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Nutritional Potential of Wild Culinary Mushroom Species

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ABSTRACT

Mushrooms are being consumed by humans for thousands of years. Nowadays mushrooms are considered a type of vegetable and are preferred by rural people for culinary purposes. Wild culinary mushrooms have been consumed by tribes due to their nutritional as well as medicinal importance. Nutritionally, they are rich in protein, carbohydrates, and dietary fibre with low fat and energy. Additionally, they contain a variety of phytochemicals, bioactive metabolites, minerals, and vitamins such as riboflavin, folates, and niacin. The nutritional value of mushrooms lies between that of meat and vegetables. Besides being used as functional foods, they are widely used as medicines too due to their antibacterial, antifungal, antiviral, antioxidant, and anticancer activities. This review sums up the diverse nutritional and health benefits of mushrooms to human beings, in the form of their nutrients such as carbohydrates, proteins, fats, vitamins, minerals, and trace elements.

Introduction

The word mushroom has a different meanings and significance for people from different regions of the world. Traditionally, the term has been used to denote a group of fungi with a macroscopic, fleshy fruiting body.

However, with an increase in exploration of the fungal world, this meaning has been modified by various researchers as per their findings. One of the most widely accepted definitions places mushrooms as a group of higher fungi, largely belonging to the phyla Basidiomycota and Ascomycota, that produces a distinctive, macroscopic spore-producing fruiting body that may be either epigeous or hypogeous (Chang and Wasser, 2017).

The exact number of fungal species inhabiting this planet is yet to be determined and the estimate keeps increasing with more exploration being conducted in previously unexplored areas. An earlier working estimate was placed at around 1.5 million species (Kirk *et al.,* 2001), but this has been increased to around 3 million total fungal species according to current recommendations (Blackwell, 2011). Of these, only around 140,000 species produce a sporocarp within the acceptable parameters to be considered as mushrooms (Chang and Miles, 2004). With an increase in sequence-based studies, novel mushroom species are being discovered regularly. However, still at best, only around 10% of the total mushroom species have been identified which leaves a wide avenue for discovery of novel mushrooms (Hawksworth, 2012).

By considering general human utility, mushrooms can be placed into three groups (Chang and Wasser, 2017).

Edible mushrooms

For such mushrooms, generally the fruiting body is consumed for its nutritional properties. These fruiting bodies may be consumed fresh (e.g., *Pleurotus ostreatus*, *Termitomyces* sp.) (Verma *et al.*, 2022) in dried form (e.g., *Lentinula edodes*) or may be preserved and stored for long periods.

Medicinal mushrooms

These mushrooms are generally used for their various bioactive constituents (polysaccharides, bioactive proteins, PUFAs, secondary metabolites, etc.,) that have various medical uses (e.g., *Cordyceps militaris*, *Ganoderma lucidum*).

Poisonous mushrooms

Accounting for less than 1% of the discovered mushroom species, some mushrooms contain mycotoxins that may be highly toxic to humans (e.g., *Amanita phalloides*).

Both the edible and medicinal mushrooms have beneficial effects for human health (Román *et al.*, 2006). Considering this, it becomes easy to understand the historical utilization of wild mushrooms by various ancient civilizations of the world. There are numerous accounts for their use both as a food source and as medicines, for instance, the ancient Greek civilization used mushrooms as a food supplement for its warriors and believed that its consumption will impart strength to them. Ancient Romans treated mushrooms as the "Food of Gods", meanwhile in south-east Asian history, their use as medicinal supplements increases dramatically, with the Chinese perceiving them as an "Elixir of Life" (Chang and Miles, 2004; Valverde *et al.*, 2015).

Some of the earlier reports came about consumption of mushrooms from Spain, around 18,700 years ago, from China, around 5000-6000 years ago, and from Egypt, around 4600 years ago (Li *et al.*, 2021).

This shows that the use of mushrooms was never limited to any particular era or a geographical region, which is not surprising given that mushrooms exhibit themselves in a highly diverse range of colours and patterns which could have easily attracted the eye of someone foraging for food.

Earlier the use of wild mushrooms was prevalent because of their organoleptic properties as well as their medicinal attributes. With an increase in their popularity, it was inevitable that instead of depending on the chance occurrence of wild mushrooms, they would be cultivated. This began with China leading the pack and cultivating *Auricularia auricula* on wooden logs in 600 A.D., followed by various cultivation attempts of different mushrooms, but the biggest advancement in mushroom cultivation came from France in around 1600s when *Agaricus bisporus* was cultivated upon a composted substrate (Chang and Miles, 2004). With a better understanding of their properties and an improvement in their cultivation practices, the mushroom cultivation industry witnessed a tremendous boom in the last few decades. Only a few species of edible mushrooms were grown under controlled climatic conditions and considered an economically important food for a long time, but recently, the number of cultivated mushrooms has increased to 30 and their worldwide production has increased considerably (Chang, 2006). A conservative valuation of the global mushroom industry is placed at a massive $63 billion as of 2013 (Royse *et al.*, 2017) and is only expected to grow.

Nutritional significance of mushrooms

With a surge of overpopulation and related challenges such as insufficient food production, dependence on agricultural sources of food, related climate crises, and the prevalent problems of Protein-Energy Undernourishment (PEU) especially in underdeveloped countries, there has been an increasing interest among both researchers and the general population towards exploring previously underutilized, non-conventional food sources in lieu of the traditional, often expensive sources of food.

Mushrooms represent one such relatively untapped alternative source of nutrition. A great amount of literature released in the past decade has highlighted mushrooms as a rich source of all the essential nutrients required for human well-being. Mushrooms demonstrate a variation in their chemical constitution even greater than plants. Different species of mushrooms may contain vastly different amounts of nutrients. In fact, even within the same species, the genetic composition and climatic conditions surrounding mushroom growth affect their nutritional composition. Even within a single mushroom, different parts of the mushroom (cap, stem, and hyphae) may show a different valuation of nutrients (Oluwafemi *et al.,* 2016).

Despite this great variation observed in mushrooms, a generalization can be made about them. They are a rich source of proteins, carbohydrates, and dietary fibres. They have very high moisture content which results in a low dry weight. They are generally not energy dense and contain low-fat content. Moreover, various mushrooms have been reported to contain all essential amino acids and also they are considered a rich source of various minerals and vitamins (Chang and Mshigeni, 2001).

Moisture content and dry weight

Mushrooms generally report a very high moisture content accounting for anywhere between 85% to as high as 95% of their total fresh weight for most species (Cheung, 2008). The total moisture content of any mushroom harvest is however dependent on various factors such as the time of cropping, availability of water during cultivation, and temperature and relative humidity during growth. Because of the high moisture content, mushrooms generally have a very low dry weight. Their dry weight can be as low as 60-140g/kg of fresh mushrooms (Kalač, 2016). In absence of factual data, for the purpose of calculation, a standard dry weight of 100g/kg fresh weight is accepted. The high moisture content of fresh mushrooms contributes to their very low shelf life. Because of this reason, many mushrooms are preserved and consumed in a dried form.

Ash content and mineral composition

The total ash content of any material is defined as the inorganic residue left after the incineration of the organic matter. In general, this ash represents the mineral constituents of the material, but its nature varies with the type of material ignited and the method of incineration. According to the available literatures, mushrooms generally don't have very high ash content and it usually ranges between 4-20g ash per 100g of the dry sample (Chang and Miles, 2004). Edible mushrooms contain an array of minerals. The commonly consumed mushrooms such as *Pleurotus ostreatus, Lentinula edodes,* and *Agaricus bisporus* have been reported to contain various levels of phosphorous, zinc, potassium, magnesium and copper. Mushrooms of *Boletus* spp. have reported the highest levels of selenium when compared to other mushrooms (Cheung, 2010).

Mushrooms also tend to accumulate heavy metals such as lead, cadmium and mercury which may have a toxic effect upon consumption. However, heavy metal accumulation is dependent on species of the mushroom, composition of the substrate and environmental factors surrounding their growth. The mineral content of mushroom varies widely among species, and even within a single sample, the distribution of minerals in different parts of the body is not uniform. The ash content of mushrooms is generally comparable to that of plants. This holds true for minerals like phosphorous and potassium, while elements like sodium and calcium are present in a lower amount than plant samples. However, proper documentation of minerals present in various mushroom samples is still lacking.

Proteins and amino acids

Proteins are biopolymers of amino acids and are essential for proper sustenance of life. They have enzymatic, structural and storage functions and are responsible for the proper growth, maintenance and repair of muscles, failing which we will be plagued by an array of serious health conditions including cardiac issues, insulin resistance, diabetes and even cancer (Wolfe, 2006). Proteins are also responsible for providing immune functions in the form of antibodies and contribute towards disease resistance of the body. Apart from this, there are a number of bioactive proteins reported to have therapeutic applications which are discussed below.

The above importance of proteins, it isn't surprising that the population of developing countries which cannot meet its daily protein requirements through traditional sources of nutrition are plagued with numerous health disorders. So, there is a requirement of finding alternate sources of protein that will serve to bridge the gap between an undernourished population and a healthy lifestyle. The crude protein content of edible mushrooms is reported generally high but shows variation within different species and their stage of development. A general range of crude protein content in mushrooms is 15% to 35% of their dry weight (Cheung, 2010; Longvah and Deosthale, 1998; Manzi *et al.*, 1999). Variations in protein content in different mushrooms are already reported. In terms of their crude protein content this fact places them below most animal meats, but above most other food items, even including milk (Chang and Miles, 2004).

Since proteins are made up of over 20 amino acids in varying amounts, they are quantitatively and qualitatively different. The human body can interconvert some of these amino acids to form others, but there exist nine essential amino acids that must be consumed in our diet. These are lysine, methionine, leucine, isoleucine, tryptophan, threonine, histidine, valine, and phenylalanine. These nine essential amino acids must be present simultaneously and in the correct proportion for protein synthesis to occur.

Generally, animal proteins are considered more well-balanced and of better quality than plant proteins which often lack some of the essential amino acids. Mushrooms have been reported to contain all essential amino acids in varying concentrations (Chang and Miles, 2004). The general trend in mushrooms shows them to contain around 30% -40% of essential amino acids. Various amino acid composition of wild culinary mushrooms is mentioned in table 1. Mushrooms are generally rich in threonine, glutamic acid, aspartic acid, valine, and arginine. They are relatively poor in methionine and cysteine and in some edible mushrooms, lysine, tryptophan, leucine, and isoleucine are the limiting amino acids (Cheung, 2010; Manzi *et al.*, 1999). Mushrooms also contain a low level of free amino acids such as glutamic acid, aspartic acid and alanine that contributes to the unique flavour of mushrooms (Kalač, 2016).

Lipids and fatty acids

Mushrooms generally have low crude lipid content, ranging from 1.1% to 8.3% of their total dry weight. Mushroom lipids are generally polar and neutral in nature. The major polar lipids are phospholipids, while the neutral lipids contain fats, esters of glycerol, fatty acids, and waxes (Chang and Miles, 2004; Kalač, 2016). The low levels of crude lipids in mushrooms account for their overall lower calorific value.

Despite their low crude lipid content, mushrooms are a rich source of various polyunsaturated fatty acids (PUFAs). The fatty acid profile of various mushrooms has been determined during last decade. There exists considerable variation in the individual fatty acid profiles of different species as well as the different samples of the same species, suggesting an influence of the genotype as well as the environmental conditions surrounding the growth of the mushrooms.

The fatty acid profile of mushrooms generally favours unsaturated, with the PUFAs accounting for around 75% of the total fatty acids. Various fatty acid composition of wild culinary mushrooms is mentioned in table 2. Among the PUFAs, linoleic acid, oleic acid, and palmitic acid are the most significant (Cheung, 2008; Kalač, 2016; Longvah and Deosthale, 1998). Linoleic acid is the precursor of various aromatic compounds such as 1-octen-3-ol, known as the "fungal alcohol" and is mainly responsible for the characteristic flavour of mushrooms.

Carbohydrates

Carbohydrates account for the major portion of the dry weight of mushrooms. The total carbohydrate content of mushrooms varies with the species and ranges from 35% to 70% of their total dry weight, these accounts for both digestible and indigestible carbohydrates (Cheung, 2010). Variations of the carbohydrate content in different mushrooms are listed in table 4. Mushroom carbohydrates are generally not consumed as a source of energy, but the indigestible part of carbohydrates including oligosaccharides and non-starch polysaccharides serve as dietary fibres and may have physiological benefits.

Mushrooms have been reported to contain carbohydrates in different forms including monosaccharides, oligosaccharides, polysaccharides, sugar alcohols, amino sugars, and sugar acids (Chang and Miles, 2004; Crisan and Sands, 1978).

Sugars

Mushroom sugars are water-soluble and partly contribute to their characteristic taste. The total sugar content of mushrooms varies widely among species and ranges from 5-25g/100g to their dry weight (Kalač, 2016). Different soluble sugar and sugar alcohol composition of wild culinary mushrooms is mentioned in table 3. The total sugar content contains monosaccharides such as arabinose, fructose, and glucose, oligosaccharides like melezitose and trehalose, and certain sugar alcohols like mannitol. Of these, mannitol and trehalose are generally the most prominent of the total sugars (Heleno *et al.*, 2015).

Polysaccharides and dietary fibre

Polysaccharides are high molecular-weight carbohydrates, formed by the polymerization of multiple monosaccharides or sugar acid units held together by glycosidic linkages. The major mushroom polysaccharides are chitin, glucans, and heteroglycans. Instead of starch, glycogen serves as the energy reserve for the cells and accounts for 5-15% of the dry weight of the mushrooms. Among the mushroom polysaccharides, β-glucans are of great research interest because they impart various bioactive properties that translate into therapeutic benefits, as discussed below.

The cell wall components of the mushroom are structural polysaccharides, the major of which is chitin. Chitin is insoluble in most solvents and cannot be digested by humans. So, it forms the major portion of mushroom insoluble dietary fibre. Dietary fibres are composed of both soluble and insoluble parts. Soluble fibre forms a gel with water, increasing the viscosity of foods and chyme. That causes slow down the digestion, which helps maintain the blood glucose, insulin, and cholesterol levels. The insoluble fractions of fibre soften the stools and increase stool bulk, contributing to good health conditions of the colon (Kalač, 2016).

Vitamins and provitamins

Generally speaking, mushrooms have been heralded as a good source of vitamins and provitamins. However, not a lot of proper research has been conducted in this area yet and this statement should be limited to a few vitamins and provitamins only.

Mushroom vitamins can be categorized into the following two groups.

Fat-soluble vitamins and provitamins

In general, mushrooms contain a very low beta-carotene content which acts as a precursor for vitamin A. Similarly, mushrooms have reported low vitamin E content present in the form of tocopherols. Thus, the contribution of mushrooms towards these two vitamins is marginal at best. However, the mushrooms content of ergosterol, which is the provitamin for vitamin D_2 is significant. Ergosterol is converted into vitamin D_2 in the presence of sunlight. The ergosterol content is the highest among the sterols of mushrooms and ranges from 400-600 mg/100g DW of mushrooms (Cheung, 2010; Kalač, 2016).

Water-soluble vitamins

According to the available literatures, among the water-soluble vitamins, ascorbic acid (vitamin C) is present in mushrooms in a comparable range as that of common vegetables, anywhere between 100-400 mg/100g DW. For the vitamin B group, riboflavin (vitamin B_2), thiamine (vitamin B_1), and folate (vitamin B_9) are present in a lower amount when compared to vegetable food sources, while niacin (vitamin B_3) is present in a comparable range. The presence of independent cyanocobalamin (vitamin B_{12}) in mushrooms is debated and more research is required to make a proper statement regarding it.

Bioactive compounds of mushrooms

The organoleptic property of mushrooms is only a part of the reason highlighting it as an alternative food source. Since the earliest accounts of using mushrooms, their therapeutic properties have also been acknowledged in the literature. They have been constantly used in preventing and treating various diseases, or in promoting healthier lifestyles. With the ongoing threat of undernourishment-related disorders, people are gaining an increased appreciation for mushrooms' pharmacological and medicinal aspects. This growing interest of the general public has led to a boost in the research towards exploring this topic. A vast amount of literature has been published in the last few decades decoding the reasons behind these therapeutic properties. All this literature concurs that the diverse medicinal and pharmacological properties of mushrooms stem from them having a number of bioactive components.

Mushrooms vary in the types and amount of these bioactive components they contain which leads to the variation in their bioactive properties. However, these bioactive components can be divided into polysaccharides, proteins, glycoproteins and secondary metabolites like phenols, flavonoids, terpenoids, steroids, glycosides, alkaloids and different vitamins like riboflavin, ascorbic acids, etc., (Valverde *et al.,* 2015). The presence of these metabolites leads to important therapeutic properties in mushrooms like antioxidant, antibacterial, antiviral, anti-inflammatory, anti-cancerous, anti-diabetic and anti-obesity functions. Usually, when we consider mushrooms for therapeutic purposes, we generally look at medicinal mushrooms. Wild mushrooms are also a good source of extracellular enzymes with biotechnological applications (Verma *et al.,* 2022).

Of the estimated 15,000 species of mushrooms, around 700 species are classified as medicinal mushrooms. There are multiple accounts placing specific mushrooms such as *Ganoderma lucidum, Cordyceps siensis* and *Lentinula edodes* as essential tools in Asian folk medicine for centuries (Wasser, 2002). But literature suggests that most, if not all of the studied mushrooms contain a good amount of different bioactive compounds, so their use as a nutraceutical or a medicinal product becomes very plausible. A few important bioactive constituents of mushrooms and their effects are described below.

Mushroom polysaccharides

As discussed earlier, polysaccharides are a group of high molecular weight carbohydrates such as glucans and heteroglycans which imparts a number of bioactive properties including antitumor, immunostimulatory, hypocholesterolemic, hypoglycemic, and other beneficial effects to mushrooms and hence, have their potential as nutraceuticals have been highlighted.

Functional microbial polysaccharides have been used for a long time as a part of the human diet or as a medicinal source. For example, there are multiple records of the use of hot water extracts of mushrooms (containing polysaccharides) in the Eastern civilization for hundreds of years for medicinal purposes. These early practices formed the basis for research into the functional properties of microbial polysaccharides (Giavasis and Biliaderis, 2006).

These mushroom polysaccharides may be a part of the structural component of the cell or may be secreted as a part of its metabolism. Mushroom polysaccharides offer a few major advantages compared to traditionally extracted plant polysaccharides.

For instance, polysaccharides extracted from mushrooms are non-toxic and generally regarded as safe (GRAS), so they have a major application in the pharmaceutical and food industry. Another benefit is that the use of mushrooms instead of plants allows a regulated and continuous production process.

Mushrooms are source of many types of polysaccharides, including heteropolysaccharides rich in fucose, galactose, mannose, and xylose, mostly glucans which are similar to glycogen and act as storage components (Leong *et al.*, 2021).

Along with the structural cell wall polysaccharides exist as well, for instance, the fungal cell wall consists of two main types of polysaccharides, a cellulose or chitin made rigid fibrillar structure, and a matrix-like structure composed of mainly three polysaccharides, α-glucans, β-glucans, and glycoproteins. A few of the well-researched mushroom polysaccharides are discussed below.

Glucans

Glucans are arguably the most abundant and most widely studied mushroom-derived polysaccharides. Among the glucans, the most important are the β-glucans with β-D-Glucopyranose units linked together by β-(1→3) or β-(1→4)-linkages in the main chain. Additional branches often arise from the main chain which may be β-(1→3), β-(1→4) or β-(1→6) linked.

Glucans with higher molecular weight have been reported to be more bioactive than lower molecular weight glucans and so are used in the designing of a number of nutraceuticals. Most of the glucans with therapeutic potential are derived from the mycelia, fruiting bodies or liquid cultures of the division Basidiomycetes while a few have also been reported from the division of Ascomycetes and Oomycetes.

Two of the earliest identified and most studied glucans are lentinan and schizophyllan isolated from *Lentinula edodes* and *Schizophyllum commune* respectively have demonstrated very potent immunomodulating and anti-tumour activities and have been recognised as immunoceuticals in China, Korea and Japan (Park *et al.*, 2009).

In the last few decades, extensive research has been done on the different types, structures and pharmacological activities of mushroom glucans. The literature shows that the structure of mushroom glucans varies widely with the source and along with the structural complexity, their bioactivities also vary.

Many therapeutic applications of glucans have now been reported such as antioxidant, anticancer, antitumor, anti-mutagenic, anti-fatigue, antibiotic, anti-proliferative, hypoglycaemic treatment, hepatoprotective and hypotensive effects, anti-HIV, anti-inflammatory, anticoagulation, anti-radiation, immune-modulating activities, and cholesterol and body fat reduction as well (Leong *et al.*, 2021). A few of the commercially important mushroom glucans are given in table 5**.**

Glycans

Glycans are polysaccharides with molecules other than glucose in their main chain. They represent another large number of bioactive polysaccharides. According to the main monosaccharide unit of their backbone, they are classified as galactans, fucans, mannans, fructans, and xylans,. Along with the main chain of these sugars, they may have side chains of mannose, galactose, arabinose, glucose, fucose, xylose and glucuronic acid.

Several groups of fungi have been reported to produce glycans with varying degrees of immunostimulating effects. For example, the fruiting body of a commonly found mushroom, *Morchella esculenta* contains a bioactive galactomannan composed of a main chain of mannose (62.9%) and galactose (20.0%), and branching of N-acetyl glucosamine (7.9%), glucose (6.5%), and rhamnose (2.7%). It has been reported to possess immunostimulating effects (Duncan *et al.,* 2002).

Sarcodonaspratus fruiting bodies have been reported to contain a highly branched immunomodulating fucogalacatan with an unusual structure, which is composed of a main chain of α-(1→6)-linked galactopyranose with side residues of β-(1→2)-linked galactopyranosyl, and α-(1→2)-L-fucosyl-α-(1→4)-D-galactopyranose. There are many other therapeutic, immunomodulating glycans isolated from other mushrooms as well; some of them are given intable5.

Heteropolysaccharides and glycoproteins

Heteropolysaccharides represent the category of polysaccharides that contain more than one type of monosaccharide unit in them and in many instances; these polysaccharides are found attached to protein molecules, forming glycoprotein entities. For example, Hetero-β-D-glucans are linear polymers of glucose with other D-monosaccharide units and have reported anti-cancerous properties. Mushrooms also contain β-D-glucans with heterosaccharide chains of galactose, mannose, xylose, uronic acid and β-D-glucan-protein complexes. There are a number of heteropolysaccharides isolated from mushrooms which are reported to have a range of anti-cancerous and immune-stimulating properties, allowing their potential use as nutraceuticals (Singdevsachan *et al.,* 2016).

For instance, a heteroglycan-protein complex isolated from *Grifola frondose* was found to possess anti-tumour and immune-stimulating properties. A heteroglycan isolated from the fruiting bodies of *Lentinus squarrosulus* contains D-glucose, D-galactose, and L-fucose units and was found to be immune-stimulating by activating macrophages, splenocytes and thymocytes. A few of the important immune-stimulating and anti-cancerous heteropolysaccharides, their source and their functions are given intable5.

Bioactive proteins

As mentioned earlier, mushrooms are a rich source of crude proteins and in fact, most of the attention directed towards using mushrooms stems from them fulfilling the nutritional protein requirements.

However, apart from them having an important nutritional role, mushrooms contain a wide range of bioactive proteins as well. These bioactive proteins are gaining increasing interest because of their pharmaceutical potential (Xu *et al.,* 2011). A few of the important bioactive proteins are described below.

Lectins

Lectins are proteins of a non-immunological nature that specifically binds to cell-surface carbohydrates including polysaccharides, glycoproteins and glycolipids and in the process, precipitate them. This property of specific binding to carbohydrates infers them the ability to agglutinate cells such as erythrocytes (Singh *et al.,* 2010). Lectins are widespread in nature and are found in abundance in mushrooms.

Table.1 Comparison of essential amino acids (% of total amino acids) in some mushrooms (Díez and Alvarez, 2001; Manzi *et al.*, 1999; Mattila *et al.*, 2002; Vetter, 1993).

Mushroom species	Val	Leu	Ile	Thr	Met	Lys	Phe	Trp	Total
Agaricus bisporus	5	6.3	3.8	4.6	1.4	5.9	4.9	-	31.4
Cantharellus cibarius	3.5	16.3	3.3	4.2	1	4.3	3.2	1.7	35.8
Hydnum repandum	3.9	14.5	3.2	4.4	1	4.2	3.4	1.4	34.5
Lentinula edodes	3.8	6.4	3.3	5.6	2.2	5	3.8	1.9	30.5
Pleurotus eryngii	6	6.3	3.8	4.7	1.4	5.9	4.4	-	32.5
Pleurotus ostreatus	4.7	6.8	4.3	5	1.9	6	4.3	1.4	34.4
Russula cyanoxantha	6.8	7.8	4.9	5	2	6.3	7.8	-	40.6
Tricholoma terreum	8.9	8.2	3.6	9.1	3.5	7.6	6.6	1.1	47.5

Val, valine; Leu, leucine; Ile, isoleucine; Thr, threonine; Met, methionine; Lys, lysine; Phe, phenylalanine; Trp, tryptophan.

Table.2 Comparison of major fatty acids (% of total fatty acids) (Barros *et al.*, 2008; Barros *et al.*, 2008; Grangeia *et al.*, 2011; Pedneault *et al.*, 2006; Obodai *et al.*, 2014; Pedneault *et al.*, 2008).

Mushroom species	Lauric acid	Myristic acid	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	SFA	MUFA	PUFA
Agaricus campestris	0.1	0.5	16.5	3	4	68.8	0.2	24.5	6.1	69.4
Amanita rubescens	0.1	0.2	14.5	4.5	58	19	0.1	21.8	59	19.2
Boletus edulis	0.1	0.2	9.8	2.7	36.1	42.2	0.2	15.5	41.4	43.1
Calocybegambosa	0.2	0.4	15.2	2.1	18.1	57.8	0.5	22.5	19.1	58.4
Coprinus comatus	0.1	0.6	18.9	1.8	7.5	64.5	0.5	23.8	10.4	65.2
Flammulina velutipes	0.3	0.5	14.6	3.6	16.4	40.9	-	20.7	18.6	60.7
Lepista nuda	0.1	0.3	11.8	2.4	29.5	51.5	0.2	17.6	30.3	52.1
Lycoperdon perlatum	0.2	0.4	12.9	3	4.6	70.7	0.2	23.6	4.9	71.5
Pleurotus ostreatus	0.2	0.7	12.4	3.7	10.4	65.3	-	21.8	11.4	66.8
Ramaria botrytis	-	0.4	9.9	2.4	43.9	38.3	-	16.4	44.7	38.9
Russula cyanoxantha	0.4	0.4	13	11.1	28.4	43.7	0.1	26.9	29.1	44
Termitomyces robustus	0.1	0.9	20.9	4	9.5	59.2	0.2	30.1	10.3	59.6

SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

Table.3 Comparison of soluble sugars and sugar alcohols in some mushrooms (Barros *et al.*, 2008; Barros *et al.*, 2008; Fernandes *et al.*, 2013; Heleno *et al.*, 2015; Obodai *et al.*, 2014; Pereira *et al.*, 2012; Vaz *et al.*, 2011)

Mushroom species	Arabinose	Fructose	Glucose	Mannitol	Melezitose	Trehalose	Total sugars
Agaricus campestris	-	0.29	-	5.59	-	0.63	6.51
Boletus edulis	-	0.41	1.57	1.13	-	17.7	20.9
Calocybegambosa	-	-	-	0.27	0.85	8.01	9.13
Coprinus comatus	-	-	-	0.4	-	42.8	43.2
Flammulinavelutipes	-	-	-	5.98	-	15.1	21.1
Hericiumerinaceus	17.5	-	-	5.63	-	0.54	-
Lepista nuda	-	-	-	0.8	-	12	12.8
Pleurotusostreatus	-	0.03	-	0.87	-	12.7	13.9
Ramaria botrytis	-	-	-	11.7	0.2	2	13.9
Russulacyanoxantha	-	0.34	-	16.2	-	1.64	18.2
Termitomyces robustus	-	-	-	4.71	-	9.92	14.63

Fig.1 Nutritional potential wild of culinary mushrooms.

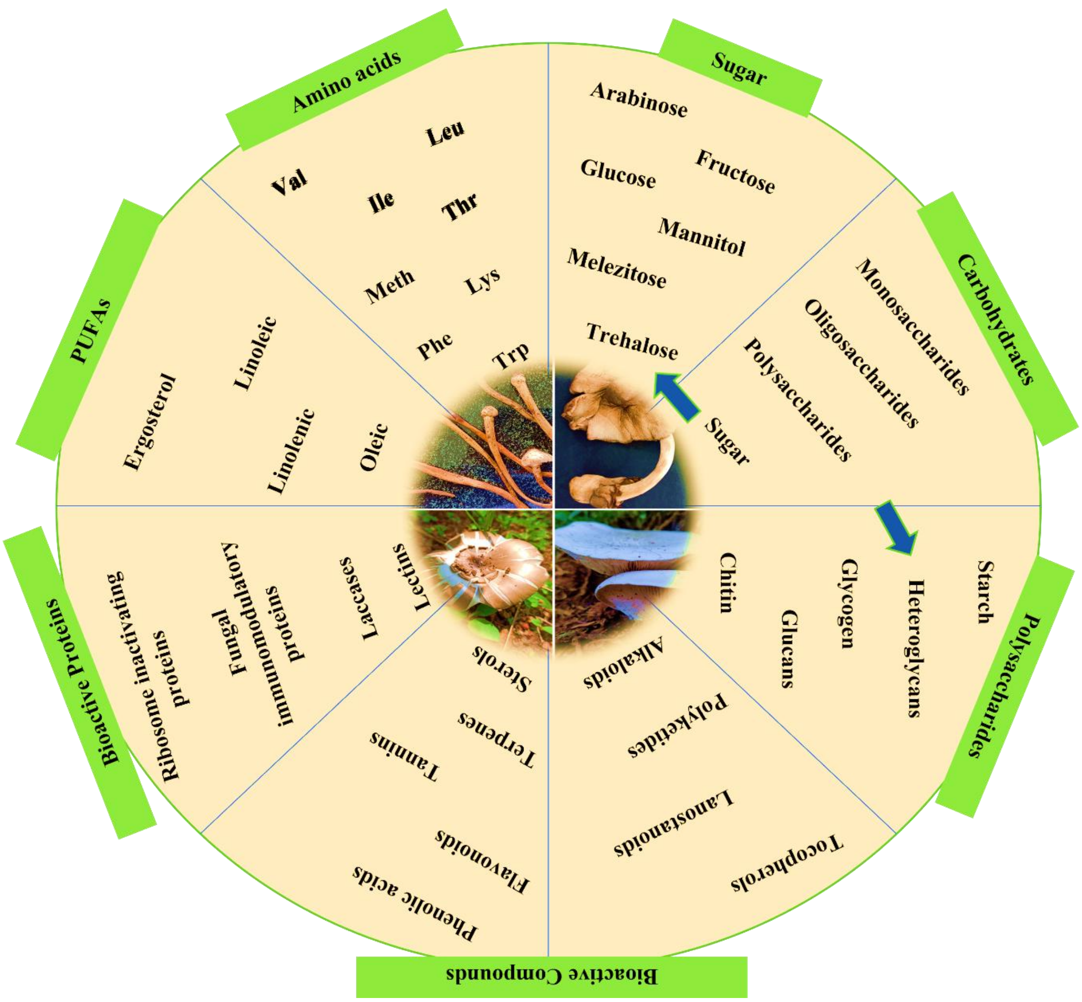

Table.4 Proximate composition of some edible mushrooms

Mushroom Species	Moisture (%)	Ash (g/100g)	Protein (g/100g)	Carbohydrate (g/100g)	Fat (g/100g)	References
Agaricus bisporus	91.27 - 91.64	9.74 - 11.63	14.09 - 15.43	71.53 - 73.8	1.67 - 2.18	(Reis *et al.*, 2012)
Boletus edulis	91.0 - 93.0	5.26	10.65	81.86	2.23	(Heleno *et al.*, 2015)
Boletus fragrans	77.99	4.74	17.15	76.29	1.83	(Grangeia *et al.*, 2011)
Calocybe gambosa	90.92	13.89	15.46	69.83	0.83	(Vaz *et al.*, 2011)
Coprinus comatus	85.19	12.85	15.67	70.36	1.13	(Vaz *et al.*, 2011)
Flammulina velutipes	87.2-89.1	9.4	17.9	70.9	1.8	(Pereira *et al.*, 2012)
Lactarius salmonicolor	87.72	23.28	37.28	37.41	2.03	(Heleno *et al.*, 2009)
Lentinus edodes	81.8-90	4.29 - 6.24	12.7 – 22.8	64.4 – 81.94	1.01-2.1	(Bisen *et al.*, 2010; Carneiro *et al.*, 2013)
Lepista inversa	87.73	10.54	76.63	10.35	2.48	(Heleno *et al.*, 2009)
Lycoperdon echinatum	85.24	9.4	23.5	65.9	1.2	(Grangeia *et al.*, 2011)
Morchella esculenta	90.79	7.9 - 11.3	11.5	74.6 - 78.3	2.3 - 2.6	(Heleno *et al.*, 2013)
Pleurotus eryngii	88.1	15	2.1	78.6	4.4	(Reis *et al.*, 2014)
Pleurotus ostreatus	85.2 - 94.7	4.5-9.36	21.4 - 23.91	70.7	3.4 – 4.6	(Alam *et al.*, 2008; Ouzouni & Riganakos, 2007)
Ramaria aurea	88.52	5.68	14.6	77.47	2.26	(Pereira *et al.*, 2012)
Russula cyanoxantha	85.44	7	16.8	74.7	1.5	(Grangeia *et al.*, 2011)

Lectins are usually made up of 2-4 subunits, held together by non-covalent forces. They show a vast degree of potentially therapeutic properties such as anti-proliferative activities shown by lectins isolated from *Volvariella volvacea* and *Pleurotus ostreatus* against sarcoma S-180 cells and hepatoma H-22 cells (Lin & Chou, 1984; Wang *et al.*, 2000), mitogenic activity as observed by lectins isolated from various mushrooms like *Flammulina velutipes* (Tsuda, 1979), *Ganoderma capense* (Ngai and Ng, 2004), *Boletus edulis* (Zheng *et al.,* 2007) and *Cordyceps militaris* (Jung *et al.*, 2007) and antiviral activities as observed by lectins isolated from *Agrocybe aegerita* against tobacco mosaic virus (Sun *et al.*, 2003) and lectins isolated from *Boletus edulis* (Zheng *et al.,* 2007) report potential anti-HIV1 reverse transcriptase activity.

Ribosome-inactivating proteins

Ribosome-inactivating proteins are enzymes that eliminate adenosine residues from rRNAs, which results in the inactivation of ribosomes. Various mushrooms like *Flammulina velutipes, Hypsizigus marmoreus, Lyophyllum shimeji* and *Pleurotus tuber-regium* have been reported to possess these enzymes, which infer a wide range of bioactivities such as anti-HIV1 reverse transcriptase, antiproliferative as well as antifungal activities to them (Lam and Ng, 2001a, 2001b; Wang and Ng, 2000, 2001).

Laccases

Laccases are a class of enzymes responsible for the pathogenesis, immunogenesis and morphogenesis of organisms and in the metabolic turnover of complex organic substances. Over the last few decades, research has been done to isolate and characterize laccases from various mushrooms.

For example, a laccase from *Pleurotus eryngii* demonstrated inhibitory activity against HIV-1 reverse transcriptase (Wang and Ng, 2006), a laccase isolated from *Pleurotus ostreatus* demonstrated antiviral activity against the Hepatitis C virus (EL-Fakharany *et al.*, 2010), a novel laccase from *Tricholoma mongolicum* demonstrated anti-HIV-1 reverse transcriptase activity along with inhibition of hepatoma HepG2 cells and breast cancer MCF7 cells (Li *et al.*, 2010).

Fungal immunomodulatory proteins

These are a relatively new class of bioactive proteins that target immune cells. There have been increasing reports of fungal immunomodulatory proteins being isolated from mushrooms. For example, mushrooms like *Ganoderma lucidum, Flammulina velutipes*, and *Volvariella volvacea* contains these proteins with varying degrees of immunomodulatory activities. Along with immunomodulation, these proteins also display a range of anti-tumour activities (Hsu *et al.,* 1997; Kino *et al.,* 1989; Ko *et al.,* 1995).

Polyunsaturated Fatty Acids (PUFAs)

The most prominent class of lipids produced in mushrooms are PUFAs. They are a very important component of our diet because they are responsible for lowering serum cholesterol and performing a variety of other important functions and generally cannot be synthesized in the human body (Valverde *et al.*, 2015). Of the PUFAs, the most important examples are described below.

Ergosterol

It is the main sterol produced by mushrooms and plays various important functions such as antioxidant, anti-cancerous, immunomodulatory, and antiviral properties and also prevents cardiovascular diseases (Altaf *et al.*, 2022; Duan *et al.*, 2021; Kalač, 2013).

Linoleic Acid

Linoleic acid is an important PUFA in the human diet and displays numerous physiological functions, especially anti-inflammatory effects by the suppression of pro-inflammatory cytokines like IL-1β, IL-6, TNF-α, NOS2, etc. and inhibiting nitric oxide (NO) production, thus reducing the inflammatory level (Saiki *et al.*, 2017). It also shows activity against Alzheimer's disease by showing an inhibitory effect on acetylcholinesterase (Ach E) and butyrylcholinesterase (BCh E) enzymes (Öztürk *et al.*, 2014).

Phenolic compounds

Phenolic compounds are one of the main

representatives of the secondary metabolites of mushrooms. Their identifying trait is that they comprise at least one aromatic ring with one or more hydroxyl groups (-OH). The range of their structural complexity is huge, ranging from a single phenolic molecule to a complex polymer.

The presence of phenolic compounds in mushrooms has been linked to a number of their bioactive properties, most remarkably their antioxidant activity, anti-inflammatory, anti-tumour, anti-hyperglycemic, antimicrobial and cosmetic properties. Phenolic compounds may be classified into the following important groups.

Phenolic acids

These are non-flavonoid molecules and have two major groups, benzoic acid derivatives (C_1-C_6 backbone) and cinnamic acid derivatives (C_3-C_6 backbone). There are numerous studies that relate the biological activities of mushrooms to the phenolic acids present in them (Abdelshafy *et al.*, 2021). The most prominent examples of this group are gallic acid, coumaric acid, caffeic acid, hydroxybenzoic acid, etc.

Flavonoids

Flavonoids represent one of the largest classes of phenolic compounds. Their basic structure contains 15-C atoms scattered over two aromatic rings linked by a 3-C bridge. They can be further subdivided into subclasses such as flavonols, flavanols, flavanones, flavones, etc. The main flavonoids present in mushrooms are hesperetin, catechin, biochanin, resveratrol, kaempferol, quercetin, anthocyanins, formononetin and myricetin (Ferreira *et al.,* 2009).

Tannins

Tannins are polyphenolic compounds which have the ability to bind to and condense with proteins, amino acids, alkaloids, nucleic acids and polysaccharides. They were initially found widespread in plants, but recent research identified their presence in various mushrooms as well (Abdelshafy *et al.,* 2021).

Tocopherols

Tocopherols represent another class of mushroom polyphenols. They are generally divided into four subclasses: α-,β-,γ- and δ- tocopherols and there are sufficient research articles that attach them to various bioactive properties of mushrooms.

Terpenes

Terpenes or Terpenoids are a cluster of volatile unsaturated hydrocarbons and represent one of the largest groups of secondary metabolites. They have been extracted from many mushrooms and exhibit a wide range of pharmacological activities and so form the basis of many nutraceuticals.

They are generally categorised as monoterpenoids, sesquiterpenoids, diterpenoids, and triterpenoids. Under this category, a few of the important representatives are carotenoids, tocopherols, saponins and simple terpenes. Much study has been conducted on the potential use of mushroom terpenoids as nutraceuticals. They have been found to exhibit many important bioactive properties such as anti-cholinesterase, anti-inflammatory, antiviral, anticancer, anti-malarial and neuroprotective effects (Altaf *et al.,* 2022).

For instance, monoterpenes and sesquiterpenoids isolated from *Pleurotus cornicopiae,* sesquiterpenoids from *Flammulina velutipes* and certain triterpenoids have been investigated for their anti-cancerous effect. Similarly, two triterpenes from *Ganoderma lucidum* is reported to have anti-cholinesterase activity, making it a potential nutraceutical for degenerative diseases like Alzheimer's disease (Rathore *et al.,* 2017).

Mushrooms are being consumed for so long, they are one of the best sources of nutrition for a healthy life. The low fat and high protein with adequate energy content make them even more nutritious and place them in between the meat and vegetables. After being a part of food, mushrooms are also used as a therapeutic agent between the tribes. Many types of research are being conducted to study their nutraceutical properties and explore their therapeutic importance. They contain a wide range of health benefits, such as boosting the immune system, providing an anticancer function as well as controlling blood glucose and lipids levels in humans. Therefore, wild edible mushrooms must be considered not only as delicacies appetite but also as functional food.

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