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Woodland specialty mushrooms: Who grows them and what are the problems?

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ABSTRACT: Values derived from woodland management can be enhanced by capitalizing on natural associations of specialty fungi with trees. Mushroom production can be integrated with most management objectives, and provides profitable avenues for recycling low-value forestry by-products. About 65% of the central USA woodland mushroom growers sampled have other primary sources of income, but nearly all consider mushroom growing a part of their career. Nearly all grow *Lentinula edodes;* about 35% grow *Pleurotus* species. Approximately 90% grow mushrooms outdoors, but half of these also have supplemental indoor operations; 85% would like to expand their business, and over half would like to grow additional species. Growers face both business and technical biological difficulties. Biological challenges involve effective integration of mushroom cultivation into forest management by matching growers' situations with appropriate fungi and cultivation systems, developing techniques which improve biological efficiency, and increasing the variety of options available to growers.

1 INTRODUCTION

A research and demonstration project has been initiated at the University of Missouri Center for Agroforestry (UMCA) to refine and develop technology for woodland-oriented cultivation of specialty mushroom fungi. Specifically, there is growing interest in the establishment of riparian forest buffers for the purposes of simultaneously stabilizing watersheds and protecting water quality in predominantly agricultural areas, while increasing landscape biodiversity. Farmers are unlikely to adopt agroforestry on valuable agricultural land, unless they are presented with agroforestry systems which generate personally appealing financial and/or aesthetic values. One approach to elevating, accelerating and diversifying the suite of values derived from agroforestry systems is to capitalize on the natural associations of specialty (gourmet and medicinal) mushrooms with trees. Mushroom cultivation is a natural extension of agroforestry, enhancing the overall efficiency and human interest levels of agroforestry efforts. We see these technologies as potent inducements encouraging more widespread adoption of agroforestry as a land management tool. Cultivation of several valuable mushroom species is ideally suited to rural watersheds and flood-plains, because the cultivation technologies involved either depend on periodic availability of water for irrigation or can take advantage of moist sites.

Specialty mushroom cultivation methods developed in the framework of less intensive, traditional woodland management will have broad application in more intensive agroforestry systems. Development of agroforestry systems should benefit from a clear understanding of the business and biological constraints encountered by growers operating in traditional woodland settings. We report here the results of a survey of 20 specialty mushroom growers in the central USA, to better understand their motivations to grow specialty fungi. The surveyed growers are all customers of Field & Forest Products, Inc., Peshtigo, Wisconsin USA, have all been in business at least 6 years, and all spend at least $500 annually on sawdust-based spawn.

The basic focus of our attention here on woodland-oriented cultivation influences our perspective on the state of technical knowledge for specialty fungus cultivation. Our concept of woodland-oriented cultivation includes systems with indoor components which are nonetheless part of the grower's woodland management plan. Knowledge derived from indoor cultivation systems is relevant to the extent that it helps us develop a better understanding of woodland-oriented systems. Relatively successful technologies already exist for the woodland cultivation of shiitake *(Lentinula edodes).* Woodland cultivation options for reishi *(Ganoderma lucidum),* maitake *(Grifola frondosd),* tooth mushrooms *(Hericium* species), blewit *(Lepista nudd),* oyster mushrooms *(Pleurotus* species), and wine-cap Stropharia *(Stropharia rugoso-annulata)* are less clearly resolved. Technologies for reliable woodland introduction or cultivation of the morels *(Morchella* species) are even more sketchy. We will focus attention here on the most glaring gaps we notice in our technologies for the woodland-oriented cultivation of these fungi.

2 WOODLAND SPECIALTY MUSHROOM GROWERS

Although only 35% of the 20 growers surveyed derive their primary income from mushroom cultivation, 75% derive their primary income from agriculture-related careers, and 90% consider mushroom cultivation to be an element of their careers. Nine growers (45%) have completely outdoor operations, 45% have both outdoor and indoor operations, and 10% have only indoor operations. The 2 indoor growers produce only *L. edodes,* and both of them use solid wood substrate. Although all 20 growers own the property on which they grow mushrooms, the amount of land owned varies greatly (mean + standard deviation, 40 + 53 ha, ranging from a city lot to 202 ha). Only three growers (15%) live more than 0.5 km (8, 19, and 241 km) from their cultivation site. Seventeen growers (85%) owned woodland (30 + 44 ha, ranging from 0 to 162 ha). Seven growers (35%) meet all or most of their substrate requirements with wood harvested from their own property, 10% grow some of their own substrate material, and 55% depend entirely on outside sources for substrate. Outside sources include arrangements with loggers, firewood cutters, or private landowners for harvested tree tops, small diameter stems from timber stand improvement operations, and land clearing for agriculture. Two of the 7 growers producing *Pleurotus* use straw obtained from local farmers; the rest use solid wood substrate.

The 13 growers (65%) who owned more than 1.0 ha of woodland indicated the following woodland management objectives: wood products (46%), wildlife (38%), recreation (38%), ginseng cultivation (8%), and agroforestry (8%). Eleven of these growers (85%) indicated that mushroom cultivation is an important land management priority.

Nineteen of these producers (95%) grow *L. edodes* (1486 ± 1298 kg per year, ranging 159 to 4540 kg per year), 35% grow *Pleurotus* species (592 ± 955 kg per year, ranging 2 to 2724 kg per year), and 5% grow *Hericium erinaceus* (23 kg per year). Most growers (80%) were satisfied with their markets' abilities to absorb their production volume. Fewer growers (60%) were satisfied with market prices, but we have noticed that woodland-oriented growers can command a higher price for their product than many larger wholesalers, based on smaller production volumes, higher percentage of retail sales, quality due to freshness, and personal service. Just over half of these growers (60%) have produced dried or value-added products: dried (6 growers) or powdered (5) or frozen (1) mushrooms, packaged soup mixes or other convenience meals (5), mushroom sauce (1), and/or pre-inoculated substrate kits (1). Types of markets supplied by these growers include restaurants (65%), farmers' markets (15%), mail order (5%), and other private sales (30%); supermarkets (25%), health food stores (15%), food service companies (15%), food cooperatives (5%), and other wholesale outlets (20%). Twelve growers (60%) expressed definite interest in growing additional species, mentioning *G. frondosa* (6 growers), *Hericium* species (3), *G. lucidum* (2), *Morchella* species (2), other *Pleurotus* species (1), *S. rugoso-annulata^),* *Tuber* species (1), and/or *L. edodes* (1).

Seventeen growers (85%) indicated they would like to expand their business; objectives included additional mushroom species, year-round production, value-added products, and/or larger facilities. These growers mentioned the following obstacles: financial considerations (35%), marketing and distribution of fresh products (29%), labor supplies (18%), time (18%), substrate shortages (6%), space limitations (6%), and restrictive food handling codes (6%).

3 TECHNOLOGY GAPS

We have classified the gaps in our technical knowledge into the following major categories: genetic diversity in specialty fungi, cultivation systems, and novel products and uses.

3.1 *Genetic diversity in specialty fungi*

The genetic diversity among species and strains of a commercial mushroom type represents the genetic universe within which the tools of genetic manipulation can be applied to select or develop desirable strains. Strains may be selected or developed which extend the ranges of productive substrates, environments, and cultivation methods (e.g. Chang et al. 1993). Greater genetic diversity also suggests greater available variance in mushroom yield characteristics, such as mushroom size, color, shape, flavor, texture, spore production, season of fruiting and biological efficiency (BE).

A modest variety of strains of *G. lucidum, H. erinaceus, L. edodes* and *Pleurotus* species are commercially widely available which yield valuable products for which markets already exist. The availability of isolates and woodland-oriented cultivation techniques for *G. frondosa,* other *Hericium* species, *L. nuda*, *Morchella* species, and *S. rugoso-annulata* (to mention a few) are still in a relatively primitive state, helping to explain why the markets for these fungi are underdeveloped even though their qualities are widely recognized. Cultivation efforts with all the above species will benefit greatly from further exploration of their genetic diversity for strain selection and development (e.g. Guinberteau et al. 1995, Bonenfant-Magne et al. 1997). For example, the magnitude of genetic variation between populations of a *Morchella* species may exceed that between putative *Morchella* species (Bunyard et al. 1994). Also, the number of *Pleurotus* biological species native to North America has recently been shown to be far greater than previously thought (Vilgalys et al. 1996).

Although most of the species under study at UMCA are indigenous to Missouri, Missouri populations of these fungi have not previously been studied. We are currently collecting promising Missouri genotypes of these species for comparison with commercially available strains. Vegetative strains obtained from local wild fruitings have at least demonstrated tolerance of the existing environment and offered useful clues to their substrate and fruiting requirements as well as their fruiting characteristics and qualities.

Relationships are being developed which may link key metabolic characteristics of mushroom strains to their relative growth rates, fruiting potential, and perhaps ultimately their BE. *Pleurotus* strain productivity has been correlated with laboratory growth rate in the presence of the secondary metabolite 2-deoxy-D-glucose (Sanchez & Viniegra-Gonzalez 1996). Histological stains have been used to visualize developing mushroom primordia (Sanchez & Moore 1999). Attention has also been drawn to possible links between production of lignin-degrading enzymes and vegetative growth and fruiting by *Pleurotus* species (Eichlerova-Volakova & Homolka 1997) and *L. edodes* (Leatham & Stahmann 1981). Techniques like these may prove useful for screening candidate strains and for evaluating fruiting potential under various environmental conditions.

3.2 *Cultivation systems*

Though all the mushroom-producing species considered here originated in the natural forest setting, their relative adaptability to various substrate species and forms (e.g. stumps, logs, wood particles, leaf litter), their preferences with respect to the microbiological condition of their substrates, and basically the nutritional and environmental constraints upon their growth and fruiting are still not very clear.

3.2.1 *Substrate species*

The North American host tree species preferences of many strains of these fungi are not clearly known from the perspectives of vegetative growth rate and fruiting. This is not surprising for those fungi which are not native to North America, such as certain *G. lucidum* strains (e.g. Okamoto & Mizuno 1997), *L. edodes,* and some *Pleurotus* species (e.g. Date 1997). *Ganoderma* *lucidum, G. frondosa, Hericium* species, *L. nuda, Pleurotus* species, and *S. rugoso-annulata* are also capable of utilizing a variety of hardwood species as substrate. Different species and strains of these fungi certainly must grow and/or fruit differently in association with different substrate/host species, and knowledge of these relationships could guide agroforesters in species and strain selection. For example, comparison of *L. nuda* and *S. rugoso-annulata* productivity on *Quercus, Acer,* and cereal straw substrates would be useful.

3.2.2 *Substrate/host form and condition*

The suite of fungi cultivated in each agroforestry situation should be based on knowledge of strain productivity on the available substrate form(s) as well as host species. Fungus strains (e.g. strains of G. *lucidum, G. frondosa, L. edodes,* and *Pleurotus* species) may rank differently in productivity on different substrate forms (e.g. stumps, logs, wood particles). Different substrate forms present fungi with different moisture and aeration regimes, and offer different opportunities for supplementation (e.g. Royse 1996). While bagged wood chip or sawdust substrates are usually used for indoor culture, at least G. *lucidum* (Cha & Yoo 1997) and *G. frondosa* (Mayuzumi & Mizuno 1997) also fruit easily outdoors from such artificial log substrates. While the relative productivity of *L. edodes* on many tree species has been fairly well established, little is known about *L. edodes* production possibilities on outdoor beds of different species of wood chips, an intriguing method practiced in the Peoples Republic of China.

It has been suggested that logs cut from living trees for cultivation of G. *lucidum* (Mayuzumi et al. 1997) or *L. edodes* (Ikegaya 1997, Kurtzman 1997) should be aged for at least one month after tree felling before inoculation. The rationale for this method is that spawn run should be faster in logs which have been allowed time for ray tissues to die. However, as these tissues die, they must also become increasingly accessible to weed fungi, depending on the conditions and duration of storage (e.g. Abe 1989). To the extent that the aging of logs may compromise their quality, it seems important to determine the extent to which the substrate quality of different tree species improves on aging with respect to the fungi to be cultivated on them.

Gramss (1978) observed a roughly inverse relationship between the pathogenicity of wood-destroying basidiomycetous fungi and their competitive ability against mixed microbial substrate contaminants. He classified G. *frondosa* as principally a pathogen, *P. ostreatus* as a saprophyte with some pathogenic tendency, *L. edodes* as a pure saprophyte, and *S. rugoso-annulata* as a saprophyte of fresh and degraded wood and straw. Following this system, we might presume to classify *G. lucidum* as relatively similar to G. *frondosa, Hericium* species as relatively similar to *Pleurotus* species, and *L. nuda* as most similar to *S. rugoso-annulata.* Gramss (1978) was only able to successfully inoculate freshly-felled stem sections of *Fagus sylvatica* with *G. frondosa* after they were autoclaved or gas-sterilized, raising questions about the prospects for cultivating G. *frondosa* or G. *lucidum* on fresh hardwood stumps. Outdoor cultivation of G. *frondosa* in Japan commonly employs sterilized blocks of sawdust amended with corn and wheat brans (Mayuzumi & Mizuno 1997). Even *Pleurotus ostreatus* can require three growing seasons to fruit following stump inoculation. The difficulty with which wood decay fungi colonize fresh stumps may depend on the extent to which the stumps are root grafted to surrounding live trees; stump root systems kept alive by root grafts can be expected to maintain some resistance to spawn run in the inoculated stump. Stump inoculation techniques may be more effective in stands of mixed tree species composition, where root grafting would be less extensive. On the other hand, partially buried or soil-surface incubation of log or wood chip substrates can improve productivity of *Pleurotus* species by maintaining substrate moisture content and favoring stimulatory microbial community development (Omori 1974). *Lepista* species seem to be more or less dependent on microbial associates as sources of nutritional factors or to produce a conducive environment for fruiting (e.g. Stott et al. 1996).

The effects of seasonal timing of substrate tree harvest on mushroom productivity need to be evaluated. It is widely thought that substrate trees need to be felled during the dormant season, primarily because sapwood at that time of year contains its annual maximum level of stored carbohydrates to fuel spawn run and fruiting. The extent of any loss in productivity associated with summer through autumn procurement of substrate wood needs to be determined for various tree species and fungi, because wind storms, land-clearing, etc., outside the dormant season produce large supplies of potential substrate of unknown value.

3.2.3 *Control of vegetative growth and fruiting*

Harvesting is most efficient when flushes of mushrooms can be anticipated, or even induced. The BE may be improved if flushes can be induced early, thus utilizing the substrate while it is in best condition and reducing energy loss to competing microbes. Water management techniques are useful in controlling flushes of some *L. edodes* strains. Tokimoto et al. (1998) have demonstrated that the extent of fruiting by *L. edodes* from bedlogs of *Quercus serrata* is determined by the balance achieved between free water content and air volume during soaking, and that the desirable free water content increases greatly as bedlog decay progresses. This relationship needs to be further characterized for various bedlog species and *L. edodes* strains. It may also be possible to identify differences among strains of other fungi in seasonal propensity for fruiting or amenability to controlled flushing (e.g. *Pleurotus* species, *S. rugoso-annulata)* which could then be used to level out mushroom production over time.

Row covers appear to be useful in maintaining favorable environmental conditions at critical stages in production cycles. In a preliminary trial, Kozak (1997) found that placing black geotextile "fruiting blankets" over soaked logs resulted in a more stable environment and earlier, more uniform flushes of *L. edodes* than were achieved with no cover; other covers provided intermediate results. Fruiting blankets also seem to provide conditions for faster more uniform spawn run by both *L. edodes* and *Pleurotus* species, and might also be used to protect logs from seasonal desiccation due to drought, heat or wind. To our knowledge, these ideas have not been adequately tested.

The duration of spawn run and, at least in the case of forced flushes of *L. edodes,* the interval between crop flushes, influences overall BE, but additional studies are needed in woodland settings. Working with three *L. edodes* strains, two artificial substrate formulations and three spawn run times (60-120 days), Royse & Bahler (1986) found a significant genotype x substrate x spawn run time interaction for BE, with the longer spawn runs most productive. In contrast, Kalberer (1998) obtained greater *L. edodes* productivity on artificial substrate with spawn runs of 30-35 days than 40-47 days. Working with logs outdoors, three spawn run times (6-12 months), and five fruiting intervals (6-18 weeks), Sabota (1997) reported a significant *L. edodes* spawn run time x fruiting interval interaction. The BE was highest and mushroom size was largest with a 12 month spawn run and 9 week fruiting intervals.

3.2.4 *Soil factors*

Some woodland fungi (e.g. *G. frondosa, G. lucidum, L. nuda,* and *S. rugoso-annulata)* may fruit most abundantly when the colonized substrate is cased, and effective casing materials for these fungi probably differ physically, chemically, and/or microbially (e.g. Szudyga 1978, Upadhyay & Sohi 1989, Guinberteau et al. 1995, Sharma et al. 1996, Mayuzumi & Mizuno 1997). The responses of these fungi to casing techniques needs to be clarified.

While we are not aware of any reproducible system for outdoor commercial culture or even establishment of morels, knowledge of *Morchella* species field biology is developing rapidly (e.g. Wipf et al. 1997, Harbin & Volk 1999). Factors favoring efforts to cultivate *Morchella* species outdoors include abundant local genotypes from which to select effective strains, the ability to produce sclerotia (e.g., Volk & Leonard 1990), and the ability to sample sclerotia in the field (Miller et al.1994). *Morchella* sclerotia can be used to establish statistically rigorous field studies. Challenges include development of appropriate field inoculation techniques, identification of appropriate soil conditions and substrata for mycelial growth, sclerotium development, and fruiting, and development of techniques for providing these appropriate conditions perennially. Dependence of morel fruiting on availability of decaying organic matter (e.g. dead root material) can be inferred from the association of fruiting with abandoned fruit orchards, dead elm trees, fires, etc.

It has been reported (Garbaye et al. 1978) that forest fertilization with mineral fertilizer induced abundant fruiting of valuable mushroom species which normally would not be found on the sites involved (including *L. nuda).* It is intriguing to speculate whether fertilization provided conditions for these species to fruit on a site they already occupied, or provided conditions which permitted these fungi to invade and flourish vegetatively at the involved sites as well.

3.2.5 *Integrated pest management*

Ganoderma lucidum merits attention as a tree root disease pathogen, capable of killing a wide range of hardwood trees species (Sinclair et al. 1987). Although the distribution patterns of this fungus in forests does not suggest tree-to-tree spread across root grafts or contacts, spread may be accomplished through basidiospore colonization of wounds. In this regard, the prospects for root disease leading to tree decline associated with tree root damage caused by farming equipment in alley cropping systems and *grazing* animals in silvopastoral systems merit study.

3.3 *Novel products and uses*

The tools for selection and breeding will provide useful new commercial strains of established mushroom species. For example, sporeless strains may be bred which circumvent concerns over allergic reactions to spore contact, especially among mushroom industry workers (Leal-Lara 1978, Imbernon & Laberere 1989).

We anticipate favorable public response as more complete and objective information becomes available regarding the nutritional (e.g. Manzi et al. 1999) and medicinal properties (e.g. Wasser & Weis 1999) of specialty fungi. The effects of handling and storage procedures on mushroom quality also need to be better understood (e.g. Minato et al. 1999), in order to best protect mushroom quality for the consumer.

As public appreciation for aesthetically pleasing mushroom forms broadens, commercial possibilities should not be underestimated for incorporating cultivated mushrooms into floral arrangements, using *G. lucidum, L. edodes, Pleurotus* species, and *Trametes versicolor,* among others (Poppe & Huengens 1991, Chen & Miles 1996).

SUMMARY AND CONCLUSIONS

Woodland cultivation of specialty mushrooms is a complex enterprise, in part because every grower's situation is different, and also because of the spatial and temporal environmental variability encountered outdoors. Most current research is dedicated to indoor cultivation systems, largely because indoor systems are more lucrative and can be studied more efficiently. Nevertheless, woodland cultivation of specialty mushrooms is a rewarding career element for individuals who enjoy working outdoors in an agricultural forestry setting. Woodland mushroom cultivation is an especially attractive land management option where low-value forestry by-products abound, and can significantly enhance the financial outlook for agroforestry activities.

Several successful woodland-oriented types of cultivation system are being utilized in the Central USA, especially for *L. edodes.* Growers have focused on *L. edodes,* and to a lesser extent on *Pleurotus* species, because those are the specialty mushrooms with which the public is most familiar and for which reliable cultivation systems exist. Many growers who have successfully marketed their products are interested in expanding their operations, in *L. edodes* and/or by adding new mushroom species. As the healthful and culinary values of additional specialty mushrooms become appreciated, markets for them will become easier to establish and interest in cultivating them will increase. Research is needed which will refine the existing cultivation models, and also develop a broader array of additional woodland-oriented cultivation systems for *G. lucidum, G. frondosa, Hericium* species, *L. nuda, Morchella* species, *Pleurotus* species, *S. rugoso-annulata,* and others.

We have drawn attention to some of the more significant information needs for broader and more efficient woodland-oriented cultivation of specialty fungi. First, it seems striking that commercial woodland production is based on such a small collection of strains from the gene pool of each specialty mushroom. It seems clear that additional valuable strains can be selected from nature to fill a variety of cultivation needs and opportunities. Second, there are abundant opportunities to refine the cultivation system models for even the best understood specialty mushrooms. Development of markets for additional species will depend both on heightening public appreciation and demand and on establishing reliable cultivation methodologies. Incorporation of indoor elements into woodland-oriented cultivation operations can facilitate 1) winter fruiting for year-round production, as well as 2) preparation of artificial or natural substrate logs for fruiting outdoors. Third, novel products, forms, and uses will improve demand for specialty mushrooms.

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