Cultivation of Oyster Mushrooms

PENNSTATE

College of Agricultural Sciences
Agricultural Research and Cooperative Extension

Total mushroom production worldwide has increased more than 18-fold in the last 32 years, from about 350,000 metric tons in 1965 to about 6,160,800 metric tons in 1997 (Table 1). The bulk of this increase has occurred during the last 15 years. A considerable shift has occurred in the composite of genera that constitute the mushroom supply.

During the 1979 production year, the button mushroom, *Agaricus bisporus*, accounted for over 70 percent of the world's supply. By 1997, only 32 percent of world production was *A. bisporus*. The People's Republic of China is the major producer of edible mushrooms, producing about 3,918,300 tons each year—or about 64 percent of the world's total. China also produces more than 85 percent of all oyster mushrooms (*Pleurotus* spp.) grown worldwide (Table 2).

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 oyster mushrooms (*Pleurotus* spp.) in some countries and regions in 1997.

	Production		
Country	**1,000 m.**	**1,000 lbs.**	**%**
China	760.0	1,675,496	86.8
Japan	13.3	29,321	1.5
Rest of Asia	88.4	194,887	10.1
North America	1.5	3,307	0.2
Latin America	0.2	441	—
EU	6.2	13,668	0.7
Rest of Europe	5.8	12,787	0.7
Africa	0.2	441	—
Total	**875.6**	**1,930,348**	**100.0**

Source: Chang (1999)

From 2001 to 2002, the United States produced 393,197 metric tons of mushrooms, or about 7 percent of the total world supply. *A. bisporus* accounted for over 90 percent of total mushroom production value, while *Lentinula*, *Pleurotus*, *Grifola*, *Flammulina*, *Hypsizygus*, *Hericium*, and *Morchella* were the main specialty genera cultivated. The value of the 2001–2002 specialty mushroom crop in the United States amounted to $37 million, down 12 percent from the 2000–2001 season. The average price per pound for specialty mushrooms received by growers, at $2.77, was down $0.27 from the previous season.

Sales volume of oyster mushrooms, at 4.03 million pounds, was up 11 percent from the 2000–2001 season, with a total of 51 growers producing 4.27 million pounds of the mushrooms in the 2001–2002 season. Total production includes all fresh market and processing sales plus amount harvested but not sold (shrinkage, cullage, dumped, etc.). Average oyster mushroom output per farm increased 249 pounds (18.3 percent) per week, from 1,359 pounds in 2001 to 1,608 pounds in 2002 (Table 3). The production of oyster mushrooms (*Pleurotus* spp.) in the United States has increased at an annual rate of 14 percent during the last 6 years, from 1,941,000 pounds in 1996 to 4,265,000 in 2002. This increase reflects an international trend toward increased production of this crop. Oyster mushrooms accounted for 14.2 percent (875,600 tons) of the total world production (6,161,000 tons) of edible mushrooms in 1997, the most recent year for which statistics were available.

Table 3. Estimated annual production (fresh weight) and production per week per grower of oyster mushrooms (*Pleurotus* spp.) in the United States, 1998–2002.

		Production (lbs.)	
Year	**No. growers**	**Annual (x1000)**	**Per wk/grower**
1998	47	2,210	904
1999	63	3,729	1,138
2000	68	3,573	1,010
2001	54	3,817	1,359
2002	51	4,265	1,608

Source: USDA (2002)

The increase in United States production is due to increased consumer demand and the relatively high compensation growers receive for the product. According to the USDA, farmers received an average of $2.00 per pound for fresh oyster mushrooms while growers of *A. bisporus* received an average of $1.07 per pound for fresh product in the 2001–2002 growing season. The higher price received for fresh oyster mushrooms reflects, in part, the less-developed and less-reliable technology available to growers for cultivating these species. Thus, growers need potentially higher incomes to help offset the increased risks associated with producing *Pleurotus* spp.

Spawn

Oyster mushrooms are grown from mycelium (threadlike filaments that become interwoven) propagated on a base of steam-sterilized cereal grain (usually rye or millet). This cereal grain/mycelium mixture is called spawn and is used to seed mushroom substrate. Most spawn is made with mycelium from a stored culture, rather than mycelium whose parent was a spore. This is because spores are likely to yield a new strain and performance would be unpredictable. Spawn-making is a rather complex task and not feasible for the common mushroom grower. Spawn of various oyster mushroom species may be purchased from commercial spawn makers who usually provide instructions for its use. Spawn frequently is shipped from the manufacturer to growers in the same aseptic containers used for spawn production. Inoculum for spawn production is frequently produced in polyethylene bags containing a microporous breather strip for gas exchange. Most commercial spawn production companies produce spawn only from inoculum that has met strict quality control standards. These standards include verification of inoculum production performance before it is used to produce spawn and insurance of the spawn's biological purity and vigor.

Culture Maintenance

Before 1970, cultivars used for commercial spawn production were maintained on various agars or cereal grains with periodic subculturing of growing mycelium to a fresh medium. This method, for the most part, was reliable, although spawn makers and researchers reported cases of culture degeneration periodically. In 1970, researchers successfully preserved and maintained stability of spawn stocks of *A. bisporus* stored in liquid nitrogen. Several research reports on culture maintenance verified the suitability of cryogenic preservation, fundamentally changing the way spawn makers handled their cultures used for commercial spawn production. In practice, cryogenic preservation is used to ensure use of superior spawn-starter cultures. Many vials (perhaps as many as 200 to 300) containing spawn or mycelium from cultures of promising spawn lines are stored in liquid nitrogen. Following successful testing of the spawn lines at both pilot plant and commercial testing facilities, the spawn maker can easily reproduce the superior lines many times during subsequent years.

Production in Bags

Substrate preparation. In the United States, the primary ingredients used for *Pleurotus* spp. production are chopped wheat straw (*Triticum aestivum* L) or cottonseed hulls (*Gossypium hirsutum* L) or mixtures of both. For production on wheat straw, the material is milled to a length of about 2 to 6 cm. Production of *Pleurotus* spp. on cottonseed hulls has some advantages over straw-based production systems in that chopping of the hulls is not required. One of the most common substrates used on modern mushroom farms is a mixture of 75 percent cottonseed hulls, 24 percent wheat straw, and 1 percent ground limestone. This mixture of cottonseed hulls and wheat straw has a higher water holding capacity than cottonseed hulls used alone. At Penn State's Mushroom Research Center (MRC), a large-capacity, scale-mounted feed mixer (Figure 1) is used to simultaneously grind and mix the material as water is added to increase the moisture content to 67 to 69 percent.

Figure 1. A large-capacity, scale-mounted feed mixer is used at the Mushroom Research Center (MRC) to process *Pleurotus* spp. mushroom substrates for filling into pasteurization containers.

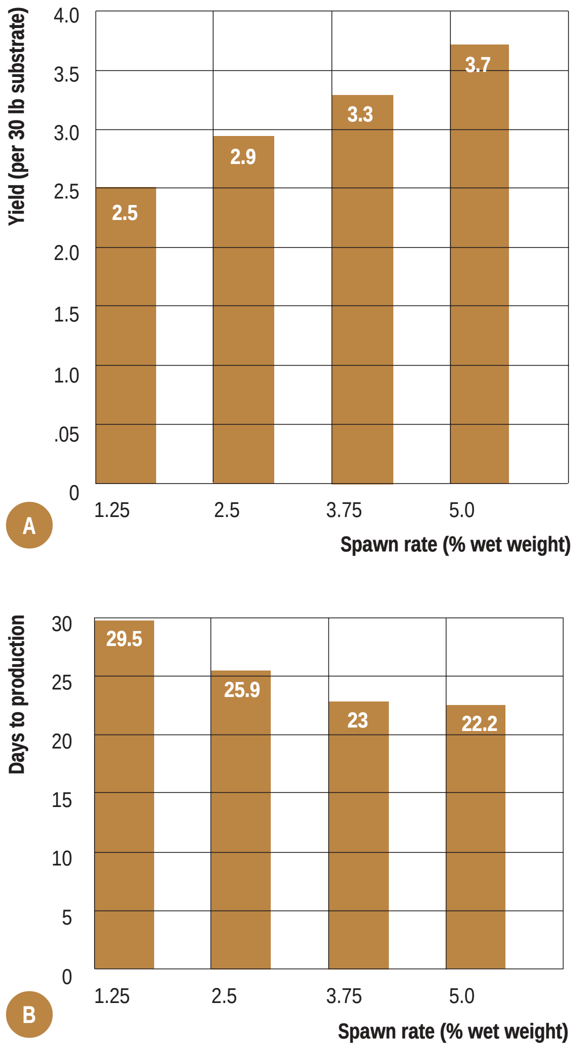
Pasteurization. On some commercial mushroom farms, ingredients are fed into revolving mixers, water is added to the desired level, and live steam is injected into the mixer while in operation. At the MRC, moistened, mixed substrate is filled into galvanized metal boxes with perforated floors (Figure 2). The substrate is pasteurized with aerated steam at 65°C for 1 hour by passing the air-steam mixture through the substrate from top to bottom. After pasteurization is complete, filtered air (HEPA filter, 99.9 percent efficiency) is passed through the substrate for cooling (approximately 1.5 hours).

Spawning and spawn rate. Growers have sought, in the past, to optimize the amount of spawn used to inoculate their substrate. Increasing the amount of spawn used (up to 5 percent of the wet weight of the substrate) has resulted in increased yields. Increasing spawn rates from 1.25 percent substrate wet weight to 5 percent may result in yield increases of nearly 50 percent (Figure 3a). Yield increases may be due to several factors. First, the increased level of nutrient available in higher levels of spawn used would provide more energy for mycelial growth and development. Second, more inoculum points, available from increased spawn levels, would provide faster substrate colonization and thus, more rapid completion of the production cycle. Finally, a more rapid spawn run would reduce the time non-colonized substrate is exposed to competitors such as weed molds and bacteria.

Figure 2. Steam boxes (A) with perforated floor (B) used for filling (C) and aerated-steam pasteurization (D) of *Pleurotus* spp. mushroom substrate.

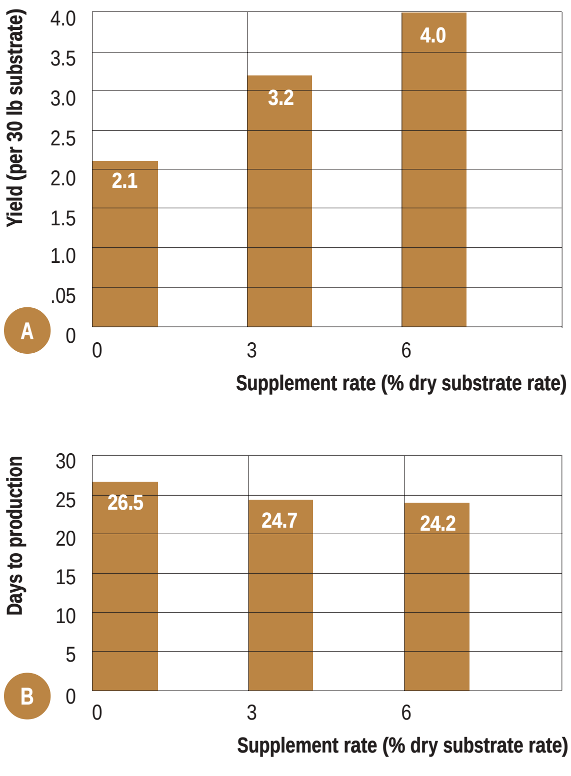
For increasing levels of spawn used (up to 5 percent), there is a negative correlation between spawn rate and days to production. As the spawn rate increases, the number of days to production decreases (Figure 3b). By using a spawn rate of 5 percent of the wet substrate weight, it is possible to reduce the time to production by more than 7 days compared to a spawn rate of 1.25 percent. Thus, growers could complete the crop cycle faster, minimizing the exposure of the production substrate to pest infestations, especially sciarid (*Lycoriella mali* [Fitch]) flies. Research has shown that the sciard fly may complete its life cycle in 25 days at 21°C, while 35 to 38 days are required at 18°C. Timely disposal of spent substrate may help to minimize the buildup of fly populations on a mushroom farm.

Figure 3. Influence of four spawn rates (1.25, 2.5, 3.75 and 5 percent of substrate wet weight) on *Pleurotus cornucopiae* mushroom yield (A) and days to production (B).



Use of delayed-release supplements. At time of spawning, a commercial delayed release supplement consisting of paraffin-coated whole soybean or formaldehyde-denatured soybean and feather meal may be added at rates of 3 to 6 percent of dry substrate weight, to stimulate yield of the mushroom. Yield increases of up to 90 percent have been observed when 6 percent (dry weight) supplement is added to substrate at time of spawning (Figure 4a). Delayed-release nutrient supplements have also been shown to decrease the number of days to harvest (Figure 4b). The addition of 3 percent nutrient at time of spawning may reduce time to production by 2 to 3 days. Thus, growers wishing to hasten the production process may do so by supplementing with only small quantities of supplement. Use of supplements, however, may cause overheating of the substrate if growers are unable to anticipate and control air temperatures to maintain a steady substrate temperature. Additional cooling capacity is required when higher levels of supplement are used.

Figure 4. Influence of three delayed-release supplement rates (0, 3, and 6 percent of substrate dry weight) on mushroom yield (A) and days to production (B).



Filling plastic bags with substrate. The pasteurized, supplemented hull/straw mixture is spawned and filled (25 to 30 pounds) into clear or black perforated polyethylene bags and then incubated at 23° to 25°C (substrate temperature) for 12 to 14 days. Mushrooms then begin to form around the edges of bag perforations and they are harvested from the substrate approximately 3 to 4 weeks after spawning depending on strain, amount of supplement used, and temperature of spawn run (Figure 5).

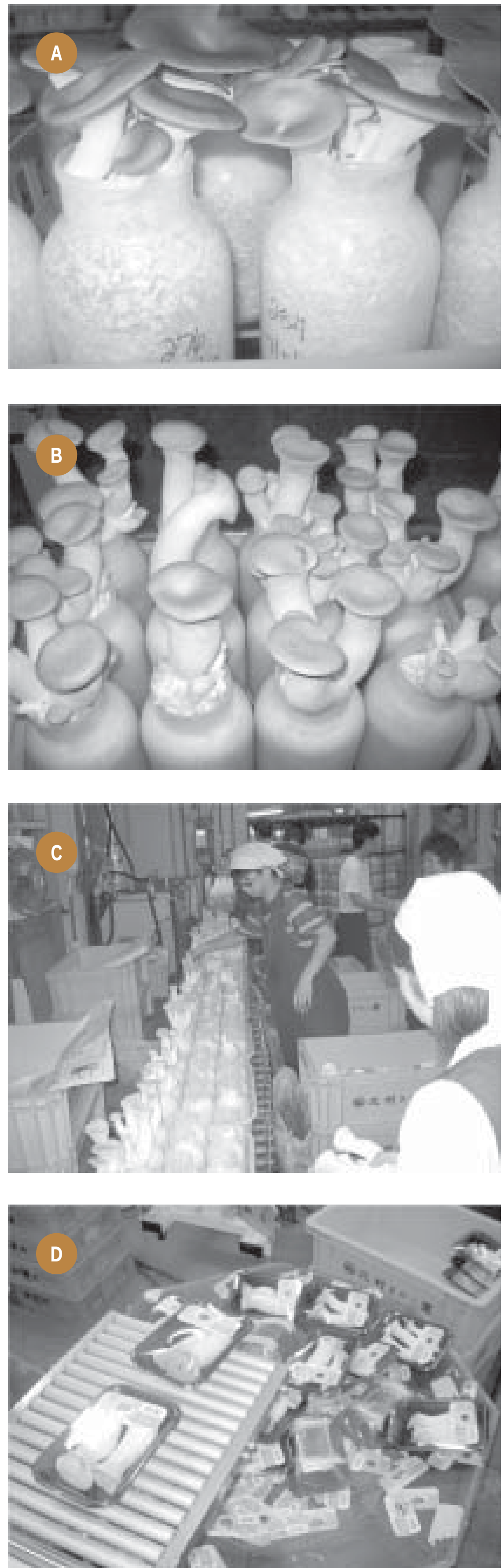
Figure 5. Yellow oyster mushrooms (*Pleurotus cornucopiae*) fruiting from pasteurized substrate (75 percent cottonseed hulls, 24 percent chopped wheat straw, and 1 percent ground limestone) contained in black bags suspended from overhead supports (MRC).

Production in Bottles

In Japan, bottle production of oyster mushrooms is most common (Figures 6a–d). Bottle production also is increasing in popularity in the United States. Substrate is filled into bottles contained in trays (usually 16 bottles per tray), sterilized, and inoculated with *Pleurotus* spp. spawn (Figure 6a–d). Upon completion of spawn run, bottle lids are removed and the surface of the substrate is scratched mechanically (1 to 2 millimeters of substrate surface containing mycelium are removed). Scratching is required to stimulate the mycelium to produce mushroom primordia uniformly on the surface. After the mushrooms are harvested, they are weighed and packaged for shipment to market (Figures 7a–d).

Figure 6. Process used for bottle production of *Pleurotus eryngii*. Bottles are filled and capped (A), autoclaved (B), the substrate is inoculated and incubated (C), and mushrooms are induced to fruit (D).

Figure 7. Fruiting of *Pleurotus pulmonarius* (A) and *P. eryngii* (B) from substrate contained in bottles. Mushrooms are harvested on a conveyor line (C) then packaged for market (D).



Production Conditions

After spawning, the bags or bottles may be moved to a spawn run room where air temperature is maintained at 18–2°C. Relative humidity is maintained at 95 to 98 percent to minimize drying of the substrate surfaces. Only recirculated air is used for cooling and air distribution. The first 12 to 21 days of spawn run may be completed without artificial lighting. Spawn run in bags usually requires less time (depending on the amount of spawn used) than spawn run in bottles. This is because spawn is thoroughly mixed in substrate contained in bags. For bottle production, the spawn is placed in a hole made in the center of the substrate contained in the bottle, so mycelium must have enough time to reach the edges of the substrate before pinning is initiated. This difference may only be 3 to 4 days. At the end of the spawn run period, 4 hours of light may be provided daily by cool white fluorescent bulbs. Light intensity, measured at various locations in the growing room, may range from 50 to 300 lux, and the lighting cycle often is controlled automatically. At time of pinning, sufficient fresh air is introduced to lower CO_2 levels below 700 ppm.

Postharvest Handling and Marketing

Marketing of oyster mushrooms in the United States is a relatively new enterprise. Since 1984, some farms have seen their production rise as prices have fallen. In the 1996–1997 growing season, growers received about $5.70/kg ($2.59/lb) for oyster mushrooms. From 1997 to 2002, the price of oyster mushrooms has declined an average of $0.22/kg ($0.10/lb) per year to $4.40/kg ($2.00/lb).

In recent years, the trend for specialty mushroom sales has been toward the retail market (Figure 8). This trend is driven partly by an increased interest in specialty mushrooms and by the convenience packaged products offer to the consumer. In some retail markets, only 10 percent of the customers buy 90 percent of the specialty types.

Oyster mushrooms typically are packaged and sold at retail in units of 100 grams (3.5 ounces). Often oyster mushrooms and other specialty types are used to highlight the common cultivated mushroom that may be sold whole, sliced, or in bulk. In fact, some purveyors insist that specialty mushrooms should not be banished to a specialty section but should be kept aligned with the mushroom section next to other best-selling produce.

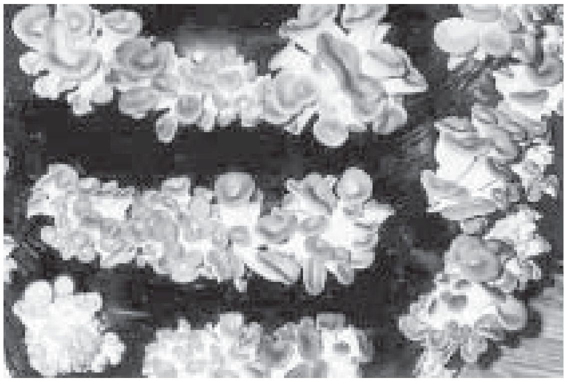
Figure 8. Supermarket display showing various mushroom types, including oyster mushrooms.

Common Problems Faced by Oyster Mushroom Growers

Pests

Bacteria. The most common bacterial problem encountered by growers is *Pseudomonas tolaasii*. This is the same bacterium that causes bacterial blotch of *A. bisporus*. Symptoms of the disease include reduced yield and orange discoloration and brittleness of the basidiocarps (Figure 9). Infected mushrooms have a reduced shelf life. Constant and high RH, insufficient air movement, overheating of the substrate (above 35°C), excessive moisture content, and especially a wet mushroom surface may exacerbate *P. tolaasii* infection. Lowering RH to 80 to 85 percent, and sprinkling the surface of the bags between flushes with 0.2 percent bleach solution may help maintain control.

Figure 9. Mushrooms emerging from pasteurized substrate contained in black plastic bags showing symptoms of bacterial blotch caused by *Pseudomonas tolaasii*. Symptoms of mushrooms produced on substrate infested with *P. tolaasii* include orange discoloration, brittleness, reduced shelf life, and reduced yield.



Fungi. Most fungi encountered in oyster mushroom production grow and develop on the substrate and are very rarely parasitic. The most frequently encountered genera include *Aspergillus, Botrytis, Coprinus, Fusarium, Monilia, Mucor, Penicillium, Trichoderma,* and *Trichothecium*. Substrates that have only been pasteurized are more susceptible to infestation than substrates that have been pasteurized and conditioned. Fungal infestation may be more of a problem when substrates are supplemented with nitrogen-rich nutrients — especially if the supplements are not commercial delayed-release nutrients. Infesting fungi may also be more of a problem when substrate temperatures rise above 35°C. Higher substrate temperatures may injure mushroom spawn, reduce mycelial growth rates, and leave the substrate vulnerable to competitors such as *Coprinus* spp. (ink caps) and *Trichoderma* spp. (green mold).

Fungi of the genera *Cladobotryum* and *Verticillium*, known to cause disease of *A. bisporus*, are rarely encountered in *Pleurotus* spp. cultivation. These fungi, when they are encountered in oyster mushroom production, may be found mainly on aged basidiocarp and stipe residues.

Insects. Insects infesting mushroom tissues cause the greatest losses for growers, particularly during summer months. The most important insect pests associated with oyster mushroom tissue include Cecidomyiidae *(Mycophila speyeri)*, Scatopsidae, Sciaridae *(Lycoriella solani)*, and Phoridae *(Megaselia halterata, M. nigra)*. Oyster mushroom primordia are very sensitive to chemical vapors, so using pesticide to control insects is difficult. Large clusters of deformed oyster mushroom tissue resembling "cauliflower" have been observed after insecticides were applied during primordial formation. Use of various flytraps and adherence to strict hygiene practices, particularly during spawning and spawn run, help keep fly populations below economic threshold levels. In the United States, *Bacillus thuringiensis* var. *israeliensis* (Bti), when incorporated into the substrate at spawning, has shown excellent effectiveness against sciarid flies.

Deformed Fruit Bodies

Deformed mushrooms may result from several causes, many of them still unknown. However, most deformed mushrooms may be traced to insufficient ventilation, smoke, chemical vapors, overheated substrate during spawn run, extreme low fruiting temperature (below 10 C), and insufficient light.

Airborne Spores

Spore production. A single mushroom may produce up to 4 million spores per hour. Worker exposure to airborne spores is a concern on most farms. Inhaled spores can cause an allergic reaction in some workers. In the United States, masks are worn to filter out spores released from the maturing mushrooms (Figure 10). Exposure can be mini-

mized by introducing higher volumes of fresh air 1 to 2 hours before harvesting and by wearing a proper mask.

Figure 10. Pickers should wear masks to reduce exposure to airborne mushroom spores. Inhalation of spores may cause flu-like symptoms among sensitized workers.

Future Outlook

As consumers become more aware of the additional culinary characteristics offered by a variety of mushrooms, demand for oyster mushrooms will increase. The development of improved technology to cultivate each species more efficiently will allow the consumer price to decline. At the same time, product quality should increase, thus furthering demand.

It is anticipated that oyster mushroom production in the United States will continue to increase due to their relative ease of production. However, research is needed to extend the shelf life of these mushrooms and to improve consistency of production. Production of various species of *Pleurotus* allows growers to take advantage of the many colors of the fruiting body for marketing purposes. In the United States, some growers currently are marketing over-wrapped packages containing several species of mushrooms. To date, these have been well received by consumers.

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