carbonate ($CaCO_3$), gypsum, and table sugar. These produce a better, more nutritious diet for the shiitake.

Once the proper ratio of ingredients is selected, they are combined in a mixer, with water added to raise the moisture content of the mix to about 60 percent. On large farms, the mix is then transferred by a spinning auger to a machine that automatically weighs the substrate and fills large bags with it, so that a uniform amount (usually about 2.5 kilograms) is filled into each bag (figure 4). The bags are made of heat-resistant polypropylene and contain a special breather patch made of microporous plastic. The micropores in the patch allow the substrate to "exhale" carbon dioxide while not "inhaling" any bacteriological or fungal agents that could act as contaminants. The filled bags are stacked on racks, loaded into an industrial-sized autoclave (figure 5), sterilized for 2 hours at 121˚C, cooled in a clean room, and then inoculated with shiitake spawn. The bags are then heat-sealed, and the spawn is through-mixed (evenly distributed) into the substrate by mechanical or manual shaking. An alternative method of substrate processing and spawning is to heat-treat, cool, inoculate, and then aseptically bag the substrate in the same machine.

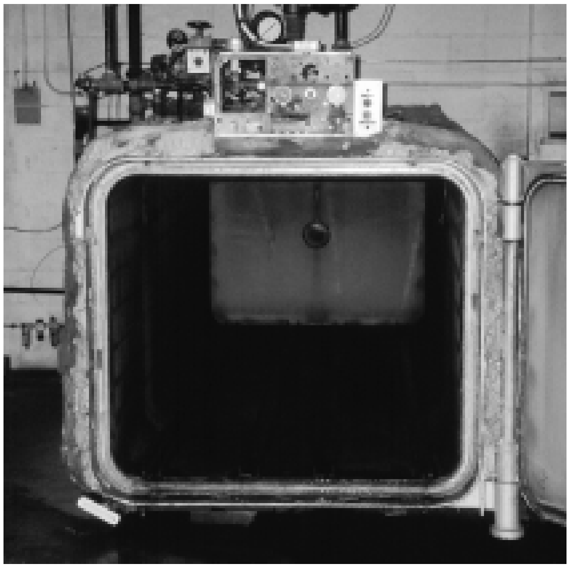
Spawn for synthetic-log production is propagated on a base of steam-sterilized sawdust or cereal grain (usually rye or millet). Because spores are likely to yield new strains and their performance is often unpredictable, most spawn is made with mycelium from a stored culture rather than mycelium grown from spores. Shiitake spawn may be purchased from commercial spawnmakers, who usually provide instructions for its use. Spawn is frequently shipped from the manufacturer to growers in the



same aseptic containers used for spawn production. In recent years, these polypropylene or polyethylene bags have become popular final spawn production containers because they are disposable, whereas the glass containers used in the 1970s were difficult to sterilize and reuse. Most commercial spawn production companies produce spawn only from inoculum that has met strict quality standards, which include verifying inoculum production performance before it is used to produce spawn and

Figure 4. Filling nutrient supplemented sawdust substrate into heat-resistant polypropylene bags for heat treatment.

Figure 5. Large autoclave (1.25 by 1.5 by 3 meters) used for steam-heat sterilization of shiitake substrate.



ensuring the spawn's biological purity and vigor.

If through-mixing of the spawn into the sterilized substrate is the method used, an 18- to 23-day spawn run at 21˚C with 4 hours of light per day is all that is required to ensure optimum growth (figure 6). With this method, the bags are sliced open and removed after the completion of the spawn run (figure 7), leaving "blocks" that are held together by tiny tendrils that have pervaded the substrate. The blocks of substrate are exposed to an environment conducive to *browning* of the exterior log surfaces. During the browning period, which is about 4 weeks long, logs are maintained at a temperature of 19˚C, while CO_2 levels are maintained at 2,200 to 3,000 parts per million. These conditions are considered to be optimal today. Logs may be watered lightly once per day to maintain continuous surface moisture, which helps to facilitate the browning process (figure 8). Excessive watering, however, will cause the surface mycelium to turn black, which may reduce shiitake yield at a later stage. Instead of watering the logs, many growers have learned to properly brown the exterior surfaces of the logs using only humidification control. As the browning process nears completion, *primordia* begin to form about 1 to 2 millimeters beneath the surface of the log, which indicates that the log is ready to produce mushrooms. If the spawn is not through-mixed, a spawn run of 45 to 90 days in the bag is necessary to achieve proper browning.

Figure 6. Inoculated substrate contained in polypropylene bags incubating in a lighted (4 hours per day) spawn-run room.

Figure 7. **Substrate colonized by shiitake mycelium removed from polypropylene bags after a 3-week spawn run.**

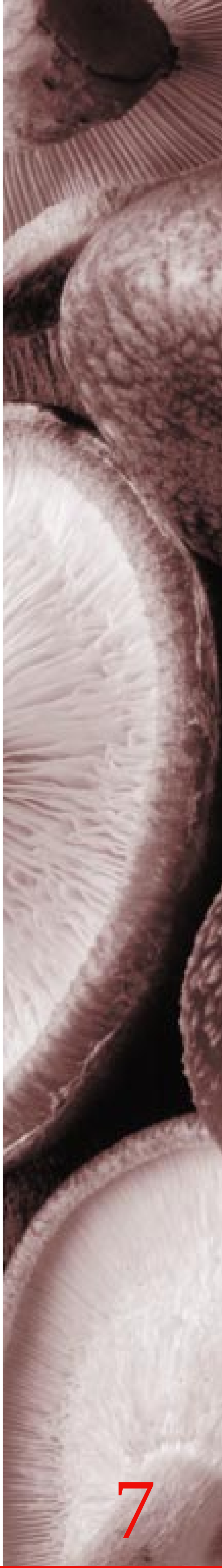
Figure 8. **Shiitake substrate in the browning room 2 weeks after removal from plastic bags.**

Browning outside of the bag has some advantages over browning inside the bag. Browning outside of the bag produces a firmer, more resilient synthetic log that will resist breaking during soaking, harvesting, and handling. In addition, browning outside of the bag allows for the use of more productive strains of mycelium, which may cause blistering of the substrate if browning is completed inside the bag. (That is, the outer surface of the log may buckle and develop air pockets, causing pieces of log to flake off when the bag is removed.) Finally, yields and mushroom quality tend to be higher when the log is browned outside the bag.

Once the synthetic logs are ready to produce fruit, primordia maturation is stimulated by soaking the logs in cool water (12˚C) for 3 to 4 hours (figure 9). For logs that are browned inside the bag, soaking is not required because sufficient water is available to support the first flush of mushrooms. However, soaking of logs is required for the second and subsequent flushes. Soaking allows water to rapidly displace CO_2 contained in air spaces in the logs, and it provides enough moisture for one flush of mushrooms. After soaking, the logs are placed on shelves and the mushrooms begin to enlarge. Approximately 7 to 11 days after soaking, mushrooms are ready for harvesting (figure 10).

Figure 9. **Shiitake logs contained in a water soak tank after 4 weeks in the browning room. Logs are soaked for 2 to 4 hours prior to placement on shelves for production.**

Figure 10. **Shiitake fruiting from synthetic logs 7 days after the logs were soaked in water.**



During harvesting, the shiitake are gently twisted from the substrate surface by hand and any residual substrate on the mushrooms is removed with a knife or scissors. After all mushrooms have been harvested from the substrate, the logs are soaked in water again. The second soaking may require up to 12 hours, and the third soaking may require up to 18 hours to replace the water lost through mushroom tissue production and water evaporation. The average time from the peak harvest of one flush to the peak of the next flush is about 16 to 20 days.

In Japan, shiitake are now being produced on colonized substrate that is first incubated in, then removed from, polypropylene bottles. In the Netherlands, shiitake are produced on shelves, while in France shiitake are produced on pasteurized chopped straw contained in polyethylene bags. These developments in shiitake-production technology are an adaptation of earlier technology used for producing other edible mushrooms.

The main advantages of using a synthetic medium over a natural one are reduced time and increased efficiency in production. The production cycle for a synthetic-medium cultivation takes approximately 3 to 4 months from inoculation to cleanup. Biological efficiency for this method averages from 75 to 125 percent. In contrast with these excellent results, the natural-log cultivation cycle usually takes about 6 years with a maximum efficiency of around 33 percent. The total time required for production on synthetic substrate is about 6 percent of the natural system cycle time, with about three times the yield efficiency. As a result of these developments, shiitake production in the United States has increased dramatically during the last decade.

Marketing shiitake

Marketing of shiitake in the United States is a relatively new enterprise. Since 1984, some farms have seen their production rise as prices have fallen. In recent years, the trend has been to sell shiitake to the retail market, a trend driven partly by an increased interest in specialty mushrooms and by the convenience that packaged products offer to the consumer. While shiitake sales have almost doubled, in some retail markets only 10 percent of the customers buy 90 percent of the specialty types.

Specialty mushrooms such as shiitake typically are packaged and sold at retail in units of 100 grams (3.5 ounces). Often shiitake are used in store displays to highlight the common cultivated mushroom, which may be sold packaged (whole or sliced) or in bulk. In fact, some grocers insist that specialty mushrooms should not displayed in a specialty section but should be kept in the mushroom section with other best-selling produce.

Some merchandisers have projected a steady growth in the consumption of shiitake. As consumers become more aware of shiitake, demand is expected to increase, and aggressive marketing should help to find new markets for this relatively new product. Shiitake producers seeking new outlets for their mushrooms may want to check sources that list reputable produce industry firms.

Future prospects for shiitake production and sales

As more consumers become aware of the special culinary characteristics offered by shiitake and other specialty mushrooms, demand is likely to increase. The development of improved technology to cultivate shiitake more efficiently will allow the retail price to continue its decline. At the same time, product quality should increase—increasing consumer demand.

At present, it appears that shiitake have the greatest future potential for production increases in the United States and perhaps in other western countries. Shiitake have a relatively long shelf life, are becoming widely accepted by consumers, and are available at a reasonable price. However, in the future, the pace of additional price reductions for consumers is expected to slow. A temporary plateau may have been reached in production efficiency for this mushroom. Additional research is needed to find ways to reduce the time of spawn run, browning, and the cycle between breaks, thereby reducing production cost by increasing shiitake output.

Finally, as economies improve in Central America, South America, and eastern Europe, production of shiitake could increase at an even faster rate in these areas than in the United States. The popularity of the culinary characteristics offered by shiitake bode well for the continued growth and development of the industry worldwide.

Sources for further reading

Chang, S. T. 1999. World production of cultivated edible and medicinal mushrooms in 1997 with emphasis on *Lentinus edodes* (Berk.) Sing. in China. International J. Med. Mush. 1:291-300.

Donovan, K. 1991. Marketing specialty mushrooms. Mushroom News 39(8):9–10.

Donovan, K. 1994. Marketing specialty mushrooms. Mushroom News 42(3):16–17.

Gunn, J. 1992. From specialty to mainstream. Mushroom News 40(5):18–22.

Ito, T. 1978. Cultivation of *Lentinus edodes*. In S. T. Chang and W. A. Hayes (eds.): The biology and cultivation of edible mushrooms. Academic Press, NY.

Lee, E. 1996. Production of shiitake and maitake mushrooms in Connecticut. Mushroom News 44(2):6–11.

Mizuno, T. 1995. Shiitake, *Lentinus edodes*: functional properties for medicinal and food purposes. Food Rev. Int. 11:111–128.

Molin, J. 1995. Specialty mushrooms: yesterday, today and tomorrow. Mushroom News 43(2):10–13.

Pirc, J. 1999. Maximize your mushrooms. Mush. News 48(12): 12-14.

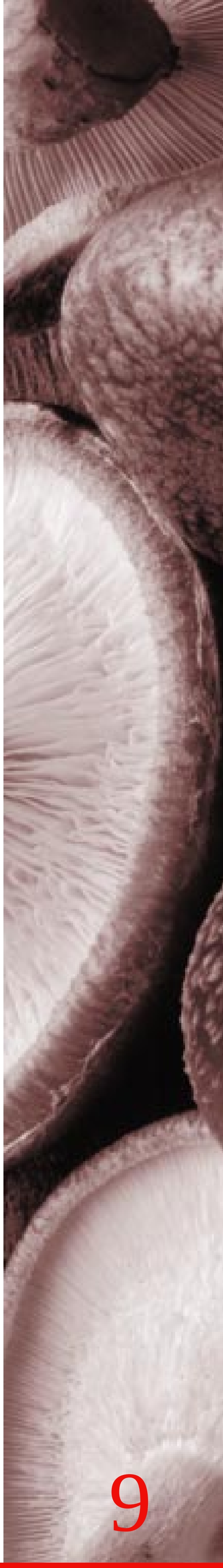
Przybylowicz, P., and J. Donoghue. 1988. Shiitake growers' handbook. Kendall/Hunt Pub. Co., Dubuque, IA.

Royse, D. J. 1997. Specialty mushrooms and their cultivation. Hort. Rev. 19:59–97.

Royse, D. J. 1996. Yield stimulation of shiitake by millet supplementation of wood chip substrate. Mush. Biol. Mush. Prod. 2:277–283.

Royse, D. J. 1995. Specialty mushrooms: cultivation on synthetic substrate in the USA and Japan. Interdisciplin. Sci. Rev. 20:205–214.

Royse, D. J., L. C. Schisler and D. A. Diehle. 1985. Shiitake mushrooms: consumption, production and cultivation. Interdisciplin. Sci. Rev. 10:329–335.



San Antonio, J. P. 1981. Cultivation of the shiitake mushroom (*Lentinus edodes* (Berk.) Sing.). HortScience 16:151–156.

Sorenson, R. 1992. Marketing of specialty mushrooms in California. Mushroom News 40(10):14–15.

Stamets, P. 2000. Growing gourmet and medicinal mushrooms. Ten Speed Press, Berkeley, CA.

Glossary

Biological efficiency is a ratio of the fresh weight of mushrooms harvested to the initial weight of oven-dry substrate, expressed as a percentage. For example, if a substrate log weighs 20 kilograms (about 40 pounds) at spawning and has a moisture content of 50 percent, the oven-dry weight would be 10 kilograms (about 20 pounds). If a total of 2.5 kilograms (about 5 pounds) of mushrooms are harvested during the lifetime of the log, the biological efficiency would be 25 percent for that log.

Browning is the oxidation of surface mycelium, also called “artificial bark formation” or “curing” by growers.

Flush is a term that describes one crop or break of mushrooms. Flushes occur three to five times per year on natural logs and every 16 to 20 days on synthetic logs.

Inoculation, or spawning, is the process of introducing the spawn into the substrate.

Mycelium is a fine, hairlike structure or tissue. It is not unlike the roots of a higher plant. Shiitake mycelium, when cultivated, spreads and colonizes its substrate, eventually producing “fruit,” or mushrooms.

Spawn is the term used to describe the vegetative growth or pure culture mycelium on a suitable sterilized substrate, such as wood chips or wood plugs. The spawn in this form is introduced to a larger, prepared substrate such as a natural or synthetic log. The mycelium grows out from its plug, wood chips, or cereal grain and colonizes the new tissue, eventually producing its “fruit,” or mushrooms.

Spawning, or inoculation, is the process of introducing the spawn into the substrate.

Substrate is the medium that mycelium bores through and grows within. In mushroom production, the substrate for the mycelium is initially wood chips, wood plugs, or cereal grain, but is later either a natural or a synthetic log.

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