African Journal of Environmental Science and Technology Vol. 4(13), pp. 936-941, December 2010 Special Review
Available online at http://www.academicjournals.org/AJEST
ISSN 1991-637X ©2010 Academic Journals

Review

Pasteurization of mushroom substrate and other solids

Ralph H. Kurtzman, Jr.

Micologia Aplicada International, 445 Vassar Avenue, Berkeley, CA 94608, U.S.A. E-mail: kurtzmanr@earthlink.net.

Accepted 25 December, 2010

Mushrooms represent an important part of natural solid waste disposal, which can be enhanced by cultivation. Cultivation provides a source of wholesome food which thus, by cultivating them we can have more food and less solid waste. However, pasteurization for cultivation requires the use of some fuel. In order to obtain the maximum environmental benefit from them, it is therefore important to use the minimum fuel and the best conditions for their cultivation. In this review, we discuss the use of fuel for pasteurization, a step in cultivation that can potentially use very large amounts of energy. The use of simple methods and good management can minimize the amount of fuel and reduce disease and pests.

Key words: Mushroom substrate preparation, heating solids, solid waste, field waste, agro-industrial waste.

INTRODUCTION

In nature, mushrooms are a primary part of controlling solid waste, building organic soil and returning minerals to the soil. Mushrooms are the only crop that actually consumes field and other solid wastes. They convert straw, sugar cane baggase, maize stalks, cotton waste, coffee waste, many other field wastes, agro-industrial waste and even animal manure into wholesome, vitamin and protein rich food (Kurtzman, 1975, 1997). In addition, yields per square meter of land occupied by them can be much greater than any other crop (Figure 1).

The soil must be prepared for green plants. Similarly, the wastes, used for mushroom substrate must be prepared to grow mushrooms. In both cases of soil and mushroom substrates, the desired objective is to destroy similar organisms which will compete. Also, if possible destroy pests and diseases. One important step in the preparation of mushroom substrate is often referred to as pasteurization and has at least some relation to the process used for milk and other liquids.

While the composition of substrates for different mushrooms vary greatly and there is variation in the preparation of substrates used for every cultivated species, most substrates are treated with moist heat and then, said to be pasteurized. However, there is confusion about the pasteurization conditions. Often, people believe that more heat is better. However, even if a temperature of approximately 60ºC is used for solids, it is not unreasonable to say that the term pasteurization must be confined to a rather specific treatment of liquids. Yet, pasteurization seems to be the best general term that has been applied to the processes of heating mushroom substrate, in order to reduce weeds, diseases and pests.

CLASSICAL PASTEURIZATION

Liquids

Pasteurization has often been confused with sterilization. Even more common is the belief that more heat and longer times are always better. In the U.S. pasteurization has officially been described as: "... heating every particle of milk products to at least 143ºF (62ºC) and holding it at such a temperature continuously for at least 30 min" (Pelcazar and Reid, 1965). More recently, on the web, the commercial description is "pasteurization: partial sterilization of liquids such as milk, orange juice, wine, and beer, as well as cheese, to destroy disease-causing and other undesirable organisms. The process was named after the French scientist Louis Pasteur, who discovered in the 1860s that undesired fermentation could be prevented in wine and beer by heating it to 135°F (57°C) for a few minutes. Milk is pasteurized by heating it to about 145°F (63°C) for 30 min or by the "flash" method of heating to 160°F (71°C) for 15 sec, followed by rapid cooling to below 50°F (10°C), at which temperature it is stored. The harmless lactic acid bacteria survive the process, but if the milk is not kept cold, they

Figure 1. Walls of oyster mushrooms. Left, to be picked the next morning; right, to be picked on the third day.

multiply rapidly and cause it to turn sour (Answers, 2010).

Although cheese is mentioned, it is not possible to heat “every particle” of any solid in the same fashion that is used for liquids, it is especially difficult to heat and cool them quickly and evenly. In general, if cheese is said to be pasteurized, the milk has to be pasteurized before cheese is made from it.

Compost pasteurization

While there have been attempts to grow mushrooms in liquid fermenters, commercial mushroom substrates are, of course, solids. So we must face some problems of heating, if we are to pasteurize them. For many years it has been customary to “pasteurize,” “peak heat,” “cook out” or “Phase II” *Agaricus* mushroom substrate (compost). All of these terms refer to blowing a 60°C mixture of steam and fresh air into compost-space at the end of composting (Lambert, 1950; Snetsinger, 1970; Denham, 1975). Apparently, the practice began some time between 1915 and 1944 and was common practice in 1950. In the experiment carried out by Duggar (1915), it was not mentioned, but Treschow (1944) mentions it for some experiments, but not others. Others have tried to set the date and origin of the practice and there is some belief that it began about 1915 in the U.S (Atkins, 1979).

When pasteurization of compost begins, the compost has some ability to self-heat remaining, so it provides heat from the inside, while the steam provides heat from the outside. The process is intended to kill and when done properly, it is quite successful in killing all seeds, nematodes, insects and other organisms that flourish at the temperatures used to grow the mushrooms. Even with the self-heat, bringing the entire mass to 60°C, requires days. Then cooling requires days, so while the temperature fits the term pasteurization, neither the heating time nor the cooling time are similar to liquid pasteurization. With the long cooling time, there is considerable opportunity for re-contamination. Although self-heating provides much of the required heat, the process is costly, but less costly than the loss of crops to pests and disease. Also, it introduces no poisons that might contaminate the mushrooms.

For many years, the compost was placed in beds or growing trays in a room. After self-heating increased the temperature, steam and air were added until both the compost and the air in the room were at 60℃. They were held at that temperature for four or more hours, then more fresh air was added for several days until the compost cooled (Kurtzman, 1979c).

While that method is still used, today most is done with the compost half-filling a room where the steam and fresh air is forced in through a grated floor and recirculated with appropriate additions of steam and air to maintain the desired temperature and oxygen (Denham, 1975).

STERILIZATION

It may be apparent to some, but from others, often we hear, "why not sterilize?" All microbiology text books state that wet heat sterilization requires 121℃, which means that a high pressure boiler and a pressure container (autoclave, retort) large enough to hold the material to be sterilized. When it is understood that a single commercial mushroom grower may process many tons of substrate every day and a great amount of time is required for the heat to penetrate large masses of substrate, it becomes clear that the cost of both equipment and fuel is prohibitive.

The more important reason to pasteurize rather than sterilize, or even to use a temperature much greater than 60℃ was eluded to by Pasteur in his 1857 landmark paper on lactic acid: "One may compare what happens in fermentation to the soil in which nothing is planted. It is soon choked with plants and insects of different kinds that mutually destroy each other" as translated by Pasteur (1957). However, since the translated quote has been removed from the original context, some interpretation may be needed. First, in general, but particularly for this discussion, mushrooms growing is solid-state fermentation.

When we sterilize, nothing living is left so, if the substrate is not protected, it is available to all microoganisms that happen to fall on it, from the air, from insects landing on it, water splashing on it, etc. When we pasteurize, we kill many organisms, but we expect those that remain to be: 1) Easily controlled. For example, thermophiles from composting, in mushroom substrate at less than 20℃, will grow very slowly; 2) poor competitors for the organisms we intend to grow; 3) beneficial to the organism we intend to grow, for example, nitrogen fixing bacteria in *Legumonosae* or the *Legumonosae* in a field of maize. A more general interpretation is that long term, absolute protection of either sterilized or pasteurized material is difficult, so it should be inoculated with the intended microoganism as soon as it is practical.

Treschow (1944) was among those who have confused the meaning of "sterilization." While calling pasteurization, sterilization and everything in between "sterilization" he treated substrate of Norway spruce needle litter in clay flower pots 60, 80, 100 and 120℃ all for 60 min before spawning with *Agaricus.* He also had control pots that were not heated. The controls yielded 40 g/pot, 120℃ yielded nothing, 100℃ 22 g/pot, 80℃ 97 g/pot, and 60℃ 242 g/pot. Rather convincing evidence is that "pasteurization" is of value and that more is not better.

PASTEURIZATION FOR OYSTER MUSHROOMS

Many countries, especially those of Africa, Asia and Latin America cultivate oyster mushrooms (*Pleurotus* spp.) (Kurtzman, 2006, 2007, 2009; Martinez-Carrera et al., 2010). Oyster mushrooms grow on dead trees, logs and other wood in nature. However, *Agaricus* grows on the ground and generally in association with manure or other previously rotted material (Smith, 1963). It is interesting, then, that many people who have been associated with the cultivation of *Agaricus* and other mushrooms have treated oyster mushrooms as though they were just *Agaricus* with a different shape. They seem to have no concept of the different needs of different species. They have promoted growing oyster mushrooms on compost (Kalberer, 1974). When they learned that it was a poor substrate they began to use cold water to wet the straw. Cold water is repelled by the natural waxy surface of straw, so cold wetting requires many days. During wetting, the material that wets first supports large populations of disease and other contaminating organisms. Then, when the straw is well damaged, they used steam to "pasteurize" it (Lanzi, 1986). Cold straw is slow to self-heat, so great amounts of fuel are required. Also, if anything resembling pasteurization is to be accomplished, the steam must be mixed with air to bring the temperature down to just slightly more than 60℃. The cool "steam" quickly condenses as it warms the wet straw. The result is that it takes many hours to warn the straw. Pockets of air will tend to occur; those pockets will exclude the "steam," so there is no assurance that all of the straw will ever reach 60℃. If the temperature of the steam-air mixture is increased, then it is likely that beneficial organisms will be killed and disease organisms will easily populate the substrate.

In the last decade, it has become common to spawn (inoculate) *Agaricus* compost, then compress it into blocks that can be easily transported. The method works well for compost substrate. However, for oyster mushrooms, in addition to problems with heating field wastes, because straw and most other field wastes do not self-heat quickly, they do self-heat slowly. Furthermore, thermotolerants and thermophiles multiply

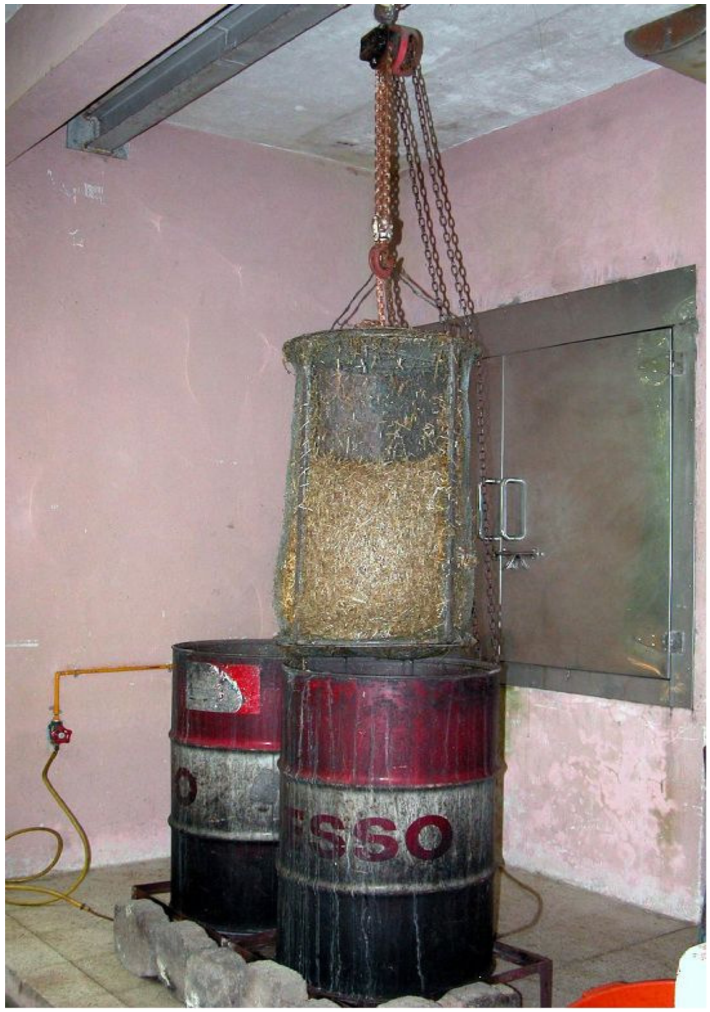

Figure 2. Steel drums on gasbunners with wire basket and chain-fall. This arrangement and one ton of dry waste-substrate (the tons of wet) in a day.

as the steam heats the straw and as it cools. The increase in thermophiles, means that the straw will now self-heat more quickly. In addition, the straw is a good heat insulator, so the heat will build up inside of the large block, killing much of the mushroom mycelium and possibly leading to spontaneous combustion. Since *Agaricus* prefers a nearly horizontal surface, those blocks are placed as a single layer on shelves, but oyster mushrooms favor vertical surfaces, so it is tempting to stack the blocks, thereby increasing their effective thickness, increasing the self-heating and increasing the danger of spontaneous combustion.

In 1974 Kurtzman (1975) poured hot water over straw to "pasteurize" it for the cultivation of oyster mushrooms and other mushrooms that prefer fresh substrate. His conditions were later changed as he found conditions that appeared more favorable to the mushrooms (Kurtzman, 1979a). Finally the conditions were codified (Kurtzman, 1978b). He then proposes two methods, one for minimal investment, which we will call the "drum method," because ordinary steel drums have most often been used as pasteurizing vessels and a second which has minimal water consumption and zero liquid waste, to be called the "mixer method," since some sort of mixing machine is required (Kurtzman, 2010) . The first consists of heating water to 60℃ in a volume approximately equal to the volume of dry field waste-substrate to be pasteurized. When the temperature is reached, the dry field waste-substrate is added to the water. It is desirable to have the field waste-substrate in a wire or fabric mesh container, so that the water may easily mix with the substrate when it is put into the hot water and can be easily drained when the pasteurization is completed (Figure 2). The substrate is held in the water for 30 to 60 min, while the water is

Figure 3. Top: Mr. Gusev demonstrates the way his mixing machine fills polyethyene tubes with the pasteurized, spawned substrate. Bottom: A concrete mixer that might be used for a pasteurization mixer. These are often available for used.

maintained at 60 ± 3°C. Then the substrate is drained and allowed to cool slowly for 16 to 20 h. The drained water may be used to pasteurize additional substrate, with some fresh water added to replace that which was consumed. Additional heat will be needed to bring the water back to 60°C, before the new batch of field waste-substrate is added and the process repeated, but both water and heat will be conserved. However, the water must not be kept after it cools because it will ferment anaerobically.

While the method may sound primitive, with wire baskets and chain-fall or block and tackle as shown in Figure 2, it is possible for a single operator with two drums to process up to one ton of dry waste-substrate in 8 to 10 h and even have time for lunch. The ton of dry material will become about three tons of wet material and may support the production of about one ton of fresh mushrooms.

In addition to supplying the water that will be used for the growth of the mushrooms and the heat required for pasteurization, water at 60°C immediately melts the natural waxy coating on straw and other plant materials. By melting the wax, the water is immediately able to penetrate and wet the dry waste-substrate material. The immediate wetting is in contrast to the many days required for cold water to penetrate; pasteurization begins as soon as the dry waste-substrate contacts the water, so there is no chance for new growth of undesirable organisms. It also means that there will be no uncontrolled run-off and that the heat is also transmitted immediately with little time for cooling to take place. Both from economic and environmental considerations, it is desirable to conserve energy and to reduce all sorts of waste. In converting solid waste into wholesome food, we can improve the environment. However, neither the use of excess fuel nor the introduction of uncontrolled run-off improves the environment and they add to the cost of the food produced.

The second method proposed by Kurtzman (2010) requires equipment capable of mixing the substrate as water at approximately 63°C is poured over it. This was really his original idea, (Kurtzman, 1974), but his equipment was inadequate to mix on a practical scale. Sergei Gusev, a grower in Russia, was able to obtain two feed mixing machines from defunct collective, Soviet, farms, he modified them to handle oyster mushroom substrate (Kurtzman, 2006). A large concrete mixer would also be a possible machine for the mixer method (Figure 3). Mr. Gusev's substrate is linen boon, the waste fiber from making flax into linen. If these fibers and many other wastes are put into excess water as described for the drum method, they will not drain adequately. That is, they will water-log so that they hold too much water and insufficient air. By pouring in the amount of hot water that has proven to be optimum, there is no waste of water or heat. The optimum water will generally be approximately the amount that will bring the pasteurized substrate to 65% water by weight. That is, the added water will weigh slightly less than twice the weight of the dry waste used to make the substrate.

The specific conditions for the mixer method differ from the drum method, primarily in the addition of hot water to the dry waste-substrate rather than the dry waste-substrate being added to the hot water. Mixing is required because it is the only way we can be certain that all substrate has the required water and has been heated to the required temperature. The conditions for the mixer method are: The mixer is started, a weighed amount of dry waste-substrate is put in, and approximately twice that weight of water at approximately 63°C is added. The mixing and a temperature of 60 ± 3°C are maintained for 30 - 60 min. The pasteurized substrate is allowed to cool for the next 16 - 20 h. Depending on conditions, mixing may be required to bring in cool air, in order to bring the temperature down to approximately 25°C at the end of the cooling time. The cooled substrate is then spawned (inoculated) and packed into polyethylene bags or other containers for growing.

Both pasteurization protocols are as close to true pasteurization as possible for solid material with the one exception that cooling is slow. Both also use less fuel and, in that way, are more environmentally friendly then methods described by others. Thus, the process uses as little fuel as possible, in concert with the ideas expressed by Maathai (2007). Slow cooling in the case of milk and other beverages might promote the growth of lactic acid bacteria and even enteric human pathogens, so fast cooling is an important part of beverage pasteurizing. In the case of mushroom substrate, we will not be eating it and rapid cooling is almost impossible. Experience with forced cooling suggests that slow cooling increases the yield of oyster mushrooms.

REFERENCES

Answers (2010). http // www answers com/topic/pasteurization

Atkins FC (1979). Who first introduced the pasteurizing boost in phase two. Mushroom J., 75: 91.

Denham TG (1975). The 3-phase-1 system. In: Hayes WA, ed. Composting. The Mushroom Grower's Assn. London 1977. p. 67-77.

Duggar BM (1915). Mushroom Growing, Orange Judd, New York. p. 240.

Kalberer P (1974). The cultivation of *Pleurotus ostreatus* Experiments to elucidate the influence of different culture conditions on crop yield. Mushroom Sci., 9(1): 653-661.

Kurtzman RH Jr. (1974). Proceedings of Seminar on Mushroom Research and Production, Agricultural Research Council, Karachi. p. 52.

Kurtzman RH Jr. (1975). Mushrooms as a source of food protein. p.305-318. *In:* M. Friedman, Ed. Protein Nutritional Quality of Foods and Feeds, Part 2. Marcel Dekker, New York.

Kurtzman RH Jr (1979a). Metabolism and culture of Pleurotus the oyster mushroom. Taiwan Mushrooms, 3: 1-13.

Kurtzman RH Jr. (1979b). Nitrogen fixation by *Pleurotus* **?** Mushroom Sci., 10(1): 427-435.

Kurtzman RH Jr. (1979c). Mushrooms: Single cell protein from cellulose. p. 305-339. *In:* D. Perlman, Ed. Annual Reports on Fermentation Processes, Vol 3. Acad. Press, New York.

Kurtzman RH Jr. (1997). Nutrition from mushrooms, understanding and reconciling available data. Myco Sci., 38: 247-253.

Kurtzman RH Jr. (2006). Mushroom farm Visits. Micol. Aplicada Int.,18:13-14.

Kurtzman RH Jr. (2007). Mushrooms in developing countries. Micol. Aplicada Int. 19: 57-61.

Kurtzman RH Jr. (2009). Mushrooms in developing countries - 2008. Micol. Aplicada Int., 21: 37-42.

Kurtzman RH Jr. (2010). The why and how of oyster mushroom cultivation: a worldwide prospective. In: Martinez-Carrera D, Curvetto NC, Sobal M, Morales O, Mora M Eds. Hacia un Desarrollo Sostenible del Sistema de Producccion-Consumo de los Hongos Comestibles y Medicinales en Latinoamerica. Colegio de Postgraduados. Montecillo, Mexico, pp. 609-644.

Lambert EB (1950). Comments on twenty years of research in mushroom culture. Mushroom Sci., 1:7-8.

Lanzi G (1986). The cultivation of oyster mushrooms (*Pleurotus ostreatus*) in Italy, In*:* Wuest PJ, Royse DJ, Beelman RB, Eds. Proc. Int'l. Sym. Scientific and Technical Aspects of Cultivated Edible Fungi. Elservier, New York. pp. 443-447.

Maathai W (2007). Unbowed. Anchor, New York, p. 326.

Martinez-Carrera D, Curvetto NC, Sobal M, Morales O, Mora M Eds. (2010). Hacia un Desarrollo Sostenible del Sistema de Producccion-Consumo de los Hongos Comestibles y Medicinales en Latinoamerica. Colegio de Postgraduados. Montecillo, Mexico, p. 648.

Pasteur VRL (1957). The story of Pasteur's discovery of the cause of fermentation, In: The Pasteur Fermentation Centennial, 1857-1957. Chas. Pfizer. New York, pp. 4-16

Pelcazar MJ Jr, Reid RD (1965). Microbiology, 2nd Ed. McGraw-Hill, New York. p. 662.

Smith AH (1963). The Mushroom Hunter's Field Guide, revised. University of Michigan Press, Ann Arbor, Michigan, p. 264.

Snetsinger R (1970). Mushrooms and Penn State, Past, Present, Future. Bull., 757. p. 34.

Treschow C (1944). Nutrition of cultivated mushroom. Dansk Botanisk Arkiv*.,* 11(6):9-180.