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Research article

Volvariella volvacea (paddy straw mushroom): A mushroom with exceptional medicinal and nutritional properties

Sadaqat Ali [a], Nousheen Yousaf [a,**], Muhammad Usman [b], Muhammad Ammar Javed [c], Maryam Nawaz [a], Baber Ali [d], Muhammad Azam [b], Sezai Ercisli [e,*], Serpil Tirasci [e], Ahmed Ezzat Ahmed [f,g]

[a] *Department of Botany, Government College University, Lahore, 54000, Pakistan*
[b] *School of Agriculture and Biology, Shanghai Jiao Tong University, 800 Dongchuan Road, Minghang District, Shanghai, 200240, PR China*
[c] *Department of Microbiology, Dr. Ikram-ul-Haq Institute of Industrial Biotechnology (IIIB), Government College University, Lahore 54000, Pakistan*
[d] *Department of Plant Sciences, Quaid-i-Azam University, Islamabad, 45320, Pakistan*
[e] *Department of Horticulture, Faculty of Agriculture, Ataturk University, 25240, Erzurum, Turkey*
[f] *Department of Biology, College of Science, King Khalid University, Abha 61413, Saudi Arabia*
[g] *Prince Sultan Bin Abdelaziz for Environmental Research and Natural Resources Sustainability Center, King Khalid University, Abha 61421, Saudi Arabia*

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ABSTRACT

Volvariella volvacea, commonly referred to as paddy straw mushroom, is renowned for its remarkable medicinal and nutritional properties. This mushroom, part of the family Pluteaceae, thrives in tropical and subtropical regions and is highly esteemed for its distinctive flavor and substantial health benefits. The fruiting body of *V. volvacea* is a rich source of bioactive compounds, including antioxidant enzymes, terpenes, polypeptides, sugars, phenolics, and flavonoids. These compounds exhibit an extensive range of therapeutic activities such as anti-tumor, anti-microbial, antioxidant, anti-malarial, anti-cancer, anti-inflammatory, and anti-allergic effects. Nutritionally, *V. volvacea* is an excellent source of carbohydrates, proteins, fibers, ascorbic acid, and essential minerals. It also boasts a comprehensive profile of amino acids, including valine, arginine, glutamine, serine, aspartic acid, leucine, isoleucine, tyrosine, asparagine, lysine, cystine, proline, glycine, tryptophan, methionine, phenylalanine, threonine, and histidine. This review emphasizes the significant medicinal and nutritional potential of *V. volvacea,* advocating its inclusion as a functional food to enhance human health and well-being. By highlighting its diverse bioactive compounds and therapeutic benefits, this review aims to foster greater recognition and utilization of paddy straw mushroom in both dietary and medicinal applications.

1. Introduction

Fungi exist almost everywhere and mushrooms have great edible and medicinal value, therefore, people use them as good sources

* Corresponding author.
** Corresponding author.
E-mail addresses: msafridi53@gmail.com (S. Ali), dr.nousheenyousaf@gcu.edu.pk (N. Yousaf), usmanphytologist@gmail.com (M. Usman), ammarjaved94@gmail.com (M.A. Javed), naveedhora53@gmail.com (M. Nawaz), baberali@bs.qau.edu.pk (B. Ali), azaamuaf@gmail.com (M. Azam), sercisli@gmail.com (S. Ercisli), serpiltirasci@atauni.edu.tr (S. Tirasci), aabdelrahman@kku.edu.sa (A.E. Ahmed).

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of functional foods and medications [1,2]. With the rise of world population, people have shifted their focus towards mushrooms production, because they require short time for cultivation and are rich in nutrition. Demand for edible mushrooms has increased in recent years due to their wonderful taste, flavor and nutritious content [1,2]. Approximately, 2000 out of 12000 worldwide mushrooms are edible, among these 35 are cultivated commercially and almost 200 wild species are used as a medicine [3]. Dry weight of protein present in cereals is; 7.3 % in rice, 12.7 % in wheat, 38.1 % in soybean and 9.4 % is in corn. On the other hand, mushrooms contain 19–35 % protein which is high as compared to protein present in cereals [4]. Flavor substance of paddy straw mushroom have been reported to be 0.001–0.0016 % of the total dry weight (Mau, 2005). There are several vitamins present in mushrooms that contribute in improvement of human health by lowering the risk of several diseases [5].

Poisonous mushrooms have garnered attention for their potential biological activities, including antioxidant, cardiogenic, and antigenotoxic effects. Notably, research has highlighted the bioactive properties of various mushroom species. For instance, the wild poisonous mushroom *Entoloma sinuatum* has demonstrated significant biological activity, suggesting potential applications in various medicinal fields [6]. Another study explored the cardiogenic effects of poisonous mushrooms, revealing that certain compounds present in these species may impact cardiovascular health, either positively or negatively [7].

Mushrooms are the great source of food and medicine. For example, *Stereum hirsutum* mushroom extracts have shown promise in treating atherosclerosis, a leading cause of cardiovascular diseases [8]. The antioxidant and antigenotoxic potential of *Infundibulicybe geotropa*, collected from northwestern Turkey, also underscores the therapeutic potential of mushrooms in combating oxidative stress and genotoxicity [9]. Additionally, research on *Cyclocybe cylindracea* highlights its phenolic content and antioxidant properties, along with its levels of heavy metals, further indicating the complex bioactivity of mushrooms [10]. These studies collectively suggest that mushrooms may serve as a valuable resource for food and developing natural therapeutic agents.

V. volvacea, also known as paddy straw mushroom, is a type of edible mushroom having tropical and subtropical distribution throughout the world [11]. It belongs to the family Pluteaceae of order Agaricales under division basidiomycota [12]. There are three growth stages of this mushroom i.e., button, egg and elongation or mature stage [13]. Paddy straw mushroom is world-famous, due to its pleasant flavor, taste, high protein content and less duration of cultivation [14,15]. On the other hand, China is first in rank and produces 3,30,000 tons of straw mushroom annually accounting for 80 % of its global production [16].

Since 18th century, *V. volvacea* has been cultivated traditionally in Southeast Asia [18]. *V. volvacea* has a great nutritional value as it contains protein, fiber, carbohydrates, moisture, minerals and vitamins (such as thiamins, biotin, riboflavin and rich quantity of vitamin C) [19]. There are several enzymes present in paddy straw mushroom that are helpful for its fast growth such as endoglucanase, laccase, polyphenol oxidase, xylanase and beta glucosidase [20,21]. Nutritional value of *V. volvacea* can also be alternative to meat, eggs, and milk products [22].

1.1. Nutritional contents of Volvariella volvacea

Mushrooms have great nutritional value for human health and are also a great source of protein, carbohydrates (such as chitin), vitamins, fats and minerals [23]. On a dry weight basis, their composition can vary widely, with protein content ranging from 10 % to 40 % [24], carbohydrates from 3 % to 28 %, fats from 2 % to 8 %, ash from 8 % to 10 %, and fibers from 3 % to 32 %. They also contain essential minerals such as calcium (Ca+), magnesium (Mg+), iron (Fe+), potassium (K+), phosphorus (P+), copper (Cu+), and zinc (Zn+) [25]. Table 1 presents the proximate composition of the edible mushroom *V. volvacea*. Mineral content seems predominant at button stage of paddy straw mushroom as compared to other stages, e.g., it contains high amount of potassium and magnesium at button stage as compared to the elongation stage [25,26]. Glycoprotein, terpenoids, nucleotides, and polysaccharides are the bioactive molecules found in edible mushrooms [27]. Mushrooms also contain low proportion of fats having no cholesterol, but are rich in unsaturated fatty acids [14].

In south Asian countries, *V. volvacea* is the most popular mushroom due to its exceptional delicacy and high protein, amino acids, vitamins and mineral content. *V. volvacea* contains only 10 %/100 % dry matter in which 56.8 % constitutes carbohydrates, 5.7 % fats, 14–27 % of crude protein and all essential amino acids. Fibers, chitin, minerals and water-soluble vitamins such as biotin, riboflavin and thiamine and are also present [28]. A total phenolic content in paddy straw mushroom was reported to be within range of 10.05 mg/g to 16.72 mg/g dry weight [29]. Young stage of paddy straw mushroom has a greatest ability to reduce ferricyanide complex to

Table 1
Proximate composition of the edible mushroom *V. volvacea* [17].

Sr. No.	Minerals	Percentage	Parameters analyzed	Percentage
1.	Sulphur	2.72	Ash	8–10 %
2.	Aluminum	0.27	Crude protein	28–32 %
3.	Calcium	0.62	Dry matter	9–10 %
4.	Chlorine	3.57	Fat	2–4%
5.	Cupper	0.07	Fiber	4–9%
6.	Iron	0.38	Free fatty acid	0.3–0.7 %
7.	Magnesium	0.99	Moisture	89–91 %
8.	Manganese	0.05	Carbohydrate	50–52 %
9.	Phosphorous	8.96		
10.	Potassium	52.52		
11.	Oxygen	28.72		

ferrous form [30].

1.2. Protein and amino acids found in Volvariella volvacea

Protein is a very important component of nutritious and functional food for human beings. Different mushrooms contain variable protein content. Proteins in each species vary according to size of pileus, type of mushroom, substratum and harvesting time [31]. *V. volvacea* contain 14–27 % of crude proteins [32]. Volvarin, a ribosome inactivating protein is also obtained from the paddy straw mushroom [33]. Lectin protein was also obtained from the fruiting body and mycelia of *V. volvacea* mushroom [34]. Protein in that mushroom resembles animal protein and it contains some essential amino acids as required by adults [35]. Table 2 presents a detailed account of the various amino acids found in the mushroom body of *V. volvacea.* Moreover, the amount of amino acids in *V. volvacea* increase within the maturity of the fruiting body. Several amino acids are also present in *V. volvacea* that are the main constituents of proteins [20].

Amino acids present in paddy straw mushroom are arginine, aspartic acid, asparagine, cystine, glutamine, glycine, histidine, Isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, tyrosine, threonine, tryptophan and valine [13]. Essential amino acid like glutamic acid (1458.9 mg/100g) is abundantly found in paddy straw mushroom at different stages of fruiting body [37, 38]. High amounts of ornithine, γ-aminobutyric acid (GABA), ammonia, urea and phosphoserine are also reported in *V. volvacea* [39, 40]. Watanabe et al. [41] reported that γ-aminobutyric acid (GABA) present in *V. volvacea* possessed antihypertensive activity. High glutamic acid and aspartic content in *V. volvacea* gives pleasant and delightful taste to mushroom, so it can be used as a natural alternative to sodium glutamate monohydrate and sodium aspartate monohydrate in enhancing the umami flavor of foods [38,42]. *V. volvacea* has been reported to have a high concentration of valine (335.5 mg/100 g), along with other essential amino acids such as leucine, lysine, and tryptophan [38]. While the high concentration of these amino acids indicates the nutritional quality of *V. volvacea* [37], it is the overall amino acid profile and protein content that collectively position this mushroom as a potential supplement to or alternative for animal-based protein sources [43]. Considering the particular stage of this mushroom, button stage has higher protein than that of elongated stage [23,26]. Based on substrate content, nitrogen content in the substratum is a key factor that affects the protein content in mushrooms and there are reports of decrease in protein content when mushrooms are stored [44].

1.3. Carbohydrates and fibers

Fresh mushrooms contain relatively significant amounts of fibers and carbohydrates, such as amino sugars (glucosamine, N-acetylglucosamine), disaccharides (sucrose), hexoses (glucose galactose), methyl pentoses (rhamnose, fructose), methyl sugars, pentoses (xylose, ribose, mannose), sugar acids (galacturonic, glucuronic acids) and sugar alcohols (mannitol, inositol) [45,46]. Mannitol is the most commonly found sugar in edible mushrooms along having 80 % of total sugar content [47,48]. Polysaccharides present in mushrooms are the best source of non-toxic medicine and they are also physiologically beneficial [49]. Generally, fruiting body of mushrooms is composed of 50–65 % carbohydrates, whereas sugar-free content is 11 % dry weight of that mushroom [50]. Mannogalactan, a water-soluble hetero polysaccharide was also obtained from the cold aqueous extract of paddy straw mushroom [51,52]. Abd-Nasir and Raseetha [26] has reported 51.47–53.14 % carbohydrate content during three different growth stages of paddy straw mushroom. In another study, Subbiah and Balan [53] reported 57 % carbohydrates content in paddy straw mushroom.

Carbohydrates content found in dry weight of *V. volvacea* vary between 40 and 50 % which increases with the maturity of mushroom [26]. Polysaccharides (chitin) are the main constituents of the cell wall of that mushroom whereas α, β-glucans and glycoprotein are important polysaccharides found in cell wall of fungi [54,55]. These polysaccharides have anti-cancer and immuno-modulatory activity [56]. Fibers in paddy straw mushroom were similar with 1.87 % similarity index at button and egg stage but decreased at elongation stage [18].

Crude fibers in edible mushrooms are in range of 4.54–6.54 g/100g [57]. The content of fibers present in paddy straw mushroom is 11.90 % [58]. Abd-Nasir and Raseetha [26] reported 2.42 % fibers at button stage and 1.39 % at elongation stage in paddy straw mushroom and they found a reduction of fibers in *V. volvacea* with its maturity. The ash content of paddy straw mushroom is 12.5 %

Table 2
Amino acid content of *V. volvacea* mushroom (g/100g of protein) [36].

Sr. No.	Amino acids	Content in grams (g)
1.	Alanine	7.14
2.	Aspartic acid	12.4
3.	Cystine	0.95
4.	Glutamic acid	27.9
5.	Leucine	7.55
6.	Lysine	5.20
7.	Phenylalanine	6.22
8.	Proline	6.60
9.	Threonine	4.88
10.	Tryptophan	14.7
11.	Tyrosine	4.79
12.	Valine	3.77

which is consistent at all growth stages [53]. Duration, humidity and temperature after harvest of mushroom, are the key factors that can change the ash content in mushroom [57].

1.4. Lipid or fats

Mushrooms are good source of fats [59], and the fruiting bodies of mushrooms contain low amount of fats as compared to protein and carbohydrates, but these contain some dominant and essential unsaturated fatty acids such as linolenic acid [54,60]. Fat content present in mushrooms vary from species to species (0.6–8%) and increases with the maturity of mushroom [23]. Mushrooms contain all types of lipids such as crude fats, diglycerides, free fatty acids, monoglycerides, phospholipids, sterols, sterol esters as well as triglycerides [23,60]. The fat present in mushrooms is 4.481 % on dry weight bases [54,60]. Abd-Nasir and Raseetha [26] reported that fat content of paddy straw mushroom is different at button stage i.e., 4.32 % which is lower than 5.82 % present at elongation stage. Another study showed that fat content of *V. volvacea* is 5.7 % [53]. Saponifiable fats (58.8 %) are in low levels in paddy straw mushroom due to ergosterol and provitamin D_2 [61].

Fatty acids found in *V. volvacea* contains high amount of unsaturated fatty acids, which is about 83.3 % of the total fatty acid content [16]. High levels of unsaturated fatty acids are due to high levels of linoleic acids (69.91 %) found in fatty acid of paddy straw mushroom [16,62]. Fatty acids that are found in paddy straw mushroom are linoleic acid 69.91 %, myristic acid 0.48 %, oleic acid 12.74 %, palmitic acid 10.5 %, palmitoleic acid 0.62 % and stearic acid 3.47 % [16,60]. In medical industry, linoleic acid, an unsaturated fatty acid, is used for treatment of skin problems such as scaly skin and tail [16,60]. It is worth noting that the stipe of paddy straw mushroom contains significantly higher values of linoleic acid i.e., 85.46 % when compared to other edible mushrooms which contain 27.98 %–76.25 % linoleic acid content [60,63].

1.5. Vitamins

Vitamins are necessary part of organisms for their normal growth and development. Mushrooms appear to be a good source of many vitamins, therefore, having great nutritional values [64]. Edible fungi are good source of minerals and vitamins such as biotin, folates, riboflavin, vitamin B complex such as B1 (thiamine), B2 (riboflavin), B3 (niacin), ascorbic acid or vitamin C, D_2 and vitamin E [17,23,46]. Niacin plays a significant role in DNA damage response and stress responses like apoptosis to reduce the risk of cancers as well as for the treatment of atherosclerotic cardiovascular diseases [65,66]. Table 3 presents the concentration of vitamins in *V. volvacea.*

Fat soluble vitamins present in *V. volvacea* are vitamin A, D, E, and K [46,68]. The concentration of these vitamins in *V. volvacea* is 0.001 mg/kg of vitamin A, 50.711 mg/kg of vitamin D and 0.006 mg/kg of vitamin K [68,69]. Source of vitamin D in the human beings is sun but we can get it from mushrooms as well. *V. volvacea* is rich in ergosterol which is a precursor of vitamin D [46]. The content of vitamin D_2 is found to be much higher in wild mushrooms as compared to dark cultivated mushrooms [17,46]. *V. volvacea* contains vitamin B complex and C, which help to boost up the immune system's efficiency [64,70]. The content of vitamin C reported in cultivated *V. volvacea* is between 20 and 62 mg/100g of dry weight [64].

1.6. Minerals

A variety of minerals are found in fruiting bodies of mushrooms [59]. Proportion of minerals found in mushrooms varies according to type of species, age of species, substratum and diameter of the fruiting body [71]. Wild mushrooms have higher mineral proportion than cultivated mushrooms [72]. Macronutrients such as K, P, Ca, Na, and Mg are abundant in mushrooms whereas micronutrients such as Cu, Fe, Zn, Mo and Cd are also reported to be present in them [73].

V.volvacea contains major minerals between 36 and 3232 mg/100 g of dry weight and trace elements are 5.2–426 mg/100 g of dry weight. Minerals such as K, P, Na, and Mg make 56–70 % of total ash in which K alone makes 45 % of ash content in *V. volvacea* mushrooms [15,74]. In *V. volvacea*, 52.52 % of potassium, 28.72 % of oxygen, and 8.96 % of phosphorous and many other elements (S, Mg, Si, Ca, Fe, Al, Zn, Cu, Mo, Na and Mn) are also present [15,74,75].

The comprehensive nutritional profile of *V. volvacea* underscores its potential as a valuable dietary supplement. The high protein content, comparable to that of animal sources, makes it an excellent alternative for vegetarians and those seeking plant-based protein

Table 3
Concentration of vitamins in *V. volvacea*

Sr. No.	Vitamins	Concentration	Reported References
1	Vitamin A	0.001 mg/kg	[17]
2	Vitamin B1 (Thiamin)	0.024 mg	[67]
3	Vitamin B2 (Riboflavin)	0.127 mg	[67]
4	Vitamin B3 (Niacin)	0.408 mg	[67]
5	Vitamin B5 (Pantothenic acid)	0.75 mg	[67]
6	Vitamin B6 (Pyridoxine)	0.025 mg	[67]
7	Vitamin B9 (Folate)	69 μg	[67]
8	Vitamin D	50.711 mg/kg	[17]
9	Vitamin E	Nil	[17]
10	Vitamin K	0.006 mg/kg	[17]

options [76]. The presence of essential amino acids, including valine, leucine, and lysine, further enhances its nutritional value, supporting muscle maintenance and overall health. The significant carbohydrate content, primarily composed of beneficial polysaccharides like chitin and glucans, contributes to its role in promoting gut health and providing sustained energy [77]. Additionally, the low-fat content, rich in unsaturated fatty acids such as linoleic acid, positions *V. volvacea* as a heart-healthy food option. The abundance of vitamins, particularly B-complex vitamins and vitamin D, along with essential minerals like potassium and magnesium, further solidifies its status as a nutrient-dense food [78]. This multifaceted nutritional profile not only supports daily dietary needs but also offers potential therapeutic benefits, emphasizing the importance of integrating *V. volvacea* into regular dietary practices [79].

1.7. Medicinal properties

Edible mushrooms are source of therapeutic agents beneficial for health. These agents are effective against allergies, asthma, cancers, cholesterol reduction, diabetes, insomnia and stress [80,81]. Several types of bioactive compounds such as lipids, polysaccharides, protein, protein-polysaccharides complex and other metabolites like β-glucan, heterocyclic, peptides, polyketides, sterols, terpenes and terphenyls are obtained from edible mushrooms [82,83]. Bioactive compounds such as antimicrobial proteins e.g. chitinases, defensins, glucanases, peroxidases, immunomodulatory protein, laccases, lectins, lipid transfer protein, other medicinally important proteins, protease inhibitors, ribonucleases and ribosome inactivating protein are reported in edible mushrooms [23,84]. It is reported that the bioactive compounds extracted from the edible mushrooms have anti-Alzheimer, anti-diabetic, anti-malaria, antimicrobial, antioxidant, antitumor properties, antiviral and hypercholesteremic [85]. Fig. 1 illustrates the medicinal activities of *Volvariella volvacea***.** Bioactive compounds such as β-glucan, Zymosan, Selenium, Flammutoxin, and Volvatoxin are found in *V. volvacea* that exhibit anti-oxidant and anti-tumor activities, while Interleukin-1β, Interleukin-8, and Tumor Necrosis Factor-α, also present in *V. volvacea*, demonstrate anti-inflammatory and anti-cancer properties [85]. Leucine, isoleucine, and phenylalanine, which are present in *V. volvacea* exhibit anti-inflammatory properties while Compounds known as 2-pyrrolidinones, demonstrate antimicrobial and antifungal activities [85]. In the past, medicinal mushrooms have been used as herbal medicines for human health [86]. *V. volvacea* also has a medicinal importance in addition to its nutritional value and is an ideal source of compounds with antitumor, antimicrobial,

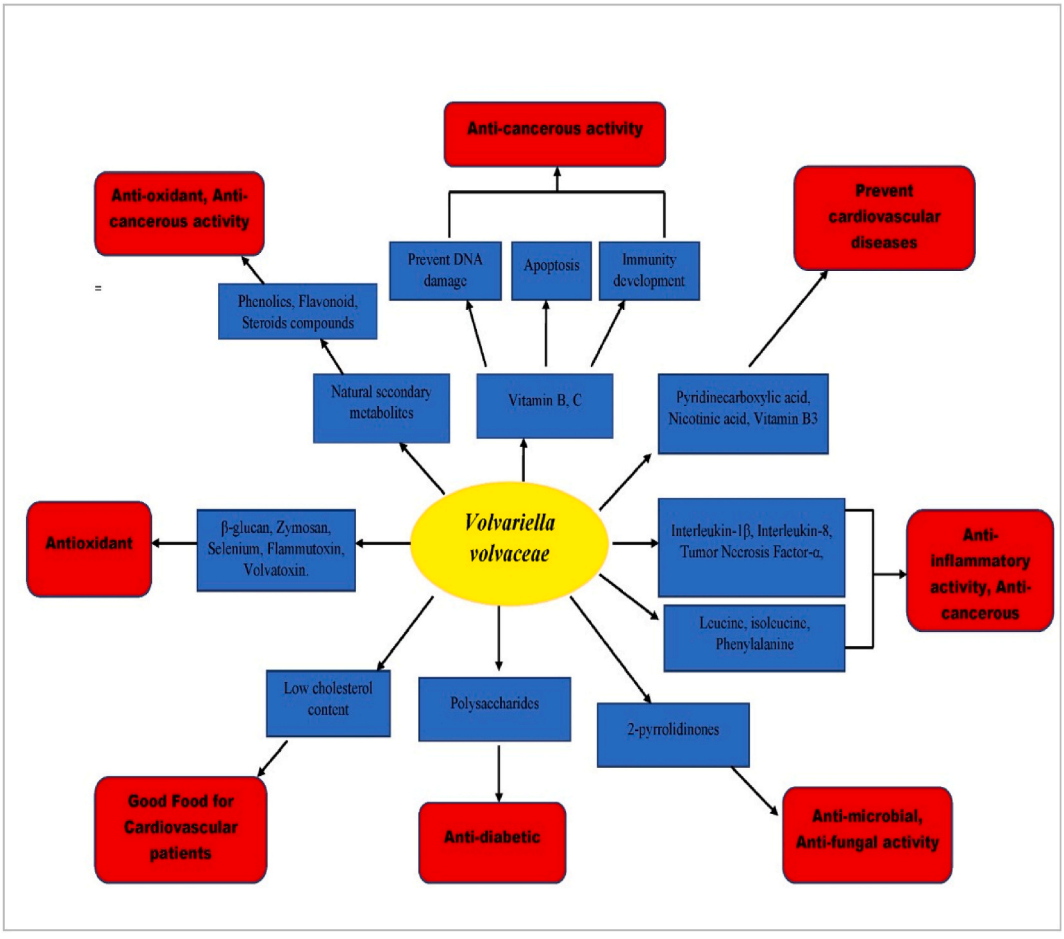

Fig. 1. Medicinal activities of *V. volvacea.*

anticancer and antioxidant activities [87,88]. Table 4 presents biological activities of some compounds identified in methanol extract of *V. volvacea.*

In the field of medicine, fungi are of significant interest to researchers, and consequently, people have moved their focus to the production and growth of mushroom industries [15]. In China, *V. volvacea* has been used in traditional Chinese medicines to treat heat stroke, lower body temperature, improve women's milk after birthing, support infant health, and promote liver and stomach health [89]. Numerous studies indicated that *V. volvacea* contains an isomerization protein that may enhance immune function, lower cholesterol levels, and prevent atherosclerosis [90].

1.8. Antioxidant properties

Mushrooms are rich in medically bioactive compounds such as phenolics, polyketides, steroids, flavinoids and terpenes which are secondary metabolites obtained from different mushrooms [91]. As a result of different metabolic processes in human body, production of free radicals especially oxygen derivatives cause cell or tissue damages however antioxidants can prevent such damages [92]. Concentration of ascorbic acid, carotenoids, lycopene, phenolic compounds, steroids and tocopherols is high in *V. volvacea* that gives anti-oxidative property to this mushroom [93,94]. Phenolic compounds are secondary metabolites having antioxidant properties that act as a free radical scavenger, hydrogen donators and single oxygen quenchers [95]. Phenolic compounds found in mushrooms have scavenging activity as well as antibacterial, anti-hyperglycemic and anti-inflammatory properties [96,97]. The content of phenolic compounds in paddy straw mushroom is 0.73 mg/g of dry weight [98]. Flavonoids are naturally occurring secondary metabolites in plants and fungi, that have strong antioxidant properties to prevent lipid peroxidation, scavenger of free radicles and chelates ferrous ions [99]. Amount of flavonoids reported in paddy straw mushroom, by using water extraction and 50 % ethanol extraction, is 7.29–9.05 mg/g dry weight [100]. Yang et al. [101] reported the presence of antioxidant activity in *V. volvacea*. Methanol and water extract from *V. volvacea* showed rich antioxidant activity [98].

V. volvacea contains flavonoid and phenolics compounds both that have highest hydrogen donating capacity to scavenge the DPPH radical. DPPH (2,2 diphenyl-1-picrylhydrazyl) which is a free radical that accept electron or hydron to become stable. DPPH has the highest free radical scavenging activity present in edible mushrooms extract compared to various edible mushrooms [102]. Abd-Nasir and Raseetha [26] reported that the content of phenolic compounds in paddy straw mushrooms is high at button stage as compared to elongation stage. High level of antioxidant activity of paddy straw mushroom is due to calcium carbonate activity [15]. Oxidative DNA damages can be protected as a result of antioxidant activity of paddy straw mushroom [103]. Cardiovascular and other diseases such as Alzheimer's, cancer, inflammation, neurodegenerative diseases and Parkinson's can be prevented through antioxidant rich food. Therefore, this mushroom can be utilized due to high level of antioxidant properties [104]. Antioxidant activity of *V. volvacea* prevents from risk of chronic angiogenic ailments like arthritis, cancer, cardiovascular and inflammation [105]. Fig. 2 presents the antioxidant mechanisms of *Volvariella volvacea.*

Table 4
Biological activities of some compounds identified in methanol extract of *V. volvacea* (GC–MS study)

Name of the Compounds	Compound Nature	Activity	Reported References
10-Octadecenoic acid methyl ester	Fatty acid ester	Enhances the immunity of hydroxy unsaturated fatty acid	[106]
2-Pyrrolidinones	Heterocyclic compounds	Anti-bacterial Anti-fungal	[107]
3-Pyridinecarboxylic acid	Nicotinic acid	Reduce the risk of cardiovascular disease Topical vasodilatora	[108,109]
8-octadecenoic acid, methyl ester	Fatty acid ester	Antioxidant, Antimicrobial.	[110]
9,12-Octadecadienoic acid (Z,Z)-	Linoleic acid	Anti-inflammatory, Hypocholesterolemic, Cancer preventive, Hepatoprotective Nematicide Insectifuge, Antihistaminic, Antieczemic, Antiacne, 5-Alpha reductase inhibitor, Antiandrogenic, Antiarthritic, Anticoronary	[110]
Adenosine 3′, 5′ cyclic monophosphate	Derivative of ATP	Prevents atherosclerosis, atherogenesis and development of acute coronary syndrome	[106]
Benzene acetic acid	Acid	Active plant hormone, Precursor of penicillin G production, used to treat type II hyperammonemia, used in some perfumes	[111]
Hexadecanoic acid, methyl ester	Palmitic acid ester	Antioxidant, Antiandrogenic, Hemolytic, Hypocholesterolemic, Nematicide, Pesticide, flavor, Alpha reductase inhibitor	[110]
n-Hexadecanoic acid	Palmitic acid	Antioxidant, Antiandrogenic, Lubricant, Hemolytic, Hypocholesterolemic, Nematicide, Pesticide, Flavor, 5-Alpha reductase inhibitor	[110]
Pentadecanoic acid	Fatty acid	Antioxidant	[110]
Pentadecanoic acid, methyl ester	Palmitic acid methyl ester	Antioxidant	[110]
Pyrazine	Heterocyclic compounds	Antianginal, anti-cancer, Antidepressant, Anti-tuberculosis, Antpsychotic, Antidiabetic, Hypolipidemic, Antihistamine, Flavouring agent	[112]
Pyrrolidine-2,5-dione	Succinimide (cyclic Imide)	Inhibitory activity against Mycobacterium tuberculosis H37Rv	[113]

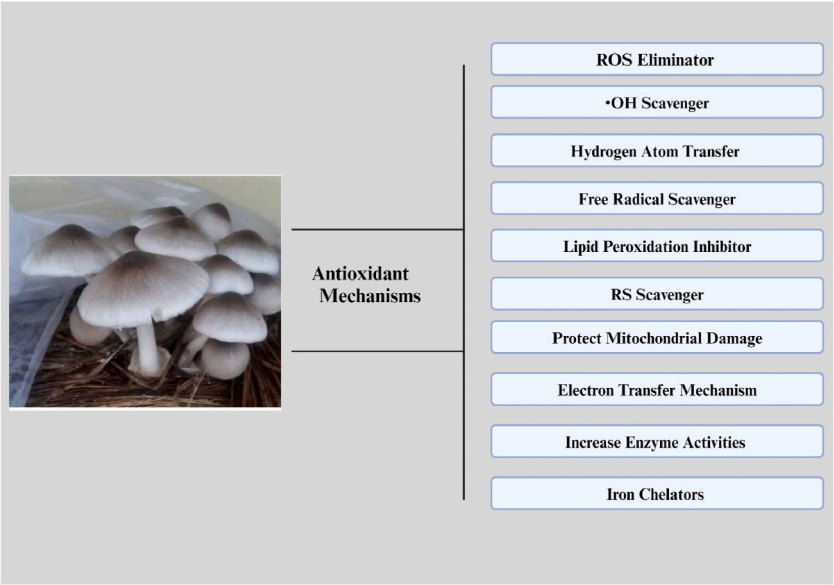

Fig. 2. Antioxidant Mechanisms of *Volvariella volvacea.* It functions as a ROS (reactive oxygen species) eliminator, neutralizing harmful oxidative molecules that contribute to cellular damage. The mushroom effectively scavenges hydroxyl radicals (•OH) and promotes hydrogen atom transfer, which helps in stabilizing free radicals. Additionally, it acts as a free radical scavenger, further preventing oxidative stress. The inhibition of lipid peroxidation is another vital mechanism, protecting cell membranes from oxidative degradation. Volvariella volvacea also scavenges reactive species (RS) and provides protection against mitochondrial damage, ensuring proper cellular energy production. Its role in electron transfer mechanisms enhances antioxidant enzyme activities, further mitigating oxidative stress. The mushroom also exhibits iron-chelating properties, reducing the availability of free iron ions that catalyze the formation of reactive radicals, thus safeguarding cellular structures from oxidative harm.

1.9. Anti-cancer and anti-tumor properties

Numerous researchers had shown anti-tumor effect of polysaccharides and zymosan before anti-tumor effect was reported in mushrooms. Now it is confirmed through research that mushrooms contain antitumor properties as well [114,115]. Cold alkali extract and polysaccharides of *V. volvacea* show antitumor activity, while protein extract show cell death due to anticancer activity [116]. Polysaccharides extracted from *V. volvacea* showed higher activity against tumors. In mice, a dose of 5–30 mg/kg extracted polysaccharides from *V. volvacea,* is enough to obtain remarkable antitumor result with 100 % inhibition ratio and very low toxicity [117]. Pharmacology department of South Korea reported that macromolecules, made up of polysaccharides and proteins, are responsible for antitumor effects [118]. Chloroform extract of *V. volvacea* showed the presence of tri-terpenoid. In medical industry, tri-terpenoid has various functions like anti-bacterial and anti-tumor effect along with reduction of blood pressure [119].

Generally, lectin protein present in mushrooms, have and immune-modulating and anti-tumor properties. Moreover, in cancer Interleukin-8 (IL-8) expression, may contribute to modification of immune response like leukocyte infiltration, metastasis, tumor cell motion and tumor progression [120].

Medicinal mushrooms retain anticancer and anti-inflammatory activity beneficial for human health [121]. Polysaccharides peptides, reported in medicinal mushrooms, have been used against cancer and boosting the immune cell production [122]. Beta-glucan and conjugated linoleic acid in *V. volvacea* may inhibit prostate and breast cancer cell proliferation. Polysaccharides content present in edible mushrooms is used against HIV and cancer effectively [123–125]. Interleukin-8 (IL-8) has been reported in the extract of *V. volvacea* and it could be used as anti-inflammatory and anticancer agent [126]. Wasser [127] reported that mushrooms polysaccharides have anti-cancer and immune-modulating property. Phenolic content in *V. volvacea* represent anti-cancer, anti-inflammatory and antioxidant activity [128]. Cardiotoxic proteins such as flammutoxin and volvatoxin are obtained from the extract of *V. volvacea* which inhibit the respiration in certain tumor cells or having anti-tumor activity [15,67]. Pyrazine is a heterocyclic compound, present in V. volvacea that have anti-cancerous activity [112].

1.10. Anti-inflammatory properties

Bioactive compounds present in *V. volvacea* show anticoagulant, antihypertensive and anti-inflammatory activity [23]. High content presence of terpenes and terpenoids in medicinal mushrooms has shown high immune-modulating and anti-infective activities [129,130]. Anti-inflammatory molecules present in the extract of *V. volvacea* are interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), interleukin-1β (IL-1β) and interleukin-8 (IL-8) [131]. Interleukin-8 (IL-8) showed neutrophil activity as a host cell defense mechanism, however, its high amount may damage several tissues [23]. Interleukin-8 (IL-8) has been reported in the extract of *V. volvacea* and it could be used as anti-cancer and anti-inflammatory agent [126]. It is reported that essential amino acids in *V. volvacea* such as leucine,

isoleucine and phenylalanine and vitamin B2 were linked to anti-inflammatory response [126].

1.11. Anti-diabetic properties

Medicinal mushrooms contain dietary fibers, essential amino acid, glucan, glycoprotein, lipopolysaccharides, minerals, polysaccharides and proteins along with numerous secondary metabolites that are used for anti-bacterial, anti-cancer, anti-diabetic, anti-hyperglycemic, anti-hypertensive, anti-oxidant, anti-viral, hepatoprotective, hypocholesterolemia, immune-stimulation and neuro-protective treatments [132,133]. For many years, it was believed that mushrooms may be used to treat heart disease, but systematic research began in 1960 when Japanese researchers started working on it and they isolated an eritadenine alkaloid from the aqueous extract of *Lentinula edodes* mushroom [134]. 3-Pyridinecarboxylic acid is a nicotinic acid present in *V. volvacea* that reduces the risk of cardiovascular diseases [108,109].

Gupta et al. [135] performed a research on rats to show the antidiabetic activity of paddy straw mushroom. The work was planned to determine the antidiabetic property of *V. volvacea* by exploring the glucose tolerance test and other vital serum profile in normal and induced diabetic rats. Mushroom extract was hydrolyzed and then dried with two equal proportions of lyophilization (LE) and hot air oven (ODE). Lyophilization (LE) and hot air oven (ODE) extracts were applied on diabetic rats and results showed that lyophilization (LE) extract of *V. volvacea* has more antidiabetic activity that significantly decreases the glucose level in serum of diabetic rat than ODE.

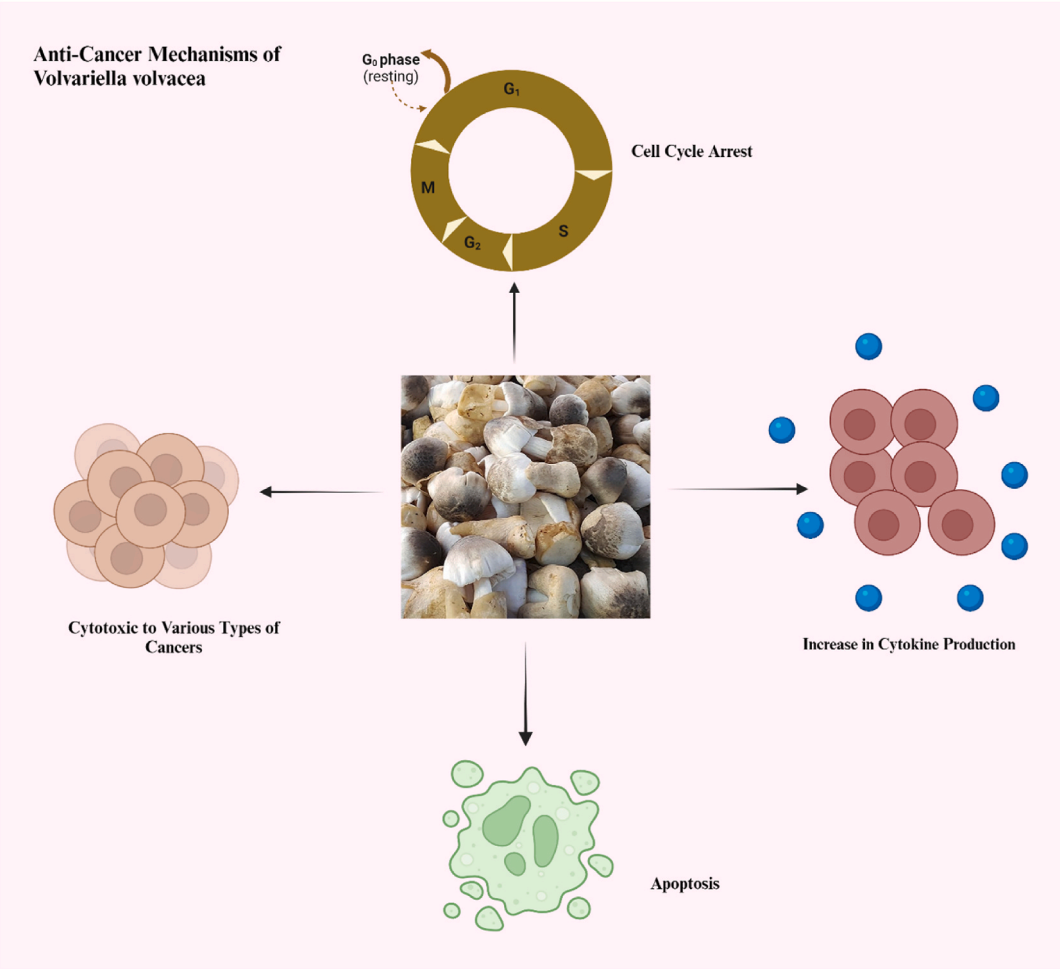

Fig. 3. Anti-Cancer Mechanisms of *Volvariella volvacea*. It exhibits notable anti-cancer properties through various mechanisms that target cancer cells. One of its key actions is inducing cell cycle arrest, particularly halting the progression of the cancer cell cycle in critical phases, thereby preventing further proliferation. Additionally, the mushroom has cytotoxic effects on various types of cancer cells, directly inhibiting their growth and promoting cell death. *Volvariella volvacea* also plays a role in enhancing cytokine production, which strengthens the immune system's ability to detect and destroy cancer cells. Furthermore, the mushroom induces apoptosis, the programmed cell death pathway, effectively leading to the elimination of cancer cells. These combined mechanisms highlight its potential as a natural therapeutic agent in cancer treatment. Fig. 3 illustrates the anti-cancer mechanisms of *Volvariella volvacea*.

1.12. Antimicrobial activities

Methanolic extract of *V. volvacea* contains secondary metabolites that have antimicrobial property such as alkaloids, flavonoids, glycosides, saponins, tannins and tri-terpenoids [136,137]. Silva et al. [87] reported antimicrobial activity of *V. volvacea* which inhibits the growth of *Klebsiella pneumoniae, Pseudomonas aeruginosa, Staphylococcus aureus* and *Streptococcus pyogenes* bacteria. Heterocyclic compound 2-Pyrrolidinones present in *V. volvacea* have antifungal and antimicrobial properties [107]. Perera et al. [138] also reported the antibacterial activity of this mushroom.

1.13. Cardio-protective activities

Compounds present in *V. volvacea* also exhibits the cardio-protective activities. Methanol extract of *V. volvacea* showed the presence of cardiac glycoside which is clinically used as a heart strengthening drug [119,139]. It is reported that β-glucan present in *V. volvacea* showed hypo-cholesterolemia activity [23,51]. Anti-hypertensive and anti-coagulant activities have been shown in *V. volvacea* due to the presence of different types of bioactive compounds [23].

The diverse bioactivities of *V. volvacea* highlight its significant therapeutic potential. The antioxidant properties, driven by phenolic and flavonoid compounds, play a crucial role in neutralizing free radicals, thereby reducing oxidative stress and lowering the risk of chronic diseases such as cancer and cardiovascular ailments [140]. The anti-tumor and anti-cancer activities, primarily attributed to polysaccharides and other bioactive molecules, suggest its potential as a complementary treatment in oncology [141]. The mushroom's anti-inflammatory properties, supported by compounds like interleukin-8, offer promising applications in managing inflammatory conditions and enhancing immune response [142]. Additionally, the antimicrobial activities, effective against various pathogenic bacteria and fungi, indicate its potential use in preventing and treating infections. These bioactive properties, combined with its nutritional benefits, position *V. volvacea* as a powerful functional food with substantial health-promoting effects [143]. Future research should focus on exploring these bioactive compounds in clinical settings to fully harness their therapeutic potential and incorporate them into mainstream medical practice.

1.14. Application potential in food and medicine industry

Given its exceptional nutritional and medicinal properties, *V. volvacea* holds significant potential for application in both the food and medicine industries. In the food industry, the high protein content of *V. volvacea*, which rivals that of animal-based sources, makes it an excellent ingredient for developing plant-based protein products [144]. This is particularly relevant in the context of the growing demand for vegetarian and vegan diets, where finding complete and high-quality protein sources is essential [145]. Additionally, the comprehensive amino acid profile, including essential amino acids such as leucine, lysine, and valine, supports muscle maintenance and overall health, making *V. volvacea* an attractive ingredient for health-focused food products [146]. The rich vitamin and mineral content of *V. volvacea* can significantly enhance the nutritional value of various food products. Vitamins such as B-complex and vitamin D, along with essential minerals like potassium and magnesium, contribute to its nutritional robustness. This makes the mushroom a valuable addition to functional foods aimed at addressing specific dietary deficiencies and promoting overall health [147]. Furthermore, the unique flavor and texture of *V. volvacea* can be leveraged in gourmet cooking and the development of innovative food products, appealing to both health-conscious consumers and culinary enthusiasts [148].

In the medicine industry, the bioactive compounds present in *V. volvacea*, such as polysaccharides, flavonoids, and terpenes, offer a wide range of therapeutic applications [149]. The antioxidant properties of these compounds play a crucial role in neutralizing free radicals, thereby reducing oxidative stress and lowering the risk of chronic diseases such as cancer and cardiovascular ailments [150]. The anti-tumor and anti-cancer activities of *V. volvacea* polysaccharides suggest its potential as a complementary treatment in oncology. Additionally, the mushroom's anti-inflammatory properties, supported by compounds like interleukin-8, offer promising applications in managing inflammatory conditions and enhancing immune response [151]. The antimicrobial properties of *V. volvacea* further expand its application potential in the medicine industry. Effective against various pathogenic bacteria and fungi, these properties can be utilized in developing natural preservatives for food safety and antimicrobial agents for clinical use. This makes *V. volvacea* a versatile resource for creating products that promote health and prevent disease [148]. Future research should focus on isolating and characterizing these bioactive compounds to fully harness their therapeutic potential and integrate them into mainstream medical and dietary practices. By exploring these applications, *V. volvacea* can significantly contribute to both nutritional and medical advancements, supporting a healthier and more sustainable future.

1.15. Nutritional and medicinal value Comparison of V. volvacea, P. ostreatus, and Agaricus bisporus

V. volvacea differs significantly from other edible mushrooms such as *Pleurotus ostreatus* (oyster mushroom) and *Agaricus bisporus* (white button mushroom) in both nutritional and medicinal values [152]. Nutritionally, *V. volvacea* is rich in proteins, vitamins (notably B vitamins), minerals (including iron, zinc, and potassium), and essential amino acids, making it a valuable dietary component [153]. In contrast, *P. ostreatus* is known for its high fiber content, substantial amounts of antioxidants like ergothioneine, and significant levels of lovastatin, a compound beneficial for lowering cholesterol [154]. *Agaricus bisporus*, widely consumed globally, provides a balanced nutritional profile with a good mix of proteins, vitamins (particularly vitamin D when exposed to sunlight), and minerals but typically has lower levels of certain bioactive compounds compared to the other two mushrooms [152].

Medicinally, *V. volvacea* stands out due to its potent antioxidant properties, attributed to high levels of phenolic compounds and its

notable DPPH free radical scavenging activity [155] like most of horticultural crops [156–162]. It also exhibits significant anti-tumor activity, primarily through its polysaccharide content. *P. ostreatus* is renowned for its immune-modulating effects and anti-inflammatory properties, which are beneficial in managing chronic diseases. Additionally, it has demonstrated anti-cancer properties and cardiovascular benefits due to its bioactive compounds [163]. *Agaricus bisporus*, while less potent in specific medicinal activities, offers a wide range of health benefits including anti-inflammatory effects, immune support, and potential anti-carcinogenic properties, primarily due to its polysaccharides and other bioactive compounds. Thus, while all three mushrooms are nutritionally rich and medicinally valuable, *V. volvacea* excels in antioxidant and anti-tumor activities, *P. ostreatus* in cholesterol-lowering and immune-modulating effects, and *A. bisporus* in overall balanced health benefits [152].

2. Conclusion and future recommendations

Paddy straw mushroom is a fast-growing mushroom having shorter lifecycle, but it contains different bioactive compounds that have a great nutritional and medicinal value. Bioactive compounds such as amino acids, carbohydrates, enzymes, sugars, fats, minerals proteins and vitamins are nutritionally important for healthy diet of human beings, and can be obtained well from paddy straw mushroom. Flavonoids, phenolic compounds, polypeptides, steroids, tannins and terpenoids are important secondary metabolites present in paddy straw mushroom having significant therapeutic values being rich in anti-allergic, anti-cancer, anti-inflammatory, anti-malarial, anti-microbial, anti-oxidant and anti-tumor properties. This species is not yet fully explored by the researchers for analyzing the much more inducing compounds for medicinal and nutritional properties. Still, the need of the research on medicinal and nutritional aspects of this mushroom is urgent and this review will improve the focus of the newer researchers to direct their research on nutritional and medicinal aspect of paddy straw mushroom. Novel compounds are needed to be identified and extracted from the mushrooms which possess these properties. Thus, this review will help in the discovery of some novel compounds from this mushroom.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

CRediT authorship contribution statement

Sadaqat Ali: Data curation. **Nousheen Yousaf:** Formal analysis. **Muhammad Usman:** Resources. **Muhammad Ammar Javed:** Conceptualization. **Maryam Nawaz:** Formal analysis. **Baber Ali:** Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Sezai Ercisli:** Writing – original draft. **Serpil Tirasci:** Writing – original draft. **Ahmed Ezzat Ahmed:** Writing – review & editing.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Declaration of competing interest

The authors declare that they have no competing interests.

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