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Review Article

Fungi, their applications in food, along with their deleterious effects

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Abstract

Fungi, a diverse kingdom of eukaryotic organisms, play a complex and vital role in the food ecosystem. They can be morphologically classified as yeasts, yeast-like fungi, molds and dimorphic fungi. In fact, fungi are very important in the filed of food microbiology. These organisms range from microscopic yeasts and molds to familiar mushrooms that are used as food. Their influence on food spans from essential contributions to culinary practices , to applications in biotechnology and harmful spoilage and toxin production. Understanding the dual nature of fungi is therefore crucial for leveraging their full benefits while minimizing risks.

Keywords: Edible fungi (Mushrooms), Kombucha, Aflatoxins, Ochratoxin A, Patulin

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1. Introduction

Fungi are very interesting eukaryotic microorganisms that find myriad applications in medicine and food science. They are important as sources of antibacterial compounds and packaging fibre. They can also help produce different types of foods like fermented foods and may also act as potent probiotic agents. Their structural and metabolic properties entail them to perform these activities. The modern era has witnessed many advancements in the usage of fungi in food science. For these reasons, fungi are deemed to be very important in the realms of public health and food microbiology.

2. Materials and Methods

Thorough and meticulous literature search was carried out using MeSH (medical subject headings) terms for collecting scientific literature.

3. Applications of Fungi in Food

3.1. Fermentation and flavor development

Fungi, particularly yeasts like *Saccharomyces cerevisiae*, are indispensable in fermentation processes.[1] This species is widely used in processes detailed below:-

a) **Bread making**, where it produces Carbon dioxide gas that causes dough to rise.
b) **Alcoholic beverages**, such as beer, wine, and spirits, by converting sugars into ethanol and CO_2.
c) Molds are also used for making food items and condiments like soya sauce and idli.
d) They are also useful for making cheese. While there are many different types of fungi that can be found in cheese, the most common are the *Penicillium* genus, including the species *Penicillium camemberti* and *Penicillium roqueforti*. Fungi play a pivotal role in breaking down milk fats and proteins, thus

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contributing to bringing out the overall creamy texture and typical umami flavour of cheese.[2]

e) Molds such as *Aspergillus oryzae* are essential in the production of traditional Asian foods like soy sauce, miso, and sake, and breaking down complex starches and proteins to enhance flavor.

3.2. Production of dairy products

Fungi are vital for the the ripening of specific types or varieties of cheeses. For instance:

1. *Penicillium roqueforti* gives blue cheese its characteristic veins and tangy taste.
2. *Penicillium camemberti* is used in soft-ripened cheeses like Camembert and Brie, contributing to their texture and aroma.

3.3. Edible fungi (Mushrooms)

Mushrooms are edible basidiomycetous fungi. Various species of mushrooms, such as *Agaricus bisporus* (button mushrooms), *Pleurotus ostreatus* (oyster mushrooms), and *Lentinula edodes* (shiitake), are held in high esteem and consumed globally for their nutritional value, typical flavor, and various health-promoting properties, including presence of antioxidants and immune-supporting compounds. White button mushrooms are the most popular in this regard. Mushrooms are therefore regarded as superfoods due to their low calorie content and high protein and dietary fibre levels.

3.4. Biotechnology and food additives

Fungi are also used industrially to produce a number of enzymes, various organic acids (like citric acid from *Aspergillus niger*), and also many types of flavour enhancers that improve food texture, shelf life, and taste.

3.5. To produce different beverages

Kombucha tea is produced with the help of fungi in broth. Kombucha tea is produced by fermenting sweetened tea with a mixture of symbiotic colony of bacteria (*Acetobacter xylinum*) and yeasts (*Brettanomyces*, *Zygosaccharomyces*, *Saccharomyces*, *Pichi a*). It is a popular traditional fermented drink with many health-promoting attributes. A popular fermented beverage named kanji was prepared from crimson coloured carrots by natural fermentation at ambient temperature (using *Lactobacillus plantarum*).[3] Although it may have many beneficial ingredients, it may also potentially contain a multitude of harmful substances.

3.6. As probiotic

Saccharomyces cerevisiae var. boulardii is a very good probiotic agent with no risk of developing antibacterial resistance. As probiotics they are useful to treat many conditions like antibiotic associated diarrhea and inflammatory bowel disease. Several clinical investigations have declared *S. cerevisiae* var. *boulardii* as a biotherapeutic agent due to its antibacterial, antiviral, antioxidant, anti-carcinogenic, anti-inflammatory and immune-modulatory effects. *S. cerevisiae* var. *boulardii* is also responsible for the formation of glutathione, which is an important antioxidant used in the food and drug industry.

3.7. Miscellaneous applications

Many fungi have other powerful applications in the food industry. *Rhodotorula* spp, Is a basidiomycetous yeast that is deemed to be quite helpful in the food industry. *Rhodotorula* are the most common carotenoid-producing yeasts with good ability to synthesize various chemical compounds like β-carotene, torulene and torularhodin. Moreover, they are widely regarded as a very good source of proteins, lipids and vitamins.[4]

5. *Candida utilis* is a yeast that is considered a valuable source of protein, and is particularly rich in amino acids like lysine.

4. Deleterious Effects of Fungi on Food

Despite their many benefits, fungi can also pose significant challenges to food safety and quality and can cause organ and tissue damage.

4.1. Food spoilage

Fungi play a very important role in spoilage of food items like bread and meat. Molds and yeasts can cause spoilage by breaking down the food components, leading to development of off-flavors, discoloration, and unappealing textures. Common spoilage-causing fungi include:

1. *Rhizopus*, which causes bread mold. It belongs to the phylum Glomeromycota.
2. *Penicillium* species, which spoil fruits and vegetables. It is a mold with green velvety colonies.
3. *Candida* yeasts, which can spoil sugary or moist foods like fruit juices and syrups.

4.2. Mycotoxin production

Toxic substances called *mycotoxins* are naturally produced by some molds (fungi). Many foods, including cereals, dried fruits, nuts, and spices, are colonized by molds that can produce mycotoxins. Mold growth can happen on or in the food itself, during storage, or before or after harvest, frequently in warm, humid, and humid environments. Food processing does not harm most mycotoxins because they are chemically stable. Notable examples include the following mycotoxins:

1. *Aflatoxins*, produced by *Aspergillus flavus* and *A. parasiticus*, are often found in improperly stored nuts, foodgrains, and spices. Aflatoxin B1, G1 and M1 are important among all aflatoxins. They are seen mostly in various grains like rice and peas. Aflatoxin consumption has been linked with ailments like liver

injury in acute cases and hepatocellular carcinoma upon long-standing consumption.

2. *Ochratoxin A*, associated with *Aspergillus* and *Penicillium* species, is found commonly in cereals, coffee, and dried fruit. It is highly nephrotoxic agent and Ochratoxin A is implicated in diseases like Balkan endemic nephropathy.[5] Among all ochratoxins, ochratoxin A occurs most frequently; however, its dechlorinated and ethyl ester derivatives, in the form of ochratoxin B (OTB) and ochratoxin C (OTC), respectively, seem to be also important.
3. *Patulin*, produced by *Penicillium expansum*, and *Aspergillus* spp. is commonly found in moldy, rotten apples and apple products. Patulin is a water-soluble, heat-stable mycotoxin that is believed to have nephrotoxic and immunotoxic effects.[6]
4. *Zearalenone***:** It causes symptoms of hyperestrogenism and is seen in fungi **(***Fusarium* spp) growing on maize.[7] Natural exposure to zearalenone in contaminated food has been put forward as a cause of female reproductive changes due to its powerful estrogenic activity. Zearalenone is metabolized by the intestinal tissue into 2 major active metabolites: α- and β-zearalenol. The estrogenic activity of zearalenone and its metabolites is mediated by means of their binding affinity to estrogen receptors. Girls chronically exposed to zearalenone through their diet suffer from various problems like early puberty and several sexual disorders.[8] Contaminated products can cause huge economic losses and also pose many other health risks to animals and humans.
5. *Fusarium graminearum* is responsible for the production and accumulation of type B trichothecenes (mycotoxins), such as deoxynivalenol, as well as other secondary metabolites in cereal grains, during growth.[9]

These toxins can cause acute poisoning and long-term health effects, including liver damage, immunosuppression, and carcinogenicity.

The table below highlights important aspects of mycotoxins. (**Table 1**)

Table 1: Mycotoxins, their sources and effects

Name of mycotoxin	From which grain	From which fungus	Ill-effects
Aflatoxin A1, B1	Peas, rice	Flavus and A. parasiticus	Liver damage, hepatocellular carcinoma
Zearaelenone	Maize, wheat, barley	Fusarium graminearum	Hyperestrogenism and related disorders
Patulin	Rotten and moldy apples	Penicillium spp. and Aspergillus spp.	Mutagenic, teratogenic and carcinogenic effects
Ergot alkaloids	Cereal grains like rye, wheat, and barley	Claviceps purpurea	Vasoconstriction and abortion

4.3. People are recommended to adopt the following measures in order to reduce the health risk associated with mycotoxins:

1. One should always check growth of mold on whole grains (particularly corn, sorghum, wheat, and rice), dried figs, and nuts (particularly peanuts, pistachios, almonds, walnuts, coconuts, Brazil nuts, and hazelnuts), all of which are frequently tainted with aflatoxins; one should promptly throw away any that appear moldy, discolored, or shriveled.
2. Prevent grain damage before, during, and after drying and storage, as damaged grain is more vulnerable to mold invasion and subsequent mycotoxin contamination.
3. Purchase fruits, grains and nuts as fresh as possible and not from supermarkets; ensure that food is stored correctly, meaning it should be dry, insect-free, and not overly warm;
4. Avoid storing food for long periods of time before using it; and maintain a balanced diet, which not only increases nutrition but also lowers exposure to mycotoxins.[10]

4.4. Allergic reactions and infections

Exposure to fungal spores from spoiled food can trigger many allergic reactions in sensitive individuals. Additionally, certain immunocompromised individuals may be at risk of contracting opportunistic fungal infections from ingesting contaminated food, although this is rare.

4.5. Mushroom poisoning

Amanitin, phalloidin and Gyromitrin, present in poisonous mushrooms can be detrimental to health. Amanitin is most commonly produced by the mushroom (basidomycetous fungus) *Amanita phalloides*, which is also known as death cap.[11] Hepatotoxicity is the hallmark of amanitin, leading to hepatocellular failure within three days of ingestion. The toxic mechanisms of action include RNA polymerase II inhibition and oxidative stress generation, thus leading to liver cell apoptosis or necrosis, depending on the doses ingested.[12]

4.6. Detection methods of fungi in food

Mycotoxins: They can be detected by methods like liquid chromatography, thin layer chromatography or ELISA. A simple method to detect is placing the foodgrains or cthe mold culture in ultraviolet light and observing the resultant fluorescence (Aftatoxin B1 emitting blue fluorescence and Aflatoxin G1 emitting green fluorescence). Aflatoxin M1 and M2 represent the toxins B1 and B2, which have been metabolized within the body of a lactating animal. Their finding in milk have led to their designation as 'M'.[13]

Other fungi: Culture can be performed on SDA (Sabouraud's dextrose agar) tube, and then identified using typical microscopic morphology in Dalmau technique on corn meal agar. Sometimes fungi like *Rhodotorula* possess

orange pigment, which can help in identification. *Penicillium* spp. may be identified by typical microscopic morphology.

Images of fungi in their various stages, and their pigment production, are shown in figures below. (**Figure 1**, **Figure 2**, **Figure 3**)

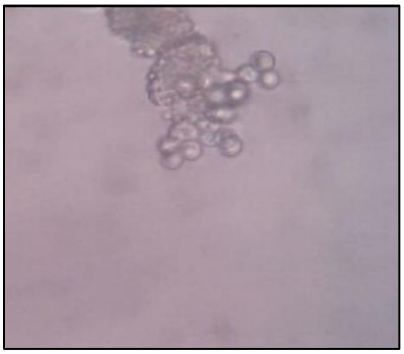

Figure 1: Terminal chlamydospores of yeasts (*Candida albicans*)

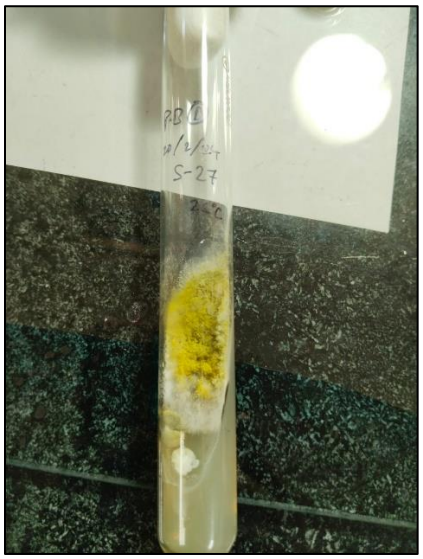

Figure 2: *Aspergillus flavus* on SDA

Figure 3: Pigmented (*Rhodotorula*) and non-pigmented yeast colonies

5. Discussion

Fungi, while beneficial to us in many ways, may pose various risks, too. They themselves can be used as food and also help in manufacturing many kinds of fermented foods and beverages. Fungal involvement or their potential applications in foods is not a very new phenomenon but has been practiced for many centuries now. Traditional food fermentation processes, like the production of cheese, bread, and alcoholic beverages, depend heavily on the activities of specific fungal strains in order to achieve desired sensory and nutritional benefits.[14] Mushrooms are the new superfoods. Some mushrooms have been described as being meat-like in constituency, like the beefsteak fungus (*Fistulina hepatica*) and chicken of the woods (*Laetiporus sulphureus*), as well as the seafood-like abalone fungus (*Pleurotus cystidiosus*) and the lobster mushroom.[15] Fungi, or to be specific mushrooms, themselves are also edible. Fungi are now considered very important sources of proteins also. Mycoprotein products are available in different forms, like beef burgers, beef steaks, chicken nuggets, fish sticks, meatballs, sausages, among others.[16] Mycoprotein products from fungal mycelia are also available in the form of a bacon substitute by a particular food manufacturing company under the trade name MyBacon. They play a very important role in preparing fermented foods. More and more novel applications of fungi in in the food industry are being discovered and explored with time. Hence much remains to be known about the putative role played by the different types of fungi in food. There should be more studies exploring the link between fungi and food.

6. Conclusion

Fungi represent a double-edged sword in the food industry. On the one hand, they are indispensable allies in creating many tasty foods and beverages, enriching flavor, and contributing immensely to food biotechnology. On the other hand, they can be serious threats to food safety and public health through spoilage and toxin production. Proper handling, storage, and processing of food are essential to harness the beneficial aspects of fungi while mitigating their harmful effects.

7. Recommendations

Fungi play diverse role in food making and may also be harmful when present in food. We should delve into more details regarding fungi and their importance in food.

8. Source of Funding

None.

9. Conflict of Interest

None.

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