SHIITAKE MUSHROOM CULTIVATION

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IN THE NORTHEAST UNITED STATES

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1. INTRODUCTION

This guidebook is an introduction into the production of shiitake mushrooms. It includes strain and formula recommendations, a basic budget for shiitake block production, and step by step instructions on producing supplemented sawdust shiitake blocks. This is intended for a beginning mushroom grower. This guidebook pertains primarily to shiitake mushrooms but many of these practices can be applied to any specialty mushroom. Currently, the specialty mushroom industry is an extremely exciting field to be in. Mushrooms are breaking out in many diverse areas, crossing different fields of science and application. Specialty mushrooms are being used and tested as medicine for people, animals, bees, and the planet. Their application as a food is expanding and more consumers are interested in mushrooms beyond the button. Specialty mushrooms are being used in the textile industry as dyes and the manufacturing industry as a plastic alternative. Specialty mushrooms are also being developed as ecological indicators, bio-insecticides, and long term plant fertilizers. It seems conditions are just right for specialty mushrooms, and they are fruiting everywhere! With the growth of the use of specialty mushrooms in a variety of fields beyond just food, knowing the basics of how to grow mushrooms is a great skill set. This guidebook will introduce you to the basics of mushroom cultivation, the shiitake mushroom industry, and how to start a business growing shiitake mushrooms.

In 2018 national mushroom sales were at $1.2 billion. Specialty mushrooms account for about $105 million of those sales. This means in the United States specialty mushrooms sales account for just under 9% of total mushroom sales. 91% of all mushrooms sold are Agaricus bisporus (commonly known as the "button mushroom"). There are several reasons why the market is skewed in this direction. First, agaricus are produced on a massive scale with equipment,

technology, and services mainly geared towards supporting the growth of this mushroom. Second, the average price farmers received was $1.20 per lb. This is an extremely cheap mushroom making it easy for a wide range of consumers to purchase. Lastly, this is the mushroom the American public is familiar with. In this predominantly mycophobic (afraid of mushrooms) culture, going beyond the button is seen as risky and undesirable. Slowly, however, there is a shift occurring, and a wider range of mushrooms are being consumed in the United States. Specialty mushroom sales in 2016 were at $92 million, so over the last 2 years there has been an increase of $13 million or 14% in overall sales.

The term, "specialty mushroom" refers to any mushroom that is not Agaricus bisporus. The most consumed specialty mushroom is shiitake. In 2018, 10 million pounds of shiitake were produced in the U.S. at an average price of $4.44 per lb. Specialty mushrooms are gaining popularity for a variety of reasons. Public desire to decrease red meat consumption and the increase in vegan and vegetarian diets provide a market for alternative protein sources.

WHAT IS A MUSHROOM?

Mushrooms have been inspiring curiosity and wonder for thousands of years. They have long been associated with fairies and magic and, depending on the culture, revered or shunned. The rapid growth and disappearance associated with mushrooms inspires wonder and curiosity as well as fear and bewilderment. The **mushroom** specifically refers to a fruiting body of a fungus that can be seen by the naked eye and picked by hand. United States culture typically shuns mushrooms into a category associated with death, decay, disgust, and danger. As a result, mushrooms in this culture are typically put in the closet and only come out in the form of a single species: Agaricus bisporus. But recently the glimmering draw of mushrooms has become more and more enticing.

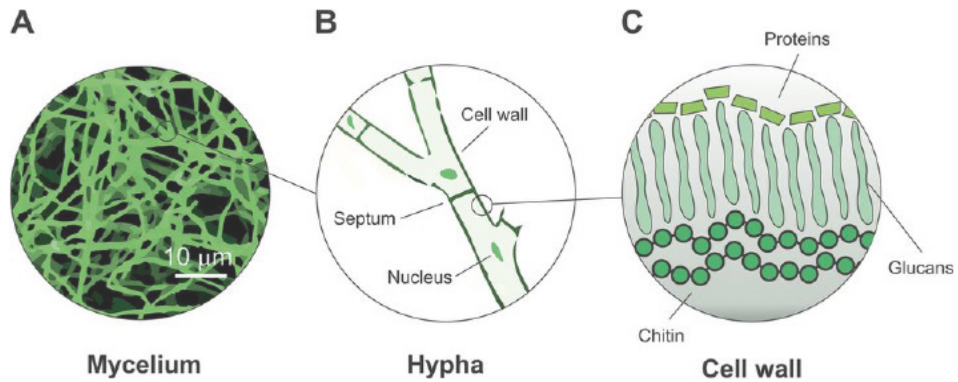
Specialty mushrooms are a great source of non-meat protein with some species offering 25% protein by dry weight. Dried shiitakes generally have about 18% protein content. General increased mushroom consumption in the American diet is a rising tide that lifts all boats. Between 1978 and 2014 United States per capita mushroom consumption rose 1.3 lbs from 2.7 lbs to 4 lbs per year. The awareness of potential health benefits of specialty mushrooms has also created a big increase in interest in mushrooms. Many new supplement companies and products are being developed and sold to cater to this market. Interestingly, by simply incorporating these mushrooms into our diets many of the same benefits can be obtained.

Modern culture continues to discover new and rediscover old uses of fungi. Some of these past uses include religious ceremonies by indigenous cultures like the Mayans; the discovery of preserved bodies like Otzi the Iceman, who was carrying two mushrooms with him 4000 years ago; and the Tassili cave paintings which could be over 10,000 years old depicting mushroom use. All of these discoveries point to a theme that mushrooms have been important to humans for a long time. Recently, wide areas of research and applications have included mushrooms. Bee health, human health, oil degradation, plastic degradation, biopesticides, bioinsecticides, plastic alternatives, protein rich food sources, and interspecies communication are all applications that mushrooms may offer. This organism that was banished to the closet is starting to get the attention it deserves.

KINGDOM FUNGI

Shiitake mushrooms, like all mushrooms, are located in the kingdom fungi. There are three factors that characterize a fungus. One, the cell walls are made of Chitin. Two, the mode of digestion is absorption. And three, they are heterotrophic. Let's pull these apart one by one. Chitin is a complex, rigid molecule which also comprises lobster and insect shells. Most human stomachs cannot digest Chitin. Since chitin is primarily indigestible when mushrooms are consumed raw, a majority of the nutritional benefits are locked away behind this chitin and unavailable. This is not to say one can eat poisonous mushrooms raw safely! Some compounds in the mushroom are available to our human system without breaking the chitin down but most require the degradation of the chitin before consumption. Chitin can be broken down simply by heat in the process of cooking or making tea or by alcohol in the case of making tinctures.

The second determining factor of a fungus is their mode of digestion. Fungi are unique from most animals because they do not have stomachs. Fungi secrete enzymes outside of their body, breaking down whatever they are growing in and absorbing the nutrients back into their body. The enzymes that are secreted by fungi are strong compounds that not only break down the food source but also protect the fungus. These enzymes are a cocktail of different antifungals, antibacterials, and probiotics which guide the microbial growth around the mycelial network. Some mushroom species, such as wine cap, require the presence of certain bacteria in order to fruit. The enzymes that are produced can be signals or food sources for certain bacteria to proliferate. One radically different consequence of this method of nutrition is that fungi need to grow on or in their food source. Fungi cannot survive in the mycelial state separate from their food source.

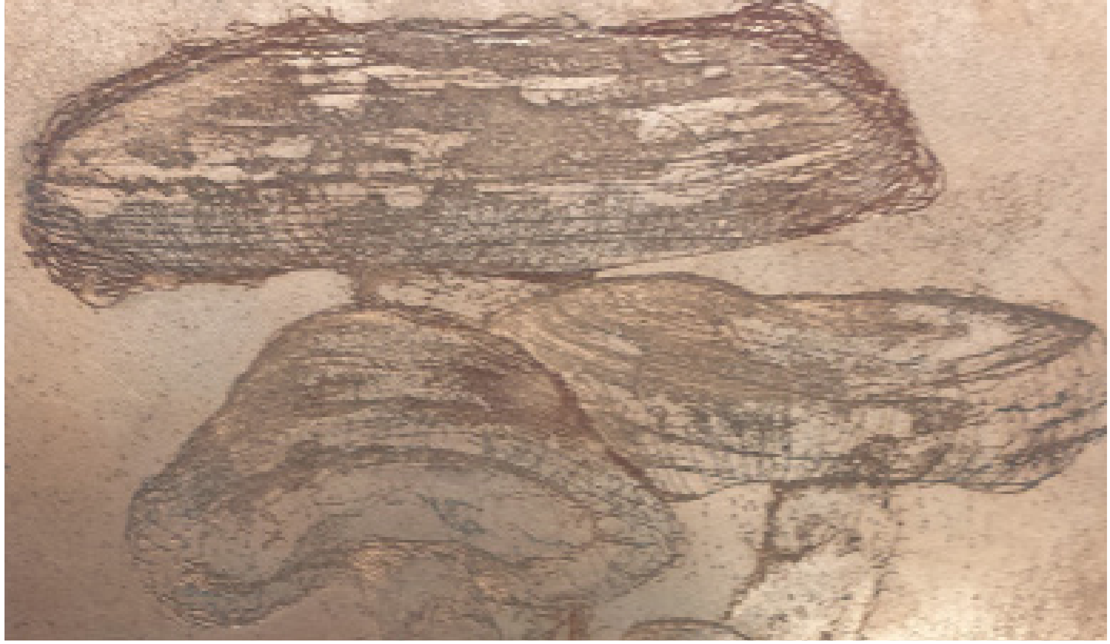


Lastly fungi are heterotrophic, meaning they rely on an external food source. Fungi are not capable of photosynthesizing. Unlike plants they cannot transform the sun's energy into matter. Fungi are the recyclers, the magicians throughout the cycle of life, that transform death into the possibility of life. Decomposition is not the only ecological role fungi play though. Let's go through 3 of the most common ecological roles fungi play.

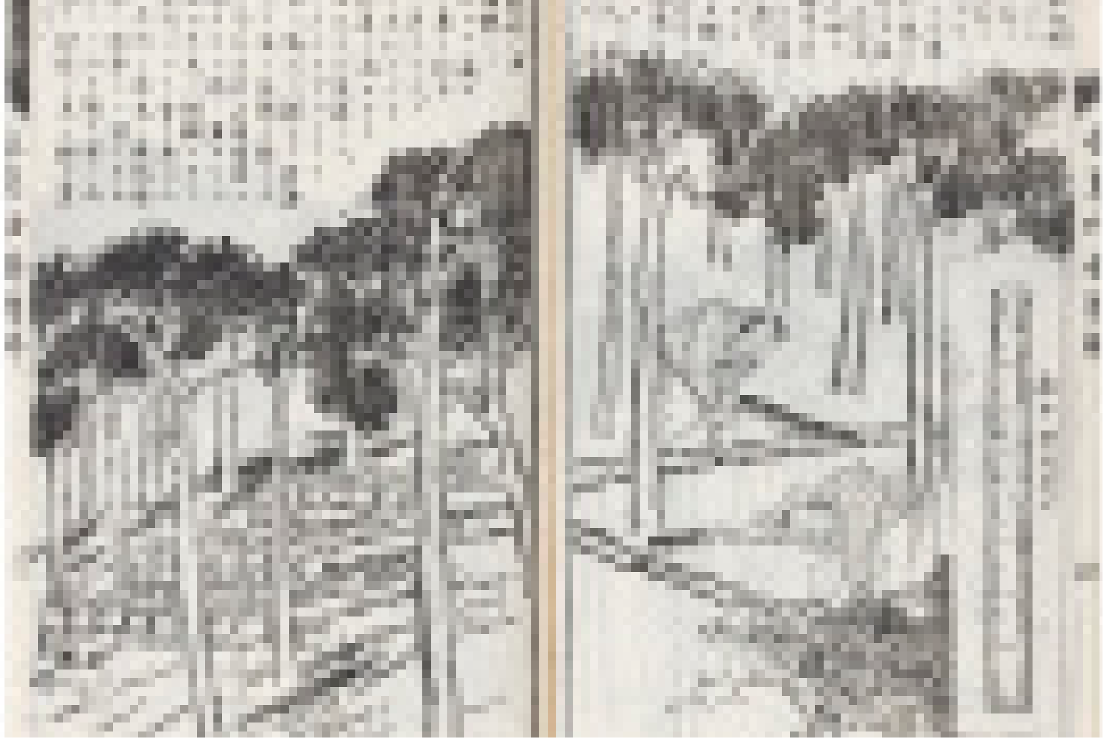
ECOLOGICAL ROLES OF FUNGI

Typically there are three ecological roles that fungi may play in an ecosystem: parasitic, mycorrhizal and saprophytic.

1. Parasitic fungi are fungi that attack a living organism. These fungi give the entire fungal kingdom a bad rap because of their perceived negative impact on human systems. Fungal parasites have a huge impact on crop loss in our agricultural systems. The continued use of monocultures and farming techniques that grow weak plants creates breeding grounds for fungal diseases. These diseases spread rapidly during wet periods and easily travel up the entire country over the course of a growing season. Many of these fungi do not create a mushroom but exist simply in the mycelial and spore stages of the fungal life cycle. Many of these fungi have asexual reproduction cycles where they can rapidly create genetically identical spores for further dissemination. There are some mushroom-forming parasites as well. Honey mushroom, an edible which grows abundantly throughout the U.S., and chaga are two examples. One network of honey mushrooms, covering a stretch of forest in Oregon that expands 2000 acres in a continuous mycelial mat has been described as the largest organism in the world. Human perception is typically that parasites are a bad thing, but when the largest organism in the world is a parasite, it gives us something to consider, it must be doing something right. Chaga is currently an extremely popular parasitic mushroom which grows on birch trees. Chaga is thought to have a variety of compounds that positively impact the human immune system.



2. Mycorrhizal fungi are a type of fungus that creates a symbiotic relationship with plant roots, "myco" meaning fungi and "rhizal" meaning roots. Simply a fungus associated with roots! These fungi are on over 90% of plant species. Most of the trees we look at in our daily lives have fungi attached to their root system. These fungi play multiple roles in assisting plant health, nutrient access, and communication across individuals. Amazing studies have been done to illustrate how connected ecosystems really are. These mycorrhizal networks literally connect individuals of the same and different species to each other. Mycorrhizae allow the exchange of nutrients, flowing from sick and healthy trees as well as old and young trees. Through these mycorrhizal networks, information is passed regarding different stressors like pests that may be invading an ecosystem. On an individual level mycorrhizal fungi also expand the root system of plants and help access nutrients that are locked in the soil like phosphorus and pockets of water. Mycorrhizal filaments are much smaller than roots so can penetrate tiny rocks and cracks that are otherwise inaccessible by the plant. In exchange for these nutrients and water plants trade sugars developed during photosynthesis.



3. Saprophytes are the last type of ecological role fungi are usually categorized into. (Figure 3) A saprophyte is an organism which consumes dead material. These fungi are what eat wood, leaves, manure, corpses. These are the fungi that link death to life, that continue the cycle of nutrient flow on earth. Saprophytes are the most common mushrooms cultivated by people. It is much easier to provide a mushroom with dead material and ideal conditions for growth and fruiting than doing the same on a living host. Things like logs and sawdust and wheat bran are very easy to store, handle, and manipulate to create favorable conditions for mushroom growth. Shiitakes are saprophytic mushrooms. Shiitakes like growing in dense hardwood logs. When grown on sawdust, bags are prepared to allow for small amounts of air exchange and minimal space between the substrate particles. Before going into the specifics of growing shiitake mushrooms we will first explore their life cycle.

HISTORY OF SHIITAKE

Shiitake mushrooms are native to Japan, Korea, and China. Shiitake is a Japanese word.. The translation of this word is simply a mushroom growing on the shii tree: "take" meaning mushroom and "shii" being a kind of evergreen tree that grows in Japan and Korea. The Shii tree is closely related to beech and oak, coming from the same taxonomic family. This is a likely reason why those are the preferred substrates for outdoor cultivation of shiitakes in the U.S. Shiitake cultivation has evolved from simple log selection methods in Japan to highly mechanized rapid growth methods also developed in Japan. In the beginning of shiitake cultivation freshly cut logs were placed next to logs producing shiitake mushrooms. The spores produced by the mushrooms hopefully colonized the freshly cut logs before another mushroom colonized the wood. Over time growers developed different methods of introducing spores to freshly cut wood but consistent colonization and fruiting was not achieved until the mid 1900's. In the 1920's K. Kitayama developed pure culture spawn, allowing mycelium with particular genetic traits to be used instead of spores. In 1943 K. Mori developed the practice of inoculating logs with wooden wedges that had mycelium throughout. Over several decades this evolved to be the drill and plug system that is now in wide use. These developments allowed log cultivation to become more efficient, reliable, and a larger commercial crop. Commercial cultivation on supplemented sawdust was developed and successfully conducted in Japan during the mid 1900's. Since then, bagging machines and methods of streamlining commercial cultivation have been extensively developed in Japan. One of the great things about shiitake mushroom cultivation is it can happen at both low- and high-tech scales. From backyard woods to large commercial farms shiitakes are now widely cultivated in the United States. Shiitakes are known by many consumers and have a great taste and texture. They can also be dried and still maintain a high quality of flavor and texture. All of these things give this mushroom a lot of versatility and potential for cultivation on any scale from homestead to large business.

LIFE CYCLE OF SHIITAKES

In total, there are 13 phylums in the fungal kingdom. Of these, only 2 produce mushrooms, a fruiting body that can be seen and picked by hand. Ascomycota and Basidiomycota are the two phylums that have fungi that produce mushrooms. Shiitakes are in the phylum Basidiomycota. The life cycle of Basidiomycota follows a circular relationship between a mushroom, spores, mycelium, and back to a mushroom. The mushroom is the fruiting body of the larger fungal organism. A mushroom is a temple of copulation with an intricate and flamboyant design. Mushrooms are an amazing expression and creation of the mycelium that enable sexual reproduction and dissemination of spores. They are the part of fungi humans have the deepest relationship with, using them as medicine, food, fire carriers, clothing, and many other things through human history. It is not until the mushroom forms that the nuclei in the mycelium fuse together and then divide to create 4 genetically unique haploid spores. Mushrooms provide a stage for spore dispersal through insects, animals, wind, and rain. Thousands of these spores are produced by each mushroom, blowing out into the forest to look for a new substrate to grow on.

When the spore lands, it can remain dormant for some time before germinating or it may immediately germinate mycelium. This mycelium starts growing into its new food source, expanding the mycelial network. Eventually the mycelium needs to fuse with another network in order to be able to produce a mushroom. The mycelium continually exudes enzymes into its growing medium to break down food, create barriers, claim territory, and communicate with its surroundings. Mycelium is a sentient dynamic stage of fungal growth. Most of the life of fungi remains at this stage. Mycelium only has one cell wall so it must remain in environments that have a high moisture content. You can find mycelium everywhere by rolling logs over or digging into leaves. Anywhere there is organic material mycelium grows. As the mycelium continues to develop, it eats more of the food source and eventually is triggered into producing a mushroom. It may be triggered by environmental cues or competition or a declining food source.

One of the amazing things about mushrooms is they can skip the spore stage and revert back to mycelium. By taking a tissue clone, a small piece of tissue from the mushroom, and placing it on a petri plate, you have an identical clone to the original mushroom. From here the mycelium can be expanded exponentially. Instead of going to spores and going through sexual reproduction a single strain can be expanded almost infinitely. This allows for growers to select mushrooms that produce well for them and use that exact same mushroom over and over. Most growers never work with the spore stage of the life cycle.

2. STRAINS AND SPAWN TYPES

Shiitake mushroom spawn comes in several different forms depending on what substrate you are growing on. Grain, sawdust, and plug spawn are the most common forms that are found. **Grain spawn** is typically a lower generation and has a higher nutrient profile. This makes grain spawn a good option when the substrate will be further expanded or if you want to add additional nutrients into the substrate. For example if inoculating grain with the intent of then adding it to a sawdust fruiting block you would want to use a first or second generation bag of grain spawn. If you were inoculating straw or supplemented sawdust, using grain could be a good option for adding additional nutrients into the substrate. One advantage of using sawdust in this case is that the mycelium is already used to eating sawdust so leap off might be faster off of sawdust than grain.

The generations of spawn are very straight forward. The first substrate inoculated from a petri plate is usually grain and called Generation 1. This is then expanded 8-10x into more grain which is Generation 2 grain. From here farmers usually either go to Generation 3 grain or sawdust. Most growers do not do transfers beyond 4 generations for fear of the strain losing vigor in fruiting, a phenomenon called strain senescence.

Sawdust spawn is the most common type of spawn used for commercial production of shiitake on logs. Sawdust is usually the cheapest of the spawn options and has a relatively quick leap-off because of the small particle sizes. Since there is very little in the way of food reserves for the mycelium to eat, it rapidly looks for a new substrate to grow on. Sawdust spawn typically comes in 5-5.5 pound bags and costs $20-25. Sawdust spawn is usually third generation when you are buying it from a spawn supplier. When inoculating logs, sawdust spawn requires a specialized tool that costs about $45 called a palm inoculator. Because of this, sawdust is best used when inoculating 20+ logs for multiple years.

{Fig.1}

Plug spawn is mycelium grown out on birch furniture dowels. The dowels are typically 5/16 in diameter and 1 inch long. They are usually a little bit more expensive than sawdust spawn and take about 30% longer to colonize. Plug spawn is a good option for growers who are inoculating 20 or less logs each year. **(Figure 1,2,3 show all three spawn types)**

Strain selection is an essential part to mushroom cultivation. Strain refers to a unique individual within a species. I like to compare this to humans. All humans are in the species Homo sapiens. But only 1 is referred to as Willie Crosby with this particular set of genetic information. Likewise all shiitake fall under Lentinula edodes but there are distinct individuals that express their genetic information differently. Just like in humans, this allows a lot of variability in the traits that are expressed. In humans, things like eye color, hair color, and size are influenced by this genetic make up. In shiitakes, things like ornamentation on the cap, substrate it grows in, size of fruiting body, yield, and speed of incubation are all influenced by strain. As you can tell, those are all critical aspects to cultivating shiitakes. For many growers a strain that grows fast, has large fruiting bodies, and fruits abundantly is the ideal. With fast growth, the timeline from raw substrate to mushroom is faster and the chance for contamination decreases. Large fruiting bodies typically lead to better shelf life, better handling capacity, and less harvest time. Obviously increased yields are a great thing when combined with the first two. The trick then is to find a strain that embodies all these things in balance. For example, during these trials there were two strains which grew at similar rates but had small differences in the mushroom size and the yield. This is where the grower will want to decide what kind of market they are focusing on. Should they go for the larger mushrooms, which consumers typically like more, but a smaller yield or the smaller mushrooms that have a slightly higher yield?


{Fig.2}

{Fig.3}

In all trials and cultivation conducted at Fungi Ally, strain selection is always the first step. To decide the best strain it is great to

- Talk to other mushroom growers or grower networks
- Trial 3 or 4 strains in your particular operation to see which performs best
- Research what the standard strain in the industry is (be sure similar methods of cultivation are used)
- Talk to spawn providers about the strains they offer.

Many spawn providers have already done a lot of trialing with strains and can point you in the right direction to suit your needs. Some of the larger spawn providers like Amycel, KSS, and Lambert only offer 1 strain. With shiitake, it is not advisable to use the strains produced by these companies because they have a unique method of cultivation where the block is browned outside of the bag. Most small scale farms do not have the capacity to do this. For this same reason you would not want to culture shiitake from the supermarket. Shiitake that has been bred to brown outside of the bag will not fruit well using other methods.

The research highlighted in this section looks to answer three questions:

1) What is the best strain to use for shiitake log cultivation?

2) What is the best strain to use for shiitake block cultivation?

3) Trialing on logs takes a minimum of 2-3 years; is there a correlation between a high yielding strain on supplemented sawdust and a high yielding strain on logs?

The answers are pretty clear from the data in this study:

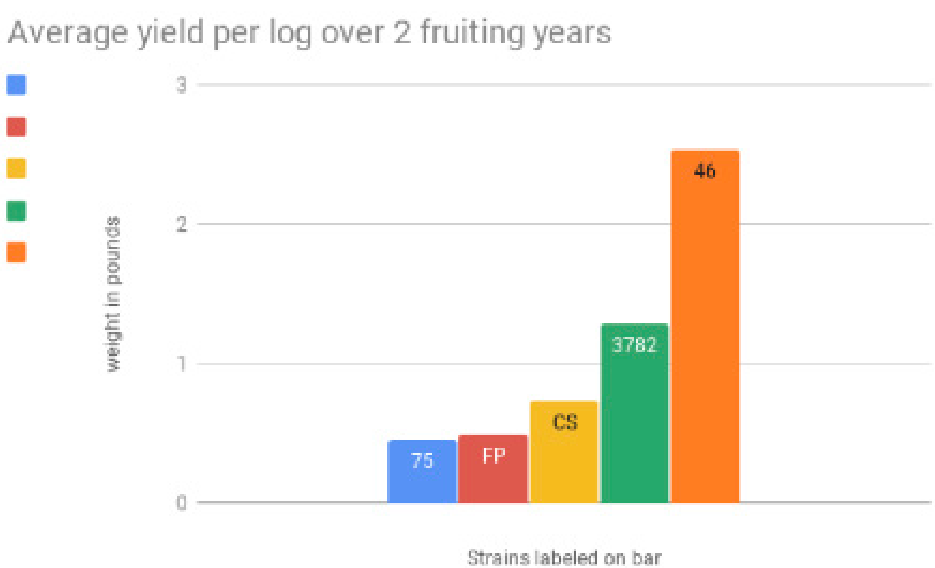
1) LE46 is the best strain to grow on logs.

2) 3782 has the highest yielding mushrooms while 3790 can approach similar yields with a larger higher quality mushroom

3) There is no correlation between high yielding strains on sawdust and on logs.

Strain selection for Logs

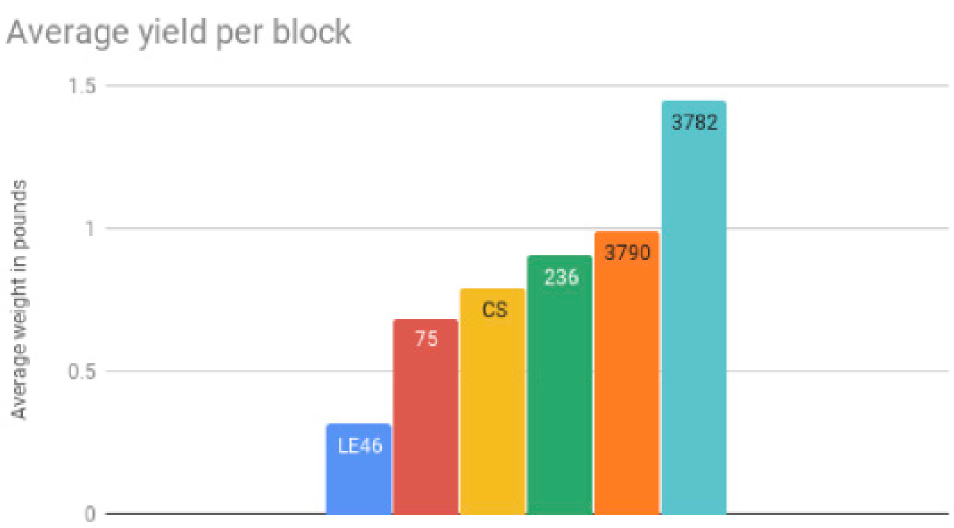
For cultivating on logs, five different strains were trialed. These strains were 75, FP, CS, 3782, and 46. The logs were inoculated in 2016 and fruited in 2017 and 2018. LE46 produced a little over 50 pounds over the course of 4 flushes, two during each year. The next highest strain was 3782 which produced about 25 pounds over the same 4 flushes. Speed of colonization was very similar between these strains with 3782 having a larger first fruiting but subsequent flushes were greatly over shadowed by LE46. Strain 3782 produced about 1/3 of a pound of mushrooms per flush. The LE46 strain had an average of about 2.5 pounds produced per log. This means each log produced about 2/3 of a pound of mushrooms per flush, which is about twice the amount of 3782! It is amazing that, controlling for all other factors, just selecting the appropriate strain can double the yield produced by a substrate. Economically this means a grower who selected 3782 to grow would get $250 while a grower that selected LE46 would get $500. This is with only 20 logs; imagine the impact on a mushroom farm that inoculated 200 logs a year. A simple switch between these two strains, while keeping everything else the same would result in increased revenue of $2,500. **(Figure 4)**



Strain selection for supplemented sawdust blocks.

The difference between strains was not as drastic in sawdust block production as on logs. Many growers aim to have about 1 pound produced on the first flush for a 5 pound shiitake block. Two strains exceeded or hit this mark, 3790 and 3782. 3782 is a fast colonizer which is typically ready to fruit in 6 or 7 weeks when incubated at 70 degrees. The mushrooms can be very small, just the size of a quarter, if the pin set is too large. They have a meaty consistency when picked with a slight curl, and fruiting is abundant; the average yield was about 1.4 pounds per block. In my experience this is a large fruiting for 3782, and in commercial production yields tend to be a little lower. 3790 averaged a fraction under 1 lb per block in our study. This mushroom has beautiful large mushrooms that are very dense. For a consumer or chef this is definitely a higher quality mushroom than 3782. 3790 took an average of a week longer in incubation and had a different pattern of popcorning. This is where the market will likely dictate which strain to have in production. There is the possibility to produce both, but it is always easier to work with one strain rather than two. If the target market is primarily farmers markets and chefs, they may be willing to pay a little more for 3790 to make up for the decreased yields. If selling on a larger scale to super markets or distributors, the higher yielding mushroom is likely the best option to stay competitive with pricing.

(Figure 5)



Correlation between different substrates

There is no correlation between fruiting yields on supplemented sawdust and log grown shiitakes. It is not possible to gather material on strains growing on supplemented sawdust and apply that information to a different substrate. Each strain needs to be tested with the substrate that it will be grown on. In this study LE46 did the worst with supplemented sawdust producing less than .4 lbs per block. On logs, however, LE46 was the best producing strain. This is part of the reason why testing strains and substrate mixture is an ever-ongoing process for all specialty mushroom farms. Depending on a farm's location and the substrate available, different mixtures of strains and substrates may work best. It is nice to have a formula of substrate and strain combination to start with that one knows works well before experimenting or even while experimenting. Keeping commercial production going while doing small trials to compare yields is a great practice for any small farm.

3. GROWING SHIITAKE MUSHROOMS ON LOGS

Log Selection

The first step to mushroom cultivation on logs is cutting and selecting logs to grow on. Logs are best cut between November and March. In trials done by Field and Forest logs that were cut in October and allowed to sit until April for inoculation had much faster spawn run than logs cut later in the winter. In some cases logs were fruiting in the same year as inoculation. It is okay to cut at any time of year but yields and colonization time are effected. A Cornell study showed yields were highest from logs cut in winter and inoculated in spring. Cornell did not look at cutting in the late fall and inoculating in the spring. The best results are achieved when logs are sourced in the fall when 30% of leaves have changed color. If logs have been sitting for 2+ months it is good to rehydrate them before inoculating by soaking them in water for 3-6 hours. The bark of the logs should be as intact as possible; avoid logs with large strips of bark removed. Dense hardwoods like oak, sugar maple, and beech are great species to use. Logs with a diameter of 3-8 inches that are about 4 feet long are ideal. Logs will be moved several times during the cycle of growing shiitake so sizes that are reasonable to move are important. Smaller logs colonize and fruit faster than larger logs. The last factor to think about during log selection is the ratio of sapwood to heartwood. Logs with a higher ratio of sapwood will offer more food for the shiitake to digest and offer a larger yield.

Source Spawn

As demonstrated earlier, sourcing strain and spawn is a key factor in abundant fruiting. Using LE46 or other strains that are high-yielding on logs is recommended. Fungi Ally offers several of these strains in both sawdust and plug spawn. A 5-pound bag of sawdust spawn can inoculate about 25 logs, while 100 dowels can inoculate 2-3 logs. Sawdust spawn tends to grow out faster than the dowels but requires a specialized tool called a palm inoculator.

Drill Holes

Depending on the type of spawn purchased and the tools available, the holes will be created differently. For plug spawn use a 5/16 drill bit to drill 1-inch deep holes. If using sawdust spawn use a 12 mm drill bit or whatever matches the inoculation tool you are using. If you are just inoculating two or three logs a regular corded drill will work fine. If you are inoculating 25+ logs and plan to do this year after year it is worth it to purchase a modified angle grinder. The angle grinder runs at about 10,000 rpm while a drill runs around 3,000 rpm. This makes the angle grinder MUCH easier and faster -

similar to the difference between using a screwdriver and a drill! To drill the holes, start about 1 inch away from the end of the log. Drill again 6 inches down the log. Continue to space holes every 6 inches down the length of the log. Start the next row of holes 2 inches away from the previous row, spinning the log around. The holes should be offset, so now you are drilling 2 inches below the original line and in the middle of the previous holes. Drill holes all the way around the circumference of the log so you end up with a diamond pattern.

{Fig.8}

Inoculate

This is the point where you add spawn to the log. If you have sawdust spawn, break it up with your fists or open palm before opening. Work the spawn into little pieces that can easily fill the tool being used. With a palm inoculator or similar tool fill the holes completely with spawn. This usually means stabbing the spawn 2 or 3 times and then inoculating each hole one at a time. There are several new tools in the U.S., like the Okuda inoculator, which allow for the inoculation of multiple holes at once after filling them up with spawn. These also seal the hole with a styrofoam cap instead of needing to wax. If using plug spawn simply place the plug on the hole and then tap it in with a hammer. The plug should be snug against the sides of the holes and be flush or slightly sunken below the surface of the log. When the spawn is slightly sunken below the surface it makes a nice area for the wax to pool and seal. This sunken seal will stay protected and last longer than wax that is protruding outside the layer of bark.

Wax

Melt wax and seal the holes with the hot wax. For the waxing process, cheese wax or beeswax is typically used. These waxes hold form as temperatures fluctuate and are a much better option than clay or paraffin wax which tend to crack. If the wax cracks or little pin holes are left, spawn can dry out and die. The wax prevents the spawn from drying out and keeps other fungi out of the log. Depending on the scale of operation, wax can be applied with a cotton ball type material on the end of a stick, a paint brush, or a specialized tool for applying wax.

Storage and Maintenance

Logs should be kept out of the sun and wind. North sides of houses and sheds are good places. Under conifer trees is a great place to store your logs. Deciduous trees allow sun in 6 months of the year so they do not provide ample year-round shade. Keep the logs off the ground on pallets or resting one end on another log. If the logs seem to be drying out, soak them for 4 hours. You can tell they are drying out if the cracks on the end easily allow a dime to be inserted into them. Spawn run, the process of the mycelium growing out into the log, typically takes 12-18 months.

Fruiting

After 12-18 months the mycelium should be grown throughout the entire log. The fruiting period in New England is between June and September. In late June of the year after inoculation, soak the log for 24 hours. Mushrooms should fruit within 7-10 days. Harvest, rest the log for 7-10 weeks, then soak and harvest again. This can be repeated 2-3 times a year. Depending on the diameter of the log, it will continue to fruit for 3-7 years!

4. GROWING SHIITAKE ON SUPPLEMENTED SAWDUST

Figure 6 below is based on per bag batch mixed of seven 18-gallon totes, 2.5 bags wheat bran, 1 gal gypsum creating 200 5-lb bags.

Item	Unit	Purchased Unit	Price	Cost
Sawdust	.25/200	Yard	10	0.01
Wheat bran	2.5/200	Bag	14	0.175
Gypsum	.1/200	Bag	16	0.008
Bag	1	Bag	1	0.23
Spawn	0.03	Bag	14	0.42
Equipment				0.05
Electricity	1/200	per run	25	0.125
Labor	1/200	16 hours @ $15/hr	240	1.2
Rent				0.25
Labor harvesting	1/30	30 blocks/ hour	15	0.5
Total				2.97
Contamination		10%		0.3
Final				$3.3

The process of indoor shiitake cultivation on supplemented sawdust follows the steps below. Fourteen steps may seem like a lot, but when this process is looked at in depth, fourteen is a simplification of all the steps along the way. When really zoomed in, this process has around 65 unique steps to turn raw substrate into raw cash all while using vegan methods. Our objective in this process is to efficiently transform substrate into fully colonized mycelial blocks that then produce copious amounts of mushrooms. To do

this, careful analysis of each step is needed, and continued trial and error on different steps is encouraged and fun.

1) Strain and formula selection. 2) Sourcing substrate. 3) Substrate storage. 4) Mixing substrate. 5) Bagging. 6) Steaming. 7) Cooling. 8) Inoculation. 9) Shaking. 10) Incubation. 11) Browning. 12) Fruiting Initiation. 13) Fruiting. 14) Harvest. (figure 11)

1) Strain and Formula Selection. Choosing the best strain and substrate formula is a critical first step to shiitake cultivation. Based on Fungi Ally trials (see Figure 6), either 3790 or 3782 should be used for indoor cultivation on supplemented sawdust. High yielding fruiting can be achieved with the basic formula put forward in Paul Stamets' Growing Gourmet and Medicinal Mushrooms. This is a mixture of hardwood sawdust, wheat bran, and gypsum. By dry weight, use 79% sawdust, 20% wheat bran, and 1% gypsum. At Fungi Ally, this equated to seven 18-gallon totes of sawdust, two and a half 25-lb bags of wheat bran, and 1 gallon of gypsum. Weights were calculated once and then placed into volume which could be easily repeated without constantly weighing. Other farms use home-built mixers which weigh out both substrate and water for each bag through a process known as dry bagging.

2) Sourcing substrate. This is a process of getting to know your local economy and local agricultural products. It is possible to simply go to Home Depot or other big box stores and order hardwood fuel pellets (HWFP) as a primary substrate. This can streamline production, but typically they are more expensive and wasteful in places where raw hardwood sawdust is available locally, which is most of the US. Finding a local sawmill that cuts exclusively oak or who will call you when they mill oak is best. Flooring mills tend to be extremely consistent and a great source of sawdust for mushroom farms. Be sure the mill knows not to mix in other dust. Our sawdust cost $10/yard when delivered in 30-yard batches. Wheat bran and gypsum can be easily sourced from local feed stores. Wheat middlings are usually available from animal feed companies and can be purchased in bulk and stored in silos to get extremely cheap pricing. Both wheat bran and mids can be used as a supplement. Wheat mids generally have more variables and contain germ, bran and sometimes flour all in one. It is best to get the nutritional analysis of this from whoever you are looking to purchase substrate from. Fungi Ally was paying $14 per 25-lb bag of organic wheat bran.

3) Substrate Storage. Dry storage is critical for any of the supplements. Gypsum should be kept in a dry place but is not typically sought after by rodents or other pests. Wheat bran, mids, or other supplements must also be kept in a dry location that is also free from rodents. If the substrate gets wet, other fungi and bacteria will develop causing it to be unusable. Do not try to use substrate that has other fungi growing on it already as this just increases the spore load you need to kill it off. Sterilization is a THEORY not a reality, so decreasing starting spore and biological load is key to having successful inoculation and inhabitation. Sawdust is okay to get wet if used within a month. It takes awhile for anything to start growing on sawdust. The biggest pitfall of sawdust is that in the winter, if dust is wet, it becomes frozen and extremely difficult to work with.

4) Substrate mixing. There are several different ways to mix substrate depending on your scale, budget, and ingenuity. The first is how Fungi Ally operated for 3 years: mixing with shovels on a concrete pad or tarp while spraying with water. This is highly labor intensive and physically demanding. It was possible while the owners were primarily doing this and in their mid-twenties but harder to turn over to employees. The second method, which I think is the best option for any mushroom farm growing more than 150 pounds of mushrooms a week, is a ribbon mixer. This is a piece of equipment designed for the potting soil industry but works great for mixing mushroom substrate. Substrate is loaded into the mixer and wet during the mixing process. This is the method that Fungi Ally moved onto using after 3 years of mixing by hand. Lastly, for more handy and industrious mushroom growers, homemade dry mixers are being developed. This allows the process of mixing and bagging to be combined into one step with sawdust and supplements added dry and then water added individually to each bag. This can all be done using a scale and flow meter to measure the exact amounts of substrate and water desired in each bag. When mixing, it is better for the substrate to be slightly dry than too wet. When it is too wet, substrate sticks to the bag, which then becomes extremely difficult to seal. Aiming for a moisture content around 55-60% is ideal. At Fungi Ally, this was measured by the “squeeze test” to see if the substrate holds shape but does not drip any water.

5) Bagging and Folding. Bagging is one of the more time consuming and repetitive tasks. Bagging and folding is a great example of a seemingly trivial unimportant task having a big impact on the overall success of cultivation. If the area where the bag will be sealed is not clean and well folded, it becomes very difficult to seal. If it is folded with a wrinkle in it, sealing becomes difficult. Bagging at Fungi Ally was done by hand with a 1-gallon lemonade pitcher. Bags were approximated to 5-6 pounds and weighed occasionally during the bagging process. Many farms are shifting to a 10-lb bag, which decreases labor costs. Pneumatic baggers are definitely a much more efficient

and realistic way to bag once using a mechanical mixer. With a push of the button, this places the exact desired amount of substrate into the bag. The operator simply holds the open bag below the hole and presses the foot pedal to move the substrate into the bag. Some machines in Japan are completely mechanized, taking the substrate out of the mixer, opening a bag, dumping the substrate and leaving it on the side to be folded and placed onto the rack. When folding by hand, the bag should be folded so the filter is on the inside. This ensures the filter does not get wet and allow for growth of organisms through the filter. Ensure the fold has no creases or extra folds in it, which will make for difficult sealing later in the process. At Fungi Ally, bags were placed in a 300-gallon stock tank with about 200 fitting at a time.

6) Steaming. The next step in indoor cultivation is steaming. One method is autoclaving. This involves using an autoclave or pressure cooker to bring the temperature of the substrate up to at least 250 degrees Fahrenheit and maintaining that temperature for at least two hours. On a commercial scale, this means making a large investment to get a commercial autoclave or buying a lot of pressure cookers, each of which can only do about 8 bags at a time. The other option is to use the atmospheric steaming method. This involves steaming at atmospheric pressure up to temperatures around 208 degrees Fahrenheit for about 16 hours. This method is very inexpensive compared to an autoclave and is efficacious. Contamination levels can be maintained below 5% using proper technique with atmospheric steaming. Steaming at Fungi Ally was done using a 9 kw sauna steamer that was on continuously. At $25 per run, the average cost of electricity using this method was not excessively high. It could be decreased by placing the steamer on a sensor which turns on when the temperature drops below 205 degrees and stays on until the temperature reaches 208 degrees Fahrenheit.

BAG TYPE

For this process of cultivation, filter patch bags are necessary. These bags are specially made for the mushroom cultivation industry. Bags come with a filter, and are made out of a special kind of plastic that does not melt at high temperatures. An impulse sealer is used to melt the plastic to itself creating a seal. Good bags to use are Unicorn with T filter and Tufpak. There are likely other quality bags, but these two have shown the most success.

7) Cooling. Cooling is best done in a positive pressure lab. After the 16-hour steaming is complete, bags are rolled into a positive pressure hepa-filtered lab to cool. Bags are left to cool for 24 hours before inoculating. During this time, bags are sucking air in so it is important to be in a clean environment. Some farms do the entire process of steaming and cooling outside. This is possible, but for a long incubating species like shiitake, contamination rates will increase.

8) Inoculation. If this process was a wave, inoculation would be the point as the wave crests and is getting ready to crash. This is the point when you either catch the wave and ride or fall of the surfboard. Of all the steps, inoculation is the most precise and technically demanding. Understanding the seven vectors of contamination, proper technique for sterile lab work, and workflow dynamics are all critical for a successful inoculation process. First, the cooled bag is opened in front of a laminar flow hood. Next, a small amount of spawn is dropped into the bag. Finally, the bag is sealed so air exchange only happens through the filter. After inoculation is complete, bags are shaken to distribute the spawn more evenly. In a trial with oyster mushrooms, mycelium bags that were shaken colonized 7 days before bags that were not shaken.

9) Incubation. Time to kick back and watch the mycelium work its magic. During incubation the mycelium jumps off the spawn and begins inhabiting all the new substrate. Watching the leading edge of the mycelium to ensure it stays healthy and that no contamination shows up is important. Ideal temperatures during incubation are around 73 degrees Fahrenheit but anywhere from 55-75 degrees will work. As temperatures rise above 75 degrees, internal over-heating can occur. There are two key things to be aware of during incubation with shiitake. First, when placing bags onto shelving, be sure there is a gap between each bag so popcorning can happen effectively. If bags are touching, popcorning will not happen and fruiting will not occur in that section of the block. Especially after about 2 weeks, it is critical that bags are not touching. Second, shiitake are sensitive to temperature swings. If incubation temperature drastically drops, the blocks can start fruiting in the bag. This leads to malformed mushrooms and an overall loss in yield. CO_2 levels, lighting, and humidity do not need to be controlled during incubation. Shiitake are also sensitive to physical disruption, so after week 4 or 5 bags should be handled minimally until they are ready to fruit.

10) Browning. Typically it takes about 7-8 weeks for shiitake blocks to be fully mature. They are ready to fruit once the outside of the block has popcorned and browned fully. Bags can be fruited with 50% or more browning, but generally yield is decreased when browning is less than 50%. During incubation, the mycelium goes through three phases. First, the mycelium inhabit all of the new substrate. Next, popcorning creates ridges and valleys on the outside of the substrate making it extremely textured. Finally, the outside of the shiitake mycelium turns brown and makes a skin-like area from which the pins develop and emerge. Because of this browning, shiitakes are the only specialty mushroom for which the bag is completely removed for fruiting.

11) Fruiting Initiation. Fruiting for shiitake is typically initiated with a temperature change. After 50-100% browning, shiitake blocks are transferred to a walk-in cooler for a 12-24 hour cold shock. This cold shock initiates the shiitake into a fruiting cycle. Blocks are stripped of the plastic bags and placed into the grow room. It is extremely helpful to spray the blocks down with a hose in the grow room 2-3 times a day for the first 3 days of fruiting.

12) Fruiting. The fruiting room is a place of transformation on any mushroom farm. Mycelial blocks turn into sellable fungal fruit bodies. During fruiting, monitoring four key environmental parameters is essential. CO_2 levels, lighting, humidity, and temperature should all be monitored and adjusted to maintain optimal conditions for fruiting. During the first 4 days of fruiting, pin set is occuring. This is when little baby mushrooms start emerging from the substrate. Size and quantity of mushrooms is determined at this point, if there are an excessive amount of pins that create little mushrooms, which happens with strain 3782, some pins can be knocked off to encourage fewer larger mushrooms. During these first 4 days, air exchange and high humidity are

extremely helpful to create a good pin set. If CO2 levels are above 1000-1200 ppm, pin set can be adversely affected. Likewise, if humidity drops below 70%, pin set can be adversely affected. To maintain high humidity at Fungi Ally, shiitake blocks were sprayed directly 2 times per day for the first 3-4 days until pins were the size of a thumb nail. After pin set, mushrooms are a little more durable to environmental fluctuations. The best measure of proper environmental parameters is the mushrooms themselves. If they look good, taste good, and store well, environmental parameters are great! In general, temperatures between 55-70 degrees Fahrenheit, CO2 levels below 1200, sufficient lighting to read comfortably, and humidity between 80-95% are ideal. Shiitakes, however, are much more tolerant to high CO2 levels and low light than oyster mushrooms.

13) Harvest. Time to harvest! Shiitakes should be harvested while the cap is still slightly curled in or just as the partial veil breaks away. When temperatures are high, mushrooms grow very fast, and in the course of 24 hours can pass their prime. If temperatures are around 60 degrees Fahrenheit, one harvest per day is sufficient. Mushrooms that are harvested before the cap margin becomes flat or flipped up have a better texture and store much better. When harvesting, cutting with scissors or a knife is the best to ensure sawdust is not on the stem base, which could then later get into the gills of the mushrooms in a bulk bin. Harvesting flush with the block also reduces possible contamination for future flushes. After harvesting, mushrooms should be immediately cooled and kept at around 36 degrees Fahrenheit.

5. GETTING STARTED

The best way to learn about mushroom cultivation is to dive into production. Using the methods outlined in this guidebook, mushrooms can be grown from start to finish in as little as 3 months or over the course of 12-18 months. If trying to grow commercially, it is important to create a realistic budget and goals/mission to stay oriented over the years. If working with limited capital, start small and focus on one particular aspect of cultivation. In general, the mushroom cultivation industry can be broken into three different businesses:

1. **SPAWN PRODUCERS**
2. **SUBSTRATE PRODUCERS**
3. **FRUITING AND SALES**

When first starting out, it can be easiest to focus efforts on the last aspect, fruiting and sales, before incorporating the other aspects into the business. This allows the grower to build up a viable customer base while exclusively focusing on fruiting. This also promotes collaboration and the sharing of skills and equipment between more advanced, experienced growers who are producing the spawn or substrate and new growers. When the grower is ready, they can build their own lab and start to produce their own substrate bringing a major expense in-house as income. This becomes an easy way to expand the business and increase the profit margin without onboarding new customers.

This basement room is 16x8 and can produce over 150 pounds of shiitake mushrooms per week. Construction of the room itself cost about $1000.

This fruiting room in a barn can fruit over 300 pounds of shiitake mushrooms a week. Temperature control is much more difficult, but for most of the months from May-October shiitake production is straight forward.

These low tunnels are used for second flushes. Fruiting can be prolific, and this is also a fine set-up for first fruiting during the spring-fall months. After the first flush, blocks are placed outside for 2-3 weeks. They are soaked for about 6 hours and then placed in these tunnels. Depending on rainfall, they are watered daily and produce mushrooms in about 8 days.

This fruiting room is inside a 53-foot trailer. 400 pounds of shiitake mushrooms can easily be produced from this size space. Placing a grow room like this in an urban setting with only a 400 square foot of warehouse space would be an amazing opportunity for a local mushroom production company.

• Mushrooms can transform unused spaces and materials into a profitable food source.

• The by-product of mushroom production is mycelium, which is great for building soils.

• For both the hobbyist and the commercial farmer, mushroom cultivation is great to include in a food production system.

• To get started growing mushrooms, first pick out a space for fruiting and incubation. Once these sites are selected and prepared, begin ordering mateavials. Below is a list of resources where some of the materials can be found.

Logs/sawdust- local farmer, arborist, or sawmill

Building materials- Hardware store

Spawn- fungially.com

Cultures- fungially.com

Brand of fans for fruiting- canfilters.com, fantech.com, Apollo

Humidifiers- jaybird-mfg.com, hydrofogger.com, thehouseofhydro.com, aeromist

For onsite consultations contact Willie Crosby at: willie@fungially.com

Additional resources and books: Shiitake Growers Handbook, Shiitake Mushroom Cultivation, https://blogs.cornell.edu/mushrooms/factsheets/

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