

An Overview and Study on Edible Mushrooms: Human Health Benefits and Promoting Quality of Life

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ABSTRACT

Mushrooms are globally appreciated for their nutritional value and medicinal properties. Their cultivation is an effective bioconversion technology of transforming wastes and woods into potentially valuable resources and could also be an important part of sustainable agriculture and forestry. The per capita consumption of mushrooms in India is also very meager and is even less than 100 g per year. Mushrooms have been consumed since earliest history; ancient Greeks believed that mushrooms provided strength for warriors in battle and the Romans perceived them as the “Food of the Gods.” For centuries, the Chinese culture has treasured mushrooms as a health food, an “elixir of life.” They have been part of the human culture for thousands of years and have considerable interest in the most important civilizations in history because of their sensory characteristics; they have been recognized for their attractive culinary attributes.

Out of the total mushroom produced in India, white button mushroom share is 73% followed by oyster mushroom (16%), paddy straw mushroom (7%) and milky mushroom (3%). Nowadays, mushrooms are popular valuable foods because they are low in calories, carbohydrates, fat and sodium: Also, they are cholesterol-free. Besides, mushrooms provide important nutrients, including selenium, potassium, riboflavin, niacin, vitamin D, proteins and fiber. All together with a long history as food source, mushrooms are important for their healing capacities and properties in traditional medicine. It has reported beneficial effects for health and treatment of some diseases. Many nutraceutical properties are described in mushrooms, such as prevention or treatment of Parkinson, Alzheimer, hypertension and high risk of stroke. They are also utilized to reduce the likelihood of cancer invasion and metastasis due to antitumor attributes. Mushrooms act as antibacterial, immune system enhancer and cholesterol lowering agents; additionally, they are important sources of bioactive compounds. As a result of these properties, some mushroom extracts are used to promote human health and are found as dietary supplements.

INTRODUCTION

Mushroom is a macro fungus with a distinctive fruiting body, which can be either epigeous or hypogeous and large enough to be seen with naked eye and to be picked by hand. It is perhaps the most well-known and documented edible forest product (Kumari and

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Atri 2014)

Mushrooms have been considered as ingredient of gourmet cuisine across the globe; especially for their unique flavor and have been valued by human-kind as a culinary wonder. More than 2,000 species of mushrooms exist in nature, but around 25 are widely accepted as food and few are commercially cultivated (Valverde *et al.* 2015). Mushrooms are considered as a delicacy with high nutritional and functional value, and they are also accepted as nutraceutical foods; they are of considerable interest because of their organoleptic merit, medicinal properties and economic significance (Ergonul *et al.* 2013). However, there is not an easy distinction between edible and medical mushrooms because many of the common edible species have therapeutic properties and several used for medical purposes are also edible (Guillamon *et al.* 2010). Mushrooms are the common components in folk medicine, especially in Africa, the Middle East, China and Japan since ages. Earlier, edible mushrooms were only harvested wild and were difficult to domesticate and cultivate. Collection from wild woodlands is still important in the world and particularly in southern Asia and other developing countries. Mushrooms belong to basidiomycetes and ascomycetes with a cell cycle including the formation of sexual spores and have two growth phases, i.e., the vegetative phase (mycelia) and the reproductive phase (fruit bodies) (Valverde *et al.* 2015) (Fig. 1).

Mushroom develops from a nodule or pinhead, less than two millimeters in diameter, called a primordium, which is typically found on or near the surface



Fig. 1. Fruiting body of Button mushroom.

of the substrate. It is formed within the mycelium, the mass of threadlike hyphae that make up the fungus. The primordium enlarges into a roundish structure of interwoven hyphae roughly resembling an egg, called a “button”. The button has a cottony roll of mycelium, the universal veil that surrounds the developing fruit body. As the egg expands, the universal veil ruptures and may remain as a cup or volva, at the base of the stalk or as warts or volval patches on the cap. Many mushrooms lack a universal veil ; therefore they do not have either a volva or volval patches. Often, a second layer of tissue, the partial veil, covers the blade-like gills that bear spores. As the cap expands, the veil breaks and remnants of the partial veil may remain as a ring or annulus, around the middle of the stalk or as fragments hanging from the margin of the cap (Gupta *et al.* 2018).

The fungal spores are located in a special structure called the basidium (for *Basidio mycetes*) or the ascus (for *Asco mycetes*). The mushroom continues its life cycle in three key stages viz., vegetative growth, reproductive growth, and spore production by fruiting bodies of the mushrooms (Kumar *et al.* 2020) as showed in picture. (Fig. 2).

The most cultivated mushroom worldwide is *Agaricus bisporus*, followed by *Lentinus edodes*, *Pleurotus* spp. and *Flammulina velutipes*. Mushrooms production continuously increases, China being the biggest producer around the world. However, wild mushrooms are becoming more important for their nutritional, sensory and especially pharmacological characteristics (Aida 2009).

Mushrooms could be an alternative source of new antimicrobial compounds, mainly secondary metabolites, such as terpenes, steroids, anthraquinones, benzoic acid derivatives and quinolones, but also of some primary metabolites like oxalic acid, peptides and proteins. *Lentinus edodes* is the most studied species and seems to have an antimicrobial action against both gram-positive and gram-negative bacteria (Alves *et al.* 2012). A balanced diet is the supporting treatment for the prevention of illness and especially against oxidative stress. In this context, mushrooms have a long history of use in the oriental medicine to prevent and fight numerous diseases (Carneiro

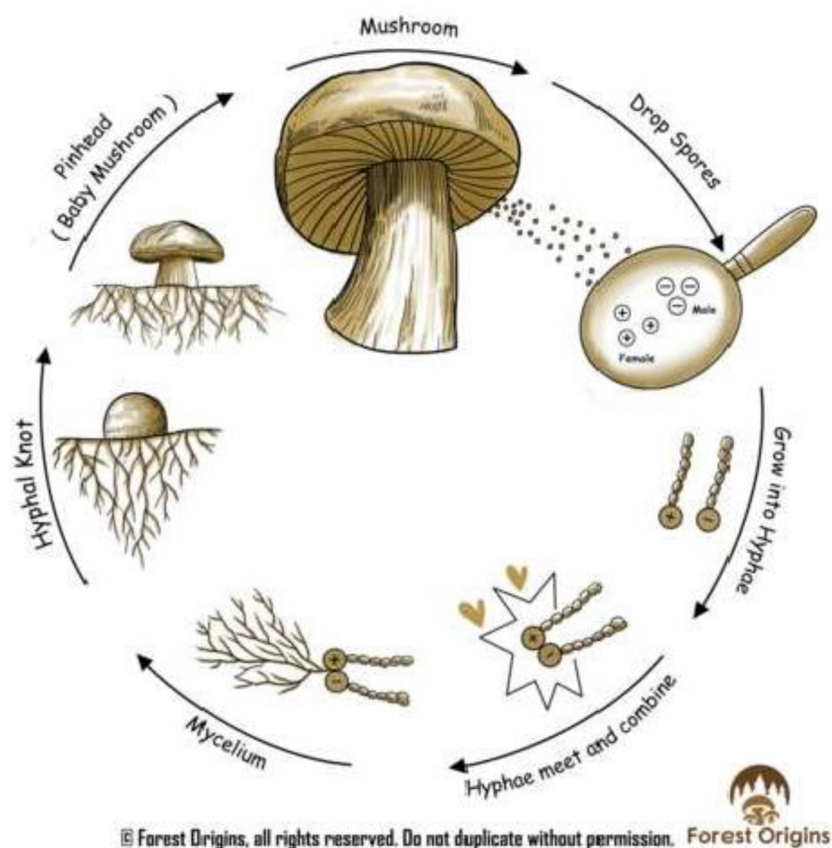


Fig. 2. Life cycle of mushroom.

et al. 2013). Nowadays, mushroom extracts are commercialized as dietary supplements for their properties, mainly for the enhancement of immune function and antitumor activity (Guillamon *et al.* 2010). In this work, we aimed to review the nutritional value as well as the chemical and nutraceutical composition and commercial potentialities of the most cultivated edible mushrooms worldwide.

HISTORY

The consumption of mushrooms probably occurred during prehistory, in the hunting and gathering period. Unlike plants, mushrooms could not be cultivated at first and were collected for a long period of time. Even today, relatively few species of mushrooms can be cultivated compared to the number of edible species (Tunday 2020). Mushrooms were thought to

be special and supernatural in origin – 4600 years ago, the Egyptians believed mushrooms to be plants of immortality; the Pharaohs decreed that only they could eat mushrooms (Azeem Abdel *et al.* 2016). The Romans thought mushrooms were the food of the gods. Many people collect mushrooms for the purpose of consumption, but lots of myths and false concepts still survive today (Valverde *et al.* 2015).

Although time to time, small efforts and simple research were conducted to introduce mushroom cultivation in India, scientific and systematic research only started in 1961, when the Indian Council of Agricultural Research, New Delhi, first cultivated *Agaricus bisporus* at Solan in Himachal Pradesh, a hilly state of North India. India, primarily being an agrarian economy, is rich in terms of agro-wastes that are not properly utilized by the nation's farmers (Gupta *et al.* 2018). India produces nearly 700 million

tons of agricultural residues which can profitably be utilized for mushroom cultivation. Even if India uses 2% of its total agroresidues for mushroom production, the production would be 7.0 million tons of fresh mushrooms, which will be equal to current global button mushroom production (Gupta *et al.* 2016). Currently, India is using only 0.03% of these residues to produce about 0.13 million tons of mushrooms and contributes of the oyster and paddy straw mushrooms in India. The country's production in 2010 was 1.00 lakh metric tons, of which button mushroom accounted for 89% of the total production, followed by oyster (6%), milky (1%) and others (4%). Punjab, Uttarakhand, Haryana, Uttar Pradesh and Tamil Nadu were the leading producers of the mushroom in the country at the time of 2010. The present production status revealed that Punjab, Haryana and Odisha are emerging as the leading states in mushroom production (Thakur *et al.* 2021).

DISCUSSION AND FINDINGS

Health benefits: Mushrooms are widely known for their great taste and amazing health benefits. Packed with a ton of essential vitamins and minerals, they make for an excellent addition to your diet, adding flavor to many different recipes. Mushrooms are a low-calorie food that packs a nutritional punch. Loaded with many health-boosting vitamins, minerals, and antioxidants, they've long been recognized as an important part of any diet. For instance, mushrooms raised with exposure to ultraviolet light are a good source of Vitamin D, an important component in bone and immune health. Crimini mushrooms are a particularly excellent source of zinc, an essential trace element. Zinc is a vital nutrient for the immune system and is also needed for ensuring optimal growth in infants and children (Elliot *et al.* 2021). Mushrooms contain protein, vitamins, minerals and antioxidants. These can have various health benefits. For example, antioxidants are chemicals that help the body eliminate free radicals. Free radicals are toxic byproducts of metabolism and other bodily processes. They can accumulate in the body and if too many collect, oxidative stress can result. This can harm the body's cells and may lead to various health conditions (Kumari *et al.* 2011).

Moreover, researchers have found a number of other excellent reasons for incorporating mushrooms into your diet, such as:

Lower blood pressure: Mushrooms are rich sources of potassium, a nutrient known for reducing the negative impact that sodium can have on your body. Potassium also lessens the tension in blood vessels, potentially helping to lower blood pressure (Thakur *et al.* 2021).

Boost immune system: The anti-inflammatory effect of mushrooms has been shown to greatly improve the efficiency of the immune system. Mushrooms help stimulate macrophages in the immune system, enhancing its ability to defeat foreign bodies and making you less susceptible to serious illnesses (Nahata 2013).

Weight loss: Long and short-term studies alike have found that mushrooms, in combination with exercise and other lifestyle changes, can have an important impact on weight loss. For example, after being asked to substitute 20% of their beef consumption with mushrooms, research participants showed improvements in their BMI and belly circumference. The antioxidants in mushrooms are also thought to reduce the risk of hypertension and other metabolic disorders (Kumar and Baojun 2018).

Cancer: An antioxidant that helps to neutralize free radicals, thus preventing cell damage and reducing the risk of cancer and other diseases. Mushrooms contain more selenium than any other form of produce (Thakur *et al.* 2021).

Diabetes: Dietary fiber may help manage a number of health conditions, including type 2 diabetes (Dilani *et al.* 2012). The Dietary Guidelines for Americans recommend that adults consume 22.4–33.6 g of dietary fiber each day, depending on sex and age. Mushrooms, beans, some vegetables, brown rice and whole-grain foods can all contribute to a person's daily requirement of fiber.

Heart health: The fiber, potassium and vitamin C in mushrooms may contribute to cardiovascular health. Potassium can help regulate blood pressure

and this may decrease the risk of hypertension and cardiovascular disease (Salxido 2016). The American Heart Association (AHA) recommends reducing the intake of added salt in the diet and eating more foods that contain potassium. According to current guidelines of National Institutes of health, people should consume around 4,700 milligrams (mg) of potassium each day. Mushrooms appear on the AHA's list of foods that provide potassium. A 2016 study of National Institutes of health concluded that people with a vitamin C deficiency were more likely to experience cardiovascular disease and suggested that consuming vitamin C may help prevent this illness.

Nutritional value: The nutritional value of edible mushrooms is due to their high protein, fiber, vitamin and mineral contents, and low-fat levels (Barros *et al.* 2008). They are very useful for vegetarian diets because they provide all the essential amino acids for adult requirements; also, mushrooms have higher protein content than most vegetables. Besides, edible mushrooms contain many different bioactive compounds with various human health benefits (Valverde *et al.* 2015). It is important to remark that the growth characteristics, stage and postharvest condition may influence the chemical composition and the nutritional value of edible mushrooms. Also, great variations occur both among and within species (P Kalac 2013). Mushrooms contain a high moisture percentage that ranges between 80 and 95 g/100 g, approximately. As above mentioned, edible mushrooms are a good source of protein, 200–250 g/kg of dry matter; leucine, valine, glutamine, glutamic and aspartic acids are the most abundant. Mushrooms are low-calorie foods since they provide low amounts of fat, 20–30 g/kg of dry matter, being linoleic (C18:2), oleic (C18:1) and palmitic (C16:0) the main fatty acids. Edible mushrooms contain high amounts of ash, 80–120 g/kg of dry matter (mainly potassium, phosphorus, magnesium, calcium, copper, iron and zinc). Carbohydrates are found in high proportions in edible mushrooms, including chitin, glycogen, trehalose and mannitol; besides, they contain fiber, β -glucans, hemicelluloses and pectic substances. Additionally, glucose, mannitol and trehalose are abundant sugars in cultivated edible mushrooms, but fructose and sucrose are found in low amounts. Mushrooms are also a good source of vitamins with high levels of riboflavin (vitamin B2),

niacin, foliates and traces of vitamin C, B1, B12, D and E. Mushrooms are the only nonanimal food source that contains vitamin D and hence they are the only natural vitamin D ingredients for vegetarians. Wild mushrooms are generally excellent sources of vitamin D2 unlike cultivated ones; usually cultivated mushrooms are grown in darkness and UV-B light is needed to produce vitamin D2 (Reis *et al.* 2012). The amount of vitamin D mushrooms contain varies widely and depends on how long the mushrooms are exposed to UV light. Estimates show that fresh wild mushrooms like chanterelles and morels can contain up to 1200 IU of vitamin D per 3.5 ounce serving, whereas mushrooms grown in darkened conditions like white button, shiitake and oyster contain less than 40 IU (Cardwell *et al.* 2018).

Edible mushrooms are important sources of food. They form very nourishing meals especially for invalids, for they are easily digestible. They are consumed not only for their innate flavor and taste, but also for their important nutritional value. On fresh weight basis mushrooms are superior in protein content (Aremu *et al.* 2009) to all vegetables and fruits, but are inferior to meat and dairy products, which are the conventional protein sources. On dry-weight basis, however, mushrooms are similar with respect to dried-yeast and superior to dried peas and beans. The nutrient content varies from species and depends on their growth requirement. Mushrooms have a high percentage of water 93–95% as compared to lean beef (70%) and fresh vegetables (92%). They also contain valuable minerals such as iron, potassium, phosphorus, calcium and copper, 56% carbohydrate, 30% protein, 2% fat and also 10% ash on dry weight basis. They are also rich in vitamin B and vitamin D. Mushrooms provide a high protein and low caloric diet and can thus be recommended to heart patients. They also contain all the essential amino-acid required by an adult (Koyyalamudi *et al.* 2009). Tryptophan and lysine are present in high concentrations as compared to cysteine and methionine. Mushrooms is reported to be an excellent source of riboflavin and nicotinic acid; a good source of pantothenic acid and ascorbic acid (Ukpebor *et al.* 2007). The carbohydrate and fat contents of edible mushrooms are quite low. The absence of starch in mushrooms makes it an ideal food for diabetic patients and for persons who wants

to shed excess fat. Edible mushrooms known as the meat of the vegetable world (Haas and James 2009) can be prepared into a variety of delicious dishes and as flavors for other dishes. Among the Nigerian mushroom dishes are mushrooms with vegetable, mushroom with vegetable and melon soup, mushroom in okro soup and mushroom in stew. These soups are used to eat a variety of foods. Some people use mushrooms as a substitute for meat in their stews (Abulude 2005).

Medicinal value of edible mushrooms: Since thousands of years, edible fungi have been revered for their immense health benefits and extensively used in folk medicine. Specific biochemical compounds in mushrooms are responsible for improving human health in many ways. These bioactive compounds include polysaccharides, triterpenoids, low molecular weight proteins, glycoproteins and immunomodulating compounds. Hence mushrooms have been shown to promote immune function; boost health; lower the risk of cancer; inhibit tumor growth; help balancing blood sugar; ward off viruses, bacteria and fungi; reduce inflammation and support the body's detoxification mechanisms. Increasing recognition of mushrooms in complementing conventional medicines is also well known for fighting many diseases (Manikandan 2011). Medicinal values of the some important mushroom are given below:

Good for heart: The edible mushrooms have little fat with higher proportion of unsaturated fatty acids and absence of cholesterol and consequently it is the relevant choice for heart patients and treating cardiovascular diseases. Minimal sodium with rich potassium in mushroom enhances salt balance and maintaining blood circulation in human. Hence, mushrooms are suitable for people suffering from high blood pressure. Regular consumption of mushrooms like *Lentinula*, *Pleurotus* spp. were shown to decrease cholesterol levels (Salvido 2016).

Low caloric food: The diabetic patients choose mushroom as an ideal food due to its low calorific value, no starch and little fat and sugars. The lean proteins present in mushrooms help to burn cholesterol in the body. Thus it is most preferable food for people striving to shed their extra weight (Manikandan 2011).

Prevent cancer: Compounds restricting tumor activity are found in some mushrooms but only a limited number have undergone clinical trials. All forms of edible mushrooms and white button mushrooms in particular, can prevent prostate and breast cancer. Fresh mushrooms are capable of arresting the action of 5-alpha-reductase and aromatase, chemicals responsible for growth of cancerous tumors. The drug known as Polysaccharide-K (Kresin), is isolated from *Trametes versicolor* (*Coriolus versicolor*), which is used as a leading cancer drug. Some mushroom-derived polysaccharides have ability to reduce the side effects of radiotherapy and chemotherapy too. Such effects have been clinically validated in mushrooms like *Lentinula edodes*, *Trametes versicolor*, *Agaricus bisporus* and others (Patel 2014).

Anti-aging property: The polysaccharides from mushrooms are potent scavengers of super oxide free radicals. These antioxidants prevent the action of free radicals in the body, consequently reducing the aging process. Ergothioneine is a specific antioxidant found in *Flammulina velutipes* and *Agaricus bisporus* which is necessary for healthy eyes, kidney, bone marrow, liver and skin (S H Patel, 2014).

Regulates digestive system: The fermentable fiber as well as oligosaccharide from mushrooms acts as a prebiotics in intestine and therefore they anchor useful bacteria in the colon. This dietary fibre assists the digestion process and healthy functioning of bowel system (Patel 2014).

Strengthens immunity: Mushrooms are capable of strengthening the immune system. A diverse collection of polysaccharides (beta-glucans) and minerals, isolated from mushroom is responsible for up-regulating the immune system. These compounds potentiate the host's innate (non-specific) and acquired (specific) immune responses and activate all kinds of immune cells. Mushrooms, akin to plants, have a great potential for the production quality food. These are the source of bioactive metabolites and are a prolific resource for drugs. Knowledge advancement in biochemistry, biotechnology and molecular biology boosts application of mushrooms in medical sciences. From a holistic consideration, the edible mushrooms and its by-products may offer highly palatable, nu-

trititious and healthy food besides its pharmacological benefits (Nahata 2013).

Main edible mushrooms: Edible fungi have been a part of home cooking for thousands of years. There are countless varieties, some commonly found at groceries and some that can only be found through foraging in the woods. Unless you are an experienced mycologist, do not eat mushrooms you find growing wild. Many poisonous species look very similar to more savoury ones (Filippone 2019).

While accepting fruits and vegetables is one thing, eating a fungus is a whole different issue. But knowledge is power! Mushrooms are low in calories, low in fat, low in sodium and free from cholesterol. They're also full of fiber, vitamins and minerals. They are also delicious when prepared properly, like say polenta cakes with a side of sautéed mushrooms and while it would be impossible to tell you about every kind of mushroom—there are more than 10,000 after all—we can discuss some of the most common mushroom types along with what they're best used for (Kostelny 2019).

Agaricus: *Agaricus bisporus* (Fig. 3), from the *Agaricus* genera, is the most cultivated mushroom worldwide. This group of edible mushrooms is nowadays widely used and studied for its medicinal and therapeutic properties (Firenzuoli *et al.* 2008). *Agaricus bisporus* is not particularly common in the wild, where like the field mushroom and the horse mushroom it springs up in fields and appears after rain. The specific name *bisporus* refers to the fact that each of the basidia bears just two spores – most *Agaricus* species have four-spored basidia (Reilly 2019).

Agaricus bisporus Imbach is the most wild and cultivated edible mushroom and represents more than 40% of the world bearing of mushrooms (Carluccio 2003). It is cultivated in over 70 countries and on every ascetic, except Antarctica. *A. bisporus* has a luscious taste with more nutritional value has very good aroma or flavoring taste is used as food and in food industries (Misharina *et al.* 2010). It is considered to have high biological activity, low toxicity and has significance folklore and ethano pharmacological significance. Apart from food and food beverages



Fig. 3. *Agaricus bisporus*.

it has a role in perfumery, cosmetic industries and pharmaceutical industries (Caglarirmak 2009). Wild *A. bisporus* were referred for customer due to their flavor and texture (Sadiq *et al.* 2008).

A. bisporus comes under the category of a food which is beneficial for humane health with excellent levels of dietary fibers and antioxidants including vitamins namely, thiamine, ascorbic acid, vitamin D2 as well as minerals like folates, ergothioneine (ET) and polyphenols which may provide favorable effects on cardiovascular diseases and diabetes suggests that the mushroom might have potential anti-inflammatory, hypoglycemic and hypocholesterolemic effects (Koyyalamudi *et al.* 2009).

A lectin from *A. bisporus* and a protein from *A. polytricha* have been found to be potent immune stimulants; thus, these macromolecules may be considered for pharmaceutical utilization and these fungi may be classified as healthy food. *A. bisporus* extract has been shown to prevent cell proliferation in breast cancer (Patel and Goyal 2012).

A. blazei is an edible mushroom native to Brazil and it has been cultivated especially in Japan. It is a very popular basidiomycete known as “sun mushroom” and at these days it is consumed globally as food or in tea due to its medicinal properties. Its fruit bodies exhibit antimutagenic, anticarcinogenic and immunostimulative activities. Its extracts have also shown immunomodulatory, anticarcinogenic and antimutagenic properties. Additionally, it has been reported that this mushroom blocks the liver lipid

peroxidation (Hakime Silra *et al.* 2013).

Lentinus: *L. edodes* or “shiitake mushroom” has been used for many years to investigate functional properties and to isolate compounds for pharmaceutical use; this is because of its positive effects on human health. It has been utilized to alleviate the common cold for hundreds of years and some scientific evidence has supported this belief (Mattila *et al.* 2001). *Lentinula edodes* (Fig. 4) is a macrofungus with great potential for therapeutic applications and serves as a model for investigating functional fungi properties and isolating pure compounds for pharmaceutical use. Mushrooms have a great nutritional value and present medicinal molecules including polysaccharides, terpenoids, sterols and lipids, that participate actively in several human disorders and modulate mechanisms involved in the immune system regulation. (Finimundy *et al.* 2013) have provided experimental information about the aqueous extracts of *L. edodes* as potential sources of antioxidant and anticancer compounds. These extracts significantly decreased cell proliferation on tumor as well (Tiane *et al.* 2014).

Manzi and Pizzoferrato (2000) reported that *L. edodes* contains high levels of β -glucans in the soluble fraction of dietary fiber. Shiitake produces lentinan and β -glucan that suppress leukemia cell proliferation and have antitumor and hypocholesterolemic activity (Manzi and Pizzoferrato 2000). Lentinan is used in clinic assays as adjuvant in tumor therapy and specifically in radiotherapy and chemotherapy. On the other hand, it has been reported that lentinan enhances host resistance against infections by bacteria, fungi, parasites and virus; it also promotes nonspecific inflammatory responses, vascular dilation, hemorrhage-inducing factors activation and generation



Fig. 4. *Lentinula edodes*.

of helper and cytotoxic T cells (Yamaguchi *et al.* 2011). In other studies, *L. edodes* exhibited capacity to inhibit the growth of mouse sarcoma, probably due to the presence of an unspecified water-soluble polysaccharide (Manzi and Pizzoferrato 2000).

Another edible mushroom is *L. polychrous*, found in northern and north-eastern Thailand, which is used as medicine in diseases like dyspepsia or envenomation caused by snake or scorpion. The methanolic extract and crude polysaccharides have antioxidative activity and inhibitory effect on cell proliferations of breast cancer. Additionally, mycelial extracts from this mushroom have antiestrogenic activity, resulting from a new polyhydroxyoctane and several ergostanoids (Thetsrimuang *et al.* 2011).

Pleurotus: Species of *Pleurotus*, commonly called oyster mushrooms, consist of gilled mushrooms that have an eccentric or lateral stem or are laterally or dorsally attached and sessile (Sharma and Jandaik 2017). *Pleurotus* species are distributed throughout the temperate and tropical hardwood forests of the world. Fungal populations are established and developed in nature through both sexual and asexual reproduction (Cohen *et al.* 2004).

The genus *Pleurotus* (Fig. 5) is one of the most diverse groups of cultivated mushrooms that have important economic and medicinal value (Cohen *et al.* 2004). One of the reasons for their success is that oyster mushrooms are by far the easiest and least expensive to grow of all industrially cultivated edible mushrooms and they grow on a number of different plant substrates. As food, the oyster mushrooms are a good source of nonstarchy carbohydrates, have a high content of dietary fiber and contain moderate quantities of good quality proteins and most of the essential amino acids, minerals and vitamins (Sharma and Jandaik 2017). A number of medicinal properties have been attributed to *Pleurotus* species. *Pleurotus* spp. have been shown to modulate the immune system, have hypoglycemic activity and antithrombotic effects, lower blood pressure and blood lipid concentrations and inhibit tumor growth, inflammation and microbial activity (Cheung *et al.* 2003). Lectin and lovastatin are therapeutic compounds isolated from *Pleurotus* species. Lectins are carbohydrate-contain-



Fig. 5. The genus *Pleurotus*.

ing proteins of non-immune origin that agglutinate cells or precipitate polysaccharides or glycoconjugates. Hemagglutinating activity in crude extracts prepared from four fungal developmental stages; vegetative mycelium, primordium, immature fruit body and mature fruit (Sharma and Jandaik 2017). Lectin activity was not seen in vegetative mycelium but increased through the other three fungal developmental stages. In a study conducted by (Sathyaprabha *et al.* 2011) *Pleurotus platypus* and *Pleurotus eous* were extracted with pure ethanol and subjected to screening of bioactive compounds by gas chromatography-mass spectrum technique; according to their results, various active compounds are presented in *P. platypus* when compared with *P. eous* (Sathyaprabha *et al.* 2011).

In addition to the nutritional value they possess medicinal properties and other beneficial effects and health-promoting effects. *Pleurotus* species have been used by human cultures all over the world for many years (Finimundy *et al.* 2013). These species have been used as medicinal mushrooms for long time since they contain several compounds with important pharmacological/nutraceutical properties. Some of these substances are lectins with immunomodulatory, antiproliferative and antitumor activities phenolic compounds with antioxidant activities; and polysaccharides (polysaccharopeptides and polysaccharide proteins) with immunoenhancing and anticancer activities. β -glucans isolated from *Pleurotus pulmonarius* demonstrated an antiinflammatory response in rats with colitis and *P. ostreatus* inhibited leukocyte migration to acetic acid-injured tissues. An extract from *P. florida* suppressed inflammation. *Pleurotus* has also been reported with hematological, antiviral, antitumor, antibacterial, hypocholesterolic and immu-

nomodulatory activities, and antioxidant properties (Kanagasabapathy *et al.* 2011).

P. citrinopileatus, *P. djamor*, *P. eryngii*, *P. flabellatus*, *P. florida*, *P. ostreatus* and *P. sajor-caju* were evaluated by (Mishra *et al.* 2013). The authors concluded that *P. eryngii* had the highest contents of phenolics, followed by *P. djamor*. Besides, *P. eryngii* had a better antioxidant activity and *P. citrinopileatus* had more ascorbic acid and chelating activity (Mishra *et al.* 2013).

Ganoderma: *Ganoderma lucidum* (Fig. 6) also known as Reishi and Ling Zhi, is one of the most important medicinal mushrooms. *Ganoderma lucidum* used in traditional system of medicine and is regarded as a substance which promotes the normal system of body mainly nervous system (Sanodiya *et al.* 2009). *Ganoderma lucidum* is considered as “the king of herbs”. *Ganoderma lucidum* is a type of fungus which grows on dead and deciduous trees especially willow, oak, sweet gum, maple, elm. *Ganoderma lucidum* has vast history of utilization as a supplement for propelling life span and the advancement of a healthier life in Asian region i.e. in China, Japan and Korea (Khatian and Aslam 2018).

Ganoderma lucidum has the capability of expanding good health and great wellbeing. *Ganoderma lucidum* is medicinal mushroom which is well known for its therapeutic potential for many disorders, that is why it is examined widely. *Ganoderma lucidum* considered as a major part of Traditional Chinese Medicine (TCM), for 5000 years it was used as a remedy for many ailments. It is called as Ling Zhi and is thought to be The Mushroom of Immortality in Korea and China (Moradali *et al.* 2007). All Traditional Chinese Medicine specialists believe that *Ganoderma lucidum* is the most highlighted one amongst the most powerful available adaptogens. Adaptogens are the herbal supplements that have capability of developing the body's impenetrability to stress and offer some assistance with defeating all the troubles and difficulties which are against health and this process is done in the most rapid and fast fashion. *Ganoderma* products are widely spread in America in the latest couple of years, practically as they have been surely believed and utilized in traditional medicine system



Fig. 6. *Ganoderma lucidum*.

of China for an extensive period (Richter *et al.* 2015). When *Ganoderma* was discovered, it was extremely costly and out of reach of the common man and only rulers, kings and lords had access to this heavenly and magical mushroom. By the virtue of time in the 21st century American biotechnology, it is possible to develop and grow *Ganoderma lucidum* (Reishi or Ling Zhi) in lab under controlled environment (Khatian Aslam 2018).

In Asia, *Ganoderma* has been administered for centuries as treatment for cancer ; it exhibits anticancer effect alone or in combination with chemotherapy and radiotherapy. *Ganoderma* decreases viability of human cancer cells, induces cell apoptosis, inhibits cell proliferation, suppresses the motility of invasive breast and prostate cancer cells, and prevents the onset of various types of cancer (Pillai *et al.* 2010).

Also, Chen and Zhong reported the inhibition of tumor invasion, metastasis and cell adhesion, promotion of cell aggregation and suppression of cell migration in human colon tumor cell lines (Chen and Zhong 2011). Additionally, Ye *et al.*(2009) reported antitumor action *in vitro* against mouse lymphocytic leukemia (Ye *et al.* 2009). Lai *et al.*(2010) reported the suppression of epidermoid cervical carcinoma. Water-soluble polysaccharides from *Ganoderma* act over more than 20 types of cancer and strongly inhibit tumor growth (Lai *et al.* 2010).

Nowadays, *Ganoderma* is recognized as an alternative adjuvant in the treatment of leukemia, carcinoma, hepatitis and diabetes, as well as an immune system enhancer with health benefits. In general, it is safe to be used for a long period of time

(Zhou *et al.* 2012). Boh studied around 270 patents for fruit bodies and mycelia cultivation methods of *Ganoderma lucidum*, basidiomycete mushroom with strong anticancer effects. Boh concluded that the anticancer activity of this fungus may be attributed to at least five groups of mechanisms: (1) activation/modulation of the immune response of the host, (2) direct cytotoxicity to cancer cells, (3) inhibition of tumor-induced angiogenesis, (4) inhibition of cancer cells proliferation and invasive metastasis behavior and (5) carcinogens deactivation with protection of cells (Boh 2013).

Huitlacoche: *U. maydis* belongs to the Ustilaginales order that includes semi-obligate biotrophic plant pathogenic fungi that infects only maize and its progenitor plant teosinte (*Zea mays*). It is a heterothallic fungus with a dimorphic life cycle, saprophytic and a parasitic phase; in nature, the pathogenic and sexual development is inseparable. Also, *U. maydis* has been established as a robust pathogenic model for studying fungi and fungi-plant relationships, especially because the morphological transitions throughout its life cycle, easy culture, genetic manipulation in the laboratory, mating type, biotrophic host interaction, genetic properties to elucidate the molecular mechanisms of the interaction between plant and pathogen and the severe disease symptoms that it induces in infected maize. On the other hand, *U. maydis* is responsible for the corn smut, characterized by the formation of galls or tumors, mainly in ears. These ear galls have been used as food in Mexico since pre- Columbian times (Valverde *et al.* 2012). The Aztec name given to these young, fleshy, and edible galls. In Mexico, it has been traditionally prized and many hundreds of tons of fresh, prepared or processed huitlacoche are sold annually. Nowadays, it is a culinary delight for international chefs and has been accepted as a food delicacy in several countries and introduced into countless worldwide markets in countries like Japan, China and some of the European Community, as France, Spain and Germany. Also, in the United States there has been a great interest to produce *Huitlacoche* due to an emerging acceptance by the North American public, who noticed it as a gourmet food and now can be purchased on the Internet at high prices. In addition to its unique flavor, *Huitlacoche* has been identified as a high-quality functional food and could be included

into the daily diet for its attractive characteristics, selected nutrients, valuable compounds and nutraceutical potential (Valverde *et al.* 2012).

Huitlacoche has a considerable amount of crude protein (9.8 % average in creole maizes and 11.3% in hybrid maize) (Valdez-Morales *et al.* 2010). In addition, the protein content of *Huitlacoche* varied from 10.0 to 14.5% (dry basis). However, Valverde and Paredes - López reported that protein content ranged from 11.5 to 16.4%. It is similar or sometimes superior to other edible mushrooms and definitely superior to the maize protein content (10%) (Valverde *et al.* 2015). In the present study, average protein content of the samples was 12% (dry basis). Our findings were coherent with the earlier reports. In this regard, being rich in protein, *Huitlacoche* could be suggested as an alternative protein source for vegetarian diets (Aydogdu and Muharren 2017). *Huitlacoche* has been recently introduced into the “nouveau cuisine” of luxury restaurants with notable success. The use of *Huitlacoche* as food has spread to the point that it is currently a culinary delight of international chefs due to the unique mixture of components that produce its flavor, aroma and organoleptic characteristic. *Cuitlacoche* is served in soups, appetizers and entrees at many fashionable Mexican restaurants in major metropolitan areas in the United States. Recipes for *Cuitlacoche* are available on the internet and in gourmet Mexican cookbooks (Aydogdu Muharren 2017). Fresh or frozen *Cuitlacoche* occasionally is available at farmers’ markets or from local suppliers in the United States (Pataky and Snetselaar 2006).

***Auricularia* Spp.**

Black fungus (Fig. 7) or wood-ear mushrooms (mostly *A. auricula* and *A. polytricha*), now widely cultivated in China, Taiwan, Thailand, Philippines, Indonesia, Malaysia are considered the earliest cultivated mushrooms (Tang *et al.* 2010). Wood-ear production accounts for about 18% of the world’s total output of mushrooms. Annual production of *Auricularia* spp. in China alone reached nearly 6.9 million kg in 2013, making them the second most widely cultivated mushrooms in that country (CEFA 2014). Production figures for 2013 for this genus represent a 91.6% increase over 2010 figures.



Fig. 7. Black fungus or wood-ear mushrooms(*Auricularia* spp).

Successful domestication of wild-type strains over an extended period of time by farmers in the Changbaishan and Shennongjia regions of China has led to rapid growth in production of these species. Some of the domesticated strains now have been introduced to new cultivation regions located in Northern and Southeastern regions of China (Diego 2017).

Flamulina velutipes

Until the mid- 1990s, Japan was the dominant producer of this species. Then, beginning in about 1997, China became the world’s largest producer of *F. velutipes*. Production has increased from about 0.12 billion kg in 1995 to about 2.7 billion kg in 2013. In the last 10 years or so, many new enoki farms, based on bottle technology, have been constructed in China (Diego 2017).

In a description of one recent new enoki farm in China, Dreve (2014) describes the first stage of a large climate- controlled production facility covering nearly 7 ha of land and producing 60,000 kg of product per day. Expansion plans, if completed, could double this amount to 120,000 kg per day. About 80% of the farm’s output is destined for the domestic market while the remainder is exported to countries in Southeast Asia and Europe (Dreve 2014).

CONCLUSION

Mushrooms have been indicated to have numerous health benefits and nutritive values but several

mushroom species have been pointed out as sources of bioactive compounds also. Their cultivation is an effective bioconversion technology of transforming wastes and woods into potentially valuable resources and could also be an important part of sustainable agriculture and forestry. Various types of mushrooms are available in nature though only few of them are cultivated and eaten as food. The inclusion of whole mushrooms into the diet may have efficacy as potential dietary supplements. The production of mushrooms and the extraction of bioactive metabolites is a key feature for the development of efficient biotechnological methods to obtain these metabolites. It has been shown by a wide range of studies that mushrooms contain components with outstanding properties to prevent or treat different type of diseases. Powder formulations of some species have revealed the presence of essential nutrients. They present a low fat content and can be used in low-calorie diets, just like the mushrooms fruiting bodies. Some formulations could be used as antioxidants to prevent oxidative stress and thus ageing. Future studies into the mechanisms of action of mushroom extracts will help us to further delineate the interesting roles and properties of various mushroom phytochemicals in the prevention and treatment of some degenerative diseases. In view of the current situation, the research of bioactive components in edible wild and cultivated mushrooms is yet deficient. There are numerous potential characteristics and old and novel properties, provided by mushrooms with nutraceutical and health benefits, which deserve further investigations.

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