Part II. Oyster Mushrooms

Chapter 5

Substrate

Mushroom is an attractive crop to cultivate in developing countries for many reasons. One of the most charming points would be that they are grown on agricultural wastes. It enables us to acquire substrate materials at low prices or even for free and to conserve our environment by recycling wastes. Most of all, oyster mushrooms (*Pleurotus* spp.) can utilize various kinds of substrate materials than any other mushrooms. The first article in this chapter, a worldwide survey on possible substrate for oyster mushroom, will illustrate oyster mushroom can be grown on "almost all types of available wastes." Then, nine examples of substrate materials for oyster mushroom are introduced in the rest part of the chapter with analyses on each material and detailed growing methods. Considering the conclusion of the following worldwide survey that about 200 different wastes are available as oyster mushroom substrate, nine materials are very much limited examples. However, more emphasis and pages than other chapters are provided to this chapter in this 300-paged handbook. Much effort is also made to offer practical experience of mushroom growers as well as scholars' experimental study on substrate materials. Therefore, the authors of this chapter have various educational, professional, cultural and national backgrounds and the quality of each article could be varying. Some scientists might emphasize academic point of view while some growers practical point of view. However, readers will find that any of them cannot be neglected and each article has its own value.

AGRICULTURAL WASTES AS SUBSTRATES FOR OYSTER MUSHROOM

Jozef Poppe
University of Gent, Belgium

Since 1999, our overcrowded world can count over 6 billion souls. Almost half of them are poor, hungry, sick or at war. They fight for a parcel of bean soil, coffee field, or rice terrace, while in the same village one can smell burning straw and forest fires or the rotting heaps of organic field waste or other agricultural by-products.

There is an enormous amount of waste in the agro-industry and the wood industry. Only using 25% of the yearly volume of burned cereal straws in the world could result in a mushroom yield of 317 million metric tons (317 billion kg) of fresh mushrooms per year, (Chang & Miles, 1989). But at this moment, the yearly world mushroom production total is only 6 billion kg. For 6 billion persons that equals 1kg per year or 3g per day

(Courvoisier, 1999).

In fact, considering the yearly available world waste in agriculture (500 billion kg) and forestry (100 billion kg), we could easily grow 360 billion kg of fresh mushrooms on the total of 600 billion kg of dry waste!! This would produce an annual mushroom crop of 60kg per head per year, all containing the 4% protein of fresh mushrooms. We know that the diet of 30% of the world population is protein deficient, and recent analysis has proved that 200g of mushrooms can efficiently replace 100g of meat as a protein source. (Souci *et al*., 1975-1989) Among mushrooms, *Pleurotus* (oyster mushroom) can make use of the largest variety of waste substrates with its fast mycelial growth and its multilateral enzyme system that can biodegrades nearly all types of available wastes.

Listed below are the results of a worldwide survey on agro-forestry waste that can be used as a substrate in the cultivation of oyster mushrooms. All of the following wastes have been used in the past or recently for small or large-scale oyster mushroom cultivation. Most of these wastes have a C/N ratio between 32 and 600 and a pH between 5.0 and 7.5 (Poppe, 2000).

Worldwide Survey on Oyster Mushroom Substrate

- Alang-alang grass, *Imperata cylindrica* - abundant herb in Asia, especially in Indonesia, used for *Pleurotus* (Poppe *et al*., 1997).
- Artichoke waste, useful after drying for different mushroom substrates (Stamets, 1993)
- Azolla, a fast growing fern in Asia, close to tropical rivers used for *Agaricus*, *Pleurotus* and *Collybia* (Poppe, 1995).
- Banana leaves, dried 1.45% N, very productive in bulk for *Pleurotus* or in combination for *Volvariella*. (Chang-Ho 1979; Bhavani *et al*., 1989) (author).
- Banana pseudostems, chopped, gave better results for *Pleurotus* compared to sawdust or rice straw. (Jandaik *et al*., 1976). Jandaik was the first mycologist to use this substrate for *Pleurotus sajor-caju*.
- Barley straw, *Hordeum vulgare*, has a biological efficiency of 96% for *Pleurotus* (Martinez-Carrera, 1989), Chang & Miles (1989): 0.64% N, 0.19% P, 1.07% K, 47% C, C/N = 72. According to Delmas (1989) : 1% protein, 14% lignin, 36% hemicellulose, 43% cellulose, suitable for *Agaricus*, *Pleurotus*, *Volvariella*, and *Stropharia*.
- Bean pods, a substrate component or in bulk for *Pleurotus* (Poppe *et al*., 1995).
- Bean straw, different genera, for *Agaricus* and as a substrate component, for *Pleurotus*, it can also be used as a basic substrate (Poppe *et al*., 1995).
- Brassica-haulms, for *Pleurotus* (Sohi *et al*., 1989), straw of *Brassica napus*, rape, contains 22.7% lignin, C/N = 70, used for *Agrocybe aegerita* (Zadrazil, 1989). On *Brassica* crop residues like rape and mustard, in India, the highest yields were obtained with 50% *Brassica* + 50% rice straw for *Pleurotus sajor-caju* (Pani *et al*., 1998).
- Buckwheat straw, *Polygonum fagopyrum*, for *Pleurotus* (author).
- Cactus, Agave and Yucca : dry-resistant plants useful as a component of mushroom substrates (Stamets, 1993).
- Cardamon pulp, *Elettaria cardamomum*, has a biological efficiency of 113% for *Pleurotus* (Martinez-Carrera, 1989).
- Cinnamon leaves, *Cinnamon zeylanicum*, biological efficiency of 82% for *Pleurotus* (Martinez-Carrera, 1989).

Figure 1. Banana and its leaves

Figure 2. Bean pods

- Citrus fruit peels, *Citrus unshiu*, dried, reasonable *Pleurotus* production (Yoshikawa *et al*., 1979; Khan *et al*., 1981).
- Coconut fiber pith and coir : can be composted and then used for cultivation of *Pleurotus* or *Volvariella* in India (Theradi Mani, 1992).
- Coconut husks, used for *Pleurotus cystidiosus* in India (Beig *et al*., 1989), used also for *Volvariella* in India (Bhavani, 1989; Gurjar *et al*., 1995).
- Coffee parchment, parche de café, suitable with or without pasteurization for *Pleurotus* (Poppe, 1995).
- Coffee pulp, sundried, stored, later rehydrated for *Pleurotus* (Martinez-Carrera 1989). Good production in Mexico for *Auricularia* when mixed with sugarcane pulp and corn-cobs (Sanchez *et al*., 1995).
- Coffee sawdust: efficient for *Pleurotus* when mixed with ipil-ipil powder (Sanchez *et al*., 1995).
- Coleseed, *Brassica napus*, in combination with straw or hay, it is a useful substrate for different mushrooms (Steineck, 1981). Contents: 2% protein, 11% lignin, 28% hemicellulose, 47% cellulose.
- Corn fiber: In Japan, this waste product of cornstarch manufacture increased the yield very noticeably when added to sawdust + rice bran, for *Pleurotus ostreatus*, *Pleurotus sajor-caju*, *Pholiota nameko* and *Hypsizygus marmoreus* (Terashita *et al*., 1997).
- Corncobs, hammer milled or crushed, tested first in Hungary in 1956, gave variable results for *Agaricus*. Generally used for *Pleurotus* and shiitake. Contains 40% cellulose, 15% lignin, 0.4% total N, 0.1% P_2O_5, 0.25% K_2O, 0.5% SiO_2, pH 7, C/N 129 (Heltay 1957; Heltay *et al*., 1960) (At least 40 author references).
- Corn stipes, corncobs, corn leaves, corn stover, *Zea mays*: 5% protein, 19% lignin, 31% hemicellulose, 18% cellulose (Delmas, 1989), chopped use for *Pleurotus* and shiitake.

Figure 3. Corn

- Corn stalks, *Zea mays*, chopped as a component of *Agaricus* substrate (Chapuis *et al*., 1951). Also useful for *Pleurotus*. It contains: 48% cellulose, 16% lignin, 0.8% total N, 0.35% P_2O_5, 0.4% K_2O, 1.8% SiO_2, pH 7.2, C/N = 63 (Heltay *et al*., 1960 MS 4). In Chang & Miles (1989), the total N is 0.5%, 0.3% P2O5, 1.7% K, C/N = 97.
- Corn stover: containing 65% polysaccharides + 30% lignin, used for *Pleurotus* (Bassous *et al*., 1989).
- Corn waste: not only corncobs but also the post-shelling dust, the cleaning fiber and the broken pith are useful for *Pleurotus* cultivation with satisfactory yields (Khan *et al*., 1989).
- Cottonseed hulls, *Gossypium hirsitum*: 1% N; were the best substrate for cultivation of *Pleurotus* without any thermic treatment (Sun Pei-Ji, 1989).
- Cotton straw silage, chopped into particles of 3cm and stored in silos of 450 tons stock for *Pleurotus* cultivation in Israel (Danai *et al*., 1989).

Figure 4. Mixture of corn waste

Figure 5. Watered mixture of corn waste

Figure 6. Dried cottonseed hulls

Figure 7. Cottonseed hulls and fiber

- Cotton wastes: cotton mill droppings, cotton ball locules, cotton husks, gin waste, cottonseed hulls: best substrate for *Volvariella*, used single or composted in combination with rice straw (Hu, 1976). Cotton also gives a productive waste for *Pleurotus*, even simply humidified without any thermic treatment (Poppe personal).

  Cotton waste contains widely variable amounts of total nitrogen from 0.25-1.45% (Chang-Ho *et al*., 1979). The gin waste is a by-product of the cotton purification machine (Khan *et al*., 1981; Cho *et al*., 1981) (more than 50 authors). Cotton waste has a biological efficiency of 56-86% for *Pleurotus*.
- Elephant grass, *Pennisetum purpureum*, for *Pleurotus*, tested in Cameroon by Poppe in 1987 with satisfactory results. In Zambia, it is used for *Agaricus* compost (author).
- *Euphorbia rayleana*, chopped branches could be successfully used for *Pleurotus florida* in India (Khanna *et al*., 1981).
- Grasses, wild grasses, ±3% protein, ±12% lignin, ±23% hemicellulose, ±18% cellulose. It should be dried for hay before using, see also hay. Up to now, not enough research has been done in order to make useful the endless amounts of lawn grass. Used in India, dried and cut, for *Pleurotus* sapidus (Kiran *et al*., 1989).
- Fern high, fern low, fern kukot: have been tried in Asia for *Pleurotus* with semi-satisfactory results (Poppe *et al*., 1997).
- Flax straw, *Linum usitatissimum*, single or in combination with flax tow, for *Volvariella* & *Pleurotus* and *Auricularia* (Chang, 1976; Chang & Hayes, 1978).
- French bean-haulms, *Pleurotus* (Sohi *et al*., 1989).
- Groundnut shells: successfully used for *Pleurotus sajor-caju* in Africa, additive of 10% water hyacinth increased the production by 22% (Tagwira *et al*., 1999).
- Gum-wood sawdust was first used by Block *et al*.,(1960) for the cultivation of *Pleurotus ostreatus*.
- Lemon grass leaves, *Cymbopogon citratus*, biological efficiency of 113% for *Pleurotus* (Martinez-Carrera, 1989).

Figure 8. Commercial waste cotton piles

Figure 9. Various wild grasses

Figure 10. Groundnut

- Legume straws, mostly rich in N, suitable as *Pleurotus* substrates (Poppe, 1995).
- Maize straw: resulted in India in a biological efficiency of 52% for *Pleurotus sajor- caju* (Pani *et al*., 1997).
- Manioc stipes and leaves, *Cassava manihotis*, chopped for *Pleurotus*, or for *Agaricus* if fermented (Delcaire, 1981).
- *Melilotus haulms*, for *Pleurotus* (Sohi *et al*., 1989).
- *Mentha* stalks: after extraction of the oil it can be used for *Pleurotus*, *Agaricus* and *Volvariella* in combination with cereal straw (Garcha *et al*., 1981).
- Mustard, yellow mustard straw, useful for *Pleurotus* (author).
- Newspapers, shredded, when combined with rice bran or with sawdust for *Pleurotus* (Hashimoto, 1976). Also useful for *Stropharia*. Oak sawdust, supplemented with 10% millet was in Canada the best pasteurized or sterilized substrate for shiitake (Rinker, 1991).
- Oat straw, *Avena sativa*, 2% protein, 17% lignin, 32% hemicellulose, 40% cellulose, *Agaricus*, *Pleurotus*, *Stropharia* (Delmas, 1989).
- Paper pulp by-product: used in South Africa as substrate component for several mushrooms (Eicker *et al*., 1981).
- Paper waste: shredded paper, used for *Pleurotus*, *Stropharia* (Poppe, 1995).
- Papyrus plants, aquatic abundant, to be dried for *Pleurotus* (Poppe, 1995).
- Pea haulms, *Pleurotus* (Sohi *et al*., 1989).
- Pea straw, *Pisum* sp.: a substrate component for *Agaricus* and a basic substrate for *Pleurotus*. Contents 43% cellulose, 15% lignine, 0.9% N, 0.15 P_2O_5, 0.3 K_2O, 1.1% SiO_2, pH 6.8, C/N 45 (Heltay *et al*., 1960).
- Pepper leaves, *Piper nigrum*, biological efficiency for *Pleurotus* is 57% (Martinez-Carrera, 1989).
- Populus wood logs: gave a little bit lower *Pleurotus ostreatus* production compared to Salix wood logs (Anselmi , 1979).
- Potato foliage: useful for *Stropharia* and *Pleurotus* (author).
- Quinoa plant, dried, in Bolivia used as substrate for *Pleurotus* (Poppe, 1995).
- Ragi straw, *Eleucena coracana*, enriched with cottonseed meal, for *Pleurotus flabellatus* in India (Bano, 1979).
- Reed, *Phragmites communis*, chopped, 20% lignin, C/N = 50, as a component of substrate for *Agaricus* (Chapuis *et al*., 1951). Also useful for *Pleurotus* and *Agrocybe aegerita*.

Figure 11. Potato field

- Rice straw, *Oryza sativa*, immense masses are burned every year or left rotting in the moistened fields, intensively used for *Volvariella* and *Pleurotus*, but also used as a chief component of synthetic *Agaricus* compost. It contains 41% cellulose, 13% lignin, 0.8% total N, 0.25% P_2O_5, 0.3% K_2O, 6% SiO_2, pH 6.9, C/N = 58 (Heltay *et al*., 1960). Rice straw crushed, is also used for *Pleurotus* in Asia (Han *et al*., 1976). Some Indian authors note 14% lignin, 37% cellulose, 0.4% P_2O_5, 0.55% total N 1.6% K_2O, 12% SiO_2 and C/N = 70 (Kaul *et al*., 1981) (also numerous other authors).
- Roadside grasses: different genera and species, should be used for *Pleurotus*, *Agaricus* and *Stropharia* (author).
- Salix wood logs = willow stumps, gave a little bit higher *Pleurotus ostreatus* production compared to poplar stumps (Anselmi *et al*., 1979).

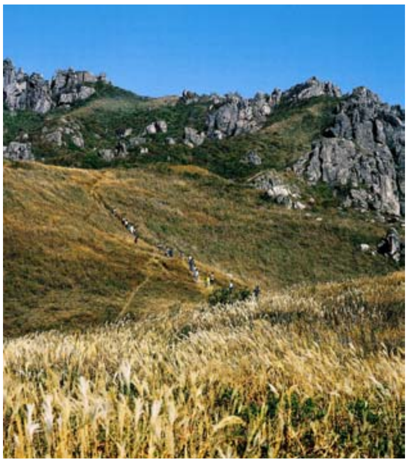

Figure 12. Reed

Figure 13. Rice straw

Figure 14. Oyster mushroom cultivated on rice straw (Photo courtesy of Chang-Hyun You)

- Sawdust, general, can be used in *Agaricus* compost as a component (more than 5%) or as an additive (less than 5%) with straw, but it can be used also as single substrate for *Pleurotus*, *Auricularia*, *Flammulina*, *Tremella*, *Pholiota*, *Hericium*, mostly sterilized. The sawdust of beech and oak: 44% cellulose, 26% lignin, 0.2% total N, 0.01 P_2O_5, 0.03 K_2O, 0.9 SiO_2, pH 6.8, C/N = 244. (Heltay *et al*., 1960; Gramss, 1979).

Figure 15. Rubber tree sawdust

Figure 16. Oyster Mushroom cultivated on sawdust substrate

- Scrubs in India: disturbing animal grazing, different assortments of these prolific scrubs were cut at the base so that grass can grow for animals. The scrubs were dried and later pasteurized for *Pleurotus sajor-caju* (Singh *et al*., 1989).
- Sesame stems: were in India a satisfactory substrate for *Pleurotus sajor-caju* with biological efficiency of 60% (Pani *et al*., 1997).
- Sorghum stover: a selected substrate for *Pleurotus sajor-caju* in Africa used alone or in combination with cotton waste (Tagwira *et al*., 1999).
- Soybean stems: were in India the best substrate for *Pleurotus sajor-caju* with 77% biological efficiency (Pani *et al*., 1997). Soybean husks and soybean straw were a good substrate for *Pleurotus ostreatus* in Yugoslavia (Bugarski *et al*., 1997).
- Spent *Pleurotus* substrate, suggested by some authors as a substrate for the King *Stropharia* (Poppe, 1995).
- Spent substrate can be used to grow successive crops of mushrooms, like spent *Agaricus* compost amended with cotton waste for satisfactory cultivation of *Volvariella*. Oei (1991) refers to Quimio who made efficient

Pleurotus substrate mixing half spent *Volvariella* substrate with 20% rice bran.

- Spent *Volvariella* compost: dried and re-used for *Pleurotus sajor-caju* with biological efficiency of 80% (Chang & Miles, 1989).
- Straw = cereal straw, 0.5% total N, 38% cellulose, 15% lignin, C/N = 90 (Kaul *et al*., 1981), basic substrate for nearly all cultivated mushrooms, can be enriched with at least 30 different supplement wastes. Straw is especially useful for *Agaricus*. Compost, chopped for *Pleurotus* and *Stropharia* (hundred author references).
- Subtropical forest dead leaves, *Platanus* spp. has a biological efficiency of 35% for *Pleurotus* (Martinez-Carrera, 1989).
- Sugarcane bagasse, *Saccharum officinarum*, sugar cane rubbish, cane trash, 0.7% N, as bulk ingredient in mushroom compost resulted in normal *Agaricus* yield as well as horse manure (Kneebone & Mason, 1972). Good production was also obtained for *Pleurotus*. For *Pleurotus*, the biological efficiency of the pure bagasse is 15%. This is relatively low compared to many other substrates (Martinez-Carrera, 1989). Alum and Khan (1989) obtained good results with *Pleurotus sajor-caju* (Derks, 1993).

Figure 17. Dry sugarcane bagasse (Photo courtesy of Dewraj Taurachand)

- Sunflower husks = Sunflower peels: the sunflower seeds are peeled before the internal seed parts can be pressed for oil. Up to now, all the precious waste was burned, millions of kilos per year. Very useful for *Pleurotus* without pasteurization and also moderate production for *Stropharia* in open field (Poppe *et al*., 1995). Cultivating *Pleurotus ostreatus* in Yugoslavia, the sunflower husks as a supplement on straw or maize stalk resulted in 8% higher yields (Bugarski *et al*., 1997).
- Sunflower stipes and heads, chopped, very suitable for *Pleurotus* and for synthetic *Agaricus* compost component (Poppe *et al*., 1995).
- Tea leaves: partial or integral substrate for different Asian mushrooms (Stamets, 1993; Poppe & Höfte, 1995).
- Tequila bagasse, *Agave tequilana*: has a biological efficiency of 60% for *Pleurotus* (Martinez-Carrera, 1989).
- Textile industry waste: card sweeping, card drops, blow gutter, chimney, testing-hard waste, reeling-hard waste, spooling-hard waste, weaving-hard waste for *Pleurotus* (Khan *et al*., 1989).

Figure 18. Tea plantation

- Treebark, chopped: can be used alone or in combination with wheat straw, corncobs and feather meal for *Pleurotus* (Imbernon *et al*., 1976) or as a fermented bulk substrate for *Agaricus* (Poppe *et al*., 1974). The origin of most tree bark is from the cellulose paper manufacturers where trees are debarked before chopping and pulp preparation. Delmas (1989) used it as a substrate for *Pholiota*, *Flammulina* and *Schizophyllum*.
- Uncrumpled rice straw: was in India the ideal substrate for *Pleurotus sajor-caju* with a biological efficiency of 85% (Pani *et al*., 1997).
- Used tea leaves: low biological efficiency for *Pleurotus sajor-caju* in India (Pani *et al*., 1997).
- Vegetable biomass: from bitter gourd, chili, cowpea, French beans, winged bean, pumpkin, tomato and okra gave good results with *Pleurotus sajor-caju* in India (Ganeshan *et al*., 1989).
- Water hyacinth, *Eichhornia crassipes*, feared boat propeller disturber; this prolific aquatic weed has gained prominence as a food source through cultivation of edible mushrooms like *Pleurotus* and *Volvariella*. Abundant in the Philippines, Indonesia, Africa and Bangladesh, should

Figure 19. Water hyacinth (Photo courtesy of Keto E. Mshigeni)

be dried before use. In India the biological efficiency of water hyacinth for *Pleurotus sajor-caju* was 50% (Gujral *et al*., 1989).

- Water spinach, *Ipomoea aquatica*, used in India for *Pleurotus sajor-caju* (Gujral *et al*., 1989).
- Wheat straw, *Triticum aestivum*, main basic component of fermented *Agaricus* compost, in different percentages, up to 90%; wheat straw contains 1% protein, 13% lignin, 39% hemicellulose, 40% cellulose. It was burned in voluminous amounts until 1963 in France. Since it can be used for *Pleurotus*, the price is USD0.1-0.2 per kg. Straw for *Pleurotus* is only pasteurized and rarely fermented (Delmas, 1989). Wheat straw can also be used for *Volvariella*, it contains 48% cellulose, 20% lignin, 0.5% total N, 0.04 P_2O_5, 0.1% K_2O, 4.1% SiO_2, pH 6.9, C/N = ratio 104 (Heltay *et al*., 1960). (Numerous other authors)
- Wood logs: very productive for *Pleurotus quebeca* (Olah *et al*., 1979), but wood logs of at least 75 hard wood species can be used for *Pleurotus*, and at least ten species are a suitable substrate for shiitake. In the book of Stamets & Chilton (1983), we find analysis of wood compared to wheat straw in average percentages.
  Pine and spruce: 0.08% N, 0.02% P_2O_5, 0.1% K_2O, 11% hemicellulose, 56% cellulose, 27% lignin, resin ±3%.
  Beech: 0.13% N, 0.02% P_2O_5, 0.2% K_2O, 11% hemicellulose, 53% cellulose, 22% lignin, 1.7% resin (birch is nearly the same). (Numerous author references)
- Wood shavings, 0.3% N, useful for *Pleurotus*, *Pholiota*, *Flammulina*, *Auricularia*, *Hericium* (Poppe, 1995).
- Wood wastes: a list of ±140 tree species is given in Stamets (1993).

Conclusion

According to this worldwide survey, about 90 kinds of wastes have been proven to be useful for oyster mushroom growing, but some listed wastes such as cereal straw, sawdust, and wood logs can be re-divided into at least 100 individual types of waste linked to different plant species. It means that in fact a range of about 200 different wastes is available as oyster mushroom substrates. So, every grower producing oyster mushrooms can make their own best substrate choice from among all those genera or species having been cited in the substrate list.

We must not be at all surprised that the evaluation of all these kinds of different wastes leads us to a renewed appreciation for what is called a waste. Growing mushrooms gives so much satisfaction and produces so much food and income that further use of this practice can result in a great complete contentment of families and villages!

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