MUSHROOM CULTIVATION IN JAPAN

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1. History of mushroom cultivation in Japan

Primitive methods of shiitake (*Lentinula edodes*) cultivation were used in the middle of the 17th century and represent the origin of mushroom cultivation in Japan. At that time, shiitake growers gathered logs bearing shitake mushrooms and placed them near fresh logs, the bark of which had been cut with a hatchet, allowing airborne spores to infect the new logs. Shiitake cultivation has developed and expanded rapidly since then. In 1943, Dr. Kisaku Mori invented a new inoculation method based on wooden dowels or plugs of colonized mycelia inserted into drilled holes in the logs. Recently, bag cultivation of shiitake has increased rapidly in conjunction with a decrease in log cultivation.

The cultivation of nameko (*Pholiota nameko*) and hiratake (*Pleurotus ostreatus*) was also based on log cultivation in the early-1950s but it changed over to bottle cultivation in the early-1960s. In 1928, in Kyoto, Hikosaburo Morimoto invented the first enokitake (*Flammulina velutipes*) production method based on a sawdust-substrate contained in glass bottles. Commercial bottle cultivation of enokitake using this method began in northern Nagano prefecture in the 1950's and since then, production has become more popular in Japan, along with a move to polypropylene bottles. The production of bunashimeji (*Hypsizygus marmoreus*) began in the early-1970s using sawdust substrate in bottles while production of maitake (*Grifola frondosa*) began in the late-1970s and was based on sawdust substrate in bags although currently 26% of production is in bottles. King oyster *(Pleurotus eryngii*) production using bottle cultivation was introduced in 1993. At present, most production of enokitake, bunashimeji, king oyster, nameko and hiratake are on sawdust or corncob substrates contained in bottles.

2. Mushroom production in Japan

In Japan, the total production of edible mushrooms in 2009 was 461,107 tonnes, the highest on record (Table 1). However, the gross production value in 2009 was 249.9 billion yen (3.01 billion U.S. dollars, 1 dollar = 83 Yen), a decrease of 5.4% compared to the crop value in 2008. Enokitake production has been steadily increasing since 1970 and was 138,501 tonnes in 2009. Production in 2009 was 5.6% higher compared to 2008 because the average yields per bottle have increased considerable with the development of cultivation techniques.

Enokitake became the dominant mushroom crop in 2000, overtaking shiitake, which had been the dominant species up until then. In contrast, the farm gate price is the lowest for cultivated mushrooms in Japan.

Production of bunashimeji, which originated in Nagano prefecture, has increased rapidly since 1989 and now this fungus is the second largest mushroom crop in Japan. In the past twenty years, production of bunashimeji has increased by about 500%. The large increase in bunashimeji production shows that Japanese consumers consider this fungus to be one of the most delicious and firm-textured species suitable for use in Japanese, Chinese, or Western-style cooking. About 44% of the total bunashimeji production of 110,741 tonnes in 2009 was produced by two large mushroom companies, Hokuto and Yukiguni.

The production of dried shiitake has been decreasing since 1984 and the total production in 2009 was only 23% of what was produced in 1984. Production of fresh shiitake also has been decreasing since 1986. However, production has increased gradually since 2006 because of a decrease in the imports of fresh shiitake from China. Total production of shitake (based on fresh shiitake and dried shiitake converted to fresh weight) was 101,392 tonnes in 2009 and is now ranked third in Japan.

Maitake grows naturally under old oak forests in central and northeastern Japan and traditionally it was eaten by inhabitants in only those districts. Maitake was not a popular mushroom in Japan prior to large scale commercial cultivation in the mid-1980s. Maitake is mainly cultivated using plastic bags and sawdust substrate. In 2009, almost 80% of total maitake production was produced by three large mushroom companies, Yukiguni, Hokuto and Ichimasa. Maitake is now popular nation-wide and in 2009, it was ranked fourth in terms of production.

King oyster is the most recently introduced fungal species to Japan. Production has increased rapidly since 2000 and 37,223 tonnes were produced in 2009 compared with 6,734 tons in 2000. King oyster has become more popular year on year because it is considered to have the best taste. Two large mushroom companies, Hokuto and Yukiguni produce 65% of total domestic production of king oyster.

Nameko production has remained stable at between 21,000 to 26,000 tonnes for twenty-two years. It is grown on a small-scale on the decayed stems of beech trees which are distributed mainly in the highlands of central and northeastern Japan. It was never popular for people in western Japan. For that reason, the sales of nameko in the central vegetable market of Osaka in west Japan is only 12% of the sales in Tokyo although nameko is well known throughout Japan.

Hiratake production has steadily decreased since 1989 and in 2009 it was down to 7% of its maximum production in the past. The Japanese considered hiratake to be one of the best tasting mushrooms for a long time. The cause of the decrease of this fungus may be that dealers and buyers are reluctant to sell hiratake because of inherent disadvantages, such as the

short postharvest shelf life.

Japanese production of cultivated edible mushrooms occurs through all seasons. However, the retail prices are high from September to February and are lower from March to August because the Japanese tend to consume a lot of mushrooms during autumn and winter , especially for Nabe (hot-pot)-cooking.

Matsutake (*Tricholoma matsutake*) is a wild mushroom harvested from *P. densiflora* forests in Japan. The retail price is in the region of US$600/kg but it can reach US$1,800/kg in a lean year. The annual yield of matsutake was 12,000 tons in 1941, but the yield in the past decade has reduced to between 30 to 100 tons per year. The main reasons for the decrease in the matsutake harvest are a reduction of forest management practices that favour matsutake fruiting and a decline in *P. densiflora* forests due to pine wilt disease as a result of nematode infection.

3. Characteristics of production technologies and commercial strains

Mushrooms have been produced by three cultivation methods in Japan, namely log culture, plastic bag culture and plastic bottle culture. Japanese cultivation of edible mushrooms began with log culture, except for bunashimeji, maitake and king oyster, which began with bottle culture. Cultivation methods for hiratake and nameko changed to bag culture and then to bottle culture. In Japan, only one flush of mushrooms is harvested for most species, except shiitake.

Shiitake

The first commercial production of edible mushrooms in Japan began by log culture of shiitake in the early-1950s. Logs of several species of broadleaf trees (*Quercus* and *Castanopsis*), about 1 meter long, were used for shiitake cultivation. Even today dried shiitake is produced by the traditional log culture method. It takes 1-1.5 years after inoculation for the shiitake mycelia to completely colonize the logs and to satisfy the necessary conditions for the development of fruit bodies. The biological efficiency for shiitake production on logs is 30 to 35%. The spawns used for log cultivation are of two types: plug spawn and sawdust spawn, and both of those are supplied by the spawn manufacturers. More than 10 spawn manufacturers supply spawn for shiitake growers. All shitake cultivars used for log culture are registered in Seeds-Law. Shiitake production by log culture is exclusively done on small-scale farms or farmers' cooperatives.

The production of fresh shiitake by bag culture has rapidly increased since 1993 and accounts for about 80% of the total fresh shiitake production. Presently in Japan, shiitake bag growers use one of two production systems. The growers either purchase colonized blocks of substrate from the block makers; or they prepare their own. The former method usually uses

cylindrical-shaped bags filled with 1-1.2 kg of supplemented sawdust substrate, and the latter method uses square-shaped bags filled with 2.5 kg of substrate. In this case, the sawdust spawn is supplied by spawn manufacturers. Bag culture of shiitake has continued to increase because of its convenient handling, compared to the difficulty in handling heavy logs, and the more effective use of indoor space. Deciduous oak sawdust substrate is supplemented with rice bran, wheat bran or corn bran and contained in micro-filtered polypropylene bags. It is then autoclaved and inoculated after cooling. Mycelia colonize the substrate for 25 to 30 days after inoculation and the total spawn run lasts about 50 to 70 days at 20 to 22°C for mycelium maturation. The substrate surface turns dark brown after the spawn run is complete and then all, or part, of the bag must be removed for fruiting. Fruit bodies develop at 12-18°C and at a relative humidity of 65-85%. Each flush is harvested over a two to three week period following a repeated soaking in water and resting after cropping. In general, the biological efficiency for the production of shitake on sawdust substrate is 65 to 100%. Most sawdust spawns that are suitable for bag culture are supplied by spawn manufacturers.

Enokitake

Enokitake was initially cultivated in 700 ml bottles with an opening of 52 mm in diameter and later in 850 ml bottles with an opening of 65 mm. More recently, 1100 ml bottles with an opening of 78 to 80 mm (16 bottles in a container) and 600 to 700 ml bottles with an opening of 65 mm (25 bottles in a container) are now generally used. The bottles with larger diameter openings produce higher yield of enokitake. The substrate for enokitake production was traditionally based on the sawdust of Japanese cedar. At present, most growers use ground corncobs as substrate. In Nagano district which is the biggest production area for enokitake, the growers purchase substrate, containing ground corncobs and supplements, from substrate makers. Usually holes are pressed down through the surface of the substrate in the bottle. These holes are filled with spawn during inoculation, to ensure distribution of the spawn vertically to the bottom of bottle. In general, there are 4 holes in 600 or 700 ml bottle and 5 holes in 1100 ml bottle. About 60% of enokitake production is on liquid inoculation in Japan. Enokitake is cultivated in highly mechanized facilities.

Low temperature condition during the growing processes is characteristics of enokitake production. After inoculation, bottles containing substrate are placed in an incubation room for 23-26 days at 13-15°C. Temperature is dropped first to 7-9°C for acclimatization (Narashi), then to 3-5°C, for slow elongation and equalization of stems at low temperature (Yokusei), and then increased to 5-7°C for continued growing. It is also characteristic of enokitake production that a paper or plastic collar is rolled around the open top of each bottle to encourage long, straight stems. Average yield from 600-700 ml-bottles is around 200 g and from 1,100 ml-bottles it is around 320-350 g. Enokitake is traditionally packaged and marketed in a 100 g pack but now an entire bunch of enokitake can be vacuum

packaged and shipped. The biological efficiency is now 95-130% due to improvements in cultivation technology compared with 60 to 75% BE in the early-1980s.

Up to the mid 1980s, enokitake growers had to use "brown-colored" cultivars whose fruit bodies turned light brown or brown when illuminated, an undesirable trait because of the market demand for "whiteness" in fruit bodies. Growers were therefore obliged to cultivate these mushrooms under dark conditions to prevent the discoloration of the caps and stems due to light exposure. However, a novel white strain, Hokuto M-50, a cultivar that does not darken on exposure to light, was developed in 1985. At present, most enokitake growers use this or similar white strains. General growers purchase the spawn from spawn manufacturers, however in JA-Nakano-city, the growers are supplied with colonized substrate, inoculated using liquid spawn, from five spawn centers of the cooperative.

Bunashimeji

Bunashimeji production, which originated in Nagano, is now widespread throughout Japan, and large-scale mechanized facilities with a production capacity of 10 tons per day are found nationwide. Commercial production of most bunashimeji is on a substrate of sawdust or corncobs contained in bottles of 850 ml in volume with the opening of 58 mm in diameter. Growers in Nagano use a substrate of mixed pine sawdust/corncobs while growers in Hokuto use only corncob substrate. The biggest production company, Hokuto, uses mainly 36 small bottles per tray during incubation. This is reduced to 18 bottles per tray after Kinkaki (removing the original inoculum mechanically) for fruiting and growing. Spawn-run and mycelial maturation is generally for 80-100 days at 20-22°C. Fruit bodies are harvested at 21-23 days after Kinkaki. In order to induce preferable fruiting, growers implement a unique Kinkaki which removes only the peripheral portion of the original inoculum leaving the center of the inoculum as dome-shape. Average yields in general for bunashimeji growers are 180 to 200 g per 850 ml bottle with a biological efficiency of 95-105%. Bunashimeji is packaged in 100 g packs and shipped to markets but more recently growers package an entire cluster of mushrooms.

For many years, only two licensed cultivars, supplied by a bio-company, have been available exclusively to the growers in Nagano. Since 1993, new cultivars of bunashimeji were developed by other mushroom companies and spawn manufacturers, and since then production has rapidly increased. Growers affiliated to Nagano agricultural cooperatives use the new cultivars developed in their spawn center. The big bunashimeji production companies have used the new cultivars developed by themselves. General growers in Japan purchase the spawns supplied from spawn manufacturers. In 2002, Hokuto developed a white bunashimeji (buna-P), a mutant induced by UV, and it produces a large quantity of the mushrooms.

Maitake

Maitake has been valued in all of Japan because of its delicious taste and its medicinal properties. Now, maitake is grown on a sawdust substrate in polypropylene bags or in plastic bottles. In general maitake growers and the big production companies, Yukiguni and Ichimasa use a broadleaf sawdust substrate (2.5, 1.0 or 1.5 kg) contained in micro-filtered plastic bags. In 2001, Hokuto company began the production of maitake in bottles. This was the beginning of so called "Mushroom War" in Japan. Large maitake production companies based on bag culture use automatic equipment for bag forming, heat-attachment of micro-filter, filling of the substrate before autoclaving and inoculation after cooling. Spawn-run lasts 25-50 days at 22 to 23°C depending on strain and substrate weight. After mycelial colonization of the substrate is complete, a dark grayish mycelial mass swells up on the upper surface of the culture block. The upper portion of the bag is opened with a knife when the mycelial mass turns completely black and 12 to 18 days after bag-opening, fruit bodies grow into a large cluster ready to harvest. The total duration for the production is 50 to 60 days for 1.5 kg bag culture and 60 to 65 days for 2.5 kg bag culture. The biological efficiency is 55 to 75% in general but can be 85 to 95% for excellent growers or companies.

Commercial maitake strain M51 (by Mori spawn manufacturer) has been used for a long time by general growers. Hokuto and Ichimasa use new hybrid cultivars which they developed themselves. Hokuto, in particular, use a cultivar which is suitable for bottle cultivation. White maitake is also produced by the big companies, Yukiguni and Ichimasa. Some people consider that black maitake is unsuitable for several types of cooking, for example, miso-soup and hot-pot cooking, as the black maitake broth darkens the soup. Therefore, white maitake has become popular and will be consumed more in near future.

King Oyster

Most king oyster is cultivated on sawdust of Japanese cedar or corncobs supplemented with rice bran or wheat bran and contained in polypropylene bottles with a capacity of 600 or 850 ml in volume. Spawn run lasts about 27-32 days at 20-23°C. Fully-colonized substrate is placed in the growing room and maintained at 15-18°C and fruit bodies are harvested at 42 to 50 days after inoculation. In Japan, consumers prefer small-sized fruit bodies - two or three fruit bodies in a package of 100 g rather than large-sized fruit bodies. This mushroom should be harvested when the cap margins are in-rolled or deeply incurved and not flattened out. Average yields are 100 to 110 g in per 600 ml-bottle and 140-160 g per 850 ml-bottle. Biological efficiency is 82 to 92%. This fungus is also produced using automatic machines for filling, autoclaving, inoculation and removal of spent substrate from the bottles as in other bottle-cultured systems.

About 45% of total production of king oyster in Japan is of the hybrid strain developed by Hokuto and the remaining production uses cultivars developed by spawn

manufacturers or public research institutions.

Nameko

Production of nameko began by "shade log culture" using long logs or log sections of hardwoods, especially beech, birch, cherry and deciduous oaks, placed under forest trees. Later, growers changed the cultivation system to wooden box culture with 6 to 8 kg of sawdust substrate wrapped in a polypropylene sheet in a wooden box. Now, most of the nameko production is based on hardwood sawdust substrate, supplemented with wheat bran and corn bran, in 800 ml plastic bottles with an opening of 80 mm diameter. Production is generally small-scale. After inoculation, the bottles of substrate are placed in incubation rooms maintained at 16°C initially and then 23°C during the spawn-run of 45 to 50 days. To initiate mushroom formation, lower temperature of 12 to 13°C, and lower carbon dioxide levels are required. Nameko has been harvested by cutting the stems near the base with scissors but recently, growers harvest an entire cluster without cutting the stems. Consumers prefer clusters of fresh nameko with stems intact because of the longer shelf life. Nowadays cut, washed and packed watery nameko is not popular. Spawn manufacturers supply all spawns for most nameko production. Average yield is 120 to 140 g per a bottle.

4. Structure of mushroom industry in Japan

We have several types of mushroom businesses in Japan. Small-scale mushroom production by farmers originated in Japan. In Nagano, farmers' cooperative began to produce mushrooms in 1960s but since the middle-1980s, large-scale production companies for maitake and bunashimeji were set up. At present, Hokuto Corporation is the first and largest mushroom production company and Yukiguni Maitake Co. Ltd. is the second largest. Mushroom production by farmers' cooperatives is dominant in JA-Nakano City, Nagano Pref. Details of the most important companies are given below.

Hokuto Corporation

Hokuto was established in 1964 at Nagano city. In 1986, the laboratory developed an excellent white strain of enokitake, known as M-50. The company built its first production farms for enokitake at Nagano city and Fukuoka Pref. in 1989. In 1990, it built the first bunashimeji production farm in Nagano Pref. followed by new large factories for bunashimeji cultivation in Niigata Pref. and Toyama Pref. in 1991. Hokuto succeeded in the cultivation of king oyster commercially in 1994. Shortly afterward, Hokuto built production factories for king oyster in the prefectures of Hokkaido, Kagawa, Miyagi, Shizuoka and Hiroshima. In 1995, the new strain for bottle cultivation of maitake was developed and thereafter, a production of maitake by bottle cultivation was begun in 2001. At present, bunashimeji

(brown strain and white strain), king oyster and maitake are produced on 27 farms at 19 locations around the country.

In 2009, production of bunashimeji was about 40,000 tonnes, accounting for about 35% of domestic production of this species. Production of king oyster and maitake in 2009 was about 16,000 and 10,000 tonnes, respectively. Total production of mushrooms by Hokuto will reach 70,000 tonnes in near future. Gross sales of mushrooms of Hokuto are estimated at 42,000 million JPY (506 million dollars) or more for 2010.

All the mushroom cultivation by Hokutu uses polypropylene bottles and the latest automatic production machines and facilities. Hokuto uses corncobs as substrate material for the cultivation of several of species of mushroom except maitake, which is grown on sawdust. The production system using movable shelves to transfer the bottles, automatic harvesting/packaging machines for the labor saving and lower costs are outstanding characteristics of Hokuto. All cultivars for production are newly developed through breeding research in their own laboratory. Original spawns are produced in spawn manufacturing centers in affiliation with the mushroom production factories in the whole country.

Yukiguni Maitake

Yukiguni was established in 1983 at Niigata Pref. and began the production of maitake at a small small scale. It has built more factories and has enlarged the production scale since 1988. In 2002, Yukiguni started the production of bunashimeji and king oyster in competition with Hokuto. All production factories are located in Niigata Pref. Mushroom production in 2009 is estimated at 15,000 tonnes of maitake, 10,000 tonnes of bunashimeji and 8,000 tonnes of king oyster. Gross sales of mushrooms by Yukiguni were 21,250 million JPY (256 million dollars) in 2009. Maitake is produced on sawdust-based substrate in plastic bags and other mushroom species are produced on bottle culture. It is believed that they produce maitake, bunashimeji and king oyster probably using commercial spawns supplied from spawn manufacturers or a bio-company. In the production by bottle culture, automatic machines and unmanned forklift trucks have been introduced, however, in the production of maitake, manpowered transportation on the growing shelves is required now.

Ichimasa Kamaboko Co., Ltd.

Ichimasa Kamaboko Co. Ltd., established in 1965, is the second major kamaboko (fish cakes and steamed fish paste) company in Japan. Gross sales of the company in 2007 were 28,000 million JPY (337.3 million dollars). In 1996 the bio-business department of Ichimasa first began to produce maitake in mushroom cultivation farms at Niigata Pref. At present, mushroom cultivation factories (7 mushroom farms in same area) produce 7,000 tonnes of black and white maitake in 2009, making Ichimasa the second largest maitake production company after Yukiguni. A white strain of maitake named “Maihime” developed by the

laboratory is getting good reviews for quality by consumers.

Hardwood sawdust is the substrate used by Ichimasa with 1.5 to 1.6 kg being filled into plastic bags. Bag filling, autoclaving, inoculation and distribution of containers on shelves are full-automatically operated. Several cultivars of black and white maitake with high-quality and yield were originally developed by breeding in the laboratory. The spawns for mushroom production are produced by the spawn making section of the factory. The cultivation technology and breeding techniques for maitake in Ichimasa are of an extremely high standard and therefore, the yield per unit weight of substrate is especially high compared with other maitake production companies and growers. Consequently, Ichimasa shows high profitability in the maitake sector.

JA-Nakano-city (Japan Agricultural Cooperatives, Nakano-city)

Nagano Pref. is the birthplace of bottle cultivation of mushrooms in Japan which started in the 1950's. Therefore, bottle cultivation of bunashimeji and nameko in Nakano in 1970's was ahead of bottle production in the rest of the country. Mushroom businesses in Nagano Pref. were therefore quite prosperous and with an excellent reputation. In 2007, Nagano Pref. produced 77,400 tonnes of enokitake, 5,034 tonnes of nameko, 47,000 tonnes of bunashimeji and 9,750 tonnes of king oyster. Nagano Pref. is rightly called "a Mushroom Kingdom!".

The production of enokitake in Nakano-city alone was about 40,000 tonnes in 2009 and total production of enokitake, bunashimeji, nameko and king oyster in JA-Nakano-city was 52,000 tonnes a year. The value of farm sales in JA-Nakano-city was about 19,900 million JPY (239.8 million dollars) in 2008 of which about 14,800 million JPY (178.3 million dollars) or 74 % depends on mushroom production.

In JA-Nakano-city, all spawns for the cultivation of enokitake, bunashimeji and king oyster have been produced in the spawn-center of JA-Nakano-city. Since 2008, the spawn-center has produced liquid spawn for growers of enokitake and king oyster. Now the spawn center supplies 7,000 tanks of liquid spawn a year for 5 incubation-centers affiliated with JA-Nakano-city. The supply of liquid spawn is equivalent to 140 million culture bottles for enokitake growers. Bottles of colonized substrate are distributed to growers 10 days after inoculation in incubation centers. Growers do not need autoclaves, machines for mixing, filling and inoculation of substrate.. They can devote their time to pinning, growing and harvesting. Enokitake harvested by each grower is packed in a joint packing-shipment center. Liquid spawn-making in the spawn center and pre-incubation for 10 days in the incubation centers have contributed to stabilization of enokitake and king oyster production in JA-Nakano-city.

Table 1. Production of Edible Mushrooms in Japan (metric tonnes: fresh weight).

Species	Common name	1960	1970	1980	1985	1990	1995	2000	2003	2005	2006	2007	2008	2009
F. velutipes	Enokitake		10,914	52,565	69,530	92,255	105,752	109,510	110,185	114,542	114,630	129,770	131,107	138,501
H.marmoreus	Bunashimeji			1,600	9,157	29,757	59,760	82,414	84,356	99,787	103,249	108,996	108,104	110,741
L. edodes	Dried Shiitake	27,448	63,976	108,632	96,552	89,904	64,560	41,888	32,864	32,728	30,888	28,528	30,936	26,376
L. edodes	Fresh Shiitake	6,634	38,064	79,855	74,706	79,134	74,495	67,224	65,363	65,180	66,349	67,155	70,342	75,016
G.frondosa	Maitake				1,501	7,712	22,757	38,998	45,805	45,141	45,985	43,607	43,398	40,998
P.eryngii	King oyster						*60	6,734	29,882	34,342	36,435	38,265	38,214	37,223
P.nameko	Nameko	2,267	8,448	16,776	19,793	22,083	22,858	24,942	25,068	24,801	26,615	26,818	25,945	26,138
P.ostreatus	Hiratake			12,060	26,211	33,475	17,166	8,546	5,210	4,074	3,384	3,024	2,578	2,424
T.matsutake	Matsutake	3,509	1,974	457	820	513	211	181	80	39	65	51	71	24
	Others						822	813	1,821	2,386	2,554	2,974	4,476	3,666
Total		39,858	123,376	271,945	298,270	354,833	368,381	189,326	400,634	423,020	430,154	449,188	455,171	461,107

***Sources*: The Ministry of Agriculture, Forestry and Fisheries, Japan. The weight of dried shiitake is estimated on fresh weight.**

***production estimated by K. Yamanaka.**