

Basic Procedures

for

Agaricus Mushroom

Growing



PENNSTATE



College of Agricultural Sciences
Agricultural Research and Cooperative Extension

Introduction

Hippocrates first mentioned mushrooms when he wrote about their medicinal value in 400 B.C. The first mention of mushroom cultivation, distinct from a chance appearance in the field, was in 1652. Unfortunately, they were described as excellent for “making into compresses for ripening boils” but not as good to eat. In 1707, a French botanist wrote about mushrooms as “originating from a horse.” He went on further to note, “Spores upon germination developed into a fluff, this fluff planted into horse manure and covered with soil, would grow mushrooms.” The first record of year-round commercial production was in 1780 when a French gardener began to cultivate mushrooms in the underground quarries near Paris. After the Civil War, gardeners introduced mushroom growing to North America by using dark areas underneath greenhouse benches to grow mushrooms.

In spite of some articles that say mushrooms can be grown in any dark hole or building, successful commercial mushroom growing requires special houses equipped with ventilation systems. While mushrooms are usually grown in the absence of light, darkness is not a requirement. Mushrooms have been grown in unused coal and limestone mines, old breweries, basements of apartment houses, natural and man-made caves, rhubarb sheds, and many other unusual structures. Mushrooms were reportedly grown in an old dairy barn, which was so damp that cows living in it had died of pneumonia. In 1894, the first structure specifically designed to grow mushrooms was built in Chester County, Pennsylvania, which is usually referred to as the mushroom capital of the world.

Growing mushrooms is a waste-recycling activity. Mushroom farms benefit the environment by using many tons of mulch hay, straw-bedded horse manure, and poultry manure. These products are considered agricultural waste products and would not have a home if it were not for mushroom production. Mushroom production is both an art and a science with many complex and distinct stages.

This fact sheet will outline the overall mushroom production cycle and give a brief description of each of the production stages. Phase I and Phase II composting, spawning, spawn colonization (Phase III), casing, case run, pinning, and harvesting are the primary stages of the mushroom production cycle. The specific criteria (temperature set points, carbon dioxide concentrations, and so forth) involved in each stage will change depending on different mushroom crops and different mushroom growers, but the basic concepts and methods of mushroom production remain constant. Although a written description of mushroom growing may seem simple, the process of preparing a composted substrate and its pasteurization is quite complex. Potential growers are encouraged to gain cultural experience on an existing farm before embarking on a private enterprise.

A few mushroom farms are located in limestone caves where the rock acts as both a heating and cooling surface, depending on the time of the year. Mushroom growing is not necessarily appropriate for caves or abandoned coal mines since they have too many intrinsic problems to be considered reliable sites for mushroom farms. The same is true for other dark, humid spaces of any sort. Limestone caves require extensive renovation and

improvement before they are suitable for mushroom growing. Composting takes place above ground on a wharf, and only growing and harvesting occur in the cave.

A Review of Mushroom Growing

The mushroom is a fungus and is quite finicky about its food source. Mushrooms lack the ability to use energy from the sun. They are not green plants because they do not have chlorophyll. Mushrooms extract their carbohydrates and proteins from a rich medium of decaying, organic-matter vegetation. This rich organic matter must be prepared into nutrient-rich substrate composts that the mushroom can consume. When correctly made, this food may become available exclusively to the mushroom and would not support the growth of much else. At a certain stage in the decomposition, the mushroom grower stops the process and plants the mushroom so it becomes the dominant organism in that environment.

The sequence used to produce this specific substrate for the mushroom is called composting or compost substrate preparation and is divided into two stages, Phase I and Phase II. Each stage has distinct goals or objectives. It is the grower's responsibility to provide the necessary ingredients and environmental conditions for the chemical and biological processes required to complete these goals. The management of starting ingredients and the proper conditions for composting make growing mushrooms so demanding.

Making a Composted Substrate

Many agricultural by-products are used to make mushroom substrate. Straw-bedded horse manure and hay or wheat straw are the common bulk ingredients. “Synthetic” composts are those in which the prime ingredient is not straw-bedded horse manure. If bulk ingredients are high in nitrogen, other high-carbohydrate bulk ingredients—such as corncobs, cottonseed hulls, or cocoa bean hulls—are added to the mix. All compost formulas require the addition of nitrogen supplements and gypsum.

Additional nitrogen-rich supplements are added to composts to increase the nitrogen content to 1.5–1.7 percent for horse manure or 1.7–1.9 percent for synthetic; both are computed on a dry weight basis. Poultry manure is probably the most common and economical source of nitrogen. A variety of meals or seeds, such as cottonseed meal, soybean meal, or brewer’s grain may also be used. Inorganic or nonprotein nitrogen sources such as ammonia nitrate and urea are also used, but only in small amounts when high-carbohydrate bulk ingredients are used. Gypsum is added to minimize “greasiness” and to buffer the pH of the compost. Gypsum increases the flocculation of colloids in the compost, which prevents the straws from sticking together and inhibiting air penetration. Air, which supplies oxygen to the microbes and chemical reactions, is essential to the composting process. Gypsum may be added early in the composting process, at 70–100 lbs per ton of dry ingredients.

A concrete slab, referred to as a wharf, is required for composting (Figure 1). In addition, a compost turner to aerate and water the ingredients and a tractor-loader to move the ingredients to the turner are needed. Water used during a substrate preparation operation can be recycled back into the process. It is, in a sense, a closed system. Water runoff into the environment is nonexistent on a properly managed substrate preparation wharf. Water collected in concrete pits or a sealed lagoon is aerated and recycled to soak bulk ingredients before the composting process begins.

Conventional Phase I composting begins by mixing and wetting the ingredients as they are stacked. Most farms have a preconditioning phase in which bulk ingredients and some supplements are watered and stacked in a large pile for several days to soften, making them more receptive to water. This preconditioning time may range from 3 to 15 days. The piles are turned daily or every other day. After this pre-wet stage, the compost is formed into a rectangular pile with tight sides and a loose center. A compost turner is typically used to form this pile. Water is sprayed onto the horse manure or synthetic compost as these materials move through the turner. Nitrogen supplements and gypsum can be spread over the top of the bulk ingredients and are thoroughly mixed by the turner. Figure 2 is a close-up of a machine

Figure 1. Traditional compost wharf, showing pre-wet pile on the right and the ricks or windrows on the left.



“eating” its way through a compost pile. Once the pile is wetted and formed, aerobic fermentation (composting) commences as microbial growth and reproduction naturally occur in the bulk ingredients. Heat, ammonia, and carbon dioxide (CO₂) are released as by-products during this process. Compost activators, other than those mentioned, are not needed.

As temperatures increase above 155°F (70°C), microorganisms cease growing and a chemical reaction begins. Concentrating and preserving complex carbohydrates is one goal of Phase I. The quantity and the quality of nitrogen in the system are changed to a type of nitrogen that Phase II microorganisms and, eventually, the mushroom will use as food.

Adequate moisture, oxygen, nitrogen, and carbohydrates must be present throughout the process; otherwise, the process will stop. This is why water and supplements are added periodically and the compost pile is aerated as it moves through the turner. Oxygenation is achieved in conventional outdoor ricks by natural convection. The high pile temperatures draw ambient air through the sides of the stack, and as the air is heated, it rises upward through the stack—a process commonly referred to as the chimney effect (Figure 3). The sides of the pile should be firm and dense, yet the center must remain loose throughout Phase I composting. The exclusion of air results in an airless (anaerobic) environment. As the straw or hay softens during composting, the materials become less rigid and more compact while substrate density increases. Thus, less air reaches the bottom and center of the pile. A lack of oxygen may occur after the large quantities of water are added to the dry bulk ingredients and before sufficient heat is generated to start the

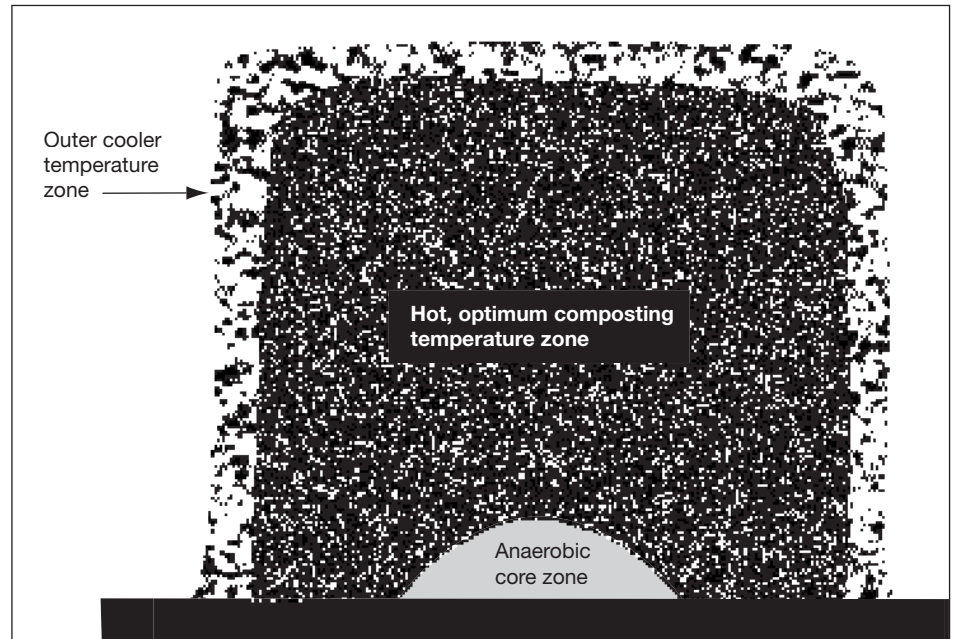
draw of air into the pile. Under anaerobic conditions, organic acids and other deleterious chemical compounds are formed. Therefore,

preparing substrate under aerobic conditions, where less offensive odors are produced, is better for mushroom growers.

Figure 2. Self-propelled compost turner moving through a compost rick or pile.



Figure 3. Cross section of a compost pile showing the different temperature zones and air movement (blue arrows) caused by the chimney effect.



Aerated Phase I Composting

Improving community relations has led to alterations in the way the Phase I mushroom composting process is carried out. As urban areas encroach on rural farmland, residents have made odor-related complaints and legal battles have ensued, which suggest a need for more stringent odor-management practices.

If the pile is not turned and aerated during Phase I composting, oxygen may become limited and anaerobic conditions may develop along the bottom of the stack. As the anaerobic

core gets larger, more offensive odors are produced. In order to maintain aerobic conditions throughout the entire substrate pile, supplemental aeration is sometimes used. This aeration is accomplished by using a fan to force air up through a concrete pad with a series of evenly distributed openings and into the substrate material. This design is referred to as an aerated floor. Systems have been built with structural sidewalls, usually of concrete and occasionally of wood, to form the piles with a uniform height and depth (Figure 4). Aside from aerated floors and structural sidewalls, there is great variation among bunker systems currently being used for Phase I.

Figure 4. This aerated substrate preparation system has a piped concrete floor under the substrate that forces air through the substrate to maintain aerobic conditions during the composting process.



Aerated composting systems are replacing conventional ricks throughout Europe and are beginning to gain acceptance in North America as the quest to manage odors continues. Europeans were the first to regulate emissions from their agricultural operations. Therefore, most European mushroom composting operations have employed some type of enclosed or environmentally controlled Phase I system. In North America, a few systems have been built to test the technology. Eventually they may become common at commercial operations. Unfortunately, little information is available to show how these systems reduce emissions. Therefore, determining how effective aerated systems are in reducing odors is difficult.

Phase I is considered complete as soon as the raw ingredients become pliable and are capable of holding water, the odor of ammonia is sharp, and the dark-brown color indicates that caramelization and browning reactions have occurred. At the beginning of Phase I, the substrate is bulky and yellow. At the end of Phase I substrate preparation, the substrate should be dense, chocolate brown in color, and have a strong odor of ammonia. The substrate still has some structure so aeration can be maintained during Phase II composting. The potential fresh mushroom yield depends on the amount of dry weight filled. In order to achieve a substrate density in the growing structure necessary to support an economical mushroom yield, the substrate at fill has to be short or dense enough to attain a high substrate dry weight.

Growing Systems (Phase II)

Once Phase I is complete, the substrate will be filled into a system for Phase II substrate preparation and to grow the mushrooms. Phase II takes place in one of three main types of mushroom-growing systems, depending on the type of production system used. The difference in the mushroom-growing systems is the container in which the crop is processed and grown. With a multizone system, the substrate is filled into boxes or trays and moved from room to room as shown in Figure 5. Each room has a different heating, ventilating, and air-conditioning (HVAC) system designed for a specific stage in crop development. A single-zone system—or bed farm—consists of several large, stacked beds or shelves within a single room (Figure 6). The substrate is filled into these beds after Phase I, and the crop remains in the one room throughout the process. Bulk pasteurization or tunnels are systems where the substrate is filled into “tractor-trailer”-type bins (called tunnels) with perforated floors and no covers on top of the compost (Figure 7). Phase II and, occasionally, the next phase of growing are carried out within these tunnels. The substrate may then be filled into a tray, shelf, or even plastic garbage bags for the remaining part of the process (Figure 8).

Figure 5. A tunnel used for Phase II and/or Phase III (spawn-growing) systems.



Figure 6. Single-zone, bed, or shelved farm. These shelves are aluminum; many farms have wooden bed boards.



Figure 7. Trays used for a multizone system, moving through a tray-filling line.



Figure 8. Bag-growing system often uses substrate prepared in a bulk composting facilities.



Phase II: Finishing the Compost

Phase II composting is the second step of compost substrate preparation. The first objective of Phase II is to pasteurize the composted substrate. The composted substrate is pasteurized to reduce or eliminate the bad microbes such as insects, other fungi, and bacteria. This is not a complete sterilization but a selective killing of pests that will compete for food or directly attack the mushroom. At the same time, this process minimizes the loss of good microbes.

The second goal of Phase II is to complete the composting process. Completing the composting process means eliminating all remaining simple soluble sugars and gaseous and soluble ammonia created during Phase I composting. Since ammonia is toxic to the mushroom mycelium, it must be converted to food the mushroom can use. The good microbes in Phase II convert toxic ammonia in solution and amine (other readily available nitrogen compounds) substances into protein—specific food for the mushroom. At the end of Phase II, volatile ammonia (concentration more than 0.05 percent) will inhibit mushroom spawn growth. Generally, ammonia concentrations above 0.10 percent can be easily detected by a person and are toxic to the spawn. Most of this conversion of ammonia and carbohydrates is accomplished by the growth of the microbes in the compost. These microbes are very efficient in using Phase I composting products, such as ammonia, as one of their main sources of food. The ammonia is incorporated as mostly protein into their bodies or cells. Eventually the mushroom uses these packets of nutrients as food.

Phase II objectives are possibly the most difficult procedures in growing mushrooms. Because of a composting or other cultural problem, growers sometimes have to adjust Phase II programs. The Phase II process takes anywhere from 7 to 18 days, depending on how the air and compost temperatures are managed to control microbial activity.

During Phase II in standard bed or tray systems, compost temperatures are brought down through all temperature ranges to ensure that all the different species have a chance to convert their specific source of carbohydrates. The composted substrate throughout Phase II should appear to have moderate “firefang”—a term referring to the white-flecking microbial growth pattern of the thermophilic microorganism (Figure 9).

Pasteurization (peak heat, boost) should be completed toward the start of Phase II. Effective pasteurization will eradicate harmful bacteria, nematodes, insects, and fungi. In general, air and composted substrate temperatures should be raised together to 140°F (60°C) for at least 2 hours. Growers make several compromises to this range, but it is a time-temperature relationship.

The good microbes grow best at temperatures from 115°F to 140°F; the more ammonia-utilizing microbes grow best in the temperature range of 120–128°F (47–49°C). The longer the microbes in the composted substrate remain in this optimum range with all the critical growth requirements available, the faster the ammonia will be converted. Understanding how these microbes grow and work in composted substrate should make the management of Phase II a little easier. The process of

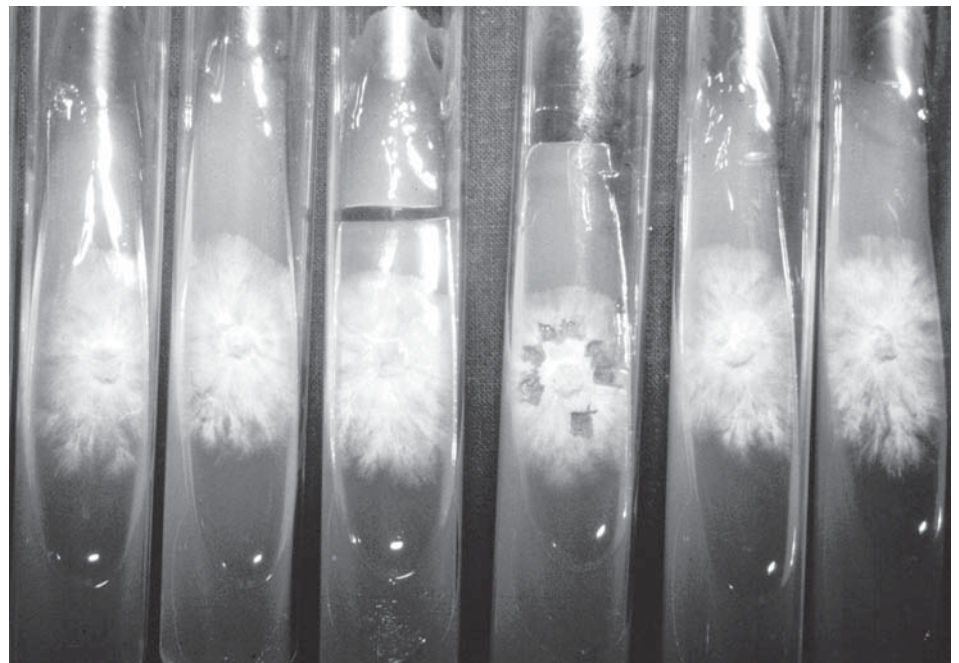
going through this temperature range will produce the most protein or the maximum amount of food for the mushroom. A good rule of thumb is not to drop the composted substrate temperature more than 5°F per 24 hours, which maintains the compost substrate in the desired range for about 4 or more days.

Near the completion of Phase II, growers check for ammonia in the compost. The nose is usually the best tool. However, ammonia-testing kits and strips are available to supplement the nose test.

Figure 9. Handful of composted substrate showing the white-flecking (“firefang”) microbial growth.



Figure 10. Pure culture of mushroom mycelium growing on an agar plate.



Spawn Maintenance

A desirable mycelial culture is pure—free of contaminants and of sectoring of other abnormalities. Contaminants include other fungi, bacteria, or insects growing on or infesting the culture media along with the desired mycelial culture. When a culture is first obtained, it should be transferred several times to fresh media to check for any form of contamination (Figure 10).

Sectoring is any type of mycelial growth that differs in appearance, growth rate, color or in any other way from the typical appearance of a given strain. Sectoring is often observed as a more rapidly growing area near the leading edge of growth, exhibiting a different growth habit from the rest of the culture. Other abnormalities that might appear in a culture are fluffy, aerial mycelia, thick or rubbery textures and color changes such as browning or darkening of the mycelium. Sectors of other change in vegetative growth could affect the productivity of the culture. Therefore, recognizing and avoiding propagation of abnormal mycelia to agar and further spawn production is very important.

There is no *in vitro* test to determine a stock culture's validity. A series of cropping trials must be conducted on the mycelial stock culture to determine a culture line's value. Mushroom yield, size, color, cap shape, and any other desired quality or growth factors are selected and then compared for each culture line.

Many commercially prepared spawn strains are available to commercial and noncommercial growers. All commercially grown strains are pure culture of edible, fresh mushrooms; some may vary in texture and growing requirements. Mushroom spawn is produced in several different strains or isolates. Hybrid White is a smooth-cap, high-yield, excellent processing strain. Hybrid Off-White has a cap that is slightly scaly on first break and is a preferred fresh-market strain, and Brown (Portabella, Crimini) produces a chocolate-brown, mature mushroom that is fleshy and has a strong, mature flavor.

Spawn Production

The process of making spawn remains much the same as Penn State professor emeritus Dr. Sinden first developed in the 1930s. Grain is mixed with a little calcium carbonate, then cooked, sterilized, and cooled. Small pieces of pure-culture mycelium are placed in small batches on the grain. Once the small batch is fully colonized, it is used to inoculate several larger batches of grain (Figure 11). This multiplying of the inoculated grain continues until the commercial-size containers—usually plastic bags with breathable filter patches—are inoculated. During the colonization of each batch, the containers are shaken every few days to distribute actively growing mycelia around the bag or bottle. During the process, temperatures are maintained at 74–76°F (23–24°C). Uniformity of the air circulating around the bags is important to ensure that all containers are kept within the desired temperature range. Mycelium is sensitive and its fruiting mechanism can be easily damaged at high temperatures.

Figure 11. Spawn grains used to seed the compost with mushroom mycelia. Spawn is cooked, sterilized, grain cooled, and inoculated with mushroom mycelia.



Spawning

On bed farms, spawn and supplement are broadcast over the surface of the substrate. Uniformity of this distribution is critical to achieve even spawn growth and temperatures. On tray or bulk farms, spawn is usually metered into the substrate during the mixing operation. Spawning is the cleanest operation performed on a mushroom farm. All equipment, baskets, tools, and so forth should be thoroughly cleaned and disinfected before spawning.

The amount of spawn used depends on the length of the spawn-growing period and compost fill weights. The use of more spawn will result in a quicker colonization and more efficient use of substrate nutrients. Improved colonization of substrate will help ensure that the mushroom mycelia will grow quicker than other fungal competitors.

During the spawn-growing period, heat is generated and supplemental cooling is required. Substrate tempera-

tures should be maintained at 75–77°F and relative humidity should be high to minimize drying of the substrate surface. Under proper conditions, the spawn will grow as a delicate network of mycelia throughout the substrate. The mycelium grows in all directions from a spawn grain. Eventually mycelia from different spawn grains fuse together, making a spawned bed appear as a white root-like network throughout the compost (Figure 12). As the spawn grows, it generates heat. If the compost temperature increases to above 80° or 85°F, depending on the cultivar, the heat may kill or damage the mycelia, reducing crop yield and/or mushroom quality. The time needed for spawn to colonize the compost depends on the spawning rate and its distribution, the compost moisture and temperature, and the nature or quality of the compost. A complete spawn run usually requires 14 to 21 days. The spawn-growing period is considered complete when spawn has completely colonized the substrate and the metabolic heat surge is subsiding.

Substrate Supplementa- tion

The compost has to provide the mushroom mycelium with a smorgasbord of food. Not only is lignin-humus complex and cellulose important, but protein, fat, and oils are also important. A good analogy is protein serves as the mushroom's "steak," carbohydrates its "potatoes," and lipids (fats and oils) its "butter." Like people, mushrooms should eat a balance of all these food types. The main source of "steak and butter" for the mushroom is from Phase II microbes. The dead cells of thermophilic fungi, bacteria, and actinomycetes "firefang" are the packages that deliver protein and fat to the mushroom (Figure 9). The addition of delayed-release supplements further enhances the protein and lipid content of the compost for the mushroom. Many of these supplements consist of a high-protein oil material, such as soybean meal, cornmeal, or feather meal, that has been treated to delay the availability of the nutrient for the mushroom. If an untreated supplement is added to the compost at this time, it often becomes a "candy bar" to other microbes, weed, or competitor molds. These molds grow more rapidly than the mushroom mycelium and can quickly colonize the compost, competing with the mushroom for nutrients. The oils or lipids in these supplements are used by the mushroom to stimulate the fruiting mechanism and increase yield by having more mushrooms initiate and develop. Yields can be increased from 0.25 to 1.5 lbs/sq. ft. of growing space. In addition, mushroom size may also be improved in compost with higher spawning-moisture content. However, in substrate that is not selectively prepared, these nutrients become more available to com-

Figure 12. Handful of mushroom substrate showing fully colonized spawn growth.



petitor molds. Often, if a farm is having composting problems, not supplementing until the problems are corrected is more economical.

Casing

The only method of forcing mushroom mycelia to change from the vegetative phase to a reproductive state is to apply a cover of a suitable material—called the casing layer—on the surface of the spawned compost. The function of a casing layer is to trigger the mushrooms to switch from a vegetative growth to a reproductive or fruiting growth. The mechanism that initiates the spawn to change from vegetative to reproductive growth is unknown, though several theories have been presented. The casing also functions to supply and conserve moisture for the mushrooms and their rhizomorphs (thicker mushroom mycelia) and acts to transport dissolved nutrients to the mushrooms. Casing supports the mushrooms and compensates for water lost through evaporation and transpiration. Rhizomorphs look like thick strings. They are formed when the very fine mycelia fuse together and grow through the casing. Rhizomorphs are thought to carry water and nutrients from the compost to the developing mushrooms (Figure 13). Mushroom initials—primordia or pins—form on the rhizomorphs. Without rhizomorphs, there will be no mushrooms.

The mushroom industry uses various materials to provide a suitable environment for fruit body formations. Presently, most mushroom growers use sphagnum peat moss or aged sphagnum peat moss buffered with limestone. Sphagnum peat is relatively inexpensive and readily available to North American growers. Pasteurized

Figure 13. Spawn growth in the casing and its thicker rhizomorph growth.



clay loam field soil; reclaimed, weathered, spent compost; and coir fibers are other materials used by growers.

Most sphagnum peat has a pH of 3.5 to 4.5. A neutralizing agent—usually calcium limestone—is added to bring the pH level up to 7.5. Processed, spent sugar beet lime or hydrated lime can be used. Due to its higher neutralizing capability and its greater solubility, only small amounts are required.

Soil, spent mushroom substrate, and coir fibers should be pasteurized to eliminate any insects and pathogens they may be carrying. However, peat moss-based casing does not need pasteurization because it is inherently free of mushroom disease spores and pests. Distributing the casing so the depth and moisture are uniform over the surface of the compost is important. Such uniformity allows spawns to move into and through the casing at the same rate and, ultimately, for mushrooms to develop at the same

time. Casing should be able to hold moisture because moisture is essential for the development of a firm mushroom.

CAC or CI

Fully colonized spawn run substrate is used to introduce mycelia into the casing layer. This is often used to improve crop uniformity, crop cycling, mushroom quality, and yields (Figure 14). Spawn run compost at casing (CAC) is used to inoculate the casing during the mixing or application of the casing. CAC is now produced much like spawn—in aseptic conditions—by those who produce and supply spawn to growers. This process is called casing inoculum (CI). By adding the mycelia uniformly throughout the casing, the spawn growth into the casing is quicker and more even. The time from casing to harvest is reduced by 5–7 days so that the rooms can be cycled faster or more breaks can be harvested in the same

time. Mycelial growth is uniform on the surface, which encourages the mushrooms to form on the surface as well. Therefore, they are cleaner. Yields are improved since the mushroom growth is uniform and crop management is easier. In addition, more mushrooms are produced from areas that may have less nutrition.

Managing the crop after casing requires that the compost temperatures until flushing be held at spawn-growing temperatures. After flushing, compost temperatures are lowered and air temperature becomes the primary control point. Throughout the period following casing, water must be applied intermittently to raise the moisture level to field capacity before the mushroom pins form.

Watering or Irrigation

The moisture content of the casing often determines the uniformity of the casing depth. Casing, both by equipment and by hand, becomes more difficult as the casing material increases in moisture (Figure 15). Peat moss casing will lump up or adhere to the different parts of the equipment, making the flow of the material uneven.

Knowing when, how, and how much water to apply to casing is an art form that readily separates experienced growers from beginners. Watering the crop is the most delicate operation in mushroom growing. Although each grower may have his or her own preference, no specific casing-management practice and casing material are universally accepted. Despite so much diversity, many growers are still able to harvest good crops with good fresh-market quality.

Although much has been written about when and how much water to apply at certain stages in the crop's development, most growers rely on their ability to "read" the crop and determine how the mushrooms look from day to day. Water constantly moves throughout the cropping period: water is lost through evaporation and transpiration, and the mushroom takes up water into its cells; water is replaced when watering the casing layer. The increase in the weight of the mushroom from pinning to maturing is related to the rapid uptake of water from the casing and compost. The mushroom doubles in size 2 days before harvest, putting more strain on the pipe system in the compost and casing. As the mushroom matures during a flush, its weight gain is attributed to the accumulation of nutrients and water from the substrate.

Figure 14. Difference in time when CAC or CI is added to the casing. The two figures on the left and the two on the right show the difference in spawn growth over time into the casing.

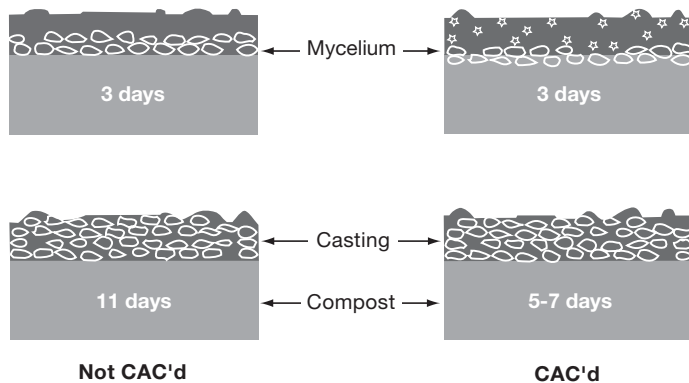


Figure 15. Most watering is done by hand, although newer farms use hand-propelled watering trees.



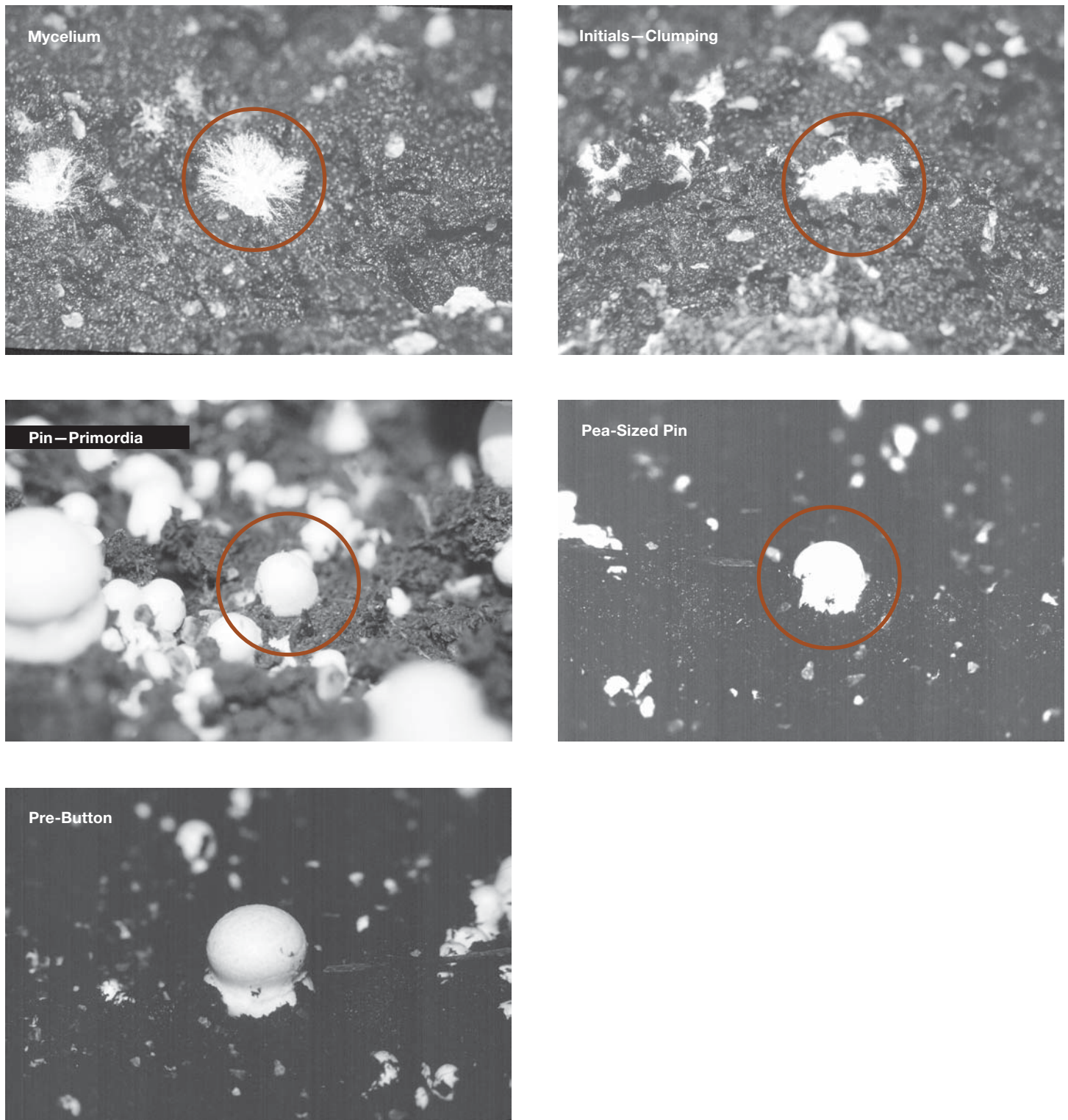
Pinning

Mushroom initials develop after rhizomorphs have formed in the casing. The initials are extremely small but can be seen as clumps on a rhizomorph. As these structures grow

and expand, they are called primordia or pins (Figure 16). Mushroom pins continue to grow larger through a pre-button stage and ultimately enlarge to mature mushrooms. Mushroom harvesting begins 15–21 days after casing, which is normally 10–12 days after flushing and 7–8 weeks after

composting started. The cultural practices used during pin development and cropping include the management of air and compost temperatures and CO₂ content of room air, and is often dependent on the strain and number of pins the grower wishes to form and develop.

Figure 16. The developmental stages of the fruiting process.



Air-handling systems regulate the amount of fresh air entering the room and temperatures within the room. Ventilation requirements depend on the amount of mushrooms to be grown on the beds, heat, and CO₂ production, which increases with temperature. Uniform air movement and circulation is important to prevent stale air with high CO₂ levels from building up around the mushrooms, which lowers fresh quality. Air temperature is maintained in a range of 60–66°F (15–17°C); CO₂ levels range from 1,000 to 2,500 ppm (1–2.5 percent) during the pinning and cropping stages. The most critical stage of the mushroom's development for fresh quality and yield improvement is during the Rapidly Expanding

Stage (RES), when the mushroom doubles in size every 24 hours (Figure 17). This expansion stage depends on temperature, moisture of the compost, and casing. The environment inside a production room determines the rate of transpiration, which aids in the flow of nutrients and moisture into the mushrooms.

Mushroom size is dependent on the number of pins that develop for a break or flush and by how the crop is prepared and managed. Portabella mushroom growers have learned to manage the pin set to achieve enough pins for good yield, yet, more important, to attain the right amount of pins to produce the large mature mushrooms for the Portabella market.

Figure 17. Mature mushrooms ready for harvesting.



Harvesting

Mushrooms are harvested over a 2–4-day period in a 7–10-day cycle called flushes or breaks. When mature mushrooms are picked, an inhibitor to mushroom development is removed and the next flush moves toward maturity. Timing of the breaks or flushes is managed by control of the watering, CO₂, and temperatures. The first two flushes account for the majority of the total yield, with the subsequent flushes tapering off to relatively low levels of production. Mushrooms are harvested by hand and are picked at a time before the cap becomes soft, indicating the mushroom is past prime fresh-quality potential (Figure 18). Harvesting rates depend mainly on the amount of crop on the beds and size of the mushrooms. Rates vary from 30 to 80 lbs/hour.

Some consumers seem to prefer closed, tight mushrooms, while others prefer stronger-flavored, more mature, open-cap mushrooms. Mushroom maturity is evaluated by how open the veil is, not by its size. Mature mushrooms are both large and small, although both farmers and consumers favor medium to large mushrooms. Growers harvest just three to four breaks per crop—a shorter harvesting time allows more crops to be produced in a year and helps to prevent disease and insect problems.

Diseased, malformed, and fly-damaged mushrooms are considered second-grade and are discarded. Diseased mushrooms should not be touched. Diseased tissue should be treated with registered chemicals, biopesticides, or common disinfectant materials such as salt or alcohol.

While mushroom yields vary, the

average yield for the United States in 2001 was about 5.75 lbs./sq. ft. With improving technology, such as air-handling systems, heavier compost dry weights, supplementation, and improved strains, growers have achieved yields higher than 8.0 lbs./sq. ft. However, these high yields are only achieved on farms that are properly equipped and have very experienced growers.

Post-Crop Pasteurization and Spent Mushroom Substrate (SMS)

When a house becomes unproductive, the crop is usually terminated. Before removing the spent substrate from the mushroom house, the grower “pasteurizes” it with steam to kill any diseases, pests or other biological activity that could interfere with a

neighboring house or subsequent crop. The steaming-off procedure is accomplished by maintaining a compost temperature of 140–150°F (60–70°C) for anywhere from 8 to 24 hours. The spent compost should be removed from the farm to reduce the chances of contaminating the subsequent mushroom crops at the farm (Figure 19).

Spent mushroom substrate (SMS) is the soil-like material remaining after a crop of mushrooms has been harvested. Spent substrate is high in organic matter, making it desirable for use as a soil amendment or soil conditioner. Sometimes this material is called spent mushroom compost. SMS still has some nutrients available for the mushroom. However, replacing the substrate and starting a new crop is more economical. Users should consider spent substrate clean of weed seeds and insects.

The typical composition of SMS fresh from a mushroom house will vary slightly. Since raw materials and other cultural practices change, each load of fresh spent substrate has a slightly different element and mineral analysis. Sometimes fresh substrate is placed in fields for at least one winter season and then marketed as “weathered” mushroom soil. This aged material has slightly different characteristics because the microbial activity in the field will change the composition and texture. The salt content rapidly decreases during the weathering or composting.

Spent mushroom substrate has many appropriate uses. SMS is excellent to spread on top of newly seeded lawns because it will provide cover against birds eating the seeds and will hold water in the soil while the seeds germinate. Since some plants and garden vegetables are sensitive to high

Figure 18. Mushrooms for the fresh market are only harvested by hand. The stem with some of the “root” attached is trimmed before the mushroom is placed in a market container.

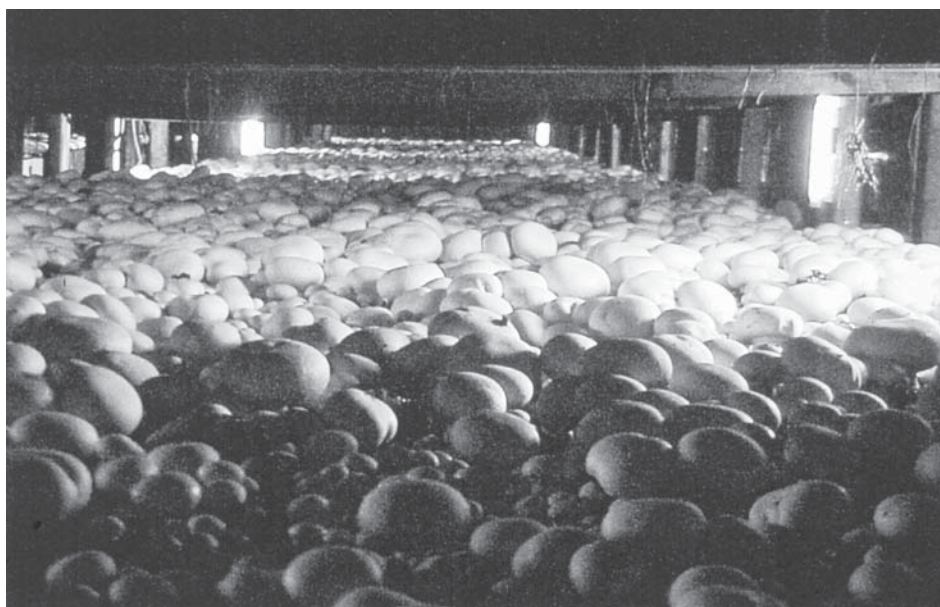


Figure 19. SMS being emptied from a mushroom farm.



salt content in soils, avoid using fresh spent substrate around those plants. You may use spent substrate weathered for 6 months or longer in all gardens and with most plants. Obtaining spent substrate in the fall or winter and allowing it to weather will make it ready for use in a garden the following spring. SMS can be applied as mulch in small amounts on turf all year-round. Spent substrate is a choice ingredient for companies that make potting mixtures sold in supermarkets or garden centers. These companies use spent substrate when they need a material to enhance the structure of a soil.

Related Readings

- Atkins, Fred C. 1974. *Guide to Mushroom Growing*. London: Faber and Faber Ltd.
- Blui-n, H. 1977. *The Mushroom Industry in Ontario*. Toronto, Ontario: Economic Branch, Ontario Ministry of Agriculture and Food.
- Chang, S. T. and W. A. Hayes. 1978. *The Biology and Cultivation of Edible Mushrooms*. New York: Academic Press.
- Lambert, L. F. 1958. *Practical and Scientific Mushroom Culture*. Coatesville, Pa.: L. F. Lambert, Inc.
- Penn State Handbook for Commercial Mushroom Growers*. 1983.
- Kligman, Albert M. 1950. *Handbook of Mushroom Culture*. Kennett Square, Pa.: J. B. Swayne.
- Vedder, P. J. C. 1978. *Modern Mushroom Growing*. Madisonville, Tex.: Pitman Press.
- Wuest, P. J., M. D. Duffy, and D. J. Royse. 1985. *Six Steps to Mushroom Growing*. The Pennsylvania State University Extension Bulletin, Special Circular 268.

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