Cultivation of shiitake, the Japanese forest mushroom, on logs: a potential industry for the United States

Gary F. Leatham

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Abstract

Shiitake (shē-ē-tâ-kay) is the major edible mushroom in Asia. In 1978, the Japanese shiitake industry employed 188,000 people and generated $1.1 billion in retail sales; dried shiitake was Japan's major agricultural export. Successful commercial cultivation began in the 1940s in Japan with the development of new inoculation techniques. Small diameter hardwood logs, especially oaks, are the preferred material on which to cultivate this nonpathogenic fungus. Trees are usually felled in the winter. In the early spring logs are cut and inoculated with pieces of wood overgrown with the shiitake fungus. After an incubation period of 1-1/2 to 2 years, mushrooms are produced for 4 to 6 years, usually during the spring and autumn. Optimum yields may be as high as 2.5 to 10.5 percent on a dry weight basis (9% to 35% fresh weight basis).

Markets exist within the United States for the sale of shiitake. With increased availability of shiitake, further market expansion is probable. Although suitable hardwood species are available in many areas of the United States and the climate often acceptable, current U.S. shiitake production is limited, primarily because of the lack of accessible information on shiitake and its cultivation. This article outlines the history of shiitake cultivation in Japan, describes the food value of shiitake, and also provides information on how to cultivate the mushroom on logs in the United States.

A promising new industry, already catching on in parts of the United States, is the production of shiitake (shē-ē-tâ-kay), the Japanese forest mushroom *(Lentinus edodes* [Berk.] Sing.). Shiitake is a nonpathogenic fungus which can be grown on a variety (1, 6, 8) of currently underutilized (5) logs (e.g., small diameter oak logs, Fig. 1). In fact, one of the largest sources of underutilized wood in the United States today is small, low-grade hardwood trees, particularly oaks (5).

Although the raw materials are often available in the United States, especially in the northern, southern, and Pacific Coastal States (5), and the climate for outdoor cultivation is acceptable in all areas with adequate rainfall, significant commercial production of shiitake is currently limited to Japan (l). One of the major reasons for this is a general lack of information in the United States. In this article I'll outline the history of shiitake cultivation in Japan, describe the food value of shiitake, and also provide information on shiitake cultivation on logs in the United States.

Shiitake cultivation in Japan

Shiitake cultivation in Japan began centuries ago when wild shiitake was collected in the forest (6, 7, 10). The mushroom was found on fallen trees during the spring and autumn. "Shiitake" means "mushrooms of the shii tree," one of the (fallen) trees (closely related to oak) on which shiitake grows. The mushroom was highly prized for its flavor and was used in folk medicine. Samurai warriors, living near forests where shiitake grew, often forbade others from collecting it. Eventually it was discovered that logs found bearing shiitake in the forest could be hauled into courtyards, after which these logs (called bed logs) would continue to produce mushrooms for several more years.

Through the centuries, further technological advances in shiitake cultivation were introduced. When fresh logs were cut and placed next to the bed logs, occasionally they, too, would produce mushrooms. Mushrooms are spread in nature by spores, much the way seeds spread plants. Damaging the bark on freshly cut logs was found to increase the rate of spread of the fungus, probably by giving windblown spores easier access to the wood. Later, spores were transferred directly to inoculate logs.

The author is a Research Microbiologist, USDA Forest Serv., Forest Prod. Lab:, P.O. Box 5130, Madison, WI 53705. The Laboratory is maintained in cooperation with the. Univ. of Wisconsin, Madison. This paper was received for publication in July 1981.

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Figure 1. — Shiitake fruiting on oak logs.

Inoculation techniques, and hence the expanding shiitake industry, remained somewhat unpredictable until 1943 when Kisaku Mori, an agricultural student from Kyoto University, developed a highly successful method. In the Mori technique. the fungus was grown on presterilized wood chips. This allowed the fungus to adapt to growing on wood. The chips, covered with a pure culture of the fungus. were then used as inoculum by placing them directly into ax cuts or into holes drilled into logs.

Since the 1940s, the success of this fungal crop has been noteworthy. Worldwide, shiitake is the second major cultivated mushroom after the common white mushroom *Agaricus brunnescens* Pk. *(=bisporus) (1).* Dried shiitake is Japan's major agricultural export. In Japan, cultivation of shiitake is still essentially a cottage industry which, in 1978, employed 188,000 people, produced $1.1 billion in retail sales, and used approximately 2 million cubic meters of hardwood logs (9). Its wholesale value in 1978 was about $1.50 per pound fresh or $15 per pound dried (equivalent value since fresh shiitake is about 90% moisture).

The United States is Japan's third largest importer of dried shiitake, with wholesale purchases in 1978 totaling over $6 million a year. The bulk of the product shipped into the United States is marketed in Oriental food markets and restaurants. However, only a small percentage of U.S. citizens have heard of, or eaten, shiitake.

Characteristics of shiitake

The characteristics of different species of mushrooms differ. Shiitake is not likely to replace the common white mushroom in the United States but, rather, will be a second variety often for use in different recipes. There are many reasons why shiitake is popular. When cooked, it imparts a full-bodied aromatic but distinctly pleasant flavor to the dish while maintaining its own original color and chewy texture. Fresh shiitake resists both bruising and spoilage remarkably well. Shiitake is easily dried. Dried shiitake is both convenient for use and inexpensive for industry to store and transport. Heat used to dry shiitake enhances certain popular flavor characteristics. Dried shiitake dehydrates well, after which it rivals fresh mushrooms for color, shape, and texture.

Mushrooms are a good source of protein, 13-vitamins, and minerals. Vitamin D is essential for humans. Shiitake contains a natural chemical compound called ergosterol which, when exposed to ultraviolet light (or sunlight), is converted to vitamin D_2 (4). In Japan, shiitake is occasionally treated with

ultraviolet light and then marketed as a source of vitamin D. If treated with sufficient ultraviolet light, 1 gram of dried shiitake can supply 400 International Units, the USDA adult minimum daily requirement, of vitamin D.

There is initial, but still limited, scientific evidence that shiitake, like other fungi, may produce chemical compounds with medicinal value (4). Several compounds from shiitake are being studied in Japan or the United States and compounds that reduce blood cholesterol levels have been identified (2). Experiments to verify the existence of potential antiviral/antitumor (3) agents are also under investigation (4).

Shiitake cultivation — business in balance with nature

Successful shiitake cultivation is not difficult. It should be remembered, however, that one is trying to harness and improve on a process which evolved in nature. Mushrooms are dependent on the environmental conditions similar to those found in a forest. There are six key cultivation phases (6, 10), each of which requires careful attention: 1) obtaining viable inoculum in pure culture and storing it until use, 2) preparing logs for cultivation, 3) inoculation, 4) laying the logs — to favor fungal growth, 5) raising — to favor fruiting, and 6) harvesting and storing the crop.

As problems are encountered, common sense, reading about standard cultural practices and the growth requirement of fungi, reviewing techniques, or innovative thinking (such as thinking back to the log in the forest) will serve as a guide in solving many problems.

Growing shiitake

Inoculum

In nature, the fungus propagates and spreads from spores produced by the mushroom. However, for cultivation, spore germination is too unreliable. Instead, logs are inoculated with actively growing fungus. The fungus is first adapted to wood by growing it directly on small pieces of wood. Active fungal cultures intended as inoculum for mushroom cultivation are called spawn. Because the quality of the crop can be no better than the spawn, one must use viable shiitake spawn of a good variety in pure culture, free of weed fungi and bacteria.

Different cultivars or strains of shiitake may perform differently under different conditions. Initially, it is best to try more than one strain to ensure success. Because the U.S. shiitake industry is just beginning, domestic companies that supply shiitake spawn are limited. A list of companies currently supplying shiitake spawn is available from the author.

Shiitake spawn is usually grown on small peglike pieces of wood, 1 to 1.5 centimeters (cm) in diameter by 1.5 to 2 cm long (1/4 to 3/8 in. by 3/8 to 3/4 in.), and usually is supplied in sealed plastic containers. Occasionally it is grown on sawdust. The spawn should be moist, white, and appear rather fuzzy. Weed fungi and bacteria are kept out by not damaging or opening the spawn container until use of the entire contents. Spawn must be kept away from direct sunlight and extremes of temperature. Storage for a month or more should be in a cool (4° to 10°C, 40° to 50° F) location away from direct sunlight. Spawn must not be frozen. During 1 to 2 weeks prior to use, it should be incubated near 21°C (70°F) to encourage active fungal growth.

Felling trees and preparing logs for inoculation

The species of tree selected for shiitake cultivation is important. It influences the overall yield of mushrooms and the likelihood of contamination. From past studies, the preferred species are often those which in the United States are referred to as low-grade “eastern” hardwoods, especially species in the beech family (Fagaceae). Examples are many of the oaks, chestnut, beech, and hornbeam. Oaks are the preferred species in Japan (6) and also have given promising results during initial studies in the United States (8). Species in other families that may be useful include maple, alder, birch, the poplars (aspen, cottonwood, poplar), and possibly others. The suitability of any particular tree species for shiitake cultivation in any given area can only be determined by attempting to grow shiitake on that species.

Shiitake will not grow in living tissue. It survives on dead wood only when allowed to establish itself before competitive fungi colonize the wood. For these reasons only live trees are cut for shiitake cultivation.

Methods for felling trees and cutting logs are designed to reduce the possibility of weed fungi being introduced and becoming established. Logs may be cut and inoculated any time of year. However, for the best results, trees should be felled when leafless, in cool or cold weather. At this time, the sugar content of the sap, which is beneficial to fungal growth, is high but low temperatures retard the growth of competitive fungi.

Logs also tend to retain their bark better when the trees were cut while leafless and especially when they were cut in the late fall. Bark benefits fungal growth and shiitake production by helping maintain the log water content, by insulating from rapid changes in temperature, and by inhibiting the growth of competitive fungi at the log surface. Bark also helps stimulate fruiting. Damaging the bark on logs should be avoided.

The felled trees should be kept on well-drained ground in a location with good air circulation and unsheltered from rainfall which is necessary to keep them moist. Prior to inoculation, the trunks and large branches are cut into logs. In Japan, some growers prefer to paint the bare wood on the ends of the logs with a wood preservative that will inhibit entry of competitive fungi. However, no fungicides have yet been registered with the U.S. Environmental Protection Agency for this purpose. The optimal log size is 5 to 20 cm (2 to 8 in.) in diameter and 1 meter(m) (3 to 4 ft.) long.

Inoculation

Inoculation is the introduction of the live fungus into the log. Shiitake spawn should be introduced into logs no sooner than 2 to 3 weeks after felling. If it. is introduced earlier, the spawn probably will not survive. This aging period after felling allows time for the tree cells to die before inoculation. Because the log is not sterile, it is important to introduce the spawn into many

places spaced evenly along the log surface. An even, heavy inoculation density gives shiitake a competitive advantage over other micro-organisms. Introduction of soil or debris into the inoculation holes must be avoided. Partially rotted logs should not be used.

Logs cut in the fall through spring are inoculated in the spring, generally when mean daytime temperatures approach 10° to 16°C (50° to 60°F). Holes are drilled into the log in rows lengthwise to the log. Holes in each row are spaced roughly 20 to 40 cm (8 to 16 in.) apart; rows are 5 to 10 cm (2 to 4 in.) apart. To equalize inoculation density across the log surface, the holes in each new row are offset 10 to 20 cm (3 to 8 in.) from the last row (Fig. 2). Usually, 10 to 30 pieces of spawn are required per log. Holes should be of a suitable diameter for a snug fit of the spawn plug—i.e., usually 1 to 1.5 cm (1/4 to 3/8 in.)—and of a depth that the spawn plug fits nearly flush with the log surface (Fig. 3). The depth of the hole may be easily standardized by attaching a locking sleeve to the drill bit which limits the depth that the bit will penetrate.

Spawn plugs are placed into the holes and gently pounded in with a hammer or mallet. A convenient method is to initially hold the spawn plug with forceps. If sawdust grown spawn is used, the holes should be completely filled with spawn. After inoculation, the surface of the log where the spawn was introduced is lightly painted with hot paraffin to seal in moisture and to disinfect the surface. Inoculation should be done in a shaded area to avoid direct exposure of the spawn to sunlight.

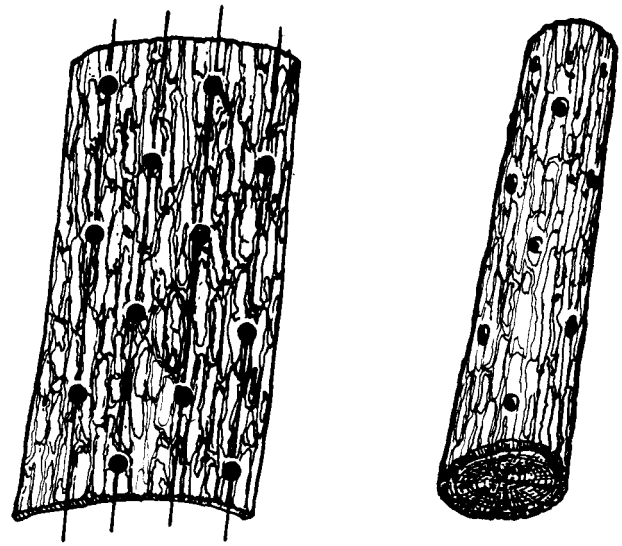

Figure 2. — Pattern to guide the placement of holes (inoculation sites) across the log surface.

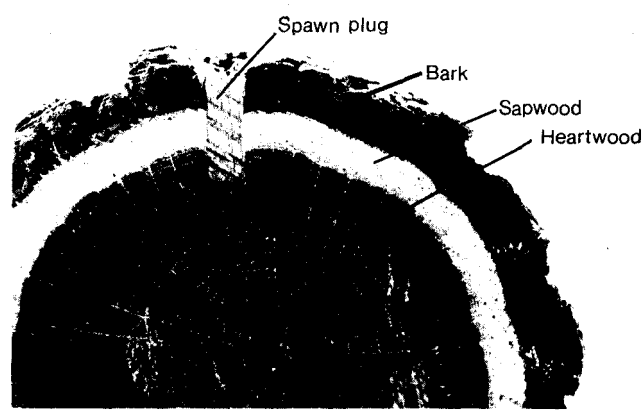

Figure 3. — Cross section of a log showing location of a spawn plug after inoculation.

Laying the logs

After inoculation, it is necessary to encourage the growth of the fungus through the log while discouraging weed fungi. Logs are laid side by side, propped up at a slant in a well-drained, shaded area with single logs placed crosswise between rows (Fig. 4). One may also want to cover the logs with a porous material such as burlap or straw mats to protect from excessive heating due to direct exposure to sunlight and to favor moisture retention while still allowing adequate ventilation and wetting during rainfall.

If excessive dehydration occurs, e.g., under 30 percent moisture content (dry weight basis), the logs should be watered. Growers usually learn how to determine if a log has enough moisture simply by hefting it. When logs are watered, they should be thoroughly soaked and then allowed to dry out for a few weeks between waterings. Continuous wet conditions favor surface contamination by weed fungi. If conditions are excessively hot and moist, the cover over the logs should be removed to promote surface drying. To encourage uniform water distribution, which promotes uniform growth, the logs should be turned (reverse the ends) every 2 to 4 months.

Optimum conditions in the laying yard are temperatures between 15° and 28°C (59° and 82°F) and a relative humidity of 80 to 85 percent. In practice, most failures in shiitake cultivation in Japan have been traced to incorrect conditions in the laying yard that favor competition from weed fungi.

Raising

Shiitake is capable of fruiting only after the fungus has completely colonized the log (1 to 2 yr.). At this time, a fuzzy white fungal growth can be seen at the cut ends of the log in the sapwood area (whitecolored wood near the log surface (Fig. 3)), especially just under the hark. From this time on, conditions should be altered to favor fruiting. To fruit, the fungus requires abundant moisture, sufficient air movement, and shaded exposure to light. Fruiting is favored by cool temperatures, near 8° to 22°C (46° to 72°F). Cool nights followed by warm days and a constantly high relative humidity of at least 85 to 90 percent are optimal.

To provide these conditions and facilitate harvesting mushrooms, the logs should be uncovered

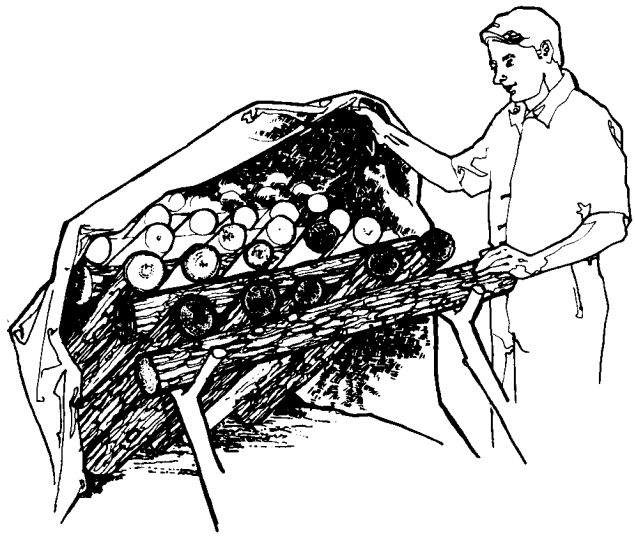

Figure 4. — Laying logs to favor fungal growth.

Figure 5. — Raising configuration to facilitate fruiting and harvesting.

and stacked in rows along boards in an upright position on well-drained, shaded ground (Fig. 5). Each log is separated by the width of another log placed on the opposite side of the board. This configuration creates rows from which mushrooms can be picked from either side. Fruiting occurs primarily in the wet, cool seasons — spring and autumn. Once shiitake begins to fruit on a log, it generally continues to do so during spring and autumn for an additional 3 to 7 years.

If a summer has been particularly dry, the logs may be too dry to support fall fruiting. For fruiting, log moisture content should be over 40 percent, the higher the better. To increase water content, overhead sprinklers can be used; or to conserve water, the logs can be soaked in a stream or tub of water for 1 to 3 days. In commercial production, dehydration followed by soaking in cool water (13° to 20°C, 55° to 70°F) is often used to stimulate fruiting. Logs that have become dehydrated usually produce bumper crops within a week of being soaked. Soaking also tends to eliminate certain insect pests. Logs in the raising yard should be turned, end for end, every 2 to 4 months to ensure even moisture distribution.

Surface contamination of logs in the raising yard may occur. Especially the older logs may become contaminated with a blue or green surface mold. Surface molds are particularly damaging to mushroom cultivation because mushroom growth is prevented from starting at the log surface. To prevent the spread of surface molds and other competitive fungi, any log found either badly contaminated (more than 10% of the log surface contaminated) or producing other mushroom species should be discarded immediately.

Logs. that have lost their bark should also be discarded. The disposal site should be in a location separate from the cultivation site. Burying, or preferably burning, the contaminated logs is a simple and effective method to prevent the spread of competitive micro-organisms. A relatively dry log surface will help discourage growth and spread of surface molds. Therefore, if logs are watered artificially, they should be watered thoroughly for a relatively short period, e.g., 1 to 3 days, followed by longer drier periods; e.g., 3 to 4 weeks. Light, frequent waterings should be avoided.

In Japan, fungicides or insecticides are occasionally used to kill surface contamination or insect pests. However, no fungicide or insecticide has yet been registered with the U.S. Environmental Protection Agency for this purpose.

Indoor (e.g., greenhouse) cultivation of shiitake can be used to produce mushrooms in seasons other than spring and fall or to intensify mushroom production. Generally, logs at the raising stage are placed indoors at 10° to 20°C (55° to 70°F). Prior to the time fruiting is desired, they are usually kept drier than normal. Fruiting is then stimulated by water soaking and maintaining a constantly high relative humidity as described earlier. This procedure can be repeated as often as every 2 to 3 months.

Shiitake requires light to fruit. However, the light requirement is relatively low. If a greenhouse is used, the glass/plastic should be shaded. If shiitake is grown in an otherwise dark chamber, lighting to provide approximately 30 foot-candles of light must be used to ensure optimal fruiting. Increasing the light intensity over this level probably will not give any further improvement. A light/dark cycle (for instance, 9 hr. of light per day) may be preferable to continuous lighting. Artificial light may be from fluorescent bulbs (including plant-growth bulbs) or tungsten filament bulbs (e.g., approximately two 40-watt fluorescent bulbs or two 100-

watt tungsten filament bulbs at a distance of 2 to 3 meters (6 to 10 ft.)).

When the cultivation method is optimal, mushroom yields are high. One hundred pounds of logs will yield as much as 9 to 35 pounds of fresh mushrooms over a 4- to 6-year production period. Because the fresh mushrooms usually contain 90 percent moisture and bed logs are approximately 50 percent moisture, optimal yields on a dry weight basis can be 2.5 to 10.5 percent.

Harvesting and crop storage

To produce a high quality crop, it is important to use correct harvesting and storage conditions. Once mushroom formation has begun, shiitake often matures to a harvestable stage in 2 to 7 days. This makes daily harvesting necessary. With experience, growers can usually predict the periods of heaviest fruiting based on temperature and previous rainfall or watering.

The preferred stage for harvesting is just before the cap completely expands. The mushrooms are snapped off cleanly at the log surface and, in Japan, are placed in baskets. Although shiitake resists bruising, care should be taken to minimize damage because damaged mushrooms have less customer appeal and spoil more easily.

Fresh mushrooms intended for market should be stored refrigerated in trays with slots for ventilation. Mushrooms should not be frozen unless they are to be marketed in this form.

Some buyers prefer dried shiitake for ease of storage and for their enhanced flavor characteristics. Heated forced air chambers are generally used for dehydration on a commercial scale. In commercial scale dehydration, shiitake is usually dried on racks at 30°C (86°F) initially, gradually increased 1° to 2°C (2° to 4°F) per hour to 50°C (122°F). They are then heated at 60°C for 1 hour. The final heating step develops popular flavor characteristics and gives the cap an attractive luster. Alternatively, shiitake is easily sun-dried.

Marketing shiitake

Consumer safety is an extremely important topic. If the cultivation method described here is followed carefully, most of the mushrooms found growing on inoculated logs should be shiitake. After observing the characteristics of shiitake, most people can easily recognize it. However, occasionally wild mushrooms will also grow on some logs. Because some wild mushrooms are poisonous, growers must be absolutely certain that the mushrooms intended for consumption are shiitake. Under no circumstances should growers mix in any wild mushrooms with their product. There is no quick, safe method known to distinguish poisonous mushrooms from edible ones, other than positive identification of the mushroom in question. If unsure of the indentity of a mushroom, one should seek outside help. Often a local college or university will have a mycologist specializing in fungal taxonomy who may be able to identify mushrooms.

Once a reliable quality product exists, successful establishment and growth of an industry is dependent on market development and marketing procedures. Markets for shiitake already exist in the United States and, fortunately, during a temporary lack of a market, shiitake can be dried and stored. Because it generally is not available to them, local Oriental food stores and restaurants will probably be especially interested in obtaining fresh shiitake. Considerable room for development of new markets exists. When one can consistently produce and deliver quality mushrooms in sufficient quantity, inquiries can be made into the possibility of supplying mushrooms through grocery markets, distributors, or to food packaging companies for use in their products.

Other potential mushroom crops

The method of mushroom cultivation described here may be useful for other edible wood-rotting fungi (1). Mushrooms common in the Orient, often cultivated on logs using similar methods, include *Auricularia auricula* and *A. polytricha* (wood ear or ear fungus begins to fruit 2 to 3 mo. after inoculation); *Pholiota nameko* ("Nameko" requires more moisture); *Pleurotus* species including *P. ostreatus* (oyster mushroom); and *Tremella fuciformis* (white jelly fungus begins to fruit 2 to 4 mo. after inoculation).

Testing of logs from domestic tree species will be necessary to determine the optimal species for each fungus. Other edible wood-rotting fungi, including native species, might also be successfully cultivated using these methods. However, one should not attempt to cultivate potentially pathogenic fungi such as *Armillariella mellea* (the native "honey mushroom") even if the mushrooms they produce are desirable. The infection that may spread to local trees and forests could be disastrous. Dutch-elm disease is caused by a fungus.

Summary and conclusions

A promising new industry for the United States is the production of shiitake on small diameter hardwood logs from currently noncommercial trees. Methods to cultivate shiitake on logs were developed in Japan. These methods may also be adapted to cultivating shiitake and other nonpathogenic edible wood-rotting mushrooms in the United States.

The cultivation method is not difficult but, to avoid contamination by competitive micro-organisms and to ensure optimal mushroom production, cultural practices must be carried out correctly. Logs are cut from live trees, aged, and then inoculated with an actively growing fungal culture. Once inoculated, logs are laid to favor fungal growth. After the fungus has colonized the logs, they are restacked to favor fruiting. Soaking logs in water may be used to stimulate the production of mushrooms.

Prior to marketing, storage of fresh shiitake is by refrigeration or shiitake may be dried. Current U.S. markets for shiitake are Oriental food stores and restaurants which purchase dried shiitake from Japan. Considerable room for market expansion exists in the United States for both fresh and dried shiitake.

Additional information[1]

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[1]Additional culture information occasionally accompanies the purchase of spawn.

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CULTIVATING THE SHIITAKE MUSHROOM
Sources of Public Information, Seminars, or Grower Cooperatives

Arkansas:
- Victor Ford, Southwest Research Extension Center, Rt. 3, Box 258, Hope, AR 71801, (501)777-9702

California:
- Bill Dost, Wood Products Specialist, Forest Products Laboratory, 47th & Hoffman Blvd., University of California, Richmond, CA 94804, (415)231-9404
- Peter Passof, Extension Forest Advisor, 579 Low Gap Road, Courthouse/Agricultural Center, Uriah, CA 95482, (707)463-4495

Illinois:
- William McCartney, Two Rivers RC&D, 110 E. Fayette Rd., Pittsfield, IL 62363, (217)285-4114
- James Veselenak, Medical Technology Program, Sangamon State University, Springfield, IL 62708, (217)786-6774

Indiana:
- Fred Peterson, Purdue Cooperative Extension, Courthouse C, Portland, IN 47371

Iowa:
- Paul H. Wray, Professor & Extension Forester or Laura E. Sweets, Extension Plant Pathologist, Bessy Hall, Iowa State University, Ames, IA 50011, (515)294-1168
- William Ritter, Iowa State Nursery, Ames, IA 50011
- Rick Zarwell, Coordinator, Geode Wonderland RC&D, 3002A Winegard Drive, Burlington, IA 52601, (319)752-6395

Maine:
- Leslie Hyde, Cooperative Extension Service, 375 Main St., Rockland, ME 04841

Michigan:
- Russell Kidd, Cooperative Extension Service, P.O. Box 507, Roscommon, MI 48653, (517)275-5043

Minnesota:
- Mel Baughman, Extension Forester, 102 Green Hall, University of Minnesota, St. Paul, MN 55949, (612)624-0734
- Joe Deden, South Eastern Minnesota Forest Resource Center, Lanesboro, MN 55949, (507)467-2437
- Mushroom Producers Inc., Gourmet House, Inc., Grand Rapids, MN 55744, (218)326-0574

Missouri:
- John Jesse, RC &D Office, 1437 A South Highway #63, Huston, MO 65483

North Carolina:
- Mike Levi, Forest Resource Center, School of Forest Resources, P.O. Box 8003, North Carolina State University, Raleigh, NC 27695-8003, (919)737-3386

Ohio:
- Steve Bratkovich/Steve Vance, Ohio Cooperative Extension Dept., 17 Standpipe Rd., Jackson, OH 45640, (614)286-2177

Oregon:
- Steve Woodward, Forestry Extension Agent, 950 13th Ave., Eugene, OR 97402, (503)687-4243
- Jerry Larson, Oregon Dept. of Agriculture, 635 Capitol Street NE, Salem, OR 97310

Pennsylvania:
- American Mushroom Institute, P.O. Box 373, Kennett Square, PA 19348
- Ed Polaski, Pennsylvania Bureau of Forestry-FAS, Room 102, Evan Press Blvd., P.O.Box 1467, Harrisburg, PA 17120

South Carolina:
- Don Ham, Associate Professor of Forestry, 272 Tehotsky Hall, Clemson University, Clemson, SC 29631, (803)656-2478

Virginia:
- Emmett Knapp, Appalachian Mushroom Growers Association, Rt. 1 Box 315, Reva, VA 22735, Mary Ellen Lambardi (703)923-4774
- Andy Hankins, Extension Agency, P.O. Box 10, Madison, VA 22727
- Robert McElwee, Extension Project Leader, 324 E Cheatham Hall, Virginia Polytechnic Inst. & State University, Blacksburg, VA 24061 (703)961-5483
- Orson K. Miller, Jr., Dept. of Biology, Virginia Polytechnic Inst. & State University, Blacksburg, VA 24061, (703)961-6765
- Joesph Hunnings, Warren County Extension Service, 912A Warren Ave., Front Royal, VA 22630, (703)635-4549

Washington:
- Kenelm W. Russell, Forest Pathologist, Division of Private Forestry & Recreation, Department of Natural Resources, State of Washington, Olympia, WA 98504

Wisconsin:

- Robert Feldt, River County RC&D Area, 3120 E. Clairemont Ave, Eau Claire, WI 54701
- Terry Mace, Wisconsin DNR, 3911 Fish Hatchery Rd., Madison, WI 53711, (608)275-3276
- Jeff Martin, Extension Forestry, Department of Forestry, 1630 Linden Dr., University of Wisconsin, Madison, WI 53706, (608)262-0134
- Ralph Monahan, 624 E. College Ave., Medford, WI 54451 (715)748-2008

University of Wisconsin Experimental Farm Demonstration Sites:

- Tom Wright, Rt.1 Box 115, Hancock, WI 54943, (715)249-5961
- Andy Louis, Youth & Agriculture Center, P.O. Box 31, Lancaster, WI 53813, (608)723-2125
- Bob Rand, Rt.2, P.O. Box 2335, Spooner, WI 54801, (715)635-3735

U.S. Research Groups

Cultivation on Logs:

- Steve Bratkovich, Ohio Cooperative Extension Dept., 17 Standpipe Rd., Jackson, OH 45640, (614)286-2177
- Joe Deden, South Eastern Minnesota Forest Resource Center, Lanesboro, MN 55949, (507)467-2437
- Kraig Kiger, Shiitake Mushroom Research Project, Itasca Development Corp., One NW Third St., Grand Rapids, MN 55744, (218)326-941 1
- Mike Levi, Forest Resource Center, School of Forest Resources, P.O. Box 8003, North Carolina State University, Raleigh, NC 27695-8003
- Elmer Schmidt, 208 Kaufert Lab., 2004 Folwell Ave., University of Minnesota, St.Paul, MN 55108

Cultivation on Lignocellulosic Particles, Genetics & Basic Biochemistry, and Spent Residue as Cattle Feed Research:

- Albert Ellingboe, Plant Pathology Dept., University of Wisconsin, Madison, WI 53706
- Daniel J. Royse, 116 Buckout Laboratory, Pennsylvania State University, University Park, PA 16802
- Gary F. Leatham, U.S. Forest Products Laboratory, Institute for Microbial and Biochemical Technology, One Gifford Pinchot Dr., Madison, WI 53705
- Larry D. Satter, Professor of Agriculture & Life Sciences, Dairy Sciences, Rm 346 Dairy Forage Center North Central, University of Wisconsin, Madison, WI 53706

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This listing is prepared by U.S. Forest Products Laboratory solely for the convenience of our correspondents and does not represent any endorsement on the part of the U.S. Department of Agriculture. Additional information and consulting are available from the spawn suppliers and contacts herein. Those extension people, grower cooperative representatives or researchers wishing to be added to this list, please contact Gary F. Leatham. October 1, 1987

North American Shiitake Spawn Suppliers and / or Consultants

Allied Mushroom Products Co.	P.O. Drawer 3487	Fayetteville	AR	72702	(501) 575-7317
Amycel	P.O. Box 637	Avondale	PA	19311	(215) 869-4041
Dr. You Farm	P.O. Box 290	College Park	M D	20740	
Elix Corporation	Rt. 1	Arvonia	VA	23004	(804) 983-2676
Far West Fungi	P.O. Box 1333	Goleta	CA	93116	
Field and Forest Products	Rt. 2, P.O. Box 41	Peshtigo	WI	54157	(715) 582-4997
Forest and Farm Products	2490 Ewald Ave	Salem	OR	97302	(503) 363-4333
Four Seasons Distributors	P.O. Box 17563	Portland	OR	97217	(503) 286-6458
Fungi Perfecti	P.O. Box 7634	Olympia	W A	98507	(206) 426-9292
Green Empire, Inc.	P.O. Box 126	Washingtonville	P A	17884	(717) 437-3888
Linnea Gillman	3024 S. Winona Ct.	Denver	c o	80236	(303) 935-2390
L.F. Lambert Spawn Co.	P.O. Box 407	Coatsville	PA	19320	(215) 384-5031/7948
Mushroompeople	P.O. Box 158F	Inverness	CA	94937	(415) 663-8504/8505
Mushroom Specialties	445 Vassar Ave	Berkeley	CA	94708	(415) 233-0555
Mushroom Technology Corporation	P.O. Box 2612	Naperville	IL	60565	(312) 961-3286
Northwest Mycological Consultants	704 NW 4th	Corvallis	OR	97330	(503) 753-8198
Sohn's Oak Forest Mushrooms	P.O. Box 20	Westfield	WI	53964	(608) 296-2456
Sylvan Spawn Laboratory, Inc.	Box N	Worthington	PA	16262	(412) 352-1521
Western Biologicals	P.O. Box 46499, Stn.G	Vancouver, B.C.	Canada	V6R 4G7	(604) 228-0986

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THE AMAZING MUSHROOM

GARY F. LEATHAM, Research Chemist, Forest Products Laboratory [1], Institute for Microbial and Biochemical Research, USDA-Forest Service, One Gifford Pinchot Drive, Madison, WI 53705-2398

Mushrooms have intrigued people for centuries... and why not. Within a few feet of each other, one may find a prized delicacy and another which is deadly poisonous. In fact, there seems to be an endless variety of them growing in lawns, gardens, and forests. There are reports of mushrooms growing up through asphalt driveways, and from walls and carpets. However, one of the mushroom's most impressive characteristics is the ability to pop up and grow overnight with no prior visual warning. This and other characteristics have led to a general misunderstanding of the mushroom. Fortunately, an explanation of the mushroom's life cycle helps clear away much of the mystery and at the same time describes what a mushroom is and how it is able to grow so quickly.

Many refer to the mushrooms as plants but actually they are only the fruit of the larger fungi. Their purpose is the production and dispersal of tiny spores whose function is somewhat like seed. The mushroom's unique often umbrella-like architecture is designed to allow thespores, that are produced on the gill surfaces on the underside of the cap, to be lifted away from the ground, discharged into the wind, and at the same time protected from the rain. Massive numbers of spores are produced by each mushroom to ensure that a few land in a moist, favorable environment for growth.

Mushrooms are only the fruit of a fungus. Now we will consider the parts of the fungi that produce them. These fungi are biological wonders in their own right. Collectively they have developed the ability to utilize almost any kind of vegetative matter for food. This adaptability has made fungi very important in nature since many are ideally suited to start the breakdown of prairie or forest litter allowing the valuable nutrients to be more expediently recycled. If the mushroom is edible, the fungus can therefore be used to turn wood, leaves or other plant residue into food for man.

The life cycle of a mushroom begins when a windblown spore is deposited in a favorable location with adequate food and moisture. Soon it germinates forming a long thread of living cells called a hypha. The hypha grows from its tip allowing it to creep forward. Vegetative matter found in its path is broken down by an arsenal of enzymes released outside the hypha. The liberated nutrients are absorbed and used to support further growth and some are stored for fruiting. When a pocket of suitable food is encountered, the hypha branches and most of the new tips grow into and around the food to allow its rapid consumption. While this is happening, some tips grow out away from the food. In this way, any food encountered is efficiently collected and the colony expanded to locate new food supplies. Repeated branching and growth of the hyphae form the extensive network of cells called the mycelium which is the vegetative part of the fungal organism, the living "body" of the fungus. Such a growth pattern can be seen in the home as the growth on moldy bread or oranges; however, these fungi do not produce mushrooms. Out of doors, mushroom mycelia can often be observed growing under the loose bark on fallen logs or within piles of leaves or forest litter where it appears as a fuzzy, white growth.

In nature, a mycelium from one spore usually cannot fruit alone; therefore, during its growth it must meet a hypha from another spore of the opposite mating type. When such a pair joins, the hyphae fuse and grow together as one organism. This mated pair forms a colony that can produce mushrooms. Some fungal colonies such as mushroom "Fairy Rings" have been estimated to hundreds of years old and are still actively growing and producing mushrooms.

How fungi form mushrooms from their extremely thin hyphae seems an amazing feat. This is made possible only because the mycelium has previously extended over a large area and absorbed the massive amount of nutrients necessary. Mushroom formation usually begins in the older hyphae where the conditions for growth are becoming unfavorable due to a scarcity of food. Hyphal tips bend toward each other and fuse; then repeated branching occurs forming a small, dense, ball-like structure called the primordium. A primordium is difficult to locate with the naked eye since it is usually only about 0.5-1 millimeter (1/64-1/32 in.) in diameter and often buried in the loose fuzzy mycelium. The problem is something like looking for a golf ball in a cotton bin. The mushroom's secret for fast growth is very simple. The primordium usually contains most of the calls required in the final mushroom and the energy source and raw materials needed to expand it have already been stored. So, when the correct environmental conditions prevail, such as adequate rainfall combined with an appropriate temperature, the hyphae collectively pump nutrients and water through themselves into the primordium thus promoting its rapid expansion. This last growth phase often only takes 12-96 hours to complete. Therefore, many mushrooms do indeed pop up overnight.

[1] Maintained at Madison, WI, in cooperation with the University of Wisconsin.

Shiitake: Cultivated Mushroom

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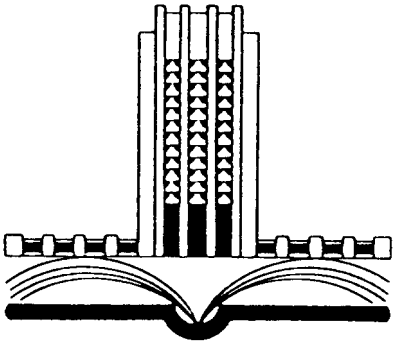

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De Jong, R. Comparison of two soil-water models under semi-arid growing conditions
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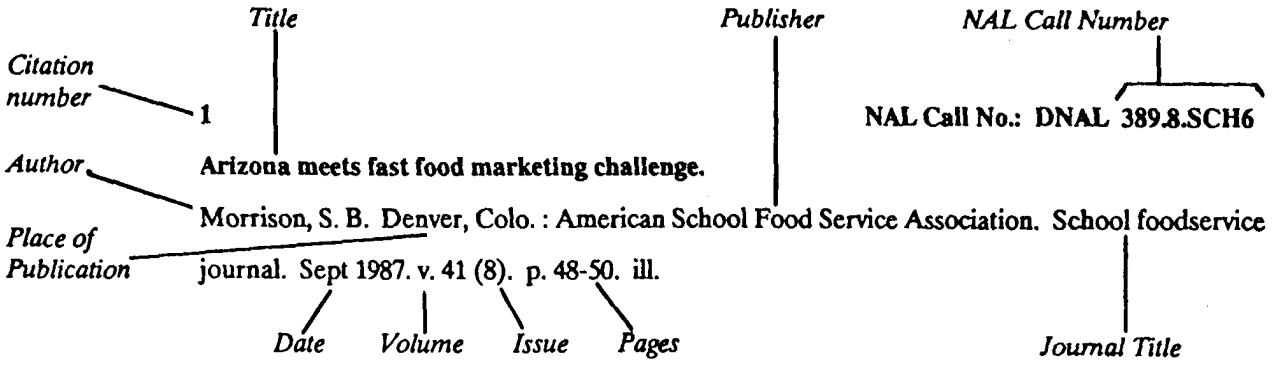

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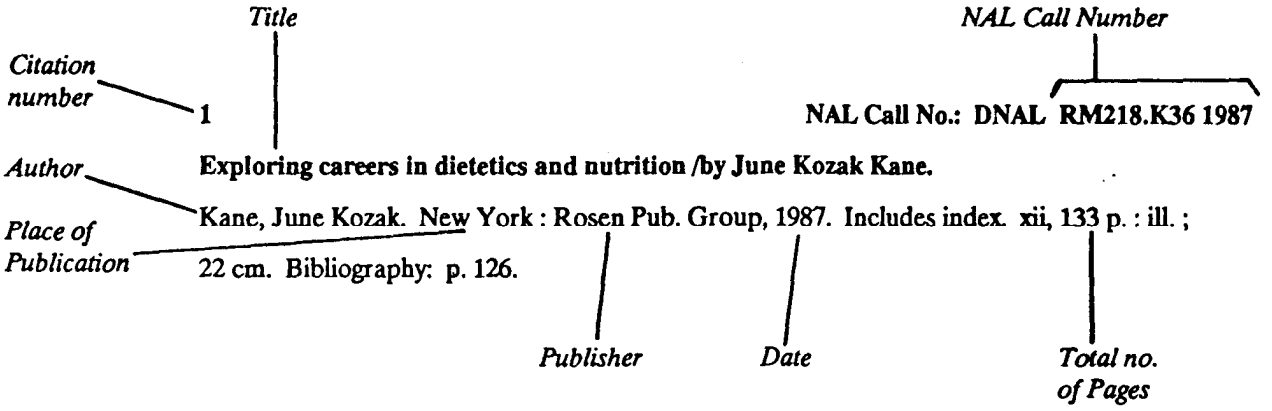

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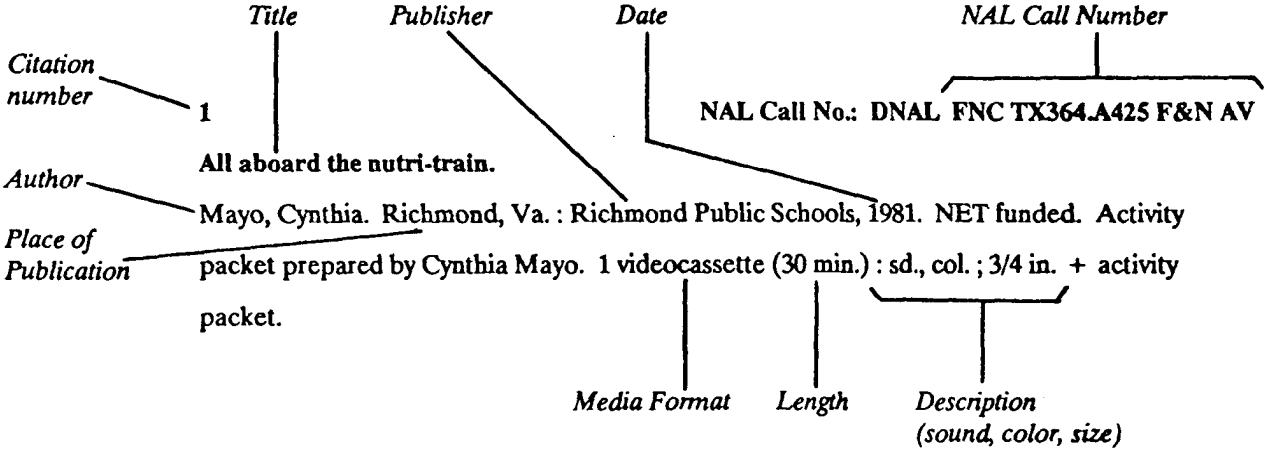

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