Potential Usage of Edible Mushrooms

Subjects: Biology

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Currently, the food and agricultural sectors are concerned about environmental problems caused by raw material waste, and they are looking for strategies to reduce the growing amount of waste disposal. Now, approaches are being explored that could increment and provide value-added products from agricultural waste to contribute to the circular economy and environmental protection. Edible mushrooms have been globally appreciated for their medicinal properties and nutritional value, but during the mushroom production process nearly one-fifth of the mushroom gets wasted. Therefore, improper disposal of mushrooms and untreated residues can cause fungal disease. The residues of edible mushrooms, being rich in sterols, vitamin D2, amino acids, and polysaccharides, among others, makes it underutilized waste. Most of the published literature has primarily focused on the isolation of bioactive components of these edible mushrooms; however, utilization of waste or edible mushrooms themselves, for the production of value-added products, has remained an overlooked area. Waste of edible mushrooms also represents a disposal problem, but they are a rich source of important compounds, owing to their nutritional and functional properties. Researchers have started exploiting edible mushroom by-products/waste for value-added goods with applications in diverse fields. Bioactive compounds obtained from edible mushrooms are being used in media production and skincare formulations. Furthermore, diverse applications from edible mushrooms are also being explored, including the synthesis of biosorbent, biochar, edible films/coating, probiotics, nanoparticles and cosmetic products.

edible mushrooms | waste valorization | food products | industrial applications

1. Introduction

Mushrooms have long been stated as a gourmet food, especially for its subtle flavor and taste, and they have been regarded as a culinary wonder by humankind. There are 2000 different mushrooms, out of which 25 are usually consumed as food, and only a few are commercially grown [1]. Mushrooms are also used as nutraceutical foods for their high functional and nutritional value. Moreover, they have gained considerable attention due to their economic importance as well as organoleptic and medicinal properties [2][3]. It is not easy to differentiate between medicinal and edible mushrooms, as few medicinal mushrooms are edible, and many common edible mushrooms have therapeutic potential [4]. The most widely cultivated mushroom is Agaricus bisporus, followed by Flammulina velutipes, Lentinus edodes and Pleurotus spp. The crude protein content of edible mushrooms is usually high, but it varies greatly and is affected by factors such as species and stage of development of the mushroom [5]. The free amino acid level of mushrooms is usually low, ranging from 7.14 to 12.3 mg g^{-1} in dry edible mushrooms, and contributes to the main flavor properties of mushrooms [6]. The essential amino acid profiles of mushrooms reveal that the proteins are deficient in sulfur-containing amino acids, including methionine and cysteine. However, these edible mushrooms are comparatively rich in threonine and valine. Several vitamins such as folates, niacin and riboflavin are found in abundance in cultivated mushrooms. Mushrooms have a higher vitamin B2 content compared to most vegetables, making them a good vitamin source [7]. The bioavailable form of folate in mushrooms is folic acid [8]. Cultivated mushrooms also comprise vitamin B1 and vitamin C in small quantities and traces of vitamin B12 [7]. Edible mushrooms contain a low amount of total soluble sugars, whereas oligosaccharides are found abundantly [9]. The carbohydrate content of edible mushrooms ranges from 35 to 70% by dry weight and varies from species to species. The fatty acid level ranges from 2 to 8% in mushrooms. Additionally, polyunsaturated fatty acids account for ≥75% of total fatty acids, in contrast to saturated fatty acids, and palmitic acid is the major saturated fatty acid [10].

Many by-products (caps, stipes, spent mushroom substrate) are produced during mushroom production, which cause environmental pollution and increase industry management costs [11]. Spent mushroom substrate (SMS) encompasses extracellular enzymes, fungal mycelia and other substances [12]. The circular economy concept of industrial ecology is regarded as the leading principle for developing new products by using waste as a raw material [13]. From economic and environmental perspectives, the waste produced during mushroom production often leads to massive damage to valuable organic constituents and raises severe management complications. Thus, there is a need to exploit mushroom residues to extract valuable compounds that could be used in different industries, such as food, cosmetics, agricultural and textile industries, as depicted in Figure 1. The current review aims to summarize information related to edible mushrooms and discuss the utilization of edible mushrooms and their residues as a valuable good for future industrial applications.

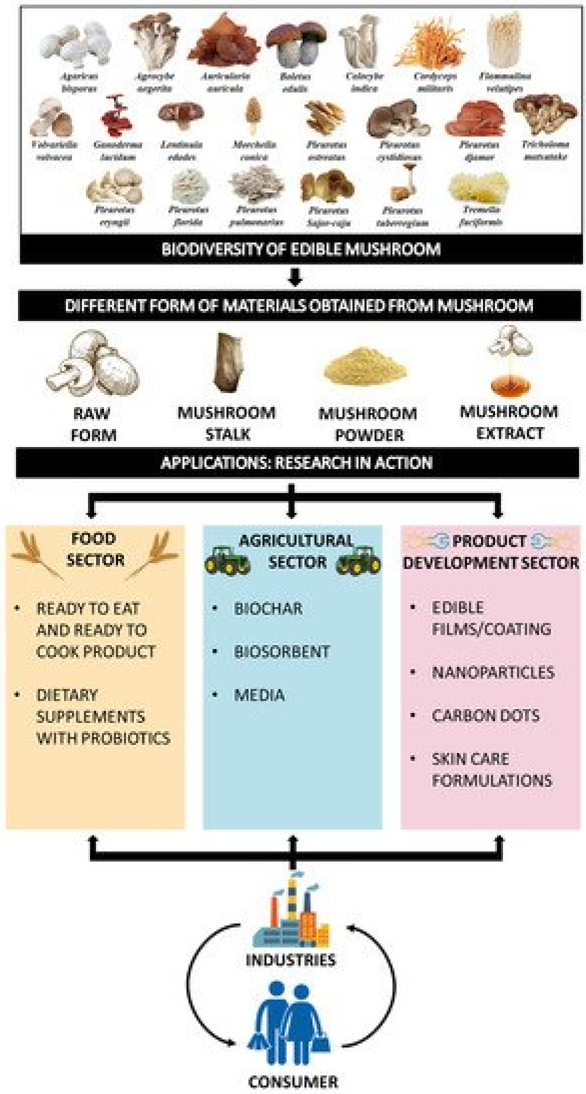

Figure 1. Utilization of edible mushrooms and their residues in novel industrial products.

2. Edible Mushrooms Fortified in Ready-to-Eat and Ready-to-Cook Foods

As the lifestyle of people is changing dramatically (due to liberalization policies, dual incomes, separate living of couples, innovative kitchen applications, media proliferation, etc.), the demand for convenient and health-promoting food is also increasing. Nowadays, people prefer fast and simple cooking methods instead of spending a long time in the kitchen [14]. Mushroom powder can be used in the food industry, especially in preparing baked goods (bread, biscuits and cakes) and breakfast cereals. The supplementation of mushroom powder in bakery products substantially increases crude fibers, minerals (calcium, copper, magnesium, manganese, potassium, phosphorus, iron and zinc), proteins and vitamins [15]. These components impart the abilities to fight tumors, lower blood pressure and blood sugar levels, maintain cholesterol levels and improve the immune system to fight against infection [16]. Rathore et al. [17] prepared cookies fortified with Calocybe indica mushroom, and the results depicted a decrease in starch hydrolysis and glycemic index. Wheatshiitake noodles enhanced the nutritional profile and reduced the glycemic index of foods [18]. The different food products developed by using mushrooms are listed in Table 1.

Table 1. Mushrooms fortified in ready-to-eat (RTE) and ready-to-cook (RTC) foods.

Edible Mushroom Common Name	Scientific Name	Food Product	Beneficial Effects	Reference
Milky white	Calocybe indica	Cookies	Increase in protein, fiber, minerals and β-glucan, phenolic, flavonoids and antioxidants; decrease in starch, reduction in glycemic index	[17]
Oyster	Pleurotus sajor-caju	Biscuits	Increase in concentration of protein, dietary fiber, ash and reduction in carbohydrate	[19]
Shiitake	Lentinula edodes	Chips	Improvement in quality attributes (color, sensory evaluation)	[20]
Oyster	Pleurotus ostreatus	Biscuits	Enhancement of nutritional quality	[21]
White button	Agaricus bisporus	Ketchup	Increase in ash content, crude fiber, protein, total soluble solids, and reducing sugars; decrease in total sugars	[22]
Oyster	Pleurotus ostreatus	Jam	Increase in total soluble solids, percent acidity and reducing sugar, decrease in pH and non-reducing sugar	[23]
White button	Agaricus bisporus	Mushroom tikki and stuffed mushroom	Increase in protein, dietary fiber, antioxidant and phenolic components	[24]
Oyster	Pleurotus ostreatus	Soup	Increase in nutritional value	[25]
Chestnut	Agrocybe aegerita	Snacks	Manipulation of glycemic response of individuals	[26]
Oyster	Pleurotus sajur-caju	Biscuit	Increase in the mineral content	[27]
Oyster	Pleurotus ostreatus	Vegetable mixture diets	Highly acceptable, nutritious, delicious, ready-to-eat diet	[14]
Oyster	Pleurotus ostreatus	Processed cheese spreads	High moisture, ash and protein content, total viable counts and spore former	[28]

Edible Mushroom Common Name	Scientific Name	Food Product	Beneficial Effects	Reference
			bacteria was lower in processed cheese supplemented with mushrooms	
Oyster	Pleurotus ostreatus	Biscuit	Higher moisture, protein, ash content, higher hardness, darker and redder in color	[29]
Oyster	Pleurotus ostreatus	Spreadable processed cheese	Increase in total solids, protein, fibers and carbohydrates	[30]
Oyster	Pleurotus sajor-caju	chicken patty	Reduction in fat content, no change in protein and β-glucan	[31]
White button	Agaricus bisporus	Pasta	Improved antioxidant activity, increase moisture content, carbohydrates, decreased crude fiber, crude protein, and fat	[32]
Oyster	Pleurotus sajor-caju	Cookies	High protein content, low-fat content, high fiber, minerals and vitamin content	[33]
White button	Agaricus bisporus	Pasta	Decrease in the extent of starch degradation, increase in total phenolic content and antioxidant capacities	[34]
White jelly	Tremella fuciformis	Patty	Oil holding capacity of mushroom has a positive effect on cooking yield of patty as well as senses	[35]
Oyster	Pleurotus ostreatus	Instant noodles	Increase in protein and fiber content	[36]
White button	Agaricus bisporus	Beef burgers	Reduction in the fat content of beef burgers	[37]
Oyster	Pleurotus ostreatus	Instant soup premix	Rich in protein, crude fiber, minerals and low in fat, carbohydrate and energy value	[38]
White button	Agaricus bisporus	Sponge cake	Increase in apparent viscosity, volume, springiness and cohesiveness values	[39]
Oyster	Pleurotus sajor-caju	Biscuit	Reduction in starch pasting viscosities, starch gelatinization enthalpy value, increases in protein, crude fiber and mineral content	[16]

Edible Mushroom Common Name	Scientific Name	Food Product	Beneficial Effects	Reference
Shiitake	Lentinula edodes	Noodles	Improvement in nutritional profile and reduction in the glycemic index of foods	[18]
King tuber	Pleurotus tuber-regium	Cookies	Higher protein, ash, crude fiber, water-soluble vitamins and minerals	[40]
Oyster	Pleurotus ostreatus	Noodles	Lower level of carbohydrate, fat, and sodium	[41]
King trumpet	Pleurotus eryngii	Sponge cake	Increase in ash and proteincontent	[42]
White button, Shitake, Porcini	Agaricus bisporus, Lentinula edodes, Boletus edulis	Pasta	High firmness and tensile strength	[43]

3. Edible Mushrooms Based Films/Coatings

Edible films/coatings are thin layers applied on the food surface to extend their shelf-life and preserve their features, functionality and properties at a low cost [44]. The mechanical strength and barrier properties of these edible films provide sufficient strength to withstand stress while handling. These films have a promising application in the agricultural, food and pharmaceutical industries. Mushrooms and their residues have many applications in food industries, but significantly fewer studies have been conducted in regards to edible film/coatings. Polysaccharides extracted/derived from edible mushrooms are extensively used in functional foods, pharmaceuticals and nutraceuticals [11]. In this regard, Bilbao-Sainz and his colleagues [45] obtained chitin from mushrooms and transformed it to chitosan.

Moreover, layer-by-layer (LbL) electrostatic deposition is used to prepare edible coatings applied to fruit bars. The application of edible mushroom coatings/films has increased the antioxidant capacity, ascorbic acid content, fungal growth prevention and firmness during storage. Additionally, Du et al. [46] developed edible films using Flammulina velutipes polysaccharides, which acted as a barrier to oxygen and water vapor, had the lowest elongation at break values and highest tensile strength for future use in food packaging industries. Table 2 lists some edible films and coatings derived from mushrooms.

Table 2. Mushrooms and their residue-based edible film/coatings.

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Edible Mushrooms Common Name	Scientific Name	Product Used	Compounds	Key Findings	References
White button	Agaricus bisporus	Fruit bars	Chitosan	Increased antioxidant capacity, ascorbic acid content, fungal growth prevention and firmness	[45]
White button	Agaricus bisporus	Fresh-cut melons	Chitosan	Enhance fruit firmness, inhibit off-flavors and reduce the microbial counts (up to 4 log CFU g^{-1}).	[47]
Velvet shank	Flammulina velutipes	ND	Polysaccharide	High tensile strength, barrier property to water vapor and oxygen	[46]
Shiitake, Velvet shank	Lentinula edodes, Flammulina velutipes	ND	Insoluble dietary fibers	Highest tensile strength and an effective barrier to water vapor	[48]
Indian oyster	Pleurotus pulmonarius	ND	Flour	Significant barrier properties and mechanical strength	[49]

ND—not defined; CFU—colony-forming unit.

4. Mushrooms as a Source of Prebiotics for Food Supplementation

The consumption of high dietary fiber food has gained considerable interest owing to its ability to reduce triglycerides and blood cholesterol via the gut microbiome. A diet rich in fibers acts as a substrate for microbes and aids in their proliferation. Thus, microbial digestion products enter the systemic circulation and help in maintaining energy homeostasis [50]. Pleurotus spp. (Oyster mushroom) comprises soluble fiber compounds, particularly a small amount of glucans (chitin and galactomannans) and non-starch glucans, favoring the proliferation of lactobacilli [51]. Edible mushrooms are stated to have carbohydrates, which help them to act as prebiotics [52]. The supplementation of oyster mushroom and probiotics in poultry feed has been reported to show beneficial, synergetic effects on the immune response, performance and serum lipids in broiler chickens [53]. The blend of prebiotics and probiotics also is beneficial, because of the synergistic effect between them [54]. Van Doan et al. [52] conducted a study to determine the effects of dietary supplements Pleurotus eryngii (as a prebiotic), Eryngii mushroom and Lactobacillus plantarum (as a probiotic), alone as well as in combination, on the innate immune response, growth and protection against Aeromonas hydrophila. The results showed stimulation in growth,

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immunity and disease resistance against Pangasius bocourti. Table 3 lists studies of different mushrooms and dietary supplementation with probiotics.

Table 3. Applications of mushrooms as prebiotics.

Edible Mushrooms Common Name	Scientific Name	Probiotic Used	Form of Mushroom Used	Applications	References
White button	Agaricus bisporus	Probiotics mixture (Protexin 6 × 10^7CFU gm^{-1})	Powder	Lowered total cholesterol, LDL cholesterol, triglyceride concentrations, oxidative stress and dyslipidemia in hypercholesterolemic rats	[50]
Wood ear/Jew's ear	Auricularia auricula	Lactobacillus acidophilus La-5, Bifidobacterium bifidum Bb-12	Extract	Enhancement in the survival rate of probiotics toabout 0.43 and 0.51 log CFU g^{-1}; improved probiotic protection and functional properties of symbiotic yogurt	[55]
White button	Agaricus bisporus	Saccharomyces cerevisiae	Powder	Improvement in the meat quality with the incorporation of mushroom and probiotics in the broiler diet	[56]
Oyster	Pleurotus sajor-caju	Lactobacillus fermentum OVL	Powder	Increase in neutrophil count in rats, decrease in lymphocyte count	[57]
Oyster	Pleurotus ostreatus	PrimaLac (Lactobacillus acidophilus, Lactobacillus casei, Bifidobacterium bifidium, Enterococcus faecium)	Powder	Decrease in abdominal fat on the carcass, increase in HDL concentration in plasma	[53]
Caterpillar	Cordyceps militaris	Lactobacillus plantarum	Spent mushroom substrate	Increase in the specific growth rate, weight gain, final weight in fish fed supplemented diets	[58]
Shiitake	Lentinus edodes	1.0 ×10^8 CFU g^{-1}(Lactobacillus acidophilus,	Extract	No weight gain in broiler chickens	[59]

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Edible Mushrooms Common Name	Scientific Name	Probiotic Used	Form of Mushroom Used	Applications	References
		Lactobacillus casei, Bifidobacterium bifdium, Enterococcus faecium)			
King oyster	Pleurotus eryngii	Lactobacillus plantarum	Powder	Growth stimulation, immunity and disease resistance	[52]

LDL—low-density lipoproteins; HDL—high-density lipoproteins.

5. Edible Mushrooms Based Media

Nowadays, mushroom processing is the primary solid-state fermentation process in fermentation industries [60]. At the commercial level, the processing occurs on a substrate made up of lignocellulose materials (corncobs, sawdust, rye, rice straw and wheat) either alone or in combination with supplements to address nutritional deficiencies [61][62]. For instance, approximately 5 kg of SMS is produced, a by-product of mushroom harvest and cultivation, from 1 kg of mushrooms [63]. The SMS comprises a high amount of residual nutrients, which pollutes the atmosphere if improperly discarded as waste [64][65]. Thus, further treatment and utilization of SMS are essential. Different types of edible mushrooms and their SMS have been used to produce low-cost growth media for various horticultural plants and microorganisms (Table 4).

Table 4. Mushrooms and their residue-based media.

Edible Mushrooms Common Name	Scientific Name	Media Composition	Purpose/Utilization	References
Velvet shank	Flammulina velutipes	Spent mushroom substrate, perlite, and vermiculite	Growing media for tomato and cucumber seedlings	[66]
White button, Oyster	Agaricus bisporus, Pleurotus ostreatus	Spent mushroom substrate, and Sphagnum peat	Growing media for tomato, courgette and pepper	[67]
Velvet shank	Flammulina velutipes	Spent mushroom substrate, and chicken manure compost	Growing media for honeydew melon	[68]
Velvet shank	Flammulina velutipes	Spent mushroom substrate, calcium	Production media for Bacillus thuringiensis	[69]

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Edible Mushrooms Common Name	Scientific Name	Media Composition	Purpose/Utilization	References
		carbonate, wheat bran, and yeast extract and inorganic salts		
Oyster	Pleurotusf lorida	Spent mushroom substrate	Production media for lignocellulolytic enzymes	[70]
Oyster	Pleurotus ostreatus	Spent mushroom substrate	Production media for Lactococcus lactis	[71]
Oyster	Pleurotus ostreatus	Spent mushroom substrate, paddy straw, and soybean cake	Biopesticide (Trichoderma asperellum) development	[72]
ND	ND	Spent mushroom substrate and peat moss	Growing media for Chinese kale	[73]
ND	ND	Spent mushroom substrate, perlite, and vermiculite	Growing media for lettuce seedlings	[74]
ND	ND	Spent mushroom substrate, polished rice, full-fat soybean, and rice bran	Production media for arachidonic acid by Mortierella sp.	[75]
ND	ND	Spent mushroom substrate, and poultry cooked bones	Production media for solubilizationphosphate by Bacillus megaterium	[76]

ND—not defined.

6. Edible Mushrooms Derived Biosorbents

Biosorption is a process in which a sorbate reacts with biomass or biomaterial (biosorbent), causing sorbate ions to acclimatize on the biosorbents surface and, as a result, lowering the concentration of sorbate in the solution [44]. This mechanism has gained significant attention among researchers because of its ability to immobilize heavy metals, which can contaminate the water as they are discharged untreated from electroplating, mining industries and metal processing industries. Various processes that explain the mechanism of how these biosorbents function in removing pollutants are expressed by the natural biomass complex compendium. Several functional groups (amides, amine, carboxyl, carbonyl, hydroxyl, sulfonate, sulfhydryl, phosphate and phenolic groups) are attached to these biosorbents to sequestrate contaminants [77][78]. Various studies were done to produce biosorbents from edible mushrooms to remove metal ions and dyes from an aqueous solution, as shown in Table 5.

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Table 5. Mushroom-derived biosorbents and their applications.

Edible Mushrooms Common Name	Scientific Name	Drying Temperature/Time	Applications	References
Oyster	Pleurotus florida	RT/24 h	Showed 100% removal of Fe^{2+} from the water sample	[79]
White button	Agaricus bisporus	80 °C/24 h	Successfully biosorbed Reactive Blue 49 dye (1.85×10^{-4} mol g^{-1}) from water	[80]
Oyster	Pleurotus ostreatus	40 °C/24 h	Showed greater adsorption against Pb^{2+}(85.91 mg g^{-1}) in water	[81]
Oyster	Pleurotus ostreatus	60 °C/24 h	Biosorbed 3.8 mg g^{-1} of Cd^{2+}	[82]
Oyster, Black morels	Pleurotus ostreatus, Morchella conica	RT/4 days	Adsorbed methylene blue (82.81 and 38.47 mg g^{-1}) and for malachite green (64.13 and 39.28 mg g^{-1})	[83]
Velvet shank	Flammulina velutipes	60 °C/24 h	Maximum removal capacity against copper ions was 15.56 mg g^{-1}	[84]
Shiitake	Lentinula edodes	Freeze-dried/24 h	Maximum absorption against Congo red was 217.86 mg g^{-1}	[85]
Oyster	Pleurotus ostreatus	78 °C/48 h	Showed maximum biosorption against uranium ion (19.95 mg g^{-1})	[86]
Oyster	Pleurotus ostreatus	80 °C/ND	Showed maximum biosorption against Ni^{2+} (20.71 mg g^{-1})	[87]
King trumpet	Pleurotus eryngii	60 °C/24 h	Showed maximum biosorption against Pb^{2+} (3.30 mg g^{-1})	[88]
Lingzhi	Ganoderma lucidum	60 °C/72 h	Maximum biosorption against malachite green (40.65 mg g^{-1}), safranine T (33.00 mg g^{-1}), and methylene (22.37 mg g^{-1})	[89]
King trumpet	Pleurotus eryngii	60 °C/24 h	Removed 88.38% of $NO3^{-}$	[90]

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RT—room temperature; ND—not defined.

7. Edible Mushrooms Derived Biochar

Biochar is a stable, carbon-rich solid prepared by thermochemical decomposition or pyrolysis of organic material at high temperatures in an anaerobic environment [44]. The highly porous structure permits the extraction of humic and fluvic-like substances from biochar [91]. Furthermore, its molecular structure demonstrates high microbial and chemical stability [92], and physical and chemical properties depend on several factors such as the feedstock form, residence time, pyrolysis and furnace temperature [93][94]. A wide range of common raw materials are used as the feedstock, including wood chips, organic wastes, plant residues and poultry manure [95]. The elemental composition of biochar generally includes carbon, nitrogen, hydrogen and, to a lesser extent, K, Ca, Na and Mg [96]. Biochar is a polar or non-polar material with a high specific surface area and good affinity towards inorganic ions such as phosphate, nitrate and heavy metal ions [97][98]. Different studies have reported on biochar production from a variety of edible mushrooms and their spent substrates (Table 6).

Table 6. Applications of biochar derived from mushrooms and their residues.

Edible Mushrooms Common Name	Scientific Name	Process and Conditions Required for Biochar Formation	Applications	References
Oyster, Shiitake	Pleurotus ostreatus, Lentinula edodes	Pyrolysis at 700 °C for 2 h	Adsorbed 326mg g^{-1} and 398mg g^{-1} of lead Pb(II) from the water	[99]
Lingzhi	Ganoderma lucidum	Pyrolysis at 650 °C for 2 h	Showed maximal adsorption against $Pb2^{+}$ (262.76 mg g^{-1}) and Cd^{2+} (75.82 mg g^{-1})	[100]
White button	Agaricus bisporus	Pyrolysis at 750 °C for 3 h	Showed maximal adsorption against Cu^{2+}(65.2 mg g^{-1}), Cd^{2+} (76.3 mg g^{-1}), and Zn^{2+}(44.4 mg g^{-1}) in water	[101]
ND	ND	Pyrolysis at 300 °C for 90 min	Showed maximal adsorption against $Pb2^{+}$ (21.0 mg g^{-1}), Cu^{2+} (18.8 mg g^{-1}), Cd^{2+}(11.2 mg g^{-1}) and Ni^{2+}(9.8 mg g^{-1}) in water	[102]
ND	ND	Pyrolysis at 450 °C for 4 h	Showed maximal adsorption against crystal violet (1057mg g^{-1}) in wastewater	[103]
ND	ND	Pyrolysis at 500 °C for 2 h	Showed maximal adsorption against fluoride (36.5 mg g^{-1}) in water	[104]

ND—not defined.

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8. Edible Mushrooms Derived Nanoparticles (NPs)

The high concentrations of extracellular enzymes serve as bio-reducing and stabilizing agents for NP synthesis. NPs made from mushrooms are of better quality than those made from bacteria. Metal NPs synthesized using constituents such as enzymes and metabolites secreted by mushroom cells reduce the toxicity of substances [105][106]. The use of NPs is rising, especially in biomedicine and pharmaceuticals, because of their unique physicochemical properties. In the bottom-up approach, biogenic NPs are synthesized, resulting in atoms/compounds that act as the building blocks, and possess the ability to self-assemble to form the final product [44]. Numerous metal NPs have been developed using extracts of edible mushrooms, as listed in Table 7.

Table 7. Mushroom-derived nanoparticles and their applications.

Edible Mushrooms Common Name	Scientific Name	Types of Nanoparticles Synthesized	Reaction Temperature/Time	Morphology	Size	Applications	References
White button	Agaricus bisporus	Copper	RT/24 h	Spherical	2–10 nm	Antibacterial activity against Enterobacter aerogens; Antioxidant activity using DPPH, and ABTS; Anti-cancer activity against cancer cell lines SW620 (colon cancer)	[107]
Brown oyster	Pleurotus cystidiosus	Gold	29 °C/24 h	ND	ND	Antioxidant activity using DPPH, and ABTS	[108]
Oyster	Pleurotus florida	Gold	70 °C/1.5 h	Spherical	2–14 nm	Anti-cancer activity against cancer cell lines A-549 (Human lung carcinoma), K-562 (Human chronic myelogenous leukemia bone marrow), HeLa (Human cervix) and MDA-MB (Human	[109]

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Edible Mushrooms Common Name	Scientific Name	Types of Nanoparticles Synthesized	Reaction Temperature/Time	Morphology	Size	Applications	References
						adenocarcinoma mammary gland)	
Oyster	Pleurotus ostreatus	Gold	29 °C/24 h	Spherical	22.9 nm	Antioxidant activity using DPPH, and ABTS	[108]
Oyster	Pleurotus sajor-caju	Gold	RT/12 h	Spherical	16–18 nm	Anti-cancer activity against cancer cell lines HCT-116 (colon cancer)	[110]
King tuber	Pleurotus tuber-regium	Selenium	RT/24 h	Spherical	91–102 nm	Anti-cancer activity against gastric adenocarcinoma AGS	[111]
Oyster	Pleurotus ostreatus	Silver	25 °C/48 h	Spherical	17.5 nm	Anti-cancer activity against cancer cell lines HepG2 (human liver) and MCF-7 (breast)	[112]
Lingzhi	Ganoderma lucidum	Silver	ND/ND	Spherical	15–22 nm	Antioxidant activity using DPPH; Antibacterial activity against Staphylococcus aureus, Enterococcus hirae, Bacillus cereus, Escherichia coli, Pseudomonas aeruginosa, Legionella pneumophila subsp. Pneumophila; and antifungal activity against Candida albicans	[113]

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Edible Mushrooms Common Name	Scientific Name	Types of Nanoparticles Synthesized	Reaction Temperature/Time	Morphology	Size	Applications	References
Matsutake	Tricholoma matsutake	Silver	RT/30 min	Spherical	10–70 nm	Antibacterial activity against Bacillus cereus, Escherichia coli	[114]
Milky white, Oyster, White button, Lingzhi	Calocybe indica, Pleurotus ostreatus, Agaricu sbisporus, Ganoderma lucidum	Silver	RT/12 h	Spherical	80–100 nm	Antibacterial activity against Staphylococcus aureus	[115]
Pink oyster	Pleurotus djamor	Titanium oxide	RT/20 min	Spherical	31 nm	Antibacterial activity against Corynebacterium diphtheria, Pseudomonas fluorescens, and Staphylococcus aureus; Anti-cancer activity against cancer cell lines A-549 (Human lung carcinoma); larval toxicity against Aedes aegypti, Culex quinquefasciatus	[116]
Pink oyster	Pleurotus djamor	Zinc oxide	RT/24 h	Sphere	74.36 nm	Antioxidant activity using DPPH, ABTS, and H2O2; larval toxicity against Aedes aegypti, Culex quinquefasciatus; Antibacterial activity against Corynebacterium diphtheria, Pseudomonas fluorescens, and	[117]

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Edible Mushrooms Common Name	Scientific Name	Types of Nanoparticles Synthesized	Reaction Temperature/Time	Morphology	Size	Applications	References
						Staphylococcus aureus	

RT—room temperature; ND—not defined; DPPH-2,2-diphenyl-1-picrylhydrazyl-hydrate; ABTS-2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid).

9. Edible Mushrooms Derived Carbon Dots

Carbon dots (CDs), photoluminescent substances with a size of less than 10 nm, can be synthesized by top-down and bottom-up approaches [44]. The top-down synthetic route involves a complex and synthetic condition; a broad carbon structure is broken down using electro-oxidation, acid-assisted chemical oxidation, and laser ablation [44]. However, the bottom-up approach, which relies on plants and their by-products instead of the chemicals, is superior compared to the top-down approach. Proteins, carbohydrates, lipids, lignin and cellulose are all abundant in biological materials. Edible mushrooms are relatively inexpensive and contain various chemical constituents such as carbon, oxygen, phosphorus and nitrogen, often depicted as carboxyl and amine groups. The presence of carbohydrates, amino acids, polysaccharides, citric acid, flavonoids, lipids, vitamins and proteins make them ideal for CDs development [118]. CDs have also shown effectiveness in biomedical applications and energy storage systems, including water purification, pathogen identification, environmental research and heavy metal and additive detection in food (Table 8).

Table 8. Mushrooms as a carbon source for preparing carbon dots.

Edible Mushrooms Common Name	Scientific Name	Production Conditions	Applications	References
Oyster	Pleurotus sp.	Hydrothermal/120 °C/4 h	Selective sensitivity for Pb^{2+}; Antibacterial activity against Staphylococcus aureus, Klebsiella pneumoniae and Pseudomonas aeruginosa; Anti-cancer activity against breast cancer cells (MDA-MB-231)	[118]
Velvet shank	Flammulina velutipes	Hydrothermal/250 °C/4 h	Sensed Cr^{6+} with a limit of detection 0.73 µM and volatile organic compounds	[119]
Oyster	Pleurotu ssp.	Hydrothermal/200 °C/25 h	Sensed nitroarenes in water samples	[120]
Paddy straw	Volvariella volvacea	Hydrothermal/200 °C/25 h	Sensed Pb^2 with limit of detection 12 nM and for Fe^{3+} 16 nM	[121]

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Edible Mushrooms Common Name	Scientific Name	Production Conditions	Applications	References
ND	ND	Hydrothermal/200 °C/6 h	Sensed hyaluronic acid and hyaluronidase	[122]

ND—not defined.

10. Edible Mushrooms Based Skin Care Formulations

Cosmetics are personal care products that are used to cleanse and beautify the skin [123]. The demand for cosmetics containing natural ingredients is increasing due to their organic, healthier and environmentally friendly characteristics [124]. Lentinan, carotenoids, ceramides, schizophyllan and ω-3, ω-6 and ω-9 fatty acids as well as resveratrol obtained from macro fungi, especially mushrooms, are now paving their way into cosmetics [125][126]. These are reported to treat beauty issues such as fine lines, wrinkles, uneven tone and texture due to the antioxidant and anti-inflammatory traits. There are few studies where edible mushrooms are used in skincare formulations, as compiled in Table 9.

Table 9. Mushroom-based skincare formulations.

Edible Mushrooms Common Name	Scientific Name	Product Base	Applications	References
White button, Oyster, Shiitake	Agaricus bisporus, Pleurotus ostreatus, Lentinula edodes	Cream	Anti-inflammatory; anti-tyrosinase; antioxidant and antibacterial activity	[127]
Lingzhi	Ganoderma lucidum	Cream	Anti-tyrosinase; antioxidant and antibacterial activity	[128]
Oyster	Pleurotus ostreatus	Cream	Skin fairness	[129]
Oyster	Pleurotus ostreatus	Gel	Anti-tyrosinase; antioxidant activity	[130]
Snow	Tremella fuciformis	Gel	Hand sanitizer	[131]
White button, Oyster	Agaricus bisporus, Pleurotus ostreatus	Cream	Anti-tyrosinase; antioxidant and antibacterial activity	[132]