Fungus characteristics, taxonomy, poison and therapeutic possibilities and therapy (Kingdom: Fungi).

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1. Introduction

This group includes diverse organisms, that live in almost all terrestrial environments and present a wide variation in shapes and sizes. They can range from microscopic fungi, formed by a single cell (unicellular), as is the case with yeast, to multicellular forms that reach considerable size, such as molds and mushrooms (Figure 1) [1-2].

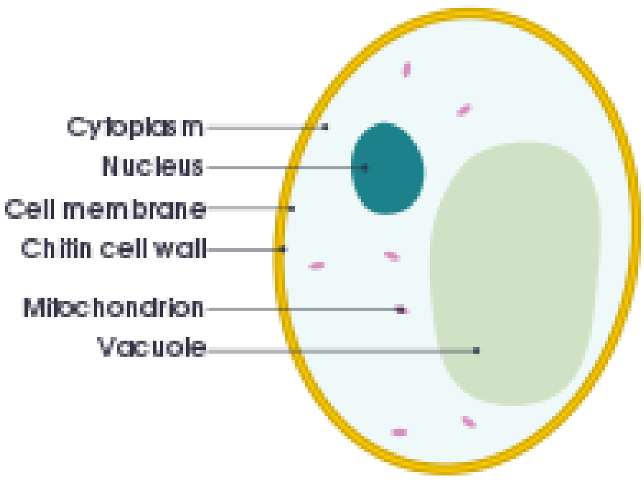

Figure 1. Single-celled fungus - Cross-sectional labelled diagram of a typical yeast cell. Source: https://en.wikipedia.org/wiki/Yeast.

1.1. Morphology

The body of multicellular species comprises two parts: the mycelium and the fruiting body. The mycelium corresponds to a tangle of long, microscopic filaments called hyphae while the fruiting body is the reproductive structure of these fungi. For example, the black mold that grows on stale bread, known as mildew, corresponds to the fruiting body. The part that remains inside the bread is the mycelium (Figure 2) [2-3].

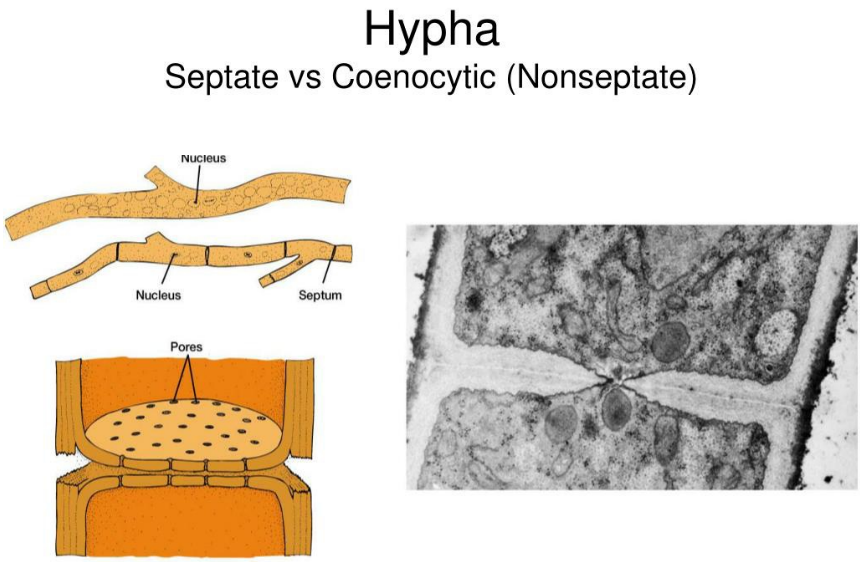

Figure 2. Septate hyphae and coenocytic multicellular fungus. Source: https://www.slideserve.com/ismet/kingdom-fungi-eumycota.

Hyphae can be coenocytic or septate. Coenocytic hyphae are continuous filaments filled with cytoplasmic material and with a portion of nuclei. As their name suggests, Septate hyphae have septa that form compartments containing one to two nuclei. In the median portion of the septum, an opening is found that allows cytoplasmic communication [3-5].

The cell wall of fungal cells is made up of chitin, a substance also found in the exoskeleton of arthropods. Its cells, in the vast majority of groups, are characterized by the absence of cilia and flagella and are therefore immobile. The movement of spores, the main form of reproduction, is done only by wind, water, or living beings (Figure 3) [5-7].

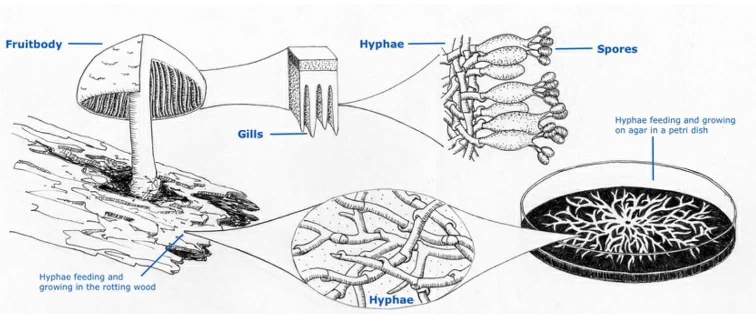

Figure 3. Soil and logs contain lots of fungal hyphae. Hyphae feed, grow and branch to form a colony and may later form a mushroom. Hyphae can also be grown on agar in the laboratory. Hyphae need O2 and produce CO2 like animals. Source: https://www.sciencelearn.org.nz/resources/2664-fungal-life-cycles-spores-and-more/.

1.2.Reserve substance

Glycogen is the main reserve substance in fungi and animals. Glycogen, as well as starch, are polysaccharides made up of a chain of glucose monomers. Starch is composed of two fractions: amylose, formed by a linear chain, with little branching, and amylopectin, which is highly branched. Glycogen resembles this last starch chain, being even more branched. Fungal respiration can be aerobic in the presence of oxygen or facultatively anaerobic, surviving in environments with low oxygenation [7-8].

Fungi can inhabit different substrates. Most of them can be found in the soil. However, we can find them in plants, water, and even animals. Parasitic fungi can inhabit various animals, insects, and plants. Saprophytic fungi are found in decaying matter. This variety in habitat is due to the structure of these organisms and also the routes of dispersal. Through dispersal, fungi are spread throughout nature, grow, and form colonies [8-9].

1.3. According to the way they feed, fungi can be classified into three different groups: saprophagous fungi: Which feed on decomposing organisms; parasitic fungi; which feed on nutrients from their hosts; and Predatory fungi: which feed on captured small animals (Figure 4) [9-10].

Figure 4. Fungus (Ophiocordycipitaceae) which parasitized and killed wasp, Tatama National Park, Colombia. Source: https://www.sciencefocus.com/nature/the-parasites-that-make-insect-bodies-their-home.

1.4. In asexual reproduction, the production of spores is also noticed, however, it is normally observed that filamentous fungi produce them through mitosis. Another form of asexual reproduction observed in fungi is by budding. It can be identified in yeast, in which a small bud appears based on the mother cell. Yeasts can also reproduce by fission, and some fungi can also reproduce asexually by fragmenting their hyphae [10-12].

Fungi that have a sexual stage are called perfect and those that do not, are imperfect. Imperfects are grouped in the Deuteromycetes Class but can be reclassified when their sexual cycle is discovered. Slime molds are considered separate from other fungi in recent classifications [12-13].

1.5. Sexual reproduction: Generally, begins with the attraction of hyphae that release sexual signaling molecules. These molecules attract the hyphae, which, when they meet, fuse. When the cytoplasm of two mycelia joins, we have the process of plasmogamy. The nuclei of each individual do not fuse immediately in some species, which can take hours, days, and even months and years (Figure 5) [14-15].

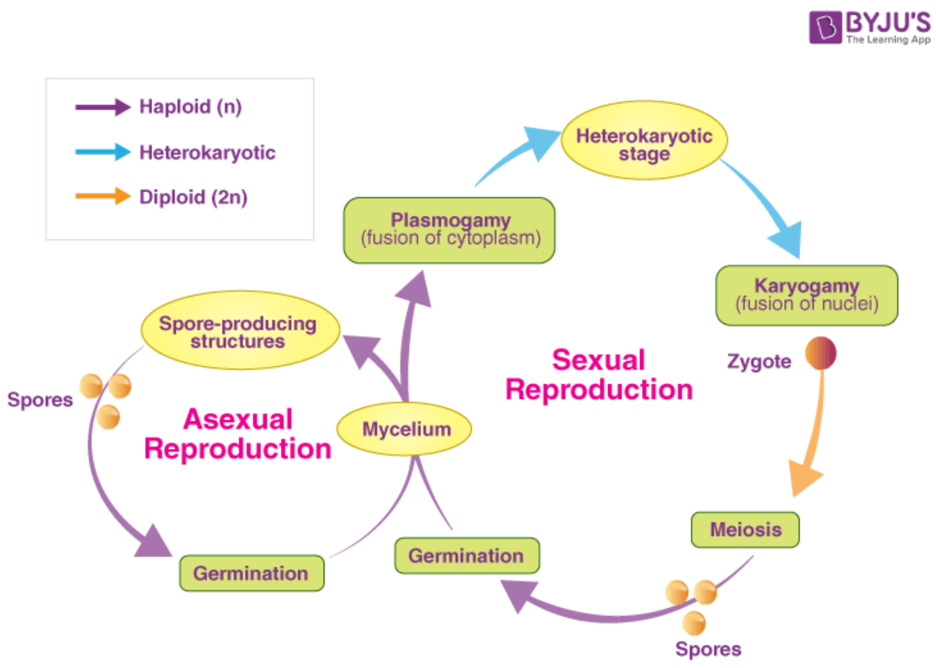

Figure 5. The life cycle of fungi has many different patterns based on the species of the fungi. Not all fungi reproduce in the same way. While some fungi reproduce sexually, others reproduce asexually. Therefore, we are going to look at the life cycle of fungi in the asexual and sexual stages. Source: https://byjus.com/biology/fungus-life-cycle/.

The next stage is called karyogamy, which occurs when haploid nuclei fuse the zygote and are formed here, which is a diploid stage. Division through meiosis restores the haploid condition, and spores are formed. It is clear, therefore, that sexual reproduction is made up of three stages: plasmogamy, karyogamy, and miosis (Figure 6)[16-17].

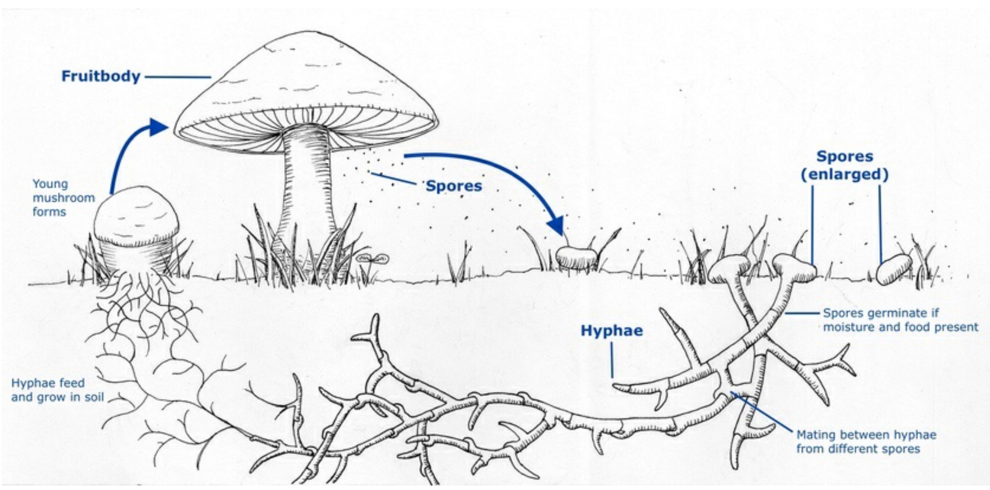

Figure 6. Simplified life cycle of a mushroom. Of the many spores produced by a mushroom, only a tiny number will land

where they can germinate – to produce hyphae. Hyphae of different species may grow in soil or in wood and may later form a tiny mushroom button. This then grows, and the stalk and cap expand to become a mushroom. Some other fungi have quite different life cycles. Source: https://www.sciencelearn.org.nz/resources/2664-fungal-life-cycles-spores-and-more.

1.6. Bioinsecticides

In addition to different shapes and sizes, fungi are also used extensively. They are essential for agriculture, especially in two biological processes: Bioyield: in this process, some types of fungi act as solubilizers of soil nutrients, optimizing production. Biocontrol: process in which a group of fungi can do the work of bioinsecticides and biofungicides, facilitating management [17-18].

1.7. Mutualism

Thanks to fungi, we can make bread and alcoholic drinks through the fermentation process. However, you need to be careful, as despite the benefits of fungi, they can also cause mold in food and mold on objects. On certain occasions, some fungi form a beneficial association with some hosts, this process is known as mutualism. An example of this is lichens when fungi are associated with some types of algae (Figure 7) [18-19].

Figure 7. Lichen is composed of two or more dissimilar organisms that form a mutually beneficial (symbiotic) relationship to produce a new vegetative body that is called a thallus. The life forms are composed of a fungus (kingdom Fungi) and most often a green alga (kingdom Protoctista) and/or a cyanobacterium (kingdom Monera). Source: https://njaes.rutgers.edu/fs1205/.

The most consumed edible fungi are mushrooms, such as champignons, shitake, and shimeji, dishes in many fine restaurants and gourmet recipes. These mushrooms have a high nutritional value and low lipid content. For those looking for a healthy diet, they are a good bet, bringing health benefits, such as increasing folic acid in the body. As already mentioned, with the fermentation process we have bread and alcoholic drinks such as beer and wine. In bread we use yeast (yeast), which from the fermentation of sugar will make the bread rise. The drinks also use a fermentation process. To produce wine, grapes are fermented, and beer is made from barley [19-23].

The presence of fungi in medicine is due to their use in the manufacture of certain medicines, as they can produce compounds that can kill some bacteria. These compounds are used in the manufacturing processes of antibiotics, such as penicillin, which combat infectious diseases caused by bacteria [23-24].

1.8. The main types of existing fungi

Yeasts can live as unicellular or multicellular with hyphae. Found in many places, even inside plants and animals. It can metabolize carbohydrates such as alcohol and carbon dioxide. Yeasts are used in the fermentation of bread, wine, and beer. **Molds:** They belong to the zygomycetes group. It is growing rapidly and is responsible for spoiling foods such as fruit, bread, and dairy products. The septate hyphae of these fungi spread through the food source by penetrating the food. **Lichens:** They are formed from a relationship between a fungus and several photosynthetic organisms (symbiotic relationship). **Mycorrhizae:** These microorganisms live in close association with plant roots helping them absorb more nutrients. The hyphae of this type of fungi grow to the roots of plants, branching into a fine network of hyphae that can absorb more nutrients (Figure 8) [23-25].

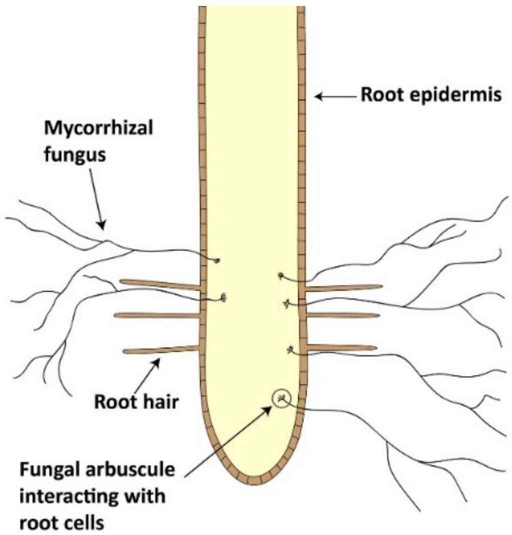

Figure 8. Mycorrhizae fungi can help: Nourish crops with water and nutrients. Build soil structure. Protect the plant from drought and other stresses. Mycorrhizae are a collection of many species of symbiotic or beneficial soil-borne fungi that help nourish a host plant. In concert with the host plant's roots, the fungi produce very fine threads (hyphae) that can be 100 times longer than the roots of the host. The hyphae serve as an extension of the plant's root system and can penetrate deeper into the soil profile for nutrients and water. The symbiotic relationship occurs when the host plant supplies the fungus with energy produced by photosynthesis and the fungus supplies the plant with water and nutrients. Source: https://www.specialtyhybrids.com/en-us/agronomy-library/benefits-mycorrhizae-fungi.html.

1.9. Diseases caused by fungi. Some fungi may be responsible for generating fungal diseases, such as:

Ringworm is a fungal infection that can be caused by three types of fungi:*Epidermophyton, Microsporum,* and *Trichophyton*; Candidiasis (infection resulting from exaggerated proliferation of the fungus*Candida albicans* (Berkhout, 1923) (Ascomycota: Saccharomycetales: Cryptococcaceae), yeast (diploid fungus) [25-26].

Family: Cryptococcaceae. This is a fungus that exists naturally in the human body and that in small quantities helps in the absorption of nutrients and digestion); Histoplasmosis is a fungal disease that particularly affects the lungs and is caused by the fungus *Histoplasma capsulatum,* or *Ajellomyces capsulatus* Darling (1906) / (Kwon-Chung) McGinnis & Katz (1979) (Ascomycota: Onygenales: Aorjellomycetaceae). This fungus is found in the feces of birds and bats [27-29]

2. Systematic

2.1. Ascomycetes

This phylum contains some edible fungi and yeasts that are used in industrial fermentation processes. These organisms form specific structures in the reproductive phase, called asci, similar to sacs containing spores inside, which are called ascospores. These fungi can be saprophages, parasites, or even symbionts, and can associate with blue algae cyanobacteria to form lichens [28-29].

2.3. Basidiomycetes

Organisms with septate hyphae form structures called basidia similar to rods during the reproduction phase, containing spores called basidiospores. Within the phylum of basidiomycetes, there are three classes, where only one class is characterized by the formation of fruiting bodies popularly known as mushrooms. A known example of fungus belonging to this phylum is the champignon. They are saprophagous fungi and symbionts and some even manage to release poisonous and attractive toxins, causing the death of small animals that come close to feed. These animals are then digested by the exoenzymes and are absorbed by the fungus-like predator [29-31].

2.4. Cytridiomycetes

Generally aquatic organisms with flagella on their body structure. Unlike the other groups, chytridiomycetes, or just chytrids, do not have chitin in their cell wall, but rather cellulose and other carbohydrates. They are mostly filamentous multicellular organisms, with coenocytic hyphae and diploid nuclei. Because they have mycolaminarin as an energy reserve structure and not glycogen, members of this group are often confused with species of algae. They are saprophages or parasites and reproduce through zoospores specialized structures that will generate an individual identical to the organism that generated the zoospore [31-33]

2.5. Deuteromycetes

Fungi with little known reproduction, so they are placed in a separate group, called imperfect. They are usually plant parasites, but they can also be used in the economy and cause diseases such as athlete's foot [32-33].

2.6. Zygomycetes

They are filamentous coenocytic fungi whose main characteristic is the formation of zygospores reproductive structures similar to spores. They are decomposers or parasites. In the past, within the zygomycetes, phylum were the fungi that formed an association with vegetable roots forming mycorrhizae, but the most current classification places these mycorrhizal fungi in a separate phylum called glomeromycetes, leaving the zygomycetes phylum only for saprophagous and parasitic fungi. Among the members of this phylum is Rhizopus, popularly known as bread mold, which is the mold responsible for the black spots on the surface of contaminated bread *Rhizopus stolonifer* (Ehrenb.) Vuill., 1902 (Zygomycota: Mucorales: Mucoraceae), the mold found on bread [32-34].

3. Poisonous mushrooms: Toxins, symptoms

Conocybe filaris (Fries 1884 ex r kühner, 1936) (Basidiomycota: Cortinariales: Bolbitiaceae)It is an innocent-looking grass mushroom that is especially common in the Pacific Northwest. Presenting the same mycotoxins as amanita, it is potentially fatal if ingested. Gastrointestinal symptoms can cause liver and kidney failure, leading to death [33-34].

Cortinarius rubellus Riviere, 2010 (Basidiomycota: Agaricales: Cortinariaceae) and *Cortinarius orellanus* Fr. 1838 (Basidiomycota: Agaricales: Cortinariaceae) Kauffman, C. H. 1905, is a genus of mushrooms that encompasses several species are similar to other edible species. **Orelanine** has an insidiously long latency period and can take anywhere from 2 days to 3 weeks. The toxin ends up causing kidney failure and death if left untreated (Figure 9) [34-35].

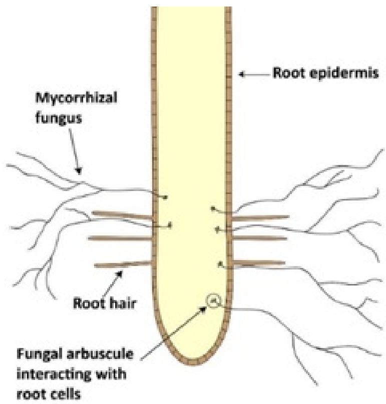

Figure 9. Other poisoning syndromes (rarely life-threatening). Source:https://www.emdocs.net/tox-cards-mushrooms/.

Galerina marginata (Batsch) Kühner, 1935 (Basidiomycota: Agaricales: Hymenogastraceae). Common throughout the northern hemisphere and parts of Australia, *G. marginata* is a mushroom with the same **amatoxins as amanita**. Its ingestion causes diarrhea, vomiting, hypothermia, and liver damage and can result in death if the poisoning is not treated. Although not especially similar to edible species, several deaths and poisonings have been attributed to collectors who mistook autumn skullcap for hallucinogenic mushrooms (Figure 9) [35-36].

Lepiota brunneoincarnata Chodat & C. Martín, 1889 (Basidiomycota: Agaricales: Hymenogastraceae). Widely distributed throughout Europe and parts of Asia, this mushroom is quite innocuous and has been confused with edible varieties, although poisonings are not very common. Accidental consumption leads to serious liver toxicity and can have lethal consequences if immediate treatment is not received. Scientifically, psilocybin found in mushrooms is converted in the body and influences serotonin levels in the brain, leading to altered and unusual perceptions (Figureb 10) [35-37].

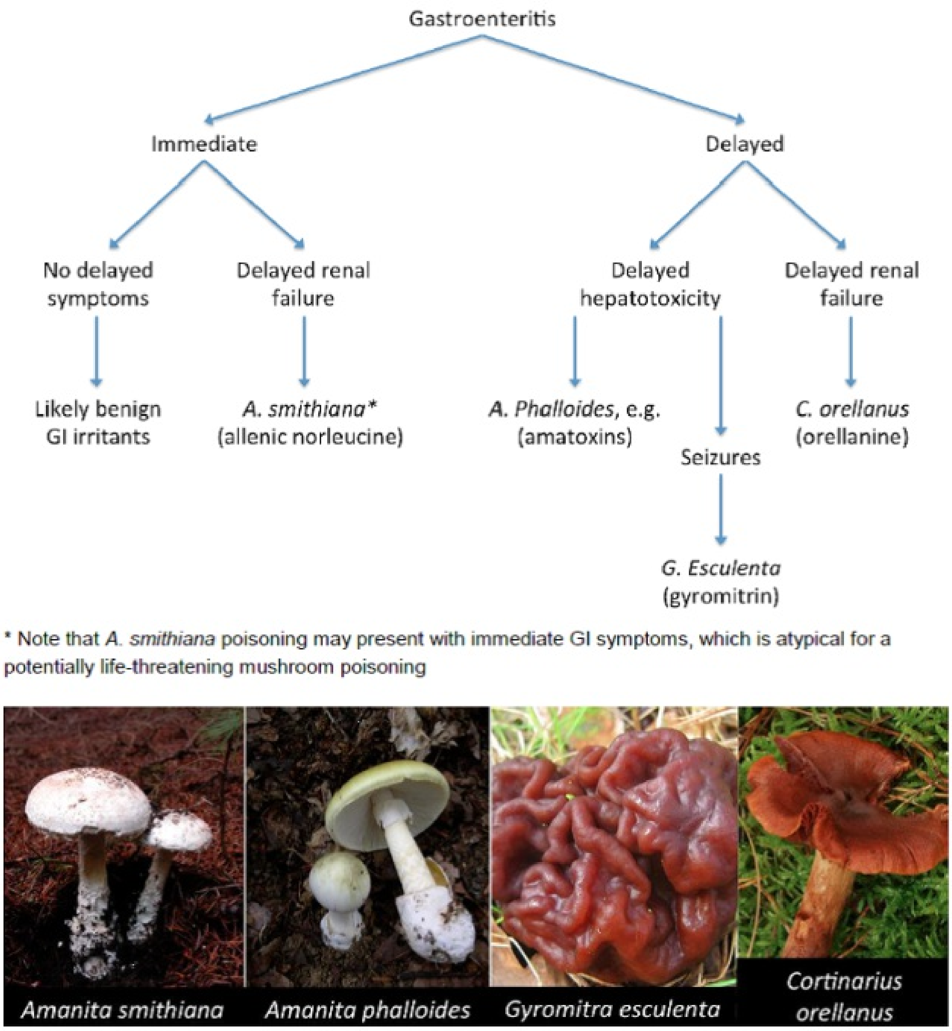

Figure 10. The most common immediate symptoms are gastrointestinal (GI): abdominal pain, vomiting, and diarrhea usually self-limited. Potentially life-threatening mushrooms may also present initially with gastroenteritis. Source: https://www.emdocs.net/tox-cards-mushrooms/.

3.1. There are four categories of mushroom toxins: a) protoplasmic poison which causes widespread destruction of cells, followed by organ failure; b) neurotoxin compounds that cause neurological symptoms such as profuse sweating, coma, convulsions, hallucinations, excitement, depression, and spastic colon; c) gastrointestinal irritants - compounds that quickly produce temporary nausea, vomiting, abdominal pain, and diarrhea and d) Disulfiram-type toxin (tetraethylthiuram disulfate. Etiological agent toxins are called amanitin, gyromitrin, orelanine, muscarine, ibotenic acid, muscimol, psilocybin/psilocin, and coprine [36-37].

3.2. Protoplasmic Poisons: Amatoxins: Hydrazines: protoplasmic gyromitrin, a volatile derivative of hydrazine orelanin

3.3. Neurotoxins: Muscarinic poisoning: Ibotenic acid/ muscimol poisoning: Psilocin poisoning [36].

3.4. Gastrointestinal Irritants: The chemical substance responsible for the toxin in this type of poisoning is unknown; however, the presence of unusual sugars, amino acids, peptides, resins, and other compounds is detected [36-38].

3.5. Disulfiram Type Toxin Poisoning: Mushrooms produce an unusual amino acid coprine, which is converted to cyclopropane hydrate in the human body.

3.6. Preventive measures: Do not eat mushrooms harvested directly from nature, only those sold in places with health control. Do not drink mushroom tea, some are extremely toxic and can lead to death. **First aid:** Remove the remains of the mushroom from your mouth. Have the person drink water if they are not vomiting. Do not induce vomiting. Keep the remains of the mushroom left over from ingestion for identification. Refer the patient to medical care [37-39].

4. Therapeutic use, and their use in biological control

4.1. A substance polymyxin B and alfa-amanitina found in*Amanita phalloides* (Vaill. ex Fr.) Link, 1833 (Vaill. ex Fr.) (Basidiomycota: Amanitaceae) was discovered for the first time that can act as an antidote to poisoning by one of the most poisonous and lethal wild mushrooms in nature, which is called *'A. phaloides'*, professor at the Faculty of Pharmacy of the University of Porto, Félix Dias Carvalho (Figure 11) [38-39].

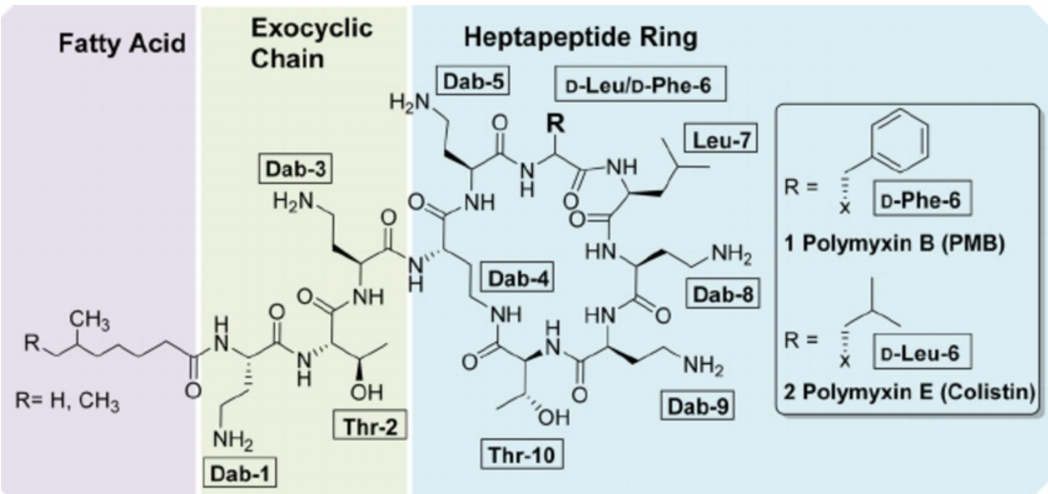

Figure 11. Structures of Polymyxin B 1 and Polymyxin E (Colistin) 2. Source: https://www.researchgate.net/figure/Structures-of-Polymyxin-B-1-and-Polymyxin-E-Colistin-2_fig1_289524053

4.2. Using computers, the researchers simulated coupling to an enzyme that is inhibited by toxins from poisonous mushrooms and is responsible for transcribing our genetic code (DNA). The inhibition of this enzyme will result in a “blockage of protein synthesis and the affected cells will die”, explained the specialist. The “interesting thing about this work is that it is a substance that already exists in therapy, it is an antibiotic, and that it exists in hospitals, and can be applied in addition to the therapy that is already established, without having to replace any therapy.” (Félix Dias Carvalho) [38-44].

4.3. Waves of highly infectious viruses sweeping through global honeybee populations have contributed to recent declines in honeybee health. Bees have been observed foraging on mushroom mycelium, suggesting that they may be deriving medicinal or nutritional value from fungi. Fungi are known to produce a wide array of chemicals with antimicrobial activity, including compounds active against bacteria, other fungi, or viruses. The honeybees may gain health benefits from fungi and their antimicrobial compounds) [38-44].

4. 4. *Amanita muscaria* (L.) Lam. (Basidiomycota: Agaricales: Amanitaceae), is considered the most famous species of fungus in the world due to its psychoactive compounds, including muscimol. Insecticides from plant extracts deserve great attention, mainly because they are ecologically safe and biodegradable and because of specific considerations when inserting targets. On the other hand, the use of these compounds is limited due to their availability and, often, their high cost of obtaining. It is used to control the mosquito *Culex quinquefasciatus* Say (1823) (Diptera: Culicida) and the fly *Musca domestica* Linnaeus, 1758 (Diptera, Muscidae)) [38-44].

5. CDQ "Amazon fungus "feeds" on plastic"

Furthermore, as natural recyclers (see CDQ "Amazon fungus "feeds" on plastic") or providing other ecosystem services (see CDQ "Trees attract biodiversity and protect rare and endangered species"), fungi are essential for the maintenance of resources and natural balance of ecosystems in the environment. Perhaps fungi are more beneficial than harmful [40-44].

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