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Edible Mushrooms as Functional Ingredients for Development of Healthier and More Sustainable Muscle Foods: A Flexitarian Approach

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Abstract

Consumers are increasingly interested in nutritious, safe and healthy muscle food products with reduced salt and fat that benefit their well-being. Hence, food processors are constantly in search of natural bioactive ingredients that offer health benefits beyond their nutritive values without affecting the quality of the products. Mushrooms are considered as next-generation healthy food components. Owing to their low content of fat, high-quality proteins, dietary fibre and the presence of nutraceuticals, they are ideally preferred in formulation of low-caloric functional foods. There is a growing trend to fortify muscle food with edible mushrooms to harness their goodness in terms of nutritive, bioactive and therapeutic values. The incorporation of mushrooms in muscle foods assumes significance, as it is favourably accepted by consumers because of its fibrous structure that mimics the texture with meat analogues offering unique taste and umami flavour. This review outlines the current knowledge in the literature about the nutritional richness,

functional bioactive compounds and medicinal values of mushrooms offering various health benefits. Furthermore, the effects of functional ingredients of mushrooms in improving the quality and sensory attributes of nutritionally superior and next-generation healthier muscle food products are also highlighted in this paper.

Keywords: mushrooms, bioactive compounds, functional ingredients, meat, fish, quality aspects, functional muscle foods

1. Introduction

Muscle foods, such as meat and fish, play an important role in the daily diet of most consumers due to their desirable sensorial attributes and beneficial nutritional properties, including high levels of good quality proteins, vitamins, and minerals. However, muscle foods are deficient in vitamin C, calcium, dietary fibre, and antioxidants [1]. Moreover, consumption of processed food has been linked to certain chronic health problems, such as an increase in diabetes and obesity [2,3]. The increased awareness of consumers about the possible links between diet and health is leading to shifts in their dietary patterns towards healthier food products. Healthier eating habits include reducing the consumption of ingredients that may cause health problems such as saturated fat, sugar, and salt, and increasing the consumption of ingredients that may promote human health such as unsaturated fatty acids, vitamins, minerals, and nutraceuticals [4]. Adopting these dietary habits favours the maintenance of a healthy weight, as well as minimizing the risk of some lifestyle diseases [5]. As a result, there is increasing demand for healthier food products that consumers can easily incorporate into their diets. Moreover, the raising of animals to produce muscle foods is undesirable from an environmental viewpoint, since it leads to more greenhouse gas emissions, land use, water use, and pollution than growing arable crops [6]. Consequently, it is also desirable to reduce the total amount of animal foods within the human diet. This can be achieved by avoiding animal products altogether (vegan), avoiding meat products (vegetarian), or reducing the amount of meat products in the diet (flexitarian). This latter approach is suitable for those who want to adopt a healthier and more sustainable diet, but still want to consume some meat.

As a result of these concerns, the food industry is reformulating existing products and creating new products to make them healthier and more sustainable [7,8]. In this article, we focus on the creation of foods designed for the flexitarian market. Specifically, we focus on replacing part of meat or fish products with healthy and more sustainable natural ingredients: mushrooms. Edible mushrooms are considered to be healthy food ingredients because they contain high levels of quality proteins, dietary fibres, vitamins, minerals, and phenolic compounds [9,10,11,12]. Moreover, they have a relatively low concentration of fat and digestible carbohydrates, which makes them suitable for improving the nutritional profile of foods [13]. Some mushrooms have also been reported to contain constituents that exhibit beneficial therapeutic effects [14]. For instance, polysaccharide-protein complexes and lectins have been reported to have immunomodulatory and antitumor activities [15,16], hypotensive effects [17], and anti-angiogenesis effects [18]. There is, therefore, growing interest in incorporating mushrooms into muscle foods, thereby reducing the proportion of meat present [19,20]. One of the advantages of using mushrooms for this purpose is that they have good compatibility with meat products because of their umami flavour and fibrous meat-like texture [21,22,23,24].

This review outlines the utilization of the edible parts of mushrooms as functional ingredients in muscle food products, such as meat and fish. In particular, the impact of mushrooms on the nutritional and quality attributes of these products are critically reviewed, including their physicochemical properties, microbiological stability, chemical stability, and sensory aspects.

2. Mushroom—A Culinary Delicacy

Mushrooms are valued around the word as culinary delicacies and are popularly known as "vegetable meat" in many cultures. Botanically, they are the fruiting bodies of macroscopic filamentous saprophytic fungi that grow above ground. Their beneficial effects on human health and nutrition were recognized in early Greek, Egyptian, Roman, and Chinese civilizations [25,26,27]. Mushrooms can be conveniently categorized into three major groups according to their applications edible (54%), medicinal (38%), and wild (8%) [28]. It has been estimated that there are at least 12,000 mushroom species worldwide, with around 2000 of them being suitable for edible and/or medicinal application, but only 35 being currently cultivated commercially [29]. Nutritionally, mushrooms have many positive benefits for the human diet: they are low in fat, high in protein, and high in dietary fibre, as well as being good sources of vitamins, minerals, and nutraceuticals [30,31]. As a result, the global mushroom market has grown considerably over the past few years with 34 billion kg production and per capita consumption exceeding 4.7 kg in 2013 [28]. Indeed, mushroom production is currently a multibillion-dollar industry with an annual turnover of around USD 35 billion in 2015 and estimated to exceed USD 59 billion in 2021, growing at around 9.2% from 2016 to 2021 (http://www.zionmarketresearch.com/report/mushroom-market , accessed on 8 January 2021). Commercially, mushrooms are mainly cultivated on agricultural residues, which enables these waste materials to be converted into a valuable human food source [32], while also reducing waste and environmental pollution.

Some of the most important commercially cultivated mushrooms are *Agaricus bisporus* (agaric or button), *Lentinula edodes* (shiitake), *Flammulina velutipes* (enoki or winter mushroom), *Pleurotus* *eryngii* (king trumpet mushroom), *Pleurotus ostreatus* (oyster mushroom), *Volvariella volvacea* (paddy straw mushroom), *Calocybe indica* (milky mushroom), *Hericium erinaceus* (pom pom or lion's mane mushroom), *Boletus edulis* (porcini, cèpe, or king bolete mushroom), *Grifola frondosa* (maitake or hen of the woods mushroom), and *Agrocybe aegerita* (pioppini) [33]. Notably, about 85% of the world's cultivated edible mushrooms is represented by only five genera viz. *Lentinula, Agaricus, Pleurotus, Auricularia* and *Flammulina* [28], despite the fact that a wide variety of other edible mushrooms could also be cultivated commercially on a large scale. There are some extrinsic and intrinsic factors that influence the stalk height, stalk diameter and cap size in cultivated mushroom. The most important factors responsible for increased production of cultivated edible mushroom are temperature, humidity, fresh air, and compact material.

3. Mushroom as Bioactive Functional Food Ingredients

Although many ingredients are used while preparing processed food products, the role of food ingredients that merits special mention are those with inherent nutritional as well as functional properties that influence the quality of finished food products. Therefore, ingredients are now considered as an essential part and parcel of any food product development process. However, the ingredients or compounds obtained from natural sources and generally regarded as safe are of great interest because of their safety and health characteristics [34]. As per the Food and Drug Administration, these are the substances that influence various attributes and properties of any food, either directly or indirectly. They are included at any down streaming stage of processing, be it production, packaging or storage of food, till it reaches the consumer. The purpose is not only to improve nutritional quality and safety but also the freshness, appearance, and overall acceptability of the food products by modifying taste and texture. These additives are often considered as nutraceuticals when these or part of their components exert medical or positive health benefits and play a vital role in the prevention and treatment of various diseases [35,36]. The nutraceuticals could be either whole food or its part, or even a single component or extract of food which is regularly being used as a dietary supplement. A food item is termed as "Functional" only when these nutraceuticals are incorporated in the food or its formulation to achieve specific target function such as improving the well-being as well as quality of human life by reducing the risk of disease beyond its nutritional value [35,37].

Mushrooms, which belong to filamentous higher fungi, are known for their nutritional richness, low caloric value, taste, and nutraceutical properties. Due to their unique nutritional as well as textural properties, they are used as a dietary supplement and often considered as an alternative source of meat, fish, vegetables, fruits, etc. [38]. Moreover, mushrooms are a source of high-quality protein produced in huge quantity from recycling worthless agro-wastes including agro-industrial waste per unit area and time [39,40]. Therefore enriching or fortifying diets or food products with such a good source of protein containing all the essential amino acids may help in reducing the incidences of protein-energy malnutrition in humans [41]. Furthermore, owing to the presence of numerous secondary metabolites or nutraceuticals or biologically active compounds having medicinal value, mushrooms can also be used as bio-therapeutic agents [42,43].

Generally, mushrooms possess all three functionalities of food—nutrition, taste, and physiological functionalities. Mushrooms have a peculiarly pleasant savory taste called umami due to presence of sodium salts of free amino acids such as glutamic and aspartic amino acids and 5′-nucleotides [44]. The umami taste, also called the palatable taste, is nothing but the overall food flavour enhanced by mono-sodium glutamate [45]. Hence, mushrooms are preferable and adaptable in most food formulations due to this unique flavour.

Again, the umami taste peptides and umami-enhancing peptides are also considered to be important components which influence the sensory quality of mushroom. Peptides with different structures and length possess unique taste properties including sweet, bitter, umami, sour and salty. They are usually tasteless in water, but they can increase the salty, sweet, sour, bitter or umami taste in combination with corresponding tastants [46]. Various researchers have reported that some dipeptides or tripeptides containing Glu such as Glu-Glu, Glu-Asp, Glu-Asp-Glu, Glu-Gly-Ser enhance umami taste [47]. Recently umami peptides (2 tripeptides and 3 dipeptides) were isolated from hydrolysates of dried shiitake mushroom and these peptides are believed to be responsible for specific taste of shiitake mushroom. They also contribute to the unique taste of mushrooms or even interact with other volatile compounds to influence the whole flavour of foods [48]. In an another study, umami taste peptides like Gly-Leu-Pro-Asp and Gly-His-Gly-Asp isolated from the mushroom *Agaricus bisporus* are reported to act as key molecules for kokumi taste [49]. Kokumi taste is best described as flavor characteristics such as mouthfulness, complexity, and continuity. Kokumi taste substances have slight taste or even no taste by themselves, but they can enhance the flavor of the basic tastes, such as sweet, salty, and umami [50]. Interestingly, when incorporated to a blank chicken broth, these peptides from *Agaricus bisporus* can elicit new taste sensations, such as mouthfulness and complexity [49].

3.1. Nutritive Profile of Mushrooms

As stated earlier, mushrooms are excellent sources of dietary fibre and rich in protein possessing all nine amino acids that are essential for humans [26] but low in fat and calories [13]. In general, the mushroom fruit bodies contain 5–15% dry matter, 19–35% protein and low fat content (Table 1). Indeed, the protein content of mushrooms is almost four times greater than tomatoes and carrots, six times greater than oranges, and 12 times greater than apples [40,51]. Mushrooms, both pilei and stems are excellent source of dietary fibre mainly due to the presence of non-starch polysaccharides. Stems of mushroom are mainly composed of insoluble dietary fibre (IDF) and glucans. Hence, mushroom stem could be utilized for preparation of biologically active polysaccharide complexes as food supplement [52]. In a recent study, stem of enoki or winter mushroom (*Flammulina velutipes*) reported to contain 32% dietary fibre [53]. Again, the low fat and high-fibre content of mushrooms may help in preventing hypertension and hypercholesterolemia, as well as being beneficial in weight control [54]. Mushrooms are also healthy sources of essential fatty acids (52–87% unsaturated fatty acids), mostly in the form of linoleic acid, which cannot be directly synthesized in the human body but is required for health [55]. Mushrooms are also rich in indigestible carbohydrates, which makes them promising sources of novel prebiotic components [56,57]. The low glycemic index and high mannitol content of mushrooms is also believed to be beneficial for diabetics [58].

Table 1.

Chemical composition of some common and popular mushroom species.

Mushroom	Common Name	Protein	Fat	Crude Fibre	Ash	Carbohydrate	Energy Value (kcal/100 g)
Fresh/Raw (g/100 g)							
Agaricus bisporus	White button, Agaric, Pizza	3.00	0.34	1.45	0.79	3.69	24
Flammulina velutipes	Winter, Enoki	2.66	0.28	2.80	0.91	8.42	29
Grifola frondosa	Maitake	1.94	0.20	2.70	0.52	2.70	29
Pleurotus ostreatus	Oyster	2.00	0.99	2.10	0.24	5.35	39
Pleurotus sajor caju	Oyster	23.3	3.0	35.6	3.2	65.5	
Dried (g/100 g)							
Pleurotus eryngii	King trumpet oyster	28.8	3.0	-	3.5	52.2	-
F. velutipes	Winter, Enoki	18.42	2.94	7.81	6.33	56.37	-
Termitomyces heimii	Wild edible	23.75	3.58		4.40	54.70	345
A. bisporus	White button,	29.29	2.22	24.56	7.12	20.57	-

Mushroom	Common Name	Protein	Fat	Crude Fibre	Ash	Carbohydrate	Energy Value (kcal/100 g)
	Agaric, Pizza						
P. sajor caju (stalk)	Oyster	22.51	2.6	16.24	8.54	40.2	-
P. sajor caju (cap)	Oyster	26.34	3.07	8.97	10.37	38.17	-
P. ostreatus	Oyster	20.04	8.65	-	7.78	60.21	421
Tricholoma nauseosum	Matsutake	18.1	2.0	30.1		31.1	-
Sarcodon imbricatus	Scaly hedgehog	12.0	2.8	5.1		64.6	-
G. frondosa	Maitake	21.1	3.1	10.1	7.0	58.8	-
Hericium erinaceus	Pom pom or Lion's mane	22.3	3.5	7.8	9.4	57.0	-
Boletus aereus	Bronze bolete or The dark cep	17.86	4.4	-	8.87	72.83	306
Boletus edulis	Cep or Porcini	21.07	2.45	-	5.53	70.95	423
Boletus reticulatus	Summer cep	22.57	2.55	-	19.72	55.16	297
Pleurotus florida	Oyster	34.56	2.11	11.41	7.40	31.59	-
Pleurotus ostreatus	Oyster mushroom	30.92	1.68	12.10	7.05	31.40	-
Calocybe gambosa	St. George or Milky	15.46	0.83		13.89	69.82	317

Mushroom	Common Name	Protein	Fat	Crude Fibre	Ash	Carbohydrate	Energy Value (kcal/100 g)
Clitocybe odora	Aniseed	17.33	2.46		9.55	70.66	431
Coprinus comatus	Shaggy ink cap	15.67	1.13		12.85	70.35	525
F. velutipes (stem waste)	Winter, Enoki	13.50	1.47	32.30	8.24	63.89	-
P. florida	Oyster	27.83	1.54	23.18	9.41	32.08	-
Russula delica	Milk-white	26.25	5.38	15.42	17.92	34.88	-
Lyophyllum decastes	Fried chicken	18.31	2.14	29.02	14.20	34.36	-
Fistulina hepatica	Beefsteak fungus	63.69	2.63	-	11.30	22.98	364
Laccaria laccata	Deceiver or Waxy laccaria	62.78	3.76	-	20.69	12.77	336
Suillus mediterraneesis	-	24.32	2.61	-	27.64	45.42	302
Tricholoma imbricatum	Matsutake	50.45	1.88	-	6.45	41.21	383
Volvariella volvacea	Paddy straw	29.5	5.7	-	10.4	60.0	374
Lentinula edodes	Shiitake	17.5	8.0	-	8.0	67.5	387
Auricularia polytricha	Wood ear, Jelly ear	7.7	0.8	-	14.0	87.6	347
Tremella fuciformis	White Jelly	4.6	0.2	1.4	0.4	94.8	-
Pholiota microspore	Nameko	20.8	4.2	-	6.3	66.7	372

Mushroom	Common Name	Protein	Fat	Crude Fibre	Ash	Carbohydrate	Energy Value (kcal/100 g)
Calvatia utriformis	Mosaic puffball	20.37	1.90	-	17.81	59.92	744
Lycoperdon echinatum	Spiny puffball	23.52	1.22	-	9.43	65.83	544
Russula cyanoxantha	Charcoal burner	16.80	1.52	-	7.03	74.65	590
Agaricus campestris	Field or Meadow	18.57	1.1		23.16	58.16	-
Boletus armeniacus	-	18.25	1.56		12.09	68.10	-
Tricholoma giganteum	Matsutake	16.1	4.3	4.5	5.0	70.1	-
V. volvacea	Paddy straw	30.1	6.4	11.9	12.6	50.90	-

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Being an excellent source of dietary fibres and proteins, mushrooms also have a low sodium content, and contain a diverse range of micronutrients, such as vitamins B_1, B_2, B_{12}, C, D, E, niacin, and folate [59]. Despite being cultivated in the dark and being a non-animal source of food, mushrooms contain significant levels of vitamin D, which is often referred to as "the sunshine vitamin". Upon exposure to sunlight or ultraviolet (UV)-B light, the vitamin D (specially vitamin D_2) content of mushrooms increases appreciably, which can play a significant role in the bone and cartilage health of vegans and vegetarians [60,61,62].

Furthermore, mushrooms are a rich source of essential minerals like iron, copper, manganese, and zinc that play an important role in the proper functioning of different metabolic pathways. Indeed, the levels of some important trace elements (such as potassium and phosphorus) are typically considerably higher in mushrooms than in most vegetables [63]. Edible mushrooms can also produce a range of flavonoids, which may exhibit health benefits [64].

It should be noted that the nutritional composition of mushrooms varies considerably depending on factors such as species, intra-species genetic variability, maturity, growth conditions, geographic location, environmental conditions, and post-harvest conditions [65,66]. The chemical composition of some popular varieties of mushroom reported by different researchers, are presented in Table 1.

3.2. Nutraceutical Components in Mushrooms

Mushroom nutraceuticals are natural compounds found in mushrooms that may have health benefits by reducing the risks of certain diseases or by improving human performance [42,81,82]. The potential health-promoting and disease-preventing effects of mushroom nutraceuticals have been attributed to a broad range of biological activities, which are discussed in this section.

Mushrooms have been reported to contain different kinds of nutraceuticals, including lectins, triterpenoids, ganoderic acid, β-glucan, phenolics, flavonoids, hispolon, calcaelin, proteoglycan, lentinan, laccase, nucleosides, nucleotides, and ergosterol [31,83,84,85]. As far as polyphenolic compounds, are concerned fruiting bodies of mushrooms as well as mushroom extracts contain significant amounts of phenolic acids, especially derivatives of benzoic acid and derivatives of cinnamic acid. Different mushroom species have been found to contain protocatechuic, p-hydroxybenzoic, vanillic, salicylic, p-coumaric, gallic, gentisic, syringic, veratric, cinnamic, caffeic, and ferulic acids [86]. The biological activities and potential health benefits of some of these nutraceuticals have been extensively studied. For example, a number of polysaccharides found in mushrooms, including chitin, β-glucan, α-glucan, mannans, xylans and galactans, have been reported to have potential health benefits [43,61,87]. In general, the nutraceuticals in mushrooms may exhibit a broad spectrum of different biological activities depending on their chemical structure and their interactions with biochemical processes, including anti-inflammatory, anticarcinogenic, antitumor, antimutagenic, antidiabetic, antibacterial, antiviral, anti-obesity, and anti-hypercholesterolemic activities [36,60,88,89]. As their application in promoting human health have been extensively reviewed by many previous researchers [42,43,55,66,82,84,90], we do not consider them further in this review.

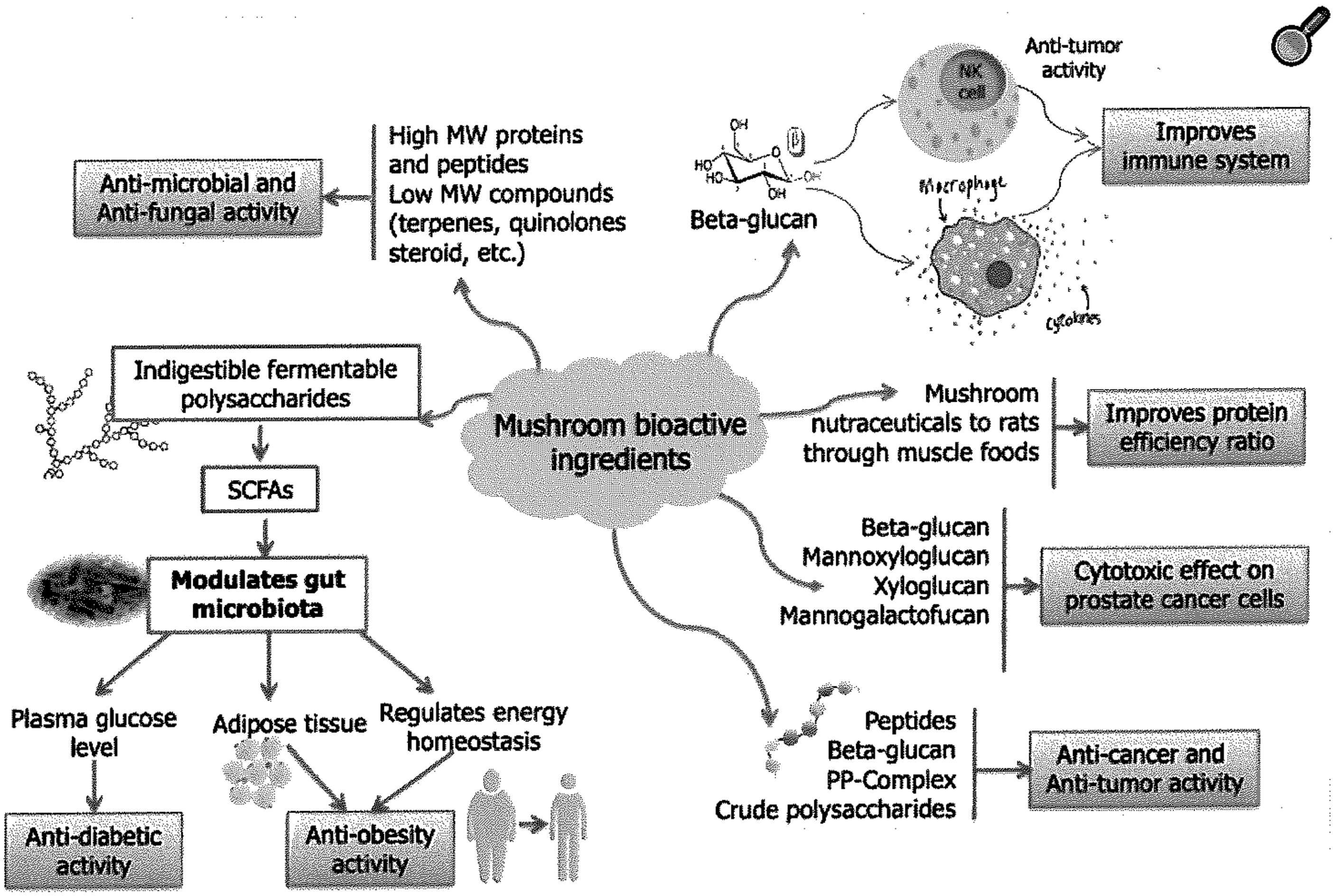
3.3. Prebiotic Effects of Mushrooms

There is growing evidence that human health can be promoted by consuming a diet that establishes a diverse microbiome in the colon [91]. In particular, diets that favour the growth of beneficial bacteria such as *Lactobacillus* and *Bifidobacterium*, while suppressing the growth of detrimental bacteria such as *Clostridia* and *Bacteroides*, may promote health [56,91]. Prebiotics are non-digestible and fermentable food components, such as oligosaccharides, dietary fibres, and non-digestible starches, that promote health by selectively modulating the composition and/or activity in the intestinal microbiota [61,92,93]. Mushrooms have been reported to contain numerous constituents that exhibit prebiotic activities, including chitin, hemicellulose, β-glucan, α-glucan, mannans, xylans, and galactans [57]. Some of the important mushroom species that have been reported to exhibit strong prebiotic activity include *L. edodes* (Shiitake), *Trametes versicolor* (Yunzhi), and *Ganoderma lucidum* (Reishi).

In a study, Chou et al. [94] reported that prebiotics (polysaccharides and protein-polysaccharide complexes) from mushrooms passed through the human stomach and small intestine without digestion, then reached the colon where they stimulated the growth of healthy bacteria (*Lactobaccilus acidophilus and Bifidobacterium longum* subsp.). Similarly, glucans from *P. ostreatus* and *P. eryngii* [95] and *G. lucidum* [90] have also been shown to stimulate the growth of *Bifidobacterium* sp. and *Lactobacillus* sp.

Prebiotic mushroom polysaccharides are also reported to exhibit antiobesity and antidiabetic effects by regulating the energy homeostasis and plasma glucose levels of the host [61]. The restoration of energy balance is believed to be due to the supply of alternate energy sources from short-chain fatty acids produced during fermentation of the non-digestible carbohydrates in the colon [96]. Some *in vitro* studies have also reported that extracts from *G. lucidum* can modulate the gut microbiota in a manner that may help prevent obesity [97,98]. Other studies have reported that the polysaccharides from various mushroom varieties may be able to ameliorate metabolic syndromes (including diabetes), such as *Agaricus brasiliensis, Agrocybe chaxingu, Catathelasma ventricosum, Pleurotus abalonus, Tremella fuciformis, G. frondosa, and G. lucidum* [61,99]. The potential health promoting and medicinal properties of various bioactive ingredients found in mushrooms are summarized in Figure 1.

Figure 1.



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Schematic diagram depicting health promoting and medicinal properties of mushroom bioactive ingredients (MW = Molecular weight; NK cell-Natural killer cell; PP-complex: Protein-polysaccharide complex; SCFA = Short-chain fatty acids).

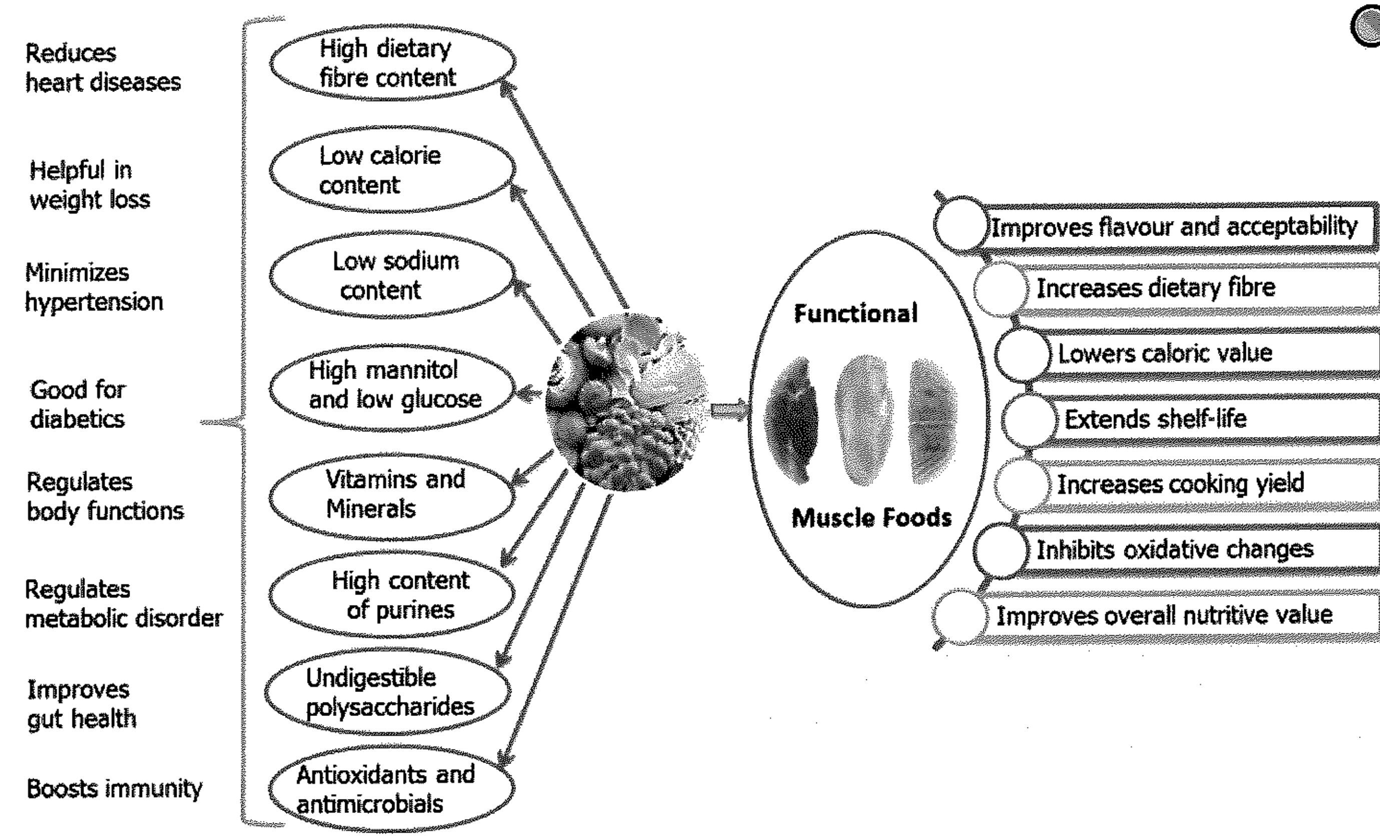
4. Effects of Edible Mushrooms on Muscle Food Products

Edible mushrooms, due to richness in nutritive value and functional food components, make them an unmatched source of healthy food and are regarded as superior nutritional supplements [36,53]. To harness the goodness of nutritional, nutraceutical and other medicinal values, mushrooms are not only used directly as food but also as raw materials in formulation and development of new functional foods for health-conscious consumers. Other than these values, mushrooms are preferred as additives by the food processors due to their aroma, taste and inherent texture-modifying functional properties [100,101] which are reported to positively influence the flavour, appearance, overall acceptance and shelf-life, when incorporated in various processed food formulations [53].

Considering their enormous benefits, varieties of food products such as breads [102], fish and meat products [103], cookies [104], other preparations like instant soups, pasta, snack seasonings, casseroles, and rice dishes [105,106] are being formulated incorporating mushrooms as functional bioactive components that is stated to improve the nutritional profile and potential health benefits [104]. Although quite a large number of research articles are available highlighting the use of mushrooms as potential functional compounds in various food applications, this review limits its focus on the potential application of mushrooms in muscle foods (meat and fish) only.

Incorporation of mushroom and its parts not only influences the desirable texture, taste, flavour, and stability of muscle food products considerably but also enriches them with nutritive and functional health values [36,104,107,108,109]. Figure 2 indicates the beneficial effect of mushrooms on quality attributes of muscle foods and associated health benefits. Further mushroom is better known for its low sodium content [110]. For example, the fruiting bodies of *Agaricus* sp. contain 396 mg sodium/kg [111] which is low amongst the vegetables [112]. On the other hand, processed meats contain 7–39 g sodium chloride/kg [113]. Dietary intake of such a higher amount of sodium is often linked with various diseases and increases the risk of hypertension and cardiovascular diseases [114]. Therefore, pre-mixing or blending mushrooms in processed meats may help in reducing the sodium content of the products, offering more nutritional and health benefits to consumers [115].

Figure 2.



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Schematic diagram showing the influence of mushroom nutrients on quality attributes of muscle foods vis-à-vis human health effects.

Over the years, a number of researchers have successfully incorporated mushrooms and its various parts (stipes and stem wastes) in formulation of various muscle food products like chicken sausages [70], salted cooked beef [116], tuna meat [117], kuruma shrimp [118], emulsion-type pork sausages [109], traditional Turkish meatball [108], fermented pork sausages [107], sutchi catfish patties [71] etc. A summary on the effects of edible mushrooms on physico-chemical properties, colour and oxidative stability, shelf-life and sensory attributes of muscle food products is presented in Table 2.

Table 2.

Effects of edible mushrooms and its parts on quality attribute of functional muscle food products.

Mushroom Variety and Level Used	Types of Muscle Food	Quality Parameters and Storage Conditions	Effects	Ref.
Dried mushroom (*Pleurotus ostreatus*) @ 4%, 8% or 12%	Beef patties	Quality attributes (stored at −18 to −20 °C for 6 months)	• Increased protein, fat and ash contents, water holding capacity • Decreased moisture, carbohydrate contents, pH value, tenderness, plasticity, cooking loss • Better organoleptic properties of patties at 4 and 8% level	[67]
Mushroom (*Agaricus bisporus* or *P. ostreatus*) powder @ 5% or 10%	Traditional Turkish meatball	Sensory and physical (colour and texture) analysis	• Imparted positive effect on hardness • Meatball with *P. ostreatus* at 5% level was the best-liked	[108]
Mushroom (*Boletus edulis*)	Beef burger	Antioxidant activities	• Protected lipid peroxidation	[119]

Mushroom Variety and Level Used	Types of Muscle Food	Quality Parameters and Storage Conditions	Effects	Ref.
extract @ 1%, 3% or 5%		(stored at 4 °C for 8 days)	• Protected arachidonic (c20:4n6) and eicosapentaenoic (c20:5n3) acids • Extended shelf-life	
Winter mushroom (*Flammulina velutipes*) powder @ 0.5, 1%, 1.5% or 2%	Emulsion-type pork sausages	Quality parameters (pH, lipid oxidation, texture and sensory properties)	• Increased water holding capacity and pH at >1% inclusion level • Decreased exudation of fat and water from the sausages • No adverse effect on colour and sensory properties at ≤1.5% inclusion level • Could replace phosphates in meat products • Had soft texture compared to control samples with phosphate	[109]
King oyster mushroom (*Pleurotus eryngii*)	Chicken burger	Physical properties and sensory evaluation	• Increased water holding capacity • Lowered weight loss during cooking and	[69]

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