Agaricus bisporus (Lange) Imbach

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Chapter 1 Introduction

Agaricus bisporus, more commonly known as the White Button mushroom is the most famous type of mushroom around the world along with the Portobello (Figure 1), Cremini (Figure 2), Maitake (Figure 3) and Shiitake (Figure 4) mushrooms.

Figure 1: Portobello Mushroom

Figure 2: Cremini Mushroom

Figure 3: Maitake Mushroom

Figure 4: Shiitake Mushroom

White Button mushrooms are commonly mistaken for vegetables, when in reality they are botanically classified as a type of fungus. Unlike a vegetable, White Button mushrooms don't have roots, don't grow from seeds and don't need sunlight to grow. Instead, just like other fungi, they produce microscopic spores that travel across the air into the ground, where it then grows more fungi. This monograph will focus specifically on *Agaricus bisporus* and will go through 5 chapters covering its **ecology**, **biology**, **production**, **propagation**, and its influence on the **world market** respectively.

Chapter 2 Ecology

2.1 Affinities

White Button mushrooms (*Agaricus bisporus*) are part of the kingdom of *Fungi*, more specifically, the subkingdom of *Dikarya*. Inside the subkingdom of *Dikarya* are included the phyla *Ascomycota* and *Basidiomycota*, the latter being *Agaricus bisporus'* division (Bionity.com, ND). Along with mushrooms, *Basidiomycota* consists of other "Higher Fungi" like puffballs, stinkhorns, bracket fungi, jelly fungi, mirror, human pathogenic yeasts, etc. Higher Fungi under the *Basidiomycota* division are characterized by their filamentous fungi composed of hyphae[1]. Some *Basidiomycota* reproduce sexually, but in *Agaricus bisporus*' case it reproduces asexually. Agaricus bisporus' genus, *Agaricus*, is one of the largest and most important. *Agaricus* contains 300 species of both edible and inedible mushrooms worldwide. Members of the genus are characterized and identified by a "fleshy cap [...] from the underside of which grow a number of radiating plates or gills on which are produced the naked spores." (Bionity.com, ND). These spores are distinguished from others because of their chocolate-brown color.

[1] Hypha: a long branching filamentous cell of a fungus.

2.2 Fossil Records

Since fungi don't go through a process of biomineralization[2] their fossil records are extremely rare. Unlike other fossils, most fungi fossils are microscopic thus being close to impossible to identify. A reason for this under-representation is that fungal bodies are soft, fleshy, and easily degradable, therefore the microscopic structure of most fungi is rarely evident. The oldest record of fossil fungi dates back to the Vendian period (650 to 543 million years ago). This fossil is the *Aglaophyton* (Figures 5), to its right is a section through a silicified stem of *Aglaophyton* from the Rhynie chert[3] (Figure 6). (University of California Museum of Paleontology, n.d)

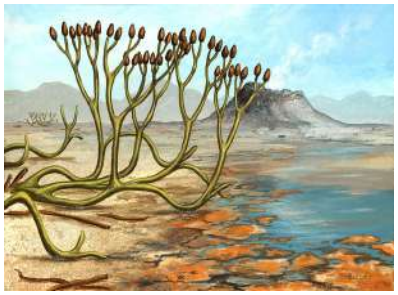


Figure 5: Prehistoric Representation of *Aglaophyton*

Figure 6: Silicified Stem of *Aglaophyton*

2.3 Origin

The cultivation of the *Agaricus bisporus* or button mushrooms originated in France, and its first scientific description was made by botanist Joseph Pitton de Tournefort in 1707. At first, cultivation was ineffective, after all, mushroom farmers would wait for mushroom flushes[4] to seem adequate to then dig up the mycelium and replant them in beds of animal dung fertilizer. With this process of cultivation, mushroom crops would often be infected or not grow at all. It wasn't until 1893 that the Pasteur Institute in Paris discovered the sterilization[5] of mushrooms, thus being able to cultivate in composted horse dung.

[2] It's the process by which living organisms produce minerals, often to harden or stiffen existing tissues.
[3] It's a rock containing exceptionally well-preserved fossil plants and animals
[4] Flush is the term used to refer to a crop of mushrooms
[5] To rid something of bacteria or other living organisms

2.4 Present Distribution

Over the last 20 years, the production of mushrooms has been on an increasing trend. The yearly increase in production volume on average was 5.5%, achieving close to 11.9 million metric tons produced in 2019. In 2019 the main producing countries were: (see figure 7)

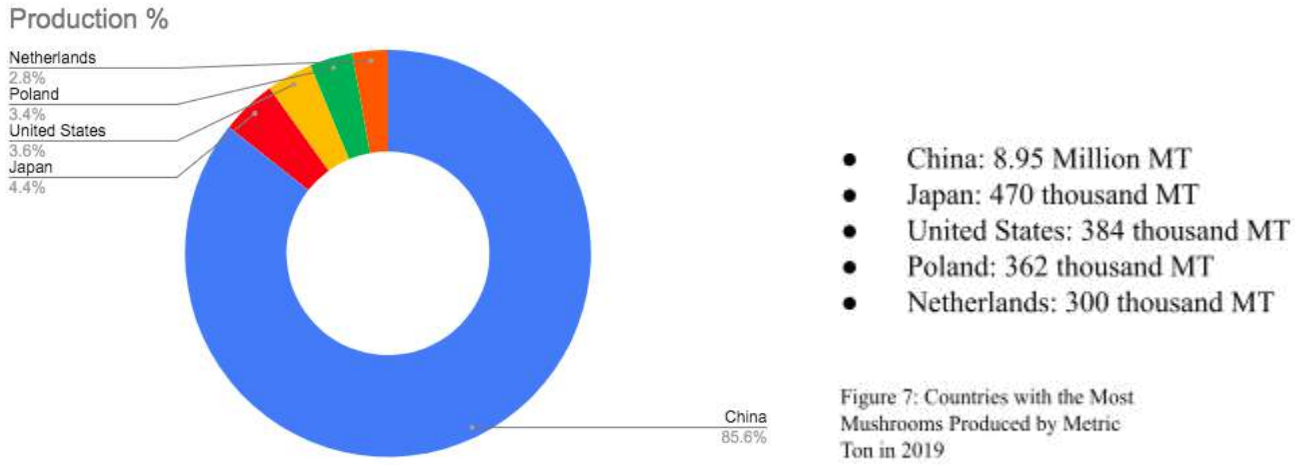


Figure 7: Countries with the Most Mushrooms Produced by Metric Ton in 2019

The trade of mushrooms is divided into two Harmonized System[6] (HS) codes, HS 0709151 and HS 070959. The former is composed of mushrooms from the *Agaricus* genus. From 2015 to the end of 2019 *Agaricus* genus mushrooms' export value increased by 21.6%; from 982 million USD in 2015 to 1.19 billion USD in 2019. The leading countries in exports were: (see figure 8)

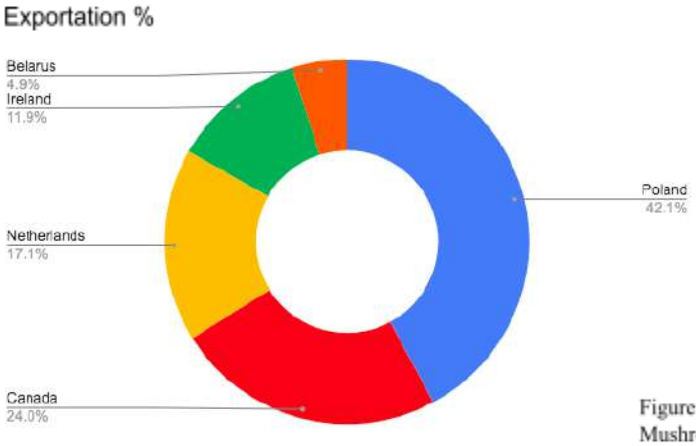


Figure 8: Countries with the Most Mushroom Exports in 2019

[6] The Harmonized System is a standardized numerical method of classifying traded products

2.5 Growing Conditions

Mushrooms grow from spores rather than seeds, and instead of soil, they rely on substances like sawdust, grain, straw, or wood to grow. Mixing these spores with nutrient sources is what makes spawn. Spawn is what supports the mushroom's mycelium[7] in its growth, but for the mushroom to fully grow it requires some other growing medium. In Agaricus bisporus' case, it's grown in composted manure. Mushrooms grow in cool, humid, and dark environments. Most grow in temperatures between 12ºC (55ºF) and 15ºC (60ºF). Mushrooms grow outdoors out of the ground and logs, but can also be grown inside in a basement or closet.

[7]Mycelium is the vegetative part of a fungus or fungus-like bacterial colony, consisting of a mass of branching, thread-like hyphae.

Chapter 3 Biology

3.1 Chromosome Complement

Inside the haploid cell, the number of chromosomes was found to be n=12. The 24 chromosomes found in the fusion nucleus are normally formed of pairs of 12 during meiosis.

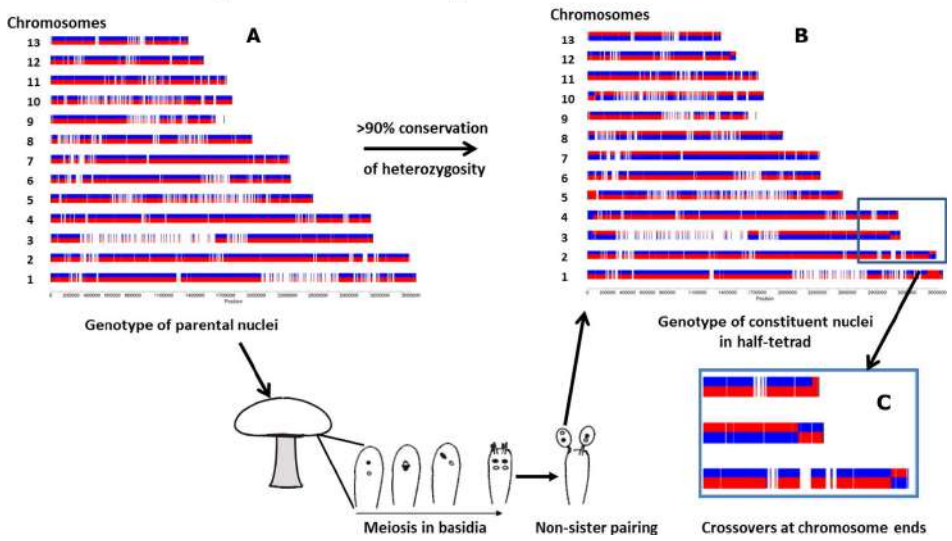


Figure 9: Chromosome Crossover on the Button Mushroom

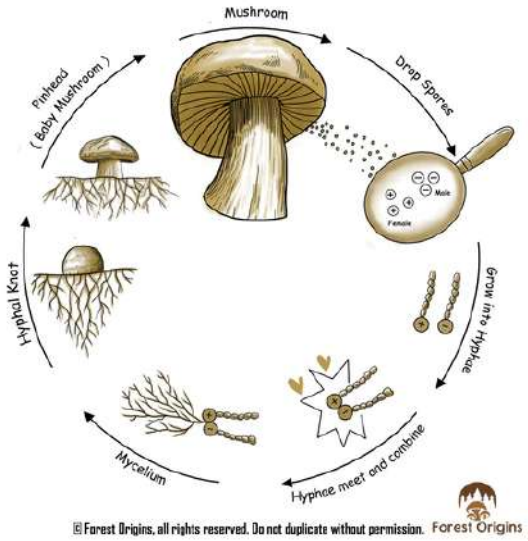
*figure 9: "The genotypes of the parental nuclei (A) and of a heterokaryotic single spore isolate (B) are almost identical except for a different distribution of chromosomes over the constituent nuclei and recombination at chromosome ends (C)." (Sonnenberg et al, 2016)

3.2 Life Cycles

Like most other mushrooms' life cycles, *Agaricus bisporus* has a cyclical reproduction. "Adult [mushrooms] produ[ce] spores that grow, develop and eventually reach an adult phase and produce spores of their own." (Somma, 2021). This life cycle can be divided into eight stages, all of which will be explained below.

3.2.1 Reproduction Stages

Agaricus bisporus' first stage in its life cycle is **inoculation**. The adult mushroom releases spores that float onto the ground, and if that ground is adequate for their survival and development they move onto the next life stage, **spore germination**. Once the spores have properly settled in the ground they begin to grow their hyphae which then come together with other hyphae from the opposite gender to produce mycelium. After that comes the next stage, **mycelial expansion**. During this stage, the fungus' mycelium starts to expand and develop in an exponential manner. As the mycelium expands it breaks down the organic matter that surrounds the fungus and absorbs nutrients in order to fuel the fungus' growth. In the next stage, the **hyphal knot**, after growing enough the mycelium starts growing in on itself and forms knot-like structures. These knot-like structures are what later help the stem or body of the mushroom rise from the ground. All the hyphal knots then condense and thus start the **formation of primordia**. The primordia are smaller versions of the fungus' fruit body[8] that later grows into the fungus' fruit body. Not all primordia grow into the fruit body, only the fastest-growing and most productive ones develop into the fruit body, this process is called **fruit body selection** (note that these primordia all grow into and form a single fruit body of an adult mushroom). From this point on the mushroom's fruit body keeps on growing until it reaches its **mature fruit body** stage. Once the mushroom has fully matured it reaches its last stage, **spore**



Maldonado, E. (2019). The Mushroom Life Cycle [Figure] Forest Origins. https://forestorigins.com/blogs/mushroom-blog-posts/the-mushroom-life-cycle

Figure 10: Mushroom Life Cycle

[8] The fruit body is the organism's reproductive structure. In Agaricus bisporus' case, the stalk and cap.

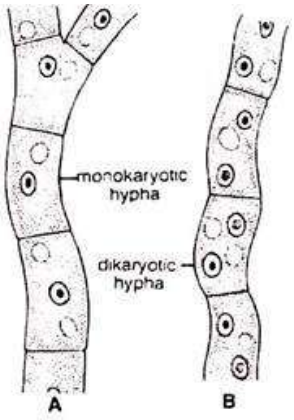
release, where large volumes of microscopic spores are released from the mushroom's gills onto the ground, beginning the life cycle of the new fungus starting its inoculation stage. (Somma, 2021)

3.3 Structure

Agaricus bisporus can be divided into sections of its structure. These two parts are: the vegetative mycelium, which is the part that lives inside the soil, and the fruiting body or basidiocarp, which is the part that is visible above the soil. More specifically the vegetative mycelium can be divided into three parts, primary mycelium, secondary mycelium, and tertiary mycelium. All three of which will be explained below.

3.3.1 Vegetative Structure

The **primary mycelium** is produced by the germination spores bore by the basidium[9] which are all uninucleate. These single nucleus cells carry either positive or negative strains. When compatible, these two cells fuse together becoming a binucleate cell, and thus forming the **secondary mycelium**. When the secondary mycelium is created, it goes through a period of growth under the soil. After growing enough, it organizes itself into special tissues that then form the fruiting body. The subterranean dikaryotic hyphae that forms the fruiting body is called the **tertiary mycelium**. These hyphae are divided into different cells and branched.



Monokaryotic means uninucleate and dikaryotic means binucleate.

Khandelwal, S. (n.d.). Agaricus: Habitat, Structure, and Reproduction [Figure 1]. https://www.biologydiscussion.com/fungi/agaricus-habitat-structure-and-reproduction/24077

[9] Is a microscopic club-shaped spore-bearing structure produced by certain fungi.

3.4 Reproduction

Agaricus bisporus can reproduce through three different means: vegetatively, asexually, and sexually. All three of which will be explained below.

3.4.1 Vegetative Reproduction

It reproduces vegetatively when dikaryotic mycelium develops its own spawn. This spawn, or mushroom seed, is divided by an external force or artificially into small sections on soil that are fermented with manure.

3.4.2 Asexual Reproduction

When in unfavorable conditions, the dikaryotic mycelium will develop the chlamydospores[10]. The chlamydospores helps the *Agaricus* survive unfavorable conditions and allows for self-germination and thus, produce more mycelium under better conditions.

3.4.3 Sexual Reproduction

Since *Agaricus bisporus* lacks sex organs, sexual reproduction takes place through somatogamy. Somatogamy consists of three stages: **plasmogamy**, **karyogamy**, and **meiosis**. First, **plasmogamy** is when two compatible cells (of opposite strains, positive or negative) come in contact with each other as explained in section 3.3.1. After this comes **karyogamy**. With the now grown fruit body, the basidium develops the basidiocarp's gills, this then allows the nuclei to fuse together and form a diploid nucleus. Finally, the **meiosis** stage is where haploid cells of either positive or negative strains, fuse together creating four haploid nuclei (Neelesh, n.d.).

[10] Chlamydospores are thick-walled hyphal cells that work as spores and function as a survival structure.

Chapter 4 Production and Propagation

4.1 Propagation

As explained in the previous chapter, *Agaricus bisporus* can reproduce vegetatively, asexually, and sexualy. In nature, its reproduction can be either asexual or sexual depending on the conditions the basidiocarp that's producing the spores faces. Taking this into consideration, *Agaricus bisporus*' reproduction is vegetative when cultivated.

4.1.1 Natural Propagation

Already grown *Agaricus bisporus* let out spores which travel through the air until they find an adequate terrain to grow on. Spores are asexual seeds as they lack an endosperm, so in order to start the growth of a new fruitbody, it must land on some sort of organic material which ideally should be through its stages of decomposition in order to provide food and energy for the spores (Stephens, 2018). Once the spores land on the ideal piece of terrain, its sexual reproduction (explained in Chapter 3 Section 3.4.3) starts.

4.1.2 Vegetative Propagation

When plating *Agaricus bisporus* indoors many steps need to be taken. Firstly, a **compost** that emulates the natural conditions *Agaricus bisporus* needs to grow must be prepared. Secondly, comes the **plating** of the spawns. Finally, it must be **managed** adequately until ready to **harvest**.

4.1.2.1 Compost Preparation

Agaricus bisporus' compost is made combining certain ingredients. Its most famous and commonly used ingredient is horse manure, but other ingredients such as hay, corncobs, cornstalks, sawdust and poultry manure are also suitable (Stephens, 2018). Once these ingredients are combined they are spread onto a tray and water or other supplements of nitrogen

are added to the compost. Eventually the compost will absorb the water and will give a strong smell of ammonia[11]. After this, the trays are covered with plastic sleeves (made out of black lawn bags) so that the compost's temperature rises to 60ºC (140ºF), thus killing the ammonia-producing bacteria (Reynolds, n.d).

4.1.2.2 Planting

With the tray of compost ready, materials with *Agaricus bisporus* spores that are already growing mycelium are scattered on top of the compost. The tray is then put in a room with ideal temperatures between 23ºC (75ºF) and 25ºC (77ºF). Thanks to the cool environment, even though the compost generates heat the temperature won't rise anywhere above 27ºC (80ºF) or 29ºC (85ºF). If the temperature were to rise any higher than that, it would kill the mycelium and interfere with the spores' growth.

4.1.2.3 Management and Nursing

The now planted spawn must be managed and nursed properly in order to survive. The two necessary things to this are **supplement administration** and **casing**. First, since spores can't create and provide nutrients for themselves, **supplements** like soybean meal and other types of protein must be added to the tray in order to fuel and help the spawn's development and consequent growth of a new fruit body. Finally, the tray of compost and spawn must be covered with a uniform 1½ to 2 inch layer of mossy peat[12]. This is called a **casing** layer, and it functions as a growing medium for the mushroom. Finally, in order to grow under the perfect conditions, the *Agaricus bisporus* needs darkness and humidity, after all those are the conditions in which it

[11] A colorless gas with a characteristic pungent smell, which dissolves in water to give a strongly alkaline solution.
[12] A brown deposit resembling soil, formed by the partial decomposition of vegetable matter in the wet acidic conditions of bogs and fens, and often cut out and dried for use as fuel and in gardening.

grows out in nature. For this, the room that the tray is kept in must be darkened and water must be sprayed on the casing layer several times a day.

4.1.2.4 Harvesting

After the casing, bits of fungus will begin to form in small bumps, these are called pins. Once this happens, the temperature of the rooms must be lowered anywhere between 15ºC (60ºF) and 19ºC (66ºF), but the darkness and humidity must be kept high during the pining period. After two or three weeks the pins will become mature *Agaricus bisporus* and will be ready to harvest.

Chapter 5 Global Market

In 2020 alone the mushroom cultivation market was estimated to account for 16.7 billion dollars (Research and Markets, 2020). In the last couple of years the global mushroom market has seen significant growth, and it will continue to grow. This is due to the increase of mushroom consumption per capita because of its cost-effective production, health benefits, and a rising demand due to veganism and other healthy diet-movements that have risen in popularity in recent years. More specifically, in *Agaricus bisporus*' case, it has accounted for the largest contributor to the mushroom market with more than 40% global production.

5.1 Important Applications

Agaricus bisporus is the most widely consumed type of mushroom in the world. It is produced in some of the most prevalent countries regarding mushroom production: China, Japan, the United States, the United Kingdom, Germany, and Poland. The reasons for this are its importance to human's **health**, and the **food industry**.

5.1.1 Health Benefits

Agaricus contains chemicals that improve the human body's ability to use insulin[13] as well as decreasing insulin resistance[14]. This is why medicine using extract from the fungus is very popular with people who suffer from type 2 diabetes. Developing research also suggests that *Agaricus* helps reduce chemotherapy side effects, probabilities of arteriosclerosis[15] and chronic hepatitis[16], as well as prevent heart disease, osteoporosis[17] and stomach ulcers. Although there's still insufficient evidence to prove these effects as completely effective.

[13] Insulin is the hormone that regulates the amount of sugar in the blood.
[14] The inability to use insulin properly.
[15] Hardening of the arteries.
[16] Ongoing liver disease.
[17] Disease that thins and weakens the bones.

5.1.2 Food Industry

Mushrooms as a whole are considered as a gourmet ingredient all over the world. This is due to its unique flavor and high nutritional value. As said before, the button mushroom is the most popular type of mushroom, and it is most commonly sold fresh or canned. Button mushrooms are mostly used to make soups and sauces, and can also be baked, roasted, sautéed, grilled or stewed.

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