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A Literature Review of "Spent" Mushroom Substrate Uses Around the World

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INTRODUCTION

Many species of mushrooms are cultivated worldwide. Global production increased to about 6.2 million tons in 1997, with a more than 12 percent increase annually from 1981 to 1997 (Chang, 1999). Seventy percent of the global mushroom production is derived from three mushroom groups, *Agaricus bisporus, Pleurotus* spp., and *Lentinula edodes.* The remaining mushroom volume is generated by at least a dozen species (Chang, 1999).

In the production of any and all species, significant residual material remains after cultivation. Every ton of mushrooms produced results in one to two tons of dry spent residual material. The important question in this day of limited natural resources and concerns over human health and the environment is, "What use or value does this residual material from mushroom production have?"

The materials and techniques used to produce the vast volumes of "spent" (used) mushroom substrate in the production of these principal mushroom species are outlined.

A BRIEF DESCRIPTION OF THE PRINCIPAL CULTIVATED MUSHROOM SPECIES

Agaricus bisporus

The commercial mushroom, *Agaricus bisporus*, represented about 32 percent of the world mushroom production in 1997 (Chang, 1999). This species is cultivated typically on a straw or hay base, amended with animal manures and gypsum. The materials initially undergo a two-phase composting process, one at high temperature (up to 85°C) and another for pasteurization and conditioning (beginning at 60°C and decreasing to about 45°C). The colonization stage by this mushroom fungus is followed by covering the surface of the colonized compost with a layer of peat, top soil or other suitable material. Within two weeks mushrooms are visibly ready for harvest. After about three weeks of mushroom harvest, the growing material is

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considered spent. After usually undergoing a post-crop heat treatment, the growing material is removed and the chamber is ready for a new crop.

Pleurotus spp.

The oyster mushroom consists of a number of several edible *Pleurotus* species. This species represented 14 percent of the world production in 1997 (Chang, 1999). *Pleurotus* can be cultivated on wood sawdust, on various plant fibers or plant residues, which are amended with locally available proteins and carbohydrates to optimize its growth requirements. The materials are generally not composted before inoculation. The wood sawdust may be aged or the plant fibres hydrated for several days. The growing materials are treated with either heat or chemicals to augment the selectivity of these materials for the oyster mushroom fungus. After colonization is complete, the colonized substrate is subjected to conditions suitable to initiation and maturation of fruiting bodies. At the end of several mushroom harvests, the growing material is considered spent. It may be heat treated before being removed from the growing chamber.

Lentinula edodes

Shiitake mushrooms, *Lentinula edodes*, represented 25 percent of the 1997 world mushroom production (Chang, 1999). This species is either cultivated on natural logs or on "synthetic" logs. Natural log production uses various species of trees, especially oak. Trees are cut down after leaf fall and the wood is cut in lengths of about one meter. Within one month these logs may be inoculated with the shiitake fungus. After up to one year of incubation, the colonized logs are brought under conditions that initiate fructification. Mushrooms are harvested about twice per year for several years. Once production ceases, these logs are considered spent. Synthetic logs for production of shiitake mushrooms are formed from sawdust, straw, corn cobs or mixtures thereof. Starch-based additives from cereals are often added to optimize the nutritional needs of the fungus. The growing materials are generally sterilized. After colonization is completed, conditions are changed to initiate the formation of mushrooms. After several harvests, these synthetic logs are considered spent.

In the next section, characteristics of SMS are discussed and uses for it are detailed: bioremediation, crop production, re-use in the cultivation of mushrooms, food for animals and fish and

pest management. Each of these uses is noted in association with one of the particular mushroom species noted above. The environmental impact of weathering spent compost is also discussed.

CHARACTERISTICS OF SPENT MUSHROOM SUBSTRATE (SMS)

Agaricus bisporus spent substrate: Microbiology of composted (Raymond *et al.*, 1997) or steamed material (Kleyn and Wetzler, 1981); Physical and/or chemical characteristics of fresh and/or weathered material (Beyer, 2001; Gerrits, 1997a; Iiyama *et al.*, 1995; Lemnaire *et al.*, 1985; Levanon and Danai, 1995; Lohr *et al.*, 1984b; Maher *et al.*, 2000; Szmidt and Chong, 1995).

BIOREMEDIATION

Purification of air

Agaricus bisporus spent substrate: As a mix with other materials for removal of H_2S (Shojaosadati and Siamak, 1999) or volatile organic compounds (Mohseni *et al.*, 1998; Mohseni and Allen, 1999).

Purification of water

Agaricus bisporus spent substrate: Treatment of metal-contaminated water from coal mines (Anon, 1997; Dvorak *et al.*, 1992; Stark *et al.*, 1994); Treatment of acid mine drainage (Chang *et al.*, 2000) in wetland environments (Karathanasis and Thompson, 1990; Manyin *et al*, 1997; Stark and Williams, 1994; Stark *et al.*, 1995; Stark *et al.*, 1996; Tarutis and Unz, 1995; Vile and Wieder, 1993; Wieder, 1993); Treatment of nickel-contaminated mine water (Hammack and Edenborn, 1992); Biological treatment of sewage (International Organic Solutions Corp., 1996); Treatment of waters polluted with radioactive elements and heavy metals (Groudev *et al.*, 1999).

Agaricus waste mushroom/tissue: Production of phenoloxidases (Steffen *et al.*, 1995).

Pleurotus spp spent substrate: Reduction of phenol content and toxicity in olive mill waste (Martirani *et al.*, 1996).

Lentinula edodes spent substrate: Treatment of acid mine drainage (Chang *et al.*, 2000); Treatment of effluents from olive mill (D'Annibale *et al.*, 1998).

Purification of soil

Agaricus bisporus spent substrate: Effect on zinc distribution (Shuman, 1999a, 1999b), cadmium and lead (Shuman, 1998) among soil fractions; Amelioration of zinc toxicity (Shuman and Li, 1997); Degradation of chlorophenols, polycyclic aromatic hydrocarbons or aromatic monomers (Semple *et al.*, 1995; Semple *et al.*, 1998; Fermor *et al*, 2000; Staments, 2001;); Inhibition of

nitrification (Bazin *et al.*, 1991); Treatment of hazardous wastes (Buswell, 1994); Stabilization of disturbed and commercial sites (Rupert, 1995).

Pleurotus spp spent substrate: Blend of fish oil and spent substrate for degradation of polycyclic aromatic hydrocarbons in age-creosote contaminated soil (Eggen, 1999); Removal/degradation of pentachlorophenol (PCP) (Chiu *et al.*, 1998).

Lentinula edodes spent substrate: Removal/degradation of pentachlorophenol (PCP) (Chiu *et al.*, 1998).

Purification of substrates contaminated with pesticides

Agaricus bisporus spent substrate: Degradation of carbaryl, 1-naphthol (Kuo and Regan, 1992, 1999) and carbamate (Kuo and Regan, 1998; Regan, 1994); Sorption and movement of atrazine and 2,4-D by soils (Baskaran *et al.*, 1996).

CROP PRODUCTION

Greenhouse crops - flowers

Agaricus bisporus spent substrate: Production of Chrysanthemum (Rathier, 1982) and Easter lilies (Dallon, 1987; White, 1976 a,d), *Helleborus* (Richter *et al.*, 1980); petunias (White, 1976c) and poinsettia (White, 1976b); Problems in use (Anon., 1985).

Greenhouse crops - vegetables

Agaricus bisporus spent substrate: Production of vegetable transplants (Lohr, 1983; Lohr *et al.*, 1984a; Lohr and Coffey, 1987; Wang *et al.*, 1984a), cucumbers (Celikel and Buyukalaca, 1999c), tomatoes (Celikel and Tuncay, 1999a; Rathier, 1982; Steffen *et al.*, 1994, 1995;Vavrina *et al.*, 1996) and eggplant (Celikel and Tuncay, 1999b); Impact on post-harvest quality (Dundar *et al.*, 1995); General evaluation (Verdonck, 1984).

Field crops - vegetables

Agaricus bisporus spent substrate: Production of asparagus, beet root, cauliflower, cabbage, capsicums, celery, cucumber, lettuce, mustard, onion, potato, radish, snap bean, spinach, sugar beet, tomato (Abak and Gul, 1994; Anon., 1979; Faassen *et al.*, 1992; Kaddous and Morgans, 1986; Maher, 1994; Maher *et al.*, 2000; Male, 1981; Massi, A., Argentina, pers. com.; Maynard, 1989; Maynard, 1991; Maynard, 1994b; Nguyen *et al.*, 1987; Pill *et al.*, 1993; Ranganathan and Selvaseelan, 1997a; Rhoads and Olson, 1995; Selvi and Selvaseelan, 1999; Sochtig and Grabbe, 1995; Stephens *et al.*, 1989; Stewart, *et al.*, 1998b, 1998c; Schwank, 1985; Wang, 1983; Wang *et al.*, 1984)

Pleurotus spp spent substrate: Interplanting with cabbage

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and eggplant (Abdallah, 2000); Wood shaving substrate for cultivation of lettuce (Batista *et al.*, 2000); Cucumber production (Nguyen *et al.*, 1987).

Lentinula edodes spent substrate: Production of tomatoes (Lin and Chuen, 1993).

Other species spent substrate: Production of cabbage (Lin, 1993).

Field crops - fruit

Agaricus bisporus spent substrate: Mulching applied to "Italian" prunes (Robbins *et al.*, 1986), apples (AntSaoir *et al.*, 2000; Delver, 1982; Delver and Wertheim, 1988), apple seedlings Koch, 1980), grapes (Beyer, D.; Pennsylvania, pers. com.); peaches (M. Derkacz, pers. com.); Organic alternative to methyl bromide in strawberries (Sances and Ingham, 1997).

Field crops - other

Agaricus bisporus spent substrate: As a soil amendment for tea (Manivel *et al.*, 1994); Effect on green gram (Ranganathan and Selvaseelan, 1994); As soil amendment for field corn (Weber *et al.*, 1997; Wuest and Fahy, 1991; Wuest *et al.*, 1991; Wuest *et al.*, 1995); Effect on perennial rye grass, wheat (Maher, 1994; Maher *et al.*, 2000).

General soil amendment

Agaricus bisporus spent substrate: Effect on soil physical and physico-chemical properties (Ranganathan and Selvaseelan, 1997b); As organic fertilizer (Cameron, K; New Zealand, pers. com.); Gerrits, 1987b; Levanon and Danai, 1997; Maher, 1990; Maher *et al.*, 2000; Pryce, 1991; Ranganathan and Selvaseelan, 1997c; Robinson, 1988; van Keulen, H., Netherlands, pers. com.).

Agaricus blazei spent substrate: As organic fertilizer (Dias, E.S.; Brasil, pers. com.).

Pleurotus spent substrate: Cotton seed substrate pelletized for organic fertilizer or mixed with *Agaricus* spent substrate for organic fertilizer (Keil, C., Pennsylvania, pers. com.); Sawdust substrate as organic fertilizer (Anderson, D., Ontario, pers. com.).

Lentinula edodes spent substrate: Pelletized for organic fertilizer or mixed with *Agaricus* spent substrate for organic fertilizer (Keil, C., Pennsylvania, pers. com.).

Nursery and landscape

Agaricus bisporus spent substrate: Production of foliage crops as potting mix (Beyer, D; Pennsylvania, pers. com.); Chong *et al.*, 1987; Chong and Wickware, 1989; Chong *et al.*, 1990, 1991 a,b,c,d,e; Chong and Hamersma, 1996 a, b; Chong and Rinker,

1994 a,b; Chong, 1991, 1999; Devonald, 1987; Eames, 1977; Henny, 1980; Poole and Conorer, 1974; Raymond *et al.*, 1998; Smith, 1982; van Keulen, H., Netherlands, pers. com.); Production of foliage crops in the field (Maynard, 1994c); Improving turf (Landschoot and McNitt, 1994).

Pleurotus spp spent substrate: Production of nursery crops (Quimio *et al.*, 1990).

RE-USE IN THE CULTIVATION OF MUSHROOMS

Casing material for Agaricus bisporus

Agaricus bisporus spent substrate: Comparisons with peats and/or other local materials (Eicker and van Greuning, 1989; Garcha and Sekhon, 1981; Happ II, 1974; Nair, 1976 a&b; Nair and Bradley, 1981; Seaby, 1999; Shandilya, 1989 a, b; Singh *et al.*, 1992, 2000; Stoller, 1979); Leaching experiments (Riahi *et al.*, 1998;) or treatment with chelating agents (Sharma *et al.*, 1999); Recomposting and leaching (Szmidt, 1994; Szmidt *et al.*, 1995); Handling and use (Kinrus, 1976; Schisler and Wuest, 1982; Wuest, 1976); Separation and reuse of casing from spawn-run compost (Hesling, 1981; Jablonsky and Srb, 1989; Nair and Bradley, 1981; Nair, 1985).

Pleurotus spent substrate: Composted sawdust media as casing (Kim, *et al.*, 1998).

Casing material for Agaricus bitorquis

Agaricus bisporus spent substrate: Comparisons with local materials (Guleria *et al.*, 1989).

Cultivation of other species

Agaricus bisporus spent substrate: Cultivation of 11 species (Flick, 1981); Cultivation of *Agaricus bisporus* (Rinker and Alm, 1990; Schisler, 1988; Till, 1963), *Auricularia* (Sharma and Jandaik, 1994), *Lentinula* (Kilpatrick *et al.*, 2000), *Pleurotus* (Mueller *et al.*, 1984; Sharma and Jandaik, 1994); *Volvariella* (Poppe, 2000).

Pleurotus spp spent substrate: Cultivation of *Pleurotus spp.* (Nakaya *et al.*, 2000; Sharma and Jandaik, 1985, 1992), *Stropharia* (Poppe, 1995).

Lentinula edodes spent substrate: Cultivation of *Pleurotus* (Jaramillo, C., Colombia, pers. com.; Royse, 1993); Mixed into *Agaricus* substrate (Yeatman, J., Pennsylvania, pers. com.).

Spent substrate from other species: *Volvariella* substrate for *Pleurotus* production (Chang and Miles, 1989; Quimio, 1988); *Flammulina* or *Ganaderma* substrate for *Coprinus comatus* (Chen, A., New York, pers. com.).

FOOD FOR ANIMALS AND FISH

Agaricus bisporus spent substrate: Feeding studies with

sheep (Wilson *et al.*, 1983).

Pleurotus spp spent substrate: Cattle feed from spent wheat straw compost (Adamovic *et al.*, 1998; Jaramillo, C., Colombia, pers. com.; Kakkar *et al.*, 1990; Keil, C., Pennsylvania, pers. com.); Spent sugarcane bagasse compost in a dietary blend for ruminants (Permana, 1990; Zadrazil and Puniya, 1995); Adult and young buffaloes fed spent wheat or rice straw from *Pleurotus* cultivation (Kakkar and Dhanda, 1998; Bakshi *et al.*, 1985); Feed for lambs and sheep (Calzada *et al.*, 1987a, b; Sanchez-Vazquez, J.E. , Mexico, pers. com.); Degradation studies (Bisaria and Madan, 1984; Braun *et al.*, 2000; Permana *et al.*, 2000; Pratt *et al.*, 1981; Sosulski and Coxworth, 1986; Streeter *et al.*, 1981; Zadrazil, 1977, 1980, 1984; Zhang *et al.*, 1996).

Lentinula edodes spent substrate: Ground waste logs from natural log shiitake cultivation (Yoshida *et al.*, 1978); Rice straw fermented with waste shiitake sawdust media, corn and molasses (Lin *et al.*, 1998a &b); Degradation studies (Braun *et al.*, 2000; Zhang *et al.*, 1996).

Other species spent substrates: *Volvariella volvacea* grown on rice straw or banana leaves for sheep (Sevilla *et al.*, 1989); *Coprinus fimetarius* grown on rice and oat straws for goats (Mann *et al.*, 1994).

Aquaculture

Agaricus bisporus spent substrate: Wheat straw substrate as a component in the diet of carp (*Cirrhina mirigala*) (Sehgal and Thomas, 1987; Sehgal and Simmi, 1991; Sehgal *et al.*, 1993).

PEST MANAGEMENT

Insect management

Agaricus bisporus spent substrate: Effects on Colorado potato beetles populations (Stoner *et al.*, 1996; Gent *et al.*, 1998).

Disease management

Agaricus bisporus spent substrate: Effect of water extracts (Yohalem *et al.*, 1994, 1996) and mechanism and dynamics of inhibition on apple scab (Cronin *et al.*, 1996); Effect on: damping-off and root rot of creeping bentgrass (Craft and Nelson, 1996); *Pythium* damping-off disease of tomatoes (Reigner *et al.*, 2001); *Verticillium* disease in commercial mushrooms (Guardino, 1998; Labuschagne *et al.*, 2000; Wuest *et al.*, 1996); root-knot nematode, *Meloidogyne incognita* (Kaul and Chhabra, 1993; Verma, 1986, 1993); chilli leaf and stem necrosis (Upadhyay, 2000); wilt of carnation and black root rot of cucumber (Ebben, 1980); suppression of turfgrass diseases (Viji *et al.*, 2000); potato early dying disease caused by *V. dahliae* and *P. penetrans* (Gent *et al.*, 1998; LaMondia *et al.*,

1999); *Rhizoctonia* in cucumbers (Nguyen *et al.*, 1987); *Fusarium* wilt of tomato (Harender *et al.*, 1997); predaceous nematodes (Koning *et al.*, 1996); Influence on gas exchange in potatoes in presence of *Verticillium dahliae* or *Pratylenchus penetrans* (Gent *et al.*, 1999).

Pleurotus spp. spent substrate: Attacks nematodes (Hibbett and Thorn, 1994; Thorn and Barron, 1984).

Lentinula edodes spent substrate: Suppression of Rhizoctonia damping-off of cabbage (Huang, 1997; Huang and Huang, 2000); Disease incidence of tomato (Lin and Chuen, 1993).

MISCELLANEOUS USES

Agaricus bisporus spent substrate: Used in airlift bioreactor used to assess plant available nutrients (Velthof *et al.*, 1998); Used in heat resistant formulas (Donnelly and Busta, 1980); As an alternative fuel (Maher *et al.*, 2000); Used as bedding for hogs (Beattie *et al.*, 2001; Durrel *et al.*, 1997); Recovery of lignocellose-degrading enzymes (Ball and Jackson, 1995); Monitoring fate of entomopathogenic nematodes (Richardson *et al.*, 2000); Carrier material for preparation of bio-inoculants (Bahl and Jauhri, 1986; Bahl *et al.*, 1989); Production of biogas (Tumwasorn *et al.*, 1980); Vermiculture (Edwards *et al.*, 1985; Massi, A., Argentina, pers. com.).

Pleurotus spp spent substrate: Production of biogas (Bisaria *et al.*, 1983, 1990; Mehta *et al.*, 1990); As alternative fuel (Rahman, H., Bangladesh, pers. com.); Extracellular enzyme production (Tan and Wahab, 1997); Vermiculture (Rahman, H., Bangladesh, pers. com.; Sanchez-Vazquez, J.E , Mexico, pers. com.).

Lentinula edodes spent substrate: As alterative fuel (Dias, E.S., Brasil, pers. com.; Pauli, 1999); Vermiculture (Pauli, 1999).

Other species spent substrate: Mushrooms in general as animal feed (Sova and Cibulka, 1980); Cellulolytic bacteria from *Volvariella volvacea* (Wong *et al.*, 1990); *Volvariella* as alternative fuel and vermiculture (Rahman, H., Bangladesh, pers. com.).

ENVIRONMENTAL IMPACT OF WEATHERING SPENT COMPOST

Spent mushroom substrates are often spread onto land and allowed to weather for several years. This allows salts and nitrates to leach from the spent materials. The impact of storage and leaching has been explored.

Weathering process

Agaricus bisporus spent substrate: Organic matter transformations during weathering process (Chefetz *et al.*, 2000).

Impact on ground water

Agaricus bisporus spent substrate: Nitrates in ground water beneath sandy terrace soil in intensive vegetable production (Maynard, 1993a, b, 1994a); Impact on water quality through applications to agriculture land (Kapland *et al.*, 1995; Pannier, 1993; Wuest, 1992; Wuest and Fahy, 1992; Wuest *et al.*, 1991); Release of sulfate-sulfur, potassium, calcium, magnesium (Stewart *et al.*, 2000) and inorganic-N (Stewart et al, 1998).

Impact on surface water

Agaricus bisporus spent substrate: Effect on adjacent surface water (Reed and Keil, 2000).

Impact on air quality

Agaricus bisporus spent substrate: Odorous components (Bazemore *et al.*, 2000); Effect on health (Cobb *et al.*, 1995).

A complete list of references is available upon request. Call the AMI Avondale office, 610/268-7483, for a copy. **MN**