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Review Article

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Schizophyllum commune: A Promising Functional Ingredient for Food and Medicine

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Abstract

Over the past decade, mushrooms have gained attention as functional ingredients due to their low calories, high fiber, vitamins, minerals, and protein content. Moreover, mushrooms are abundant sources of bioactive compounds such as polyphenols, flavonoids, alkaloids, saponins, tannins, and trehalose. They have been traditionally used as medicines due to their therapeutic properties. *Schizophyllum commune*, also known as split gill mushroom, is a widely distributed mushroom species found throughout the world. It is an edible mushroom with a unique gill structure, which splits longitudinally to create a two-layered appearance. It has been used for food and medicine in various cultures and exhibits antioxidant, antimicrobial, anticancer, antidiabetic, immunomodulating, and hepatoprotective effects. This review article provides an overview of the taxonomy, morphology, nutritional and phytochemical composition, potential health benefits, utilization, and toxicity of *S. commune*. It will help the researchers and scientists involved in today's scientific research to explore its potential in various disciplines including medicine, pharmacy as well as food industries.

Keywords

Schizophyllum commune, Nutritional value, Chemical composition, Health effects, Applications, Toxicity

Introduction

Edible mushrooms play a crucial role in both the natural world and the economy, having been used for thousands of years as ingredients and medicinal remedies [1]. Mushrooms are a type of macro-fungus having a unique fruiting body. There are approximately 14,000 known species of mushrooms, most of which are from the Basidiomycetes family. Of these, around 2,000 species are safe for human consumption, and about 650 have medicinal properties that contribute to treating various diseases [2]. In recent years, the popularity of mushrooms has surged and they are currently regarded as a "functional food" that can boost and complement a nutritious diet [3]. Mushrooms are an excellent source of antioxidants due to their diverse secondary metabolites and phenolic compounds, which can scavenge free radicals [4]. Edible mushrooms are good sources of minerals including iron and phosphorous, vitamins (riboflavin, thiamine, ergosterol, niacin, and ascorbic acid), and various dietary fibre [5]. Polysaccharides primarily β-glucans and glycoproteins are the main components of mushrooms.

S. commune is an edible mushroom that is widely distributed on every sub-continent except Antarctica [4]. It is not found in Antarctica since it has no wood to be used as a substrate for its growth [6, 7]. It has a wide distribution in various Asian countries, including North-East India and South-East Asian nations like Thailand, Laos, and Myanmar [8]. It grows on dead, fallen, or

standing wood from broadleaved trees during the rainy season. The term *Schizophyllum* is derived from the Latin word "Schizo" which means split, and "phylum", meaning lamella or membrane [9]. The species was named "*commune*" because it is grown widely, and the spores can spread over long distances, leading to significant intra and inter-population genetic variations due to genetic drift [10]. It is different from other gill fungi as it typically leads to white rot [11]. Its distinguishing features include dense white hairs, lack of stalks, and pale yellow to brown gills. The cell wall of the split gill mushroom contains chitin-crosslinked β-glucans having triple-stranded helical structure and consisting of a β-1,3-D-glucan polymer with β-1,6-D-branches [8].

Despite being widely distributed and able to grow in various environments, *S. commune* remains an underutilized non-timber forest product. This cultured fungus can live as a saprophyte or pathogen and can be easily found on decaying wood or trees in forests, agroforestry lands, plantations, and home gardens. It is highly favored globally for its adaptability to sub-tropical and tropical climates, as observed in countries such as Mexico, Peninsular Malaysia, Northeast India, Sumatra Island, Indonesia, and Southern Thailand [10]. In South Asian countries such as Thailand, Taiwan, Malaysia, Vietnam, Southern China, and Northeastern India, it is consumed both as food and medicine. The fungus is valued in these countries as a source of food and medicine due to its nutritional content, which includes fibre (0.044%), carbohydrates (81.59%), protein (99.63%), and lipids (1.28%) [12]. In addition to this, numerous functional ingredients such as schizophyllan, phenolics, flavonoids, terpenoid compounds, saponin, tannins, alkaloids, and ergosterol have also been found in *S. commune*.

Schizophyllan is a polysaccharide produced by *S. commune*, which shows several bioactivities such as immunomodulator, anticancer, antitumor, anti-inflammatory, and antioxidant activities [13]. It also contains several compounds having antioxidant properties like hydroxybenzoic acid, protocatechuic acid, and tocopherol which produces iminolactones that can suppress the growth of cancer cell lines [14]. The bioactive compound schizocommunin and schizophyllan, found in the fungus, has been shown to inhibit the growth of cervical cancer cells [15, 16]. Additionally, it produced schizolysin, a hemolysin from the fungus which inhibits HIV disease [17]. *S. commune* also has the potential to be used as an anti-pigmentation agent in cosmetics [18]. It also shows an immunomodulating effect due to the production of linear chain β-D-(1-3)-glucopyranosyl and β-D-(1-6)-glucopyranosyl groups [19]. β -glucan present in *S. commune* is particularly effective in wound healing because of its capability to stimulate re-epithelialization and dermal contraction by activation of Integrin/FAK/Src in the epidermis as well as by dermal transformation via NOX4 expression and integrin up-regulation making it a potential agent for treating skin injury [20]. Owing to the nutritional and medicinal properties of *S. commune*, it serves as the healthiest food choice.

Taxonomic classification and common names

S. commune is commonly known as 'Split-gill mushroom' or 'Split-fold mushroom'. It is known by different names in different states of India, for instance, Kanglayen in Manipur, Pasi in Mizoram, and Hubsi in Arunachal Pradesh [21]. The local name of this species in Central Sulawesi, Indonesia is 'Tanggidi' or 'Tanggojo' [22]. The taxonomical classification of this mushroom is given in table 1.

Table 1: Taxonomic classification of *S. commune*.

Kingdom	Fungi
Phylum	Basidiomycota
Order	Agaricales
Class	Agaricomycetes
Sub-class	Agaricomycetideae
Family	Schizophyllaceae
Genus	*Schizophyllum*
Species	*commune*

Plant morphology

S. commune, a type of basidiomycete, completes its life cycle within 10 days [23]. It is a saprophyte that grows on dead wood, either alone or in clusters and is widely distributed all around the world. The texture of the mushroom is tough, felt, and hairy to the touch, becoming slippery when moist [21]. The fruiting body of *S. commune* is approximately 1-5 cm wide, with a fan-like shape when attached to the side of a log [24]. When viewed from the dorsal surface, the fruiting body resembles a small white bracket fungus with radial gill-like folds, each of which is centrally split (Figure 1). The fruiting body starts with small stipes during its young phase and becomes stipe less at maturity. This mushroom features a shade of greyish white for its cap, and its gills are either pale reddish or grey in color [25].

The gills tend to split once they dry out, and when rehydrated, they appear to be closed. The cap of the mushroom is shell-shaped, fixed at a lateral point of attachment, and becomes wavy and lobed. When wet, the cap has a split edge that becomes in-rolled. The mature basidiocarp has a distinct structure, with a pileus region and gills that split through the



Figure 1: Morphological structure of *S. commune*.

mid-region, a characteristic feature of this mushroom. During dry weather, the gills of this mushroom tend to curl back to protect the fertile surfaces (hymenium) [26]. The sporiferous part and the hymenophore of the fruiting body are located only on the underside of the cap, indicating its gymnocarpous nature. The mushroom has very short and rudimentary stems, which are usually not visible above the substrate [21].

Nutritional value and phytochemical composition

Mushrooms possess a wide range of vitamins and minerals that are lacking in many vegetables and meats. Drying at high temperatures may lead to the degradation of polysaccharides and proteins. On the other hand, freezing is one of the best ways to preserve total sugars, ascorbic acid content, and bioactive components during storage [27].

S. commune is consumed as fresh or dried food in many tropical countries. It can be obtained from both wild sources and through cultivation [10]. Based on the substrate of *S. commune*, its protein content varies between 9.63% to 21.7% [10]. The fat content ranges from 0.82% to 1.57%, which indicates that it is a great choice for people concerned with weight and maintaining good health [28]. The nutritional analysis of *S. commune* indicates that it is a good source of nutrients and qualifies as a good food material. *S. commune* provides high energy 299 kcal/g to 399 kcal/g, carbohydrates 32.43% to 81.59%, and ash content 7.46% to 8% [2, 29, 30]. A detailed description of the nutritional composition of *S. commune* is presented in table 2.

Table 2: Nutritional composition of *S. commune*.

Nutrient	Amount	Ref.
Energy (kcal/100 g)	376.4	[31]
Macro-nutrients (g/100 g)		
Protein	18.83	[29]
Fat	3.45	
Carbohydrates	66.06	
Micro-nutrients (mg/100 g)		
Phosphorus	408	[29, 31]
Magnesium	227	
Calcium	188	
Iron	12.3	
Zinc	5.7	
Copper	0.9	
Nitrogen	1.54	
Sodium	0.375	
Ascorbic acid	0.49	
Niacin	8.29	
Riboflavin	0.89	
Thiamine	0.29	
Folic acid	0.27	
Amino acids (%)		
Lysine	5.38	[29]
Threonine	5.23	
Valine	6.57	
Cystine	3.37	
Isoleucine	3.9	
Leucine	7.24	
Phenylalanine	4.16	
Tyrosine	4.16	
Histidine	2.18	
Arginine	5.98	
Aspartate	9.69	
Serine	6.25	
Glutamate	18.89	
Proline	3.87	
Glycine	4.82	
Alanine	6.91	
Methionine	1.39	
Bioactive compound (mg/100 g)		
Alkaloids	4.26	[32]
Flavonoids	4.67	
Phenolics	10.8	
Saponins	23.83	
Tannins	1.24	

Pharmacological properties and health benefits

Antioxidant Properties

Free radicals are highly unstable and can oxidize biomolecules leading the cell death and tissue damage [33]. Several degenerative disorders such as aging, cancer, cardiovascular disease, Alzheimer's disease, and other chronic conditions are found to be linked with excess reactive species [34]. Antioxidants play a crucial role in controlling oxidative stress in the body and preventing these diseases [35]. In a recent study, crude extracts of *S. commune* were investigated for their antioxidant capacity using various assay methods and found that the ethanolic extract showed the most potential for antioxidant activity [8].

According to Chandrawanshi et al. [24] the ethanolic extract of *S. commune* exhibits the highest DPPH scavenging activity (IC_{50} = 18.56 µg/µl) followed by hot water extract and methanol extracts. It was also observed that the hot water extract showed the highest scavenging activity (IC_{50} = 20.00 µg/µl) compared to the other extracts. Aqueous extract with 0.11 at 10 mg/ml of concentration has the highest reducing power activity [36]. The ethanolic extract also exhibited the most potent H_2O_2 scavenging activity in the assay (IC_{50} = 19.24 µg/µl) [24]. The phenolic compounds, including flavonoids 29.80 ± 0.27 mg QE/g and phenolic acids, are major dietary components that have been associated with inhibiting

free radicals, preventing vascular diseases and some forms of cancer, and reducing oxidative stress that can cause damage to DNA, proteins, and membranes [37]. Studies have reported that the aqueous extract of *S. commune* showed the highest total phenolic activity at 81.97% followed by methanol extract at 75.11%, while the ethanol extract showed the lowest total phenolic content at 47.08% [24].

Antimicrobial properties

Being a good source of various bioactive compounds such as saponin, tannins, alkaloids, flavonoids, terpenoids, and proteins, *S. commune* is known to possess biological activity and contribute to the extract's antimicrobial properties [38]. The antibacterial activity of *S. commune* extracts has been found to be more effective against Gram-positive bacteria, including *Bacillus cereus*, *B. subtilis*, *Enterobacter faecalis*, and *S. sanguis*, compared to Gram-negative bacteria such as *Escherichia coli*, *Salmonella sp.*, *S. typhi*, *Shigella sp.*, *Proteus vulgaris* and *Pseudomonas aeuroginosa* [39]. The extracts of *S. commune* such as methanol, ethyl acetate, dichloromethane, and aqueous extract were compared to determine the zone of inhibition. It was found that the inhibition zone of dichloromethane extract was 12 ± 1 mm against *Streptococcus sanguis* at a concentration of 2.0 mg/ml as the most active form, whereas ethyl acetate and methanolic extract showed moderate antimicrobial activities [39].

A study conducted by Jayakumar et al. [40] assessed the antimicrobial activity of oxidized schizophyllan (scleraldehyde) against Gram-positive and Gram-negative bacteria using various assays like disc diffusion assay, minimum inhibitory concentration and minimum bactericidal concentration and the readings of minimum inhibitory concentration and minimum bactericidal concentration were found to be in the range of 3.0–8.0 mg/ml which proved that scleraldehyde possessed antimicrobial property.

Anticancer properties

Schizophyllan, a polysaccharide found in *S. commune* is proven to have antitumor properties and promotes the synthesis of acute phase proteins and cerebrospinal fluid, leading to the proliferation of macrophage, peripheral blood mononuclear cells, and lymphocytes along with the stimulation of the complementary system [41]. Bioactive compounds like alkaloids, terpenoids, and flavonoids which are obtained from this mushroom are also responsible for anti-cancer properties. These bioactive compounds have the potential to induce cell apoptosis by inhibiting the cancer cell line at IC_{50} of 5.44 µg/ml [42]. A study of the antiproliferative activity of *S. commune* against human cholangiocarcinoma (KKU-M213) using MTT assay and wound healing assay was performed and it was reported that 200 µg/ml of crude ethanol extract inhibits the proliferation of KKU-M213 and suppressed the cell migration [43]. MTT cytotoxicity report showed cell growth inhibition of breast cancer cell lines by EA-SPG-NP and EA-Ch-NP at IC_{50} of 60 and 115 µg/ml, respectively [44].

Anti-diabetic propertie

Diabetes mellitus is a chronic hyperglycaemic disorder, characterized by disturbances in lipid and carbohydrate metabolism, as well as glucose homeostasis [45]. Hydrolysis of α-1,4-glycosidic bond which is a major pathway for producing simple sugar in humans is inhibited by *S. commune* enzymes α-glucosidase which results in delaying carbohydrate metabolism and rate of glucose absorption. Hence, decreasing postprandial plasma glucose levels and improving glucose tolerance in diabetes patients [46]. The anti-diabetic properties of *S. commune* crude extracts were investigated through various assays and it was observed that the ethanolic extract exhibited the highest anti-diabetic rate of 23.74 ± 0.09, while the aqueous extract showed the lowest rate of 21.49 ± 0.0. The methanolic extract demonstrated an anti-diabetic rate of 22.98 ± 0.06 [47].

Immunomodulating effects

Schizophyllan can bind to various immune cells such as polymorphonucleocyte cells (PMC) and peripheral blood mononuclear (PBM) cells, leading to the production of cytokines like interleukin (IL-8). Activation of macrophages mediates the systemic immunomodulation which results in the binding of two non-complement receptor 3 receptors on promonocytic U937 cells, leading to the activation of macrophages both *in vitro* and *in vivo*. This enhances T-cell activities and increases the sensitivity of cytotoxic lymphokine-activated killer cells and natural killer cells to IL-2 as shown in figure 2 [13, 48]. Moreover, the schizophyllan complex can easily be taken up through phagocytosis by macrophages producing the macrophage inhibitory factor that plays a major role in inflammatory bowel disease [49].

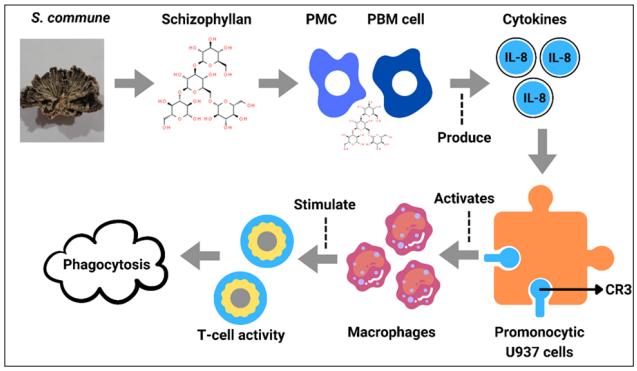

Figure 2: Mechanism of action of schizophyllan in immunomodulation.

Hepatoprotective effects

Schizophyllan also exhibits a protective effect on liver mitochondria by inducing sirtuin 3, a mitochondrial Nicotinamide adenine dinucleotide (NAD+) dependent deacetylase that results in deacetylation of succinate dehydrogenase A and superoxide dismutase 2. Schizophyllan when supplemented activates sirtuin 3 inhibiting the damage in liver mitochondria, caused by alcohol, and conjugated linoleic acid in mice [50]. Pre-treatment of HepG2 cells with the polysaccharide extract before H_2O_2 exposure increased cell viability, inhibited lipid peroxidation, and increased glutathione levels, thus indicating its potential hepatoprotective effects [51].

Utilization and applications of *S. commune* in food and non-food sector

Owing to the bioactive components and benefits of *S. commune*, it is used in various food preparations. Manipuri-Pancake also known as 'Paaknam' is a popular dish where *S. commune* is used as an ingredient [21]. The processed form of this mushroom is used by the Kaili tribe along the Palu-Koro fault area for making 'Utadada Tanggidi' [22]. Finely ground *S. commune* is consumed by the Lore tribe in the Napu Valley of Poso Regency with cooked rice [22].

Although *S. commune* is used in food preparation, it is also renowned for its therapeutic properties [17]. *S. commune* can treat cancer and hence it is used as a drug for cancer. This ability is due to the presence of bioactive compounds like alkaloids, terpenoids, and flavonoids which inhibit the growth of cancer cells. *S. commune* essence is capable of being utilized as high value-added functional food rich in bioactive compounds with antioxidant properties which provide benefits to human health [47].

In addition to its utilization in foods and drugs for cancer, it is also used in the non-food sector for instance several enzymes like cellulases, xylanases, pectinases, lipases, laccases, manganese peroxidase, and lignin peroxidase are produced by *S. commune*. These enzymes are utilized in various industrial processes, including wine and beer production, food processing, pulp and paper production, textile manufacturing, animal feed production, and biofuel production [52].

Toxicity

S. commune is safe to be consumed as reported by Debnath et al. [53] and has shown less toxicity but it should be noted that it can lead to health problems in some individuals who inhale their spores. This mushroom has been linked to various disease conditions, including fungal infection leading to paranasal sinuses due to the presence of toxin-hallucinogenic compounds [54]. *S. commune* showed reports of causing squamous cell carcinoma with fungal ball formation in the lungs also revealed by [55]. On the other hand, it can cause otitis externa accompanied by allergic sinusitis, allergic bronchopulmonary mycoses, bronchopneumonia, bronchogenic cysts, and bronchial mucoid impaction [56]. Amphotericin B, an antibiotic works against fungal infection like ulceration of the hard and soft palates caused by this mushroom however the doses, type, and duration of treatment is uncertain [57]. The antifungal agent "Azole" also shows a positive effect in treating *S. commune* infections [58].

Future Perspective and Conclusion

While mushrooms are utilized in meat and starch-based food formulations, their functional role in food applications is yet to be explored, particularly in the emerging meat-free, clean-label marketplace. As a result, this paper aims to provide a complete overview of the current scientific data regarding the unique properties of *S. commune*, their distinctive functional and nutritional features, their importance in the world of food business, and possible prospects for the invention of protein-rich food using this mushroom. *S. commune* possessed numerous bioactive compounds which act as antioxidant, antimicrobial, anticancer, anti-diabetic, hepatoprotective, and immunomodulating effects. Further research might lead to the invention of novel medicines or therapeutic agents. Although *S. commune* is evenly distributed in many countries, particularly in South-east Asian, it has low commercial applications, such as in the production of food, beverages, and textiles. As a result, this mushroom could possibly be used to generate valuable and practical products which are feasible and safe to consume.

The various pharmacological properties of *S. commune* are studied in this paper and all these properties are observed in this mushroom due to the presence of schizophyllan, a polysaccharide, and other bioactive compounds. Overall *S. commune* is found to possess high protein, high fibre, and low fat which make this mushroom a healthy food choice and a valuable resource for researchers, health professionals, and consumers interested in the health and risks associated with it.

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Conflict of Interest

None.

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