7- The benefits of using mushrooms in food, agriculture and public health

Fungi have an active and highly diverse metabolism, allowing their use in several fields, particularly in the food and pharmaceutical industries. Indeed, yeasts and molds are increasingly used by humans due to the numerous benefits they offer. In the food industry, they can be used as food or in the preparation of many products (e.g., cheeses, bread, alcoholic beverages). Similarly, in the pharmaceutical industry, they are used in the production of many bioactive molecules (e.g., vitamins, enzymes, antibiotics).

7.1. Use of fungi in the food industry

7.1.1. Use of molds

7.1.1.1. The main phases of mold growth

Molds have a growth cycle similar to that of all microorganisms, namely a lag phase, an acceleration phase, an exponential phase, a deceleration phase, a stationary phase and a decline phase (Figure 16).

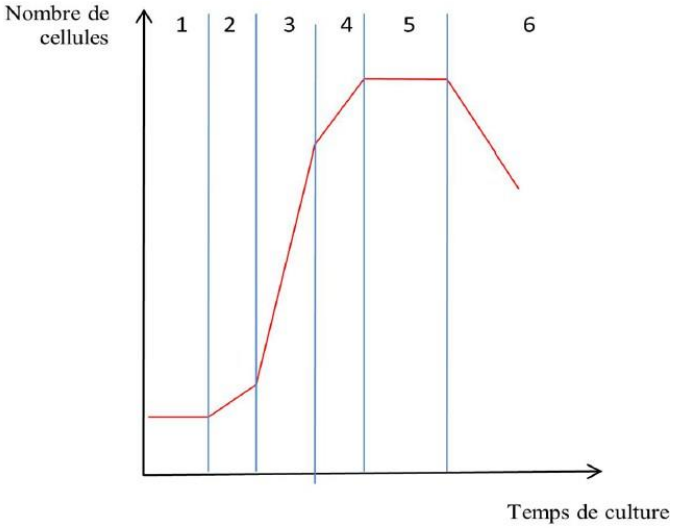

Figure 20: Courbe de croissance des mycètes

1 : Phase de latence, 2 : Phase d'accélération, 3 : Phase exponentielle, 4 : Phase de ralentissement, 5 : Phase stationnaire, 6 : Phase de déclin.

1. **The latency phase**, during which the mass remains identical to the initial fungal mass, is characterized by a value of µ equal to zero.
2. **The acceleration phase**It is characterized by an increasingly rapid increase in mass. The growth rate becomes greater than zero and increases progressively.
3. **The exponential growth phase**During this phase, the mass increases exponentially and µ reaches a maximum and constant value. The generation time of fungi during this phase is the shortest. Almost all of the cell mass is represented by viable cells (zero mortality).
4. **Slowing-down phase (deceleration)**where µ decreases.
5. **Stationary phase:**There is a balance between the fungi that die, through autolysis, and those that continue to multiply. This phase is triggered by the depletion of the environment and the accumulation of toxic waste (e.g., organic acids) released into the environment by the fungi.
6. **Decline phase (µ < 0)**The number of viable fungi decreases during this phase. This is due to cell lysis under the action of endogenous proteolytic enzymes (autolysis).

When cultivating molds for industrial purposes, only two growth phases are important:

- **"The trophophase"**or "trophic phase": This represents the phase where the microorganism feeds and exhibits significant, even maximal, growth. It occurs when environmental conditions are favorable. The trophophase encompasses the acceleration phase and the exponential phase (Figure 17). It is ideal for the production of primary metabolites (e.g., organic acids, vitamins) and biomass production.

- **"The idiophase"**It is reached when environmental conditions become unfavorable. It encompasses the slowing-down phase and the stationary phase (Figure 21). The idiophase is suitable for the production of secondary metabolites (e.g., antibiotics, aromas).

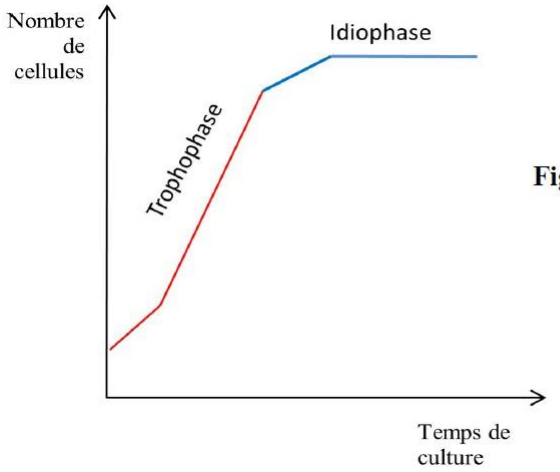

Figure 21 : La trophophase et l'idiophase

7.1.1.2. Examples of cultures on solid and liquid media

Mushrooms can be cultivated in liquid, solid and semi-solid media.

- ✓ Liquid media are used for the culture of pure fungi.
- ✓ The liquid medium allows for discontinuous (batch) or continuous culture.
- ✓ Solid or semi-solid media based on agar are used for the isolation of fungi.
- ✓ The solid medium allows for discontinuous (batch) culture.

7.1.1.3. Production of primary and secondary metabolites

The production of primary and secondary metabolites depends on the growth phase of the mold. As explained previously, primary metabolites are obtained when culture conditions are favorable for growth (trophophase) and secondary metabolites when culture conditions are unfavorable (idiophase).

7.1.1.4 Use in the production of dairy products

Molds are widely used in the production of dairy products, particularly cheeses, where they allow for ripening while providing highly valued aromas, textures, and appearances.

- ***Penicillium camemberti:***It produces a white, felt-like coating on soft, bloomy-rind cheeses, thus forming Camembert. This species is white and slow-growing. Optimal growth occurs at 22°C and pH 5. During production

With Camembert, care must be taken to ensure that the salt content is not too high because

*Penicillium camembert*idoes not tolerate high salt concentrations.

- ***Penicillium roqueforti:***Unlike Penicillium camemberti, this species is green and grows rapidly. It grows in the cavities of blue cheeses, thus producing Roquefort. This species has an optimum pH ranging from 4.5 to 6, but tolerates a wide range from 3 to 9. It grows well at 25°C and withstands high salt concentrations, up to 22%.

7.1.1.5. Edible mushrooms

Many mushrooms are edible for humans. Some offer distinctive flavors and are considered "tasty," while others are used as condiments or to decorate dishes. That said, it is crucial to distinguish edible species from toxic and poisonous ones.

1. ***Tuber:*****(Truffles):**Truffles are subterranean Ascomycetes.
2. ***Agaricus*****(the Psallots):**The genus Agaricus belongs to the Basidiomycetes.
3. ***Cantharellus*****(Chanterelles):**Chanterelles are Basidiomycetes.

7.1.2. Use of yeasts

Yeasts are widely used in the food industry. They are used in the production of numerous food products, the valorization of agricultural waste, and the preparation of protein-rich foods. The main genera used are Saccharomyces (alcohol-producing yeasts).

As examples, we are interested in two fundamental uses of Saccharomyces cerevisiae. The first is to produce bread and the second is to produce an alcoholic beverage (beer).

The use of this species is based on its ability to produce ethanol and CO2 from glucose. The ethanol is used to make alcoholic beverages and the CO2 to make dough rise.

7.1.2.1. Bread fermentation

Yeast production for industrial use is carried out by culturing on molasses rich in sucrose (molasses yeasts) or on cereal wort rich in maltose (grain yeasts). The yeasts are cultivated at 30°C, with agitation to ensure aerobic conditions. Once the biomass reaches the desired level, the cells are separated from the medium by centrifugation.

(at 3500 rpm for 15 minutes), then the pellet is collected and rinsed several times with sterile distilled water. The resulting Saccharomyces cerevisiae is then ready to be packaged and sold. However, to allow for long-term storage, it is dried.

7.1.2.2. Beer production

Barley is the raw material for beer. After an initial germination period of about 8 days, the grains become rich in the enzymes necessary for brewing. They are dried in a kiln, and the resulting wort is added to water. This is when the brewing process begins.

In a boiler with an agitator, the temperature is gradually increased to achieve optimal activity of the enzymes produced. At 40°C, beta-glucanases are activated, at 50°C it's the proteases, at 62°C the beta-amylases, and then the amylases at 73°C. The stirring lasts approximately two hours. This process breaks down the macromolecules present in the barley, particularly starch, which yields dextrins and maltose. The latter is easily broken down by Saccharomyces cerevisiae.

After filtration, yeast is added to the filtrate and fermentation takes place over 8 days at a temperature between 5 and 10°C to produce "bottom-fermented beers". These beers are in high demand because they are strongly aromatic and invigorating.

If Saccharomyces cerevisiae is replaced by Saccharomyces uvarum, fermentation takes place between 15 and 25°C and produces "top-fermented beers". These are finer and less aromatic.

7.2. Use of fungi in the pharmaceutical industry: Fungi producing metabolites: vitamins, antibiotics and enzymes

7.2.1. Origin

Fungi used in the pharmaceutical industry have several origins. Species are generally isolated from their natural habitats (soil, air, plants, etc.). The most important sources are soil and plants where they live as saprophytes, symbionts, or parasites. However, other sources can also be used for mold and yeast research, such as biodegradable food, damaged textiles, grains, patients with fungal infections, etc.

That said, fungi are also sold as pure strains. These then require only simple revitalization before use.

The same species can be used for several products. Indeed, depending on the constitution

Depending on the environment and growing conditions, a fungus can be directed towards the production of organic acids, vitamins, and antibiotics.

Table 1 lists some products of pharmaceutical interest and the producing microorganisms.

Table 1: Main products of pharmaceutical interest and their origin

Product	**Microorganismsproducers**
Citric acid	*Aspergillus niger, Aspergillus kawachi, Aspergillus awamori*
Fumaric acid	*Rhizopus nigricans*
Glucanic acid	*Aspergillus niger*
Fusidic acid	*Fusidium coccineum*
Vitamin D	*Aspergillus fumigatus, Saccharomyces cerevisiae*
Alpha amylase	*Aspergillus niger, Penicillium expansum,*

7.2.2. Isolation

Isolation conditions and techniques must be carefully chosen to promote the viability of microorganisms. For species that are difficult to culture, particularly fastidious or unidentified ones, it is important to replicate as closely as possible the culture parameters of their natural habitat (temperature, pH, aeration, anaerobic conditions, minerals, carbon and nitrogen sources, etc.). For example, fungi isolated from a salt-rich source require an osmophilic medium. For species isolated from refrigerated foods, the incubation temperature must be low. For species responsible for human infections, incubation at 37°C is recommended.

The most commonly used media for isolation are routine media (Sabouraud, Malt agar, Czapek, etc.). They can be combined or modified according to culture requirements.

After the first inoculation, a pure culture is rarely obtained. Purification sometimes requires several successive subculturings. For good results, subculturing should be carried out at the edges of the mycelium or colony: a small amount is taken with a Pasteur pipette or a sterile platinum loop, from the side furthest from the contaminant.

7.2.3. Extraction and purification

For intracellular products, the first step always involves breaking down the cells by centrifugation or by degrading the cell wall and membrane (using enzymes or a

osmotic pressure). This allows the metabolites to be released into the medium. Then come the extraction methods, which can also allow for partial purification of the product. Among the most commonly used are:

*** Filtration**This process is carried out using a rotary filter or a membrane. The objective is to separate the metabolites according to size. It is notably used to recover the largest or smallest molecules relative to the other constituents of the medium.

***Solvent extraction**This step allows the solvents to transition from an aqueous phase to an organic phase. It partially purifies the product by removing molecules that are insoluble in the extraction solvent.

7.2.4. Therapeutic applications and uses

- **Antibiotics:**The enzymes produced by fungi are numerous and allow the development of medications against many serious bacterial infections. For example, severe skin infections, typhoid fever in children, cervicitis, and urethritis are treated with cephalosporins, such as cephalexin and cefixin. Otitis media, sinusitis, bronchitis, acute pneumonia, Helicobacter pylori infections, and typhoid fever in adults are all treated with amoxicillin (an antibiotic in the penicillin family).
- **Hormones**Fungi also have the ability to convert a molecule into several others that are more beneficial to humans. For example, they bioconvert steroids into hormones. These include estrogens, progesterone, testolactone, and androgens, which are used to treat hormonal imbalances in humans. The main species used for this purpose are Rhizopus nigricans and Curvularia lunata.
- THE Organic acids: Humans are often deficient in organic acids, but these are essential for proper metabolic function. By producing various types of acids, fungi help to fill these gaps. The main acid commercially available in the pharmaceutical industry is fumaric acid, which is used to fix iron.

8. Pathological Aspects

4.1. In humans and animals

Fungi are not always beneficial. They can also cause illness in humans and animals. Although fungal infections are generally benign, in some cases, such as during immunosuppression, they can become very serious, even fatal.

Among these infections, we provide the example of candidiasis and dermatophytosis.

8.1.1. Candidiasis

Candidiasis refers to infections caused by the Candida genus. They can be superficial, affecting the skin and mucous membranes, or systemic, affecting one or more internal organs.

The majority of infections are caused by Candida albicans, but other species have also been encountered.

Candida are natural commensal bacteria of the esophagus and mouth. They can normally be present in humans and animals without causing disease. However, under certain conditions, they multiply and abnormally colonize certain parts of the body, resulting in a process called "filamentation" (spreading). The ability of these species to adhere to and invade plays a significant role in induced parasitism.

Depending on the degree of resistance to antifungals, candidiasis can be easy or difficult to treat.

- ✓ **Superficial candidiasis**

They mainly affect the mucous membranes (oral, vaginal and esophageal) and the skin.

They are due to the adhesion, multiplication and filamentation of yeasts at the level of epithelial cells.

Factors that promote these infections include immunosuppression, immaturity of the immune system (in people under 18 and young animals) and trauma to the skin and mucous membranes (e.g., burns or abrasions of the skin, wearing dentures that damage the gums).

*** Systemic candidiasis (visceral or invasive candidiasis)**

These infections are internal and deep-seated. They are generally difficult to cure because they are often diagnosed late. Systemic candidiasis can be caused by Candida entering the bloodstream after a superficial infection, particularly oral or esophageal. However, in the majority of cases, it is due to nosocomial species and is found in post-surgical patients.

There are many risk factors, including: antibiotic treatments, immunosuppression (e.g., HIV, burns), kidney failure and neutropenia (low levels of granulocytes and neutrophils in the blood).

8.1.2. Dermatophytoses (or dermatophytias)

Dermatophytoses are infections caused by molds capable of degrading keratin. These infections are benign and result in:

- **Epidermophytosis**: colored spots on the epidermis.

- **Intertrigo**: mycelial growth in cells of body folds, such as the interdigital space, under the arms, etc.

- **Onychia**: alteration that distorts the appearance and color of the nails.

- **Ringworms**: fungal growth on the scalp causing breakage and hair loss.

- **Folliculitis**: alteration of the skin and hair.

The main species responsible belong to the genera Trichophyton, Microsporum and *Epidermophyton*.

8.2. In the plant world

8.2.1. Storage mushrooms

The storage of vegetables is often problematic due to biodeterioration caused by fungi. This poses a risk of contamination for consumers (human or animal) and often results in significant economic losses. The majority of fungi involved belong to the Mucorales, an Ascomycete order.

The biodeteriorating activity is primarily due to the cellulolytic, lipolytic, and proteolytic enzymes of the fungi. Storage conditions also play an important role in

the deterioration of products because they inhibit the growth of many microorganisms and therefore promote the proliferation of harmful fungi.

8.2.2. Mycotoxins

Mycotoxins are secondary metabolites of molds. As their name suggests, they are "toxins"; they can harm the health of humans and animals.

These substances can be present in various biodegradable foods, but primarily in plants infected by molds (field or storage plants). The products containing the most mycotoxins are cereals, fruits, nuts, almonds, and animal feed grains.