Cultivation of Shiitake on supplemented sawdust

by Daniel J. Royse and Lee C. Schisler

The production and consumption of shiitake mushrooms (Lentinus edodes) has increased rapidly since World War II (Figure 1). Not only has production and consumption increased as the population has increased but per capita consumption of shiitake has increased as well. These gains have occurred mainly in Japan, the largest producer of shiitake in the world (Table 1). Over 60% of the total world production is dried before consumption. In Taiwan, South Korea, and China, nearly all shiitake mushrooms are used in the dried form. Most shiitake are produced on natural logs. However, many farms in the USA, Taiwan, Canada, and Singapore are now producing shiitake on synthetic substrate.

Optimum yields from natural log cultivation may be as high as 9 to 35% (fresh weight basis) over a 6 year period (Leatham, 1982; San Antonio, 1981). On the other hand, mean efficiencies as high as 14% in 6 months have been reported from synthetic logs by Royse et al. (1985). Thus, approximately 3 to 4 times as much production can be obtained in one-tenth of the time on supplemented sawdust as compared to the natural log. Considerable research effort is now being directed toward the elucidation of factors contributing to yield and size variation (Fergus, 1982; Royse et al., 1985). From a commercial standpoint, sawdust substrate producing at consistent, predictable efficiencies would be preferable. Factors such as length of spawn run, concentration and type of nutritional supplements, content of water, rate of gas exchange, etc., may greatly affect yields. (Royse, 1985).

Development of the Shiitake Industry. In the early 1900s, laboratories for research on mushroom growing were established by government experimental stations in the USA as well as many countries of Europe and in Japan, Taiwan and South Korea (Royse and Schisler, 1980). Interdisciplinary research efforts in the USA and Europe were primarily devoted to research on Agaricus, while efforts in Japan, at Kiryu and other locations, were primarily devoted to shiitake. Private institutions such as The Mushroom Research Institute of Japan are almost entirely devoted to shiitake research. As a result, progress from the more primitive shiitake culture to the more controlled methods of cultivation today, had led to a rapid increase in shiitake production worldwide, especially since 1945 (Figure 1).

While many Japanese continue to grow mushrooms outdoors, some have adopted a greenhouse method in which fresh mushrooms can be produced during the winter. The greenhouse provides a more controlled environment, allowing growers to produce several crops per year.

In Taiwan, shiitake growing began in 1953, with major commercial-scale operations commencing only about 12

Continued page 2
Figure 1. World production of shiitake (fresh equivalent) since 1936.

--- | --- | --- | --- | --- | --- | --- | ---
Shiitake Production (x 1,000 tons) | 20 | 60 | 180 | 250 | 400 | 600 | 800

years ago. Shiitake production in Taiwan has increased rapidly, not only because of plastic-bag culture, but also because of an increase in knowledge of natural log cultivation. However, plastic-bag cultivation accounts for approximately 70% of the total shiitake production in Taiwan. Most production is carried out in straw-lined bamboo-framed buildings that have been built in the higher elevations of Taiwan. Cool conditions can thus be maintained, resulting in more favorable production conditions.

Contrary to reports by other authors, (Zadrzil and Grabbe, 1983) some growers in the USA and Canada are now producing shiitake mushrooms entirely on synthetic logs in a more controlled environment. Many of the buildings used are insulated and vapor-proofed, with air-conditioning equipment designed to provide controlled temperature, relative humidity and air exchange. Shiitake is growing on synthetic logs in the USA and Canada in nearly independent of outside climatic conditions, with modern structures and equipment providing conditions most favorable to the mushrooms during the various phases of the growing cycle.

Synthetic logs. The first report of obtaining mushrooms of L. edodes on an exotic substrate appeared in 1933. Passecker (1933) used blocks of beechwood contained in a glass cylinder that was sterilized, cooled and inoculated with shiitake mycelium. In one experiment he reported producing shiitake on artificial medium in total darkness, although it is now known that light is necessary for primordial formation.

A more recent report indicates that shiitake mushrooms may be obtained on a chemically defined medium (Leatham, 1983). Synthetic media have also been used to obtain mushrooms, (Mori et al., 1974; Han et al., 1981; Patrick, et al., 1983). The substrate usually consists of a mixture of woodchips and cereal bran. The method used to obtain mushrooms on synthetic substrates involve autoclaving the substrate in plastic bags, cooling, then inoculating with spawn. Alternatively, it has been demonstrated that the substrate may be sterilized in larger volumes (Royse, 1985). Mushroom production from pasteurized (heat-treated with aerated steam at 80°C for 30 minutes) substrate has been accomplished by the authors (unpublished), but yield is less than that produced with identical ingredients that have been sterilized. Viable bacteria cannot be isolated from pasteurized substrate, so they do not appear to be the limiting factor. Perhaps higher temperatures favorably alter the chemical nature of the wood. We have observed that wood treated at 95°C turns a darker color than wood treated at 80°C. Additional research is needed in this area.

Spawn run, the time required for the mycelium to colonize the substrate, may range from 12 days to 4 months. At the end of spawn run the plastic bag is cut away and the synthetic logs subjected to production conditions. The wood chips are held together by the fungal mycelium. In some cases portions of the bag may be totally removed and the log placed in a production room where either high humidity or misting by nozzles, or both, is provided. Mushrooms will usually begin to appear within 2 to 3 weeks after placement in the production room. By the time of fruiting the logs' surfaces usually begin to darken, but this may vary, depending on whether or not overhead misting is used.

The main advantages of synthetic log cultivation over the natural log method are time and efficiency. The cycle for synthetic log cultivation lasts approximately 6 months from time of inoculation to cleanout. Efficiencies for this method may average from 50% to 150%. In contrast, the natural log cultivation cycle usually lasts about 6 years with maximum efficiencies around 33%. The time required on synthetic substrate, therefore, is about 1/10 that of the natural system with up to 3 to 4 times the efficiency.

Variation in efficiency between synthetic logs. In early experiments with synthetic logs produced at the Pennsylvania State University Mushroom Research Center, it was observed that considerable variation in productivity occurred between logs. Additional experiments confirmed this observation. Data from six such experiments are presented in Table 2. Mean efficiencies for production were, in all cases but on Experiment 3 higher than 100% when logs were kept for 6 months. The efficiency range showed a considerable difference between the highest and lowest value recorded.

In addition, the coefficient of variation, a value used to compare variation between experiments, derived for each experiment is relatively high. While there is no previously published data on the variation of yield between synthetic logs within the same experiment, these results raise questions about why between-log variation exists (Royse, 1985). From a commercial standpoint a grower would certainly want to have a group of synthetic logs producing at the maximum efficiency. Perhaps differences in such factors as water content, substrate density, gas exchange rate, and so on could explain yield differences. Coefficients of variation closer to 5% would result in much more uniform production. Further research is required to elucidate factors contributing to this variation.

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Effect of spawn run time on yield. In experiments designed to determine the effect of spawn run time on the rate of mushroom production, Royse (1985) found that a spawn run of 116 days resulted in an increase in the production rate compared to a spawn run of 56 days. Larger mushrooms generally were produced by the longer spawn run. Practical applications of longer spawn runs should increase the efficiency during the production stage. For example, it would be less costly for mushroom growers to deploy substrate with longer spawn runs since they could expect up to twice the rate of production as compared to substrate with shorter spawn runs. Conditions required for spawn run are less stringent than conditions required for mushroom production. In addition, more growing cycles can be completed in growing rooms where more fully colonized substrate is deployed.

The reasons for increased yield from logs with longer spawn runs may include greater mycelial biomass, increased levels of enzymes present in the substrate, increased solubility of wood components, and combinations of these factors. The presence of lignin and tannins in lignocellulosic wastes has been suggested as the rate-limiting step in the utilization of the more valuable polymeric carbohydrates (Crawford, 1981; Kirk et al., 1977; Kirk and Highley, 1973). The importance of lignin as a barrier to microbial degradation of plant tissues is demonstrated by the observation that lignification is important as a component of disease resistance in plants (Vance et al., 1980).

White-rot fungi, like L. edodes, are capable of decomposing all the important structural components of wood, including both cellulose and lignin (Kalabata et al., 1974). Many white-rot fungi deplete the lignin and carbohydrate components of wood at about the same proportional rates (Crawford, 1981). Other white-rot fungi deplete much of the lignin in wood more rapidly than polysaccharides (Kirk and Moore, 1972; Kawase, 1962). Differences in proportional rates between strains of the same species have also been observed (Crawford, 1981). The proportionality of carbohydrate-lignin depletion for this line of L. edodes is not known, however.

It is important to note that the composition of the growth medium used greatly influences the results of investigations of wood-component degradation patterns (Crawford, 1981). Malt extract is generally stimulatory toward fungal lignin degradation as compared to other nitrogen sources (Ander and Eriksson, 1977). Some authors also found that culture parameters such as O2 concentration, presence or absence of a readily usable growth substrate other than lignin, the medium pH, and agitation had marked effects on lignin degradation rates of Phanerochaete chrysosporium (Kirk et al., 1978). Thus, it would be necessary to study lignin-carbohydrate degradation using the substrate formulations and growing methods in this study before any meaningful conclusions could be reached in regard to mushroom yield and wood solubility.

Additional research is urgently needed to determine other factors influencing yield and size of the shiitake mushroom. Hybrid development and selection, as outlined by Royse et al. (1983a, b), may result in decreased time requirements for spawn run. Development of physiologically more efficient high yielding white-rot fungi to reduce the cost of spawn production but may greatly reduce the time required to complete a growing cycle.

Pests The occurrence of "weed fungi" is a troublesome problem in the cultivation of shiitake on natural logs. Most of these fungi are wood decayers and, in many environments, are more competitive than shiitake mycelium. Many Japanese growers have experienced severe or complete loss of bed logs due to these competitors. Species reported to cause serious losses to shiitake growers in Japan include Trichoderma spp.,

### Table 2

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<th>Experiment</th>
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<td>83c</td>
<td>46 - 110</td>
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a Ratio of fresh mushrooms harvested (g) to dry substrate weight (g) expressed as a percentage.
b Sample standard deviation expressed as a percentage of the sample mean.
c Harvest period of 4 months. Mushrooms were harvested from logs in other experiments for 6 months.

Hypothenium suaveolens, Fuscocitrum quercinum, Trametes sanguinea, Stereum hirsutum, and many other wood-inhabiting fungi (Ino, 1979) and insect pests are not a significant problem with natural log cultivation as they are fungal competitors.

On synthetic logs the major weed molds thus far encountered are Trichoderma spp. These fungi not only can cause problems if inadvertently introduced during inoculation of the prepared substrate but also can grow on noncolonized wood chips of synthetic logs. If below optimum water content of logs is maintained, Trichoderma spp. may tend to colonize undersides of synthetic logs. This is especially likely if an overhead sprinkling system is used to maintain optimum log water content.

Synthetic logs that are deployed before colonization of the substrate is complete may be colonized by Trichoderma spp., resulting in a water-soaked area of the logs. The water-soaked area then becomes the preferred site for oviposition of scarid and moth flies (Rosse et al., 1985). The larvae of these species can then develop into adults, completing the life cycle. The scarid is also a major pest of the common cultivated mushroom in many areas of the world.

Control of both green mold and mushroom-infesting flies is probably best effected by deployment of only completely colonized substrate. Complete colonization of the logs by shiitake mycelium tends to exclude pests that may become a serious problem. Additionally, logs that are nearly nutritionally exhausted are a prime source for invasion by insect pests. Prompt removal and disposal of these wasted logs also helps to prevent buildup of weed mold and insect populations.

Outlook. Consumption and production of shiitake, especially in the more industrialized countries, is expected to continue at a rapid rate over the next 8 to 10 years. The USA should see annual production increases of 15-20% or more. Consumers in western countries should soon see shiitake in grocery stores at a cost to rival the common cultivated mushroom.

Literature Cited
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<td>97330</td>
<td>(503) 753-8198</td>
</tr>
<tr>
<td>Sohn's Oak Mycological Mushrooms</td>
<td>P.O. Box 20</td>
<td>Westfield</td>
<td>WI</td>
<td>53964</td>
<td>(608) 296-2456</td>
</tr>
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Route 2, Box 156A
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