Commercial Production of Button Mushrooms (Agaricus bisporus) in California

Commercial production of mushrooms is not unlike growing vegetables. The grower needs a thorough understanding of crop nutrition, irrigation, pest management, and marketing. In addition, a mushroom farmer must have the knowledge and capital investment to provide strict environmental controls required for mushroom production. As with any horticultural crops, consistent high yields of the highest quality are paramount for turning a profit. Mushroom growers are also very resourceful, a trait fortunately demonstrated in most small commercial growers.

Cultivated button mushrooms are organisms of the Kingdom Fungi, Division Eumycota, subdivision Basidiomycotina, formerly known as Basidiomycetes. Hyphae, their somatic structures are tubular, septated (cross walled) and branched filaments, which mass is called mycelium. They go through a complex fusion and sexual reproduction process to produce fruiting bodies (basidiocarp or mushroom). They are heterotrophic saprophytes, obtaining their nourishment by colonizing dead organic matter, and secondary decomposers that grow from composted materials. Composting for mushroom production is an ecologically controlled process, where the action of other fungi, actinomycetes, bacteria, and yeasts in a microbial succession, break down plant residues into smaller components to make up the substrate where mushrooms grow.

In the United States Agaricus hybrids dominate the market. Mushroom growers have a choice of four major mushroom cultivars:

a) Pure white or smooth white, characterized with a smooth white cap, and a white stalk;

b) Off-white, a scaly white cap with a white stalk;

c) Cream, a smooth to scaly, white to cream cap with a white stalk;

d) Brown, a smooth chocolate brown cap with a white stalk. Variations in the production system for browns yield Crimini, Portobellini, and Portobello mushrooms.

Generally, Crimini, Portobellini, Portobello, white and off-white cultivars are grown for the fresh market, while cream and button brown cultivars are used for processed foods like sliced mushrooms, soups and

Selection of Production System

There are several types of growing systems used in the mushroom industry worldwide. Farm types can be divided into three generic systems: one-zone, two-zone or three-zone (multi-zone) systems. These systems stand according to the number of rooms that are required to accomplish three important steps in mushroom production: pasteurization, spawn running and harvesting. One-zone implies all three steps are accomplished in the same room, two-zone in two rooms and three-zone in three. Besides the system, there is a choice of production units. Production units can be polyethylene bags, metal or wooden shelves, or plastic or wooden trays. The production system and production units to be used to grow a crop can be chosen after the basics of mushroom growing are understood. When using trays, the tray system also called the California or western system, relies on moving large wooden trays filled with compost by forklift from one room to another. It is a three-zone or multi-zone system since pasteurization, spawn running and harvesting are carried out in separate rooms. The California production system uses controlled environments inside the pasteurization, spawn running and harvesting rooms and it is accomplished either manually, in a mechanized way, or a combination of both. These rooms can be easily adapted from existing infrastructures or buildings newly constructed for mushroom production.

Preparation of Mushroom Growing Substrate or Compost

• Parental Materials or Feedstock

Mushroom compost develops as the chemical nature of the raw ingredients is converted by the activity of microorganisms, heat, and some heat-releasing chemical reactions. Agricultural by-products or waste materials are converted under specific horticultural parameters to a readily available food source most suited for the growth of the mushroom to the exclusion of other fungi and bacteria. Composting is the conversion of parental materials into a nutritious medium or semi-selective substrate for mushroom production. Composting develops certain physical qualities (permeability to air and water holding ability) and chemical properties (nutrient availability to the mushroom, the exhaustion of nutrients for competitors, and an appropriate pH), while the heat generating properties of the substrate are also removed. The raw

ingredients, parental materials or feedstock for mushroom composting are primarily inexpensive agricultural by-products or wastes, self produced in the farm or out-of-farm inputs. Straw (main carbon source), either alone (called synthetic compost) or as horse manure (straw of racetrack or boarding stable bedding with some feces and urine) is the starting material of compost and provides structural and chemical properties to the substrate. By its nature, straw is able to absorb plenty of moisture and simultaneously allow for enough pore space to prevent anaerobic conditions. Straw contains about 0.6% nitrogen while horse manure contains about 1 to 1.2% nitrogen, depending on the amount of horse droppings and urine. Straw provides carbohydrates mostly cellulose and lignin to the compost. Cellulose breaks down into simple sugars, which supply energy to the microbes. Lignin is changed during composting to a nitrogen-rich-lignin-humus-complex, and provides 40 to 70% of the nitrogen utilized by the mushroom. This complex is resistant to bacterial decomposition but not to mushroom enzymes, making the substrate somehow specific and selective. Decomposition is mainly due to chemical reactions of humification (formation of the nitrogen-rich-lignin-humus complex) and caramelization (a process which eliminates water from carbohydrates and darkens the compost), essential to the formation of a substrate specific for mushroom growth. During decomposition the soluble carbohydrates are used first and their carbon is converted into CO_2, water and heat or it is incorporated into the microbial biomass. The nitrogen and minerals are incorporated into the protein structure of the microorganisms and extracellular enzymes' production, although some nitrogen is lost as volatilized ammonia. It is critical to emphasize that all microbes involved require oxygen.

• Supplements

To make the straw or manure more efficient for the production of mushrooms, some supplements are added during composting. These supplements are designed to improve physical structure and provide protein (nitrogen) and carbohydrates to feed the biomass responsible of the composting process. Many nitrogen sources can be used as long as sufficient carbohydrates are readily available to supply energy for the nitrogen utilization. Because of the tough nature of cellulose, most carbohydrates in straw are not initially usable and energy comes from the supplements. A balanced supplementation is therefore highly desirable. It should contain not only nitrogen but also sufficient organic matter to supply these essential carbohydrates. For this reason certain manures and animal feed meals are widely used for composting. Since composting is an alkaline process, acidic supplements are not used.

Nitrogen supplements are used to bring the nitrogen content up to 1.5% for horse manure or 1.7% for synthetic compost, calculated on a dry weight basis. Common supplements are nitrogenous fertilizers such as ammonium sulfate, ammonium nitrate, and urea for a rapid burst of ammonia, and plant and animal products such as chicken manure, dried poultry waste (DPW), brewer's grain, cocoa bean or cottonseed hulls, sugar beet pulp, corn cobs, shredded hardwood bark, neutralized grape pomace, and seed meals of soybean, peanut, or cotton. Synthetic compost requires the addition of ammonium nitrate or urea at the starting of composting to provide the microflora with a readily available form of nitrogen. Management of a compost pile containing any one of these materials is unique in the requirements for watering and the interval between turnings.

Gypsum ($CaSO_4$) is a necessary supplement added to act as a buffer, to minimize compost greasiness (counteracts harmfully high concentrations of potassium and magnesium), to supply calcium for mushroom metabolism, to improve the physical structure of the compost, to increase the flocculation and adhesiveness of certain chemicals, and to cause aggregation of colloidal particles. This results in greater air spaces and greater water holding capacity, so air, essential to the composting process can permeate the pile more readily. Airless (anaerobic) environment promotes the formation of deleterious chemical compounds which detract from the selectivity of mushroom compost. Gypsum is added at the outset of composting at a rate of 40 Lb (~18 Kg) per ton of dry ingredients.

• Composting Phase I or Fermentation

In California, composting occurs outdoors although an enclosed building or a structure with a roof over it may be used, on a concrete slab or floor, called a wharf. Provision for drainage to collect excess water and nutrients for recycling, should be considered. For sanitation purposes it is suggested that composting Phase I occurs downwind and at a sensible distance from the growing rooms. This is the dirtiest area in the mushroom farm. This phase lasts from 7 to 20 days, depending on the nature of the material at the start and its characteristics at each turn. A microbial succession is established, with each new generation decomposing the remains of the previous one. There are two stages involved:

a) Pre-wetting, Piling, Watering and Mixing

To activate microorganisms, breakdown the waxy layer and soften the plant fibers, straw bales are broken, chopped, and pre-wetted thoroughly (70 to 75% moisture) in a flat or peaked pile, either with sprinklers and recirculated water, to the point of run-off, or dunked in a pit. If the formulation selected asks for animal nitrogen sources, the mix needs to be soaked for 2-21⁄2 more days. Mix and wet the rest of the ingredients as they are stacked and shaped in rectangular piles any length by 5 to 6 ft (~1.5 to 2 m) in width and 4 to 7 ft (~1.3 to 2 m) high, called ricks or windrows. Once the windrows are formed, aerobic fermentation commences as a result of the growth and reproduction of the feedstock naturally occurring microorganisms. Microbes quickly breakdown the waxy coating of straw, the straw softens, the materials become less rigid and compaction occurs while internal temperatures in the windrow rise. There is a strong ammonia odor associated with composting, which is usually complemented by a sweet, moldy smell. Heat and CO2 are also released as by-products during this phase. Run-off water must be collected and recycled, in order to reduce unnecessary nutrient losses, to prevent pollution of the environment, and comply with water quality ordinances. The pre-wetting period may take 1 to 2 weeks.

b) Ricking, Turning, Watering and Supplementing

Bulk ingredients in the piles are put through a compost turner or composter. The compost materials are picked up by a rotating drum and placed on fast-turning beaters that throw it into a container which controls the width and height of the required stack. Supplements and gypsum are spread over the top of the ricks or windrows; water is sprayed onto the materials as they move through and are thoroughly mixed by the composter. Water addition is critical since too much will exclude oxygen by occupying the pore space, and too little can limit the growth of bacteria and fungi; it is added up to the point of leaching when the pile is formed and at the time of first turning, and thereafter either none or only a little is added for the duration of composting. The sides of the windrows should be vertical, dense, tight and firm to allow insulation for the loose center or inner part and permit higher temperatures near the sides. The inner side should be relatively loose to prevent anaerobic conditions as the pile compacts. Once the center of the windrow is hot, reaching 145 to 170oF (63 to 77oC) usually after 48 hr of construction, turning and watering are done at 2-day intervals depending on the compost activity and its stage of completion. The higher the compost activity indicated by the temperature of the windrow, the shorter the time interval between turns. The number and interval time between turnings depend on the condition of the feedstock and the time necessary for the compost to heat to temperatures above 145oF (63oC). The windrow runs out of oxygen in 48 to 96 hours and must be turned to prevent an anaerobic center. There must be adequate moisture, oxygen, nitrogen and carbohydrates present throughout this phase, or else the process will stop. As the compost pile moves through the turner, turning provides the opportunity to water, aerate, supplement, and mix the ingredients to a more homogeneous stage. Turning must provide a good mixing of the raw materials and rebuild the structure. Thermophilic (heat-loving) microorganisms replace mesophiles as temperatures rise from 115 to 145-155oF 46 to 63-68oC). Above 130oF (54.5oC), bacteria dominate and are responsible for the ammonification that occurs at these temperatures. At temperatures of 145 to 155oF (63 to 68oC), the straw softens further, absorbs water, and starts releasing ammonia. Temperatures in the compost can reach up to 170 to 180oF (77 to 82oC) during the second and third turnings when a desirable level of biological and chemical activity is occurring. At this point the width of windrow is reduced to 4 ft (1.2 m). During the later stages of Phase I, intervals between turns should be shortened. On the last turning, water can be applied generously so that when the compost is tightly squeezed, water drips from it, an indication of optimal moisture content of 70 to 74%.

At the end of Phase I the compost should have (see figure 1):

a) homogeneous dark-chocolate brown color;

b) soft, pliable straw;

c) lightly flecked throughout with whitish colonies of actinomycetes (firefang);

d) moisture content of 70 to 74%;

e) C:N ratio of 20-22:1;

f) nitrogen level of 1.6 -1.8%;

g) ash content of 20-35%;

h) pH of 8.0 to 8.5; and

i) strong smell of ammonia (0.40%). Generally, a person can smell ammonia when the concentration is above 0.10%.

• Composting Phase II or Pasteurization

While Phase I is a combination of biological and chemical processes, Phase II is purely a biologically controlled compost management. There are two major purposes to composting Phase II. It is necessary to kill any insects, nematodes, pest fungi, or other deleterious microorganisms that may be present in the compost. And second, it is necessary to completely remove the ammonia which formed during composting Phase I since it is inhibitory and lethal to mushroom growth. This phase is managed by strict manipulation of air and compost temperatures and oxygen levels. Proper insulation, heating, live steam, air conditioning, adequate ventilation and air circulation systems are required to achieve a proper Phase II. It is usually automated or microprocessor (computer) controlled via remote sensors.

Composting Phase II can be viewed as a controlled, temperature-dependent, ecological process using air to maintain the compost in a temperature range best suited for the de-ammonifying organisms to grow and reproduce. In this process, certain organisms are favored by high temperatures. At 100 to 170oF (38 to 77oC), many species of bacteria are active. The growth of these thermophilic organisms depends on the availability of usable carbohydrates and nitrogen, some of the nitrogen in the form of ammonia. This Phase II system requires approximately 10 to 14 days to complete and consists of three processes:

a) Filling and Pre-pasteurization

At the end of Phase I, compost from the wharf is pressed packed into plastic or wooden trays filled uniformly in depth and density or compression; avoid over-compaction. Tray dimensions vary from farm to farm and depend on the size of the production rooms, but average 41⁄2 -5 ft (1.4-1.5 m) wide by 6-7ft (1.8-2.1 m) long and 3⁄4 to 11⁄4 ft (23 to 38 cm) tall. They are filled with a special tray-filling machine and are mechanically emptied by some form of dump-shaker. Compost density should allow for gas exchange; since ammonia and CO2 will be replaced by outside air it is desirable to have as homogeneous a material as possible. The trays are moved by forklift and stacked six to eight high into special pasteurizing rooms with controlled temperature, humidity, and fresh air that produce the appropriate conditions for certain groups of microorganisms to use and exhaust readily available carbohydrates and free ammonia. The result is a succession and build-up of microbes that contain vitamins, fats, and proteins. The mushroom mycelium will utilize this biomass. During Phase II, temperatures are monitored and measured constantly. Because Phase II is an aerobic fermentation process, fresh air is essential. When trays are stacked on top of each other they are separated by 6-inch (15 cm) wooden “extension legs”, allowing air to circulate better and maintain homogeneous temperature and humidity throughout all the compost.

a) Peak Heat

Aerated or live steam is introduced into the pasteurizing room and the compost and the air temperatures are held at 140 and 150oF (60 and 65.5oC) respectively, for 4 to 6 hours. At excessively long periods above 140oF (60oC), too many microorganisms, especially those that lower ammonia, are killed. In addition, the selectivity of the compost may be destroyed. Peak heat kills harmful organisms like nematodes, flies, mites, fungal pathogens and endospore forming bacteria. Temperatures much above 140oF (60oC) must be avoided since fungi and actinomycetes are inactivated and ammonifying bacteria are stimulated. Peak microbial activity normally occurs 24 to 48 hours after pasteurization. These microorganisms provide a major source of polyunsaturated fats, important nutrients for Agaricus. As the food supply diminishes, activity and compost temperatures drop.

b) Conditioning

The main purpose of conditioning is to improve the selectivity of the compost for Agaricus bisporus, accomplished by optimizing conditions for thermophilic microorganisms to convert ammonia and nitrates to proteins that will be later used by the mushroom. The compost is re-conditioned by immediately lowering the temperature of the compost to 140oF (60oC) by flushing the room with fresh air. Thereafter, the compost is allowed to cool gradually from 140 to 115oF (60 to 46oC), at a rate of 2 to 5oF (0.5 to 2oC) each day for 5 to 6 days. Temperatures are held at 122oF (50oC) or slightly lower, if necessary, until all traces of ammonia are dissipated. Gaseous ammonia is inhibitory of mushroom growth. At 115 to 140oF (46 to 60oC), the actinomycetes Streptomyces and Thermomonospora spp. are common. At 110 to 130oF (43to 55oC) the fungi Humicola and Torula spp. are common. These fungi are the most efficient deammonifiers. During conditioning, the ammonia is converted into microbial protein by de-ammonifying actinomycetes and fungi. Levels of ammonia should be below 10 ppm and is measured by sense of smell, cresyl orange on filter paper, red litmus paper, and/or air samplers using gas detection tubes.

Figure 1. Diagram of the changes taking place during preparation of substrate (Compost), from stacking of the pile until spawning (from Vedder).

During conditioning the compost becomes well flecked with whitish actinomycetes and on the surface gray mycelium of Humicola spp. appears. Microorganisms convert ammonia and nitrates to proteins, causing a change in the compost from alkaline to near neutrality. The production of proteins shelters nitrogen, giving an apparent increase of nitrogen in the compost as a function of dry weight. Once ammonia is gone, the temperature of the compost is dropped to spawning temperatures of 76 to 80oF (24

A finished compost at the end of Phase II has the following characteristics (see figure 1):

a) the ammonia odor is gone (less than 10 ppm-Dräger and red litmus paper no longer turns blue) and it doesn’t smell raw;

b) pH is about 7.5;

c) lost its stiffness, it is soft and pliable and can be sheared easily;

d) has plasticity, when squeezed holds its form;

e) moisture content is about 68%;

f) temperatures are lower than 75-80oF;

g) nitrogen content is 2.0 to 2.3%;

h) C:N ratio is 16:1; and

i) ratio of fungal/actinomycetes/bacteria biomass is about 2:8:1. The total microbial biomass of compost is approximately 2% of the compost dry weight.

Up to 30% of the dry matter of the raw materials that went into making the compost is consumed during Phase I and another 20% during Phase II. Consider this at starting so at the end of Phase II there is 5 to 7 Lb of dry compost per ft2 (24 to 34 Kg/m2

“Seeding” and “Cultivation”

• Spawning or Inoculation

The inoculation of substrates is called spawning. Microscopic spores form within a mushroom cap, but their small size precludes handling them like seeds. Mycelium can be propagated vegetatively on a sterilized mixture of grain, water and chalk, and commercial mushroom producers purchase spawn from specialized spawn companies. The sterilized mix with the grains is inoculated with Agaricus mycelium, and incubated at 74oF (23oC). Millet or rye is commonly used since the small seed can be efficiently mixed and distributed throughout the compost. Once the grain is fully colonized by the mycelium, the product is called spawn. Spawn can be refrigerated at about 34-36oF (1.1-2.2oC) for few months.

Mushroom compost must be inoculated with mushroom spawn. Within each of the four major cultivars of Agaricus, there are various isolates varying in flavor, texture, and cultural requirements. The spawning rate is expressed either as a unit or quart per so many ft2 of bed surface (1 unit per 10 ft2 (~1m2 desirable) or on the basis of spawn weight versus compost weight. A 2 % spawning rate is desirable, although rates from 0.5 to 3% are used depending on strain. Compost is about 68% moisture out of Phase II; bring it to 70-72 % moisture at spawning.

With the tray system, the pasteurized and conditioned compost is re-mixed with the spawn as it moves along a conveyor belt or while falling from a conveyor into a mechanical tray handling line, where the trays are dumped, spawn, supplemented, surface leveled and compressed. Then, they are moved by forklift to the spawn running room designed to handle the vigorous environmental demands of spawn running. At spawning, delayed release nutrients (oils encapsulated in a denatured protein coat) or supplements also may be added. With spawning supplements yields can be increased one pound or more per ft2 (~4.9/m2

on the nutrient base. These nutrients become available to the growing mushrooms over the life of the substrate in the tray.

• Spawn Running, Incubation or Colonization

The colonization of the substrate is called spawn running. Colonization of the compost must proceed as rapidly as possible to prevent other organisms from becoming established. The optimum compost temperature for mycelial growth is 75-77oF (24-25oC). Air temperatures must be several degrees cooler to maintain this substrate temperature. Because of the heat generating potential of the compost, beds are not filled deeper than 12 inches (30 cm). Thermogenesis can cause damage to the fungus as well as stimulate thermophilic microorganisms and must be avoided. If the compost temperature increases to above 80 to 85oF (27 to 29oC), the heat may kill, damage or diminish mushroom quality. At temperatures below 74oF (23oC), spawn growth is slowed and the time interval between spawning and harvesting is extended. Relative humidity must be at least 90% during spawn run to minimize drying of the compost surface or the spawn. Room CO2 levels of 10,000 to 15,000 ppm (1 to 1.5%) are beneficial. Within 2-3 days after spawning, spawn grows producing a thread-like network of mycelium from all directions from a spawn grain throughout the compost. Mycelium from the different spawn grains fuse together, making a spawned bed of compost one biological entity. The spawn appears as a white to blue-white mass throughout the compost. Spawn runs of 13 to 20 days are common. The color of the compost changes from brown-black to a brown-yellow.

• Casing

The only economical method of forcing mushroom mycelium to change from its vegetative stage into its reproductive stage is by applying a casing layer atop the surface of the colonized compost. Casing is a top-dressing applied to the 85-90% spawn-run compost on which the mushrooms eventually form. This layer

) of tray surface to obtain profitable mushroom yields.

) of compost surface or as much as 25% and help reduce competitor fungi growing

provides a humid microclimate, a water reservoir, supports microbial activity, and a place where rhizomorphs form. The physical properties of the casing layer and the changes in the environmental conditions in the production room modify the micro-environment around the mushroom mycelia. These alterations to the nutritional and gaseous environment stimulate various bacteria which aid in the fruiting body formation.

Most growers use five parts of peat moss which is very acidic and must be neutralized with one part volume to volume hydrated lime [$Ca(OH)_2$]. Other mixtures include clay-loam field topsoil, a mixture of Sphagnum peat moss with ground calcitic limestone ($CaCO_3$), or reclaimed weathered, spent compost. These materials are good water reservoirs, have a neutral pH or are easily neutralized, are permeable to O_2 and CO_2, are low in nutrients and soluble salts, have an abundance of microorganism conducive to fruiting, and provide a place where rhizomorphs form.

Casing should have a pH of 7.0 to 7.5, which will fall as the casing is colonized due to acids (mostly oxalacetic acid) secreted by the mushroom mycelium. Casing should be able to hold moisture since moisture is essential for the development of a firm mushroom. The moisture level in a typical peat based casing is 70 to 75%, or 2 to 4% below saturation.

The thickness of the casing layer is about 1 1⁄2 to 2 inches (1.5 to 5 cm) distributed so the depth is uniform over the surface of the compost, and should be heat-pasteurized or formaldehyde-fumigated before applying to eliminate any insects and pathogens it may be carrying.

There are four commercial techniques that can be used for casing:

a) CACing (Compost Added to the Casing):

Most growers will CAC the casing layer, that is, chopped their best fully colonized compost and mixed into the casing material prior to placement on top of compost. The spawn strain used in the CACing must be the same as that of the compost. CACing is done at a rate of 0.05 - 0.1 Lb colonized compost per ft^2

(240-490 g/m^2

b) SPACing (Spawn Added to the Casing):

Some growers will mix grain spawn with casing material before placement. The principles of disease-free, reliable and identical strains pertain to this technique.

c) CI (Casing Inoculum):

Major spawn companies released a product similar to spawn that is mixed into the casing material.

Insures mushroom strain purity, ease of application, reduced disease problems and technical support.

d) SACing (Supplementation At Casing)

Nutritional supplements may also be added at casing. These products may increase the yield potential. Commercial products rich in proteins such as Spawn Mate ® are widely used. They are treated and formulated to provide a slow release of nutrients.

With the California tray system, the colonized compost trays are covered with the casing layer as they move along a conveyor belt, where they are surface leveled, pressed, and moved by forklift to the production room. In the production room they are stacked 4 to 6 tiers high, separated by 10-12 inches extension legs.

To prevent casing from desiccating, compost temperature should be kept at around 75-78oF (24-25oC). Some growers place moist newspaper over casing to maintain moisture and high CO2 concentrations for 6-7 days in growing room until pins form. Other means to provide high relative humidity is by watering the floor and walls of the growing room while the mycelium grows through the casing.

Within three days of application, the mycelium should be growing into the casing layer. Once mycelial growth is firmly established, the casing is gradually watered up to its optimum moisture holding capacity, by a series of light watering with a misting nozzle over a two to four day period. Water in the casing moves by capillary action to the surface where it is drawn into the air by evaporation, which slowly depletes the casing of the moisture needed to protect mushroom development. Therefore, in conjunction with an optimum casing moisture level, the relative humidity of the room must be held at 95%. Lower humidity must be accompanied by light but regular watering, 2 to 4 times daily. Optimum moisture capacity should be achieved at least two days before the mycelium reaches the top surface of the casing layer.

Agaricus will not fruit in the absence of microorganisms in compost but will fruit if activated charcoal is incorporated into sterile casing mixtures. The microbial flora especially Pseudomonas putida in the casing layer removes or decreases one or more substances produced by the mushroom mycelium

) of substrate surface.

including ethyl alcohol, ethyl acetate, and acetone that cause it to stay in a vegetative state.

Pseudomonas spp. have also been observed growing along mushroom mycelium.

• Ruffling, Scratching, Sealing and Overlay

Environmental conditions in the producing room after casing should be the same as during spawn running. The relative humidity is maintained between 90-100% and fresh air is kept to a minimum. The casing layer surface should be rough and open (ruffling) with minute mountains and valleys.

Watering must not damage the surface of the casing. Scratching the top of the casing may repair the casing surface. Some growers do this as a matter of routine. Scratching or ruffling should not be done when CACing. In a dry casing layer, the mycelium is characterized by a lack of rhizomorphs and an abundance of fine capillary type mycelia. The fine growth can totally permeate the casing layer, which then becomes hard, compact, and unreceptive to water (sealing). Most first-time growers apply too much water and the surface of the casing seals, seen as a loss of texture at the surface of the casing. Dry casing, high levels of CO2, and/or low humidity directly produce overlay, a dense mycelial growth that covers the casing surface and shows little or no inclination to form rhizomorphs. In contrast, the mycelium grows coarse and stringy in saturated compost, also resulting in poor growth. Generally, it is best to ventilate with fresh air as little as possible until the mycelium has begun to show or "lays over" at the top surface of the casing.

• Fruiting Body Formation

There is a sequence of stages for the fruiting body of the mushroom to be formed:

a) Rhizomorphs

Rhizomorphs look like thick strings and form when the very fine mycelium fuses together. Mushroom initials, and primordia, form on the rhizomorphs, so without rhizomorphs there will be no mushrooms. Also, it is important that the casing be uniform for the spawn to move into and through the casing at the same rate and, ultimately, for rhizomorphs and therefore the mushrooms to develop at the same time.

Five days after casing the compost temperature should be lowered about 2oF (~1oC) each day down to 63 oF (~17oC);air temperature may have to be 55-60oF(13-15oC), until small mushroom initials have formed. Throughout the period following casing, water must be applied intermittently to raise the moisture level to field capacity before the mushroom initials form.

b) Initials and Flushing

Mushroom initials develop after rhizomorphs have formed in the casing. Stop watering at the time when initials are forming. When the mycelium reaches the valleys of the casing surface the air in the growing room is flushed by introducing fresh air. The timing of flushing is very important and is something learned only through experience. With flushing air temperatures reduces to about 63oF (17oC), substrate temperatures are lowered, humidity is maintained at 95%, and the CO_2 level is reduced below 1000 ppm (0.1%) to initiate fructification. Flushing is started about 6 to 7 days after casing if the casing was CAC'd or up to 12 days if it was not. The initials are extremely small but can be seen as outgrowths on a rhizomorph. If the CO_2 is lowered too early by airing too soon, the mycelium stops growing through the casing and mushroom initials form below the surface of the casing. As mushrooms continue to grow, they push through the casing and are dirty at harvest time. Too little moisture can also result in mushrooms forming below the top surface of the

c) Pinning or Primordia Stimulation

Once an initial quadruples in size, the structure is a pin. Primordia, pins or pinheads are knots of mycelium that precede development into small mushrooms. Pins continue to expand and grow larger through the button stage, and ultimately a button enlarges to a mushroom. Sealed casing prevents the exchange of gases essential for mushroom pin formation. Pinning affects both the potential yield and quality of a crop and is a significant step in the production cycle.

Pins develop when the CO_2 content of room air is lowered to 0.08% or lower, depending on the cultivar, by flushing the growing room. Outside air has a CO_2 content of about 0.04%. All species of mushrooms require a set of environmental conditions for pinning that are different from the conditions for optimum mycelial growth. Cultivated mushrooms fruit at lower temperatures than the optimum for the growth of mycelium.

d) Flushes or Breaks

Harvestable mushrooms appear 18 to 21 days after casing. The mushroom crop grows in cycles called flushes, blooms or breaks. Other than light misting, any substantial watering before the button stage can result in damaged pins. But once the mushrooms have reached the button size, it is time to begin building the casing moisture back up to the peak reached at pre-pinning. Breaks occur in roughly 7 to 10 day harvest periods intervals, but this may be longer or shorter depending on the temperature, humidity, cultivar, and the stage when they are picked. This cycle repeats itself in a rhythmic fashion, and harvesting can go on as long as mushrooms continue to mature. Some fresh air is continually introduced into the growing room since high CO_2 levels cause long stems and underdeveloped caps. CO_2 levels may be slightly raised (depending on strain) for enlargement of the first break and the remainder of cropping. Button mushrooms are picked before the veil breaks and the stem elongates. Portobello mushroom, which are grown same as white button, except that fewer pins are produced by thinning, are picked after opening and expanding.

Most mushroom producers harvest for 35 to 42 days, although some harvest a crop for 60 days, and harvest can go on for as long as 150 days. Commercially the first 3 or 4 breaks are harvested. After that, the risk of building up pests is too great.

Crimini, Portobellini, and Portobello all darken and become scaly, a desirable trait, in low humidity and high air flow.

Harvesting & Post-Harvest Care

• Cropping or Harvesting Cycle

The air temperature during cropping should be held between 57 to 62oF (14 to 16.5oC) for good results. This temperature range not only favors mushroom growth, but cooler temperatures can lengthen the life cycles of pathogens and pests that might be present. The relative humidity in the growing rooms should be high enough to minimize the drying of casing but not so high as to cause the cap surfaces of developing mushrooms to be clammy or sticky. Water is applied to the casing so water stress does not hinder the developing mushrooms; in commercial practice this means watering 2 to 3 times each week. The amount of water depends on the dryness of the casing, the cultivar being grown, and the stage of development of the pins, buttons, or mushrooms. One can estimate how much water to add after first and each break has been harvested by realizing that 90 % of the mushroom is water and a gallon (3.78 L) of water weighs 8.3 Lb (3.77 Kg). One litter of water weighs one kilogram..

Outside air is used to control both the air and compost temperatures during the harvest period. Outside air also displaces the CO_2 given off by the growing mycelium. The more mycelial growth, the more CO_2 produced, and since more growth occurs early in the crop, more fresh air is needed during the first two breaks. The amount of fresh air also depends on the growing mushrooms, the area of the producing surface, the amount of compost in the growing room, and the condition or composition of the fresh air being introduced. Experience seems to be the best guide regarding the volume of air required, but there is a rule of thumb: 0.3 ft^3

volume 50 to 100% must be outside air.

Growing rooms can be illuminated to facilitate harvesting or cropping practices, but it is more common to use miner's lamps rather than illuminating an entire room.

Ventilation is essential for mushroom growing, and it is also necessary to control humidity and temperature. Moisture can be added to the air by a cold mist or by live steam, or simply by wetting the walls and floors. Moisture can be removed from the growing room by admitting a greater volume of outside air, introducing drier air, or moving the same amount of outside air and heating it to a higher temperature since warmer air holds more moisture and thus lowers the relative humidity. Heat can originate from hot water circulated through pipes mounted on the walls. Hot, forced air can be blown through a ventilation duct.

When mature mushrooms are picked, an inhibitor to mushroom development is removed from the system and the next flush moves toward maturity. Mushrooms are normally picked at a time when the veil is not too far extended. Consumers in North America want closed, tight, mushrooms (button) while in England and Australia open, flat mushrooms are desired. The maturity of a mushroom is assessed by how far the

/ft2

/min (0.09 m3

/m2

/min) when the compost is 8 inches (20 cm) deep, and of this

veil is stretched, and not by how large the mushroom is. Consequently, mature mushrooms are both large and small, although producers and consumers alike prefer medium-to large-size mushrooms. Picking methods often vary from farm to farm, usually by twisting the stipe and pulling the individual mushroom and cutting the base of the stipe or "stem".

• Spent Compost and Cookout

At the end of production cycle the remaining compost plus mushroom tissues is called spent compost. After cropping the production room may be steamed, cookout, for at least 12 hours at temperatures up to 160oF (171oC) to kill mushroom viruses, fly larvae and other pests which may be present in the crop or the woodwork. The spent compost is then hauled away and may be used as organic matter in agricultural fields. It can be used in gardens or soil mixes but the salts must be leached, since levels of calcium oxalate salts are high.

• Packing and Marketing

Packaging and presentation often vary from farm to farm. Freshly harvested mushrooms must be kept refrigerated at 35 to 45oF (1.7 to 7.2oC). After mushrooms have been harvested, they continue the respiration process. In addition to the heat of respiration, they contain “sensible heat” or “field heat”, which must be removed quickly so that the mushrooms can achieve a lower respiration rate. Among vegetables, mushrooms have the highest postharvest respiration rate. Vacuum cooling is the most effective method by using a tightly sealed refrigerated container and then moved to a conventional cooler. To prolong the shelf life of mushrooms, it is important that mushrooms “breathe” after harvest, so storage in a nonwaxed paper bag is preferred to a plastic bag. For transportation to the marketplace, use a climate-controlled truck, and display them on refrigerated shelves.

Yields and Biological Efficiency

For the 15-20 weeks it takes to complete an entire production cycle, from the start of composting to the final cookout, a mushroom grower can expect yields anywhere from 0 to 61⁄2 Lb /ft2 (~32 Kg/m2 yield depends on how well a grower has monitored and controlled the temperature, humidity, pests, and Biological efficiency is computed as the fresh weight of mushrooms produced divided by the dry weight of the substrate, expressed as a percentage. Thus, one pound of fresh mushrooms grown from one pound of dry substrate is 100% biological efficiency. In Agaricus production, a value of 100% is considered excellent, 70% is average, and 40% is poor. Economically, the most meaningful measure of performance may be the biological efficiency per unit of time, or percent biological efficiency divided by time.

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