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The beneficial role of edible mushrooms in human health

Irene Roncero-Ramos[1] and Cristina Delgado-Andrade[2]

Mushroom species have the potential to be developed into functional foods for their high nutritional value and because they are a source of biologically active compounds of medicinal importance. The investigation on the beneficial properties of edible mushrooms has gained attention by the scientific community during the last decades. In the light of the emerging literature, the objective of this review was to compile the more recent information about the health benefits associated to the edible mushrooms intake. It can be concluded that the consumption of mushrooms as a part of daily diet could be a natural adjuvant for the treatment and prevention of several chronic diseases.

Addresses
[1] Mushroom Technological Research Center of La Rioja (CTICH), Autol (La Rioja), Spain
[2] Department of Physiology and Biochemistry of Animal Nutrition, Estación Experimental del Zaidín (CSIC), Armilla, Granada, Spain

Corresponding author: Roncero-Ramos, Irene (irene_rr20@hotmail.com)

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Introduction

Mushrooms have been consumed by many cultures for centuries. Edible mushrooms are considered a delicacy because of their sensory characteristics and their attractive culinary attributes. The most consumed mushrooms worldwide is *Agaricus bisporus* followed by *Pleurotus* spp. and *Lentinula edodes*. They are easy to cultivate and are characterized by both high nutritional value and culinary features [1]. As a demonstration of the development occurred in the world mushroom market, Table 1 depicts data of mushrooms and truffles production for years 2004, 2009 and 2014 in some of the different countries considered as major producers [2]. Excepting the cases of Belgium, France and Denmark, whose production slightly dropped during this decade, the rest of the great mushrooms producers around the world have increased their production for this period. From a nutritional point of view, mushrooms are valuable health foods since they have a significant amount of dietary fiber and are poor in calories and fat. Moreover, they have a good protein content (20–30% of dry matter) which includes most of the essential amino acids; also provide a nutritionally significant content of vitamins and trace minerals [3].

Recently, mushrooms have become increasingly attractive as functional foods for their potential beneficial effects on human health [4]. They contain bioactive compounds of high medicinal value such as lectins, polysaccharides, phenolics and polyphenolics, terpenoids, ergosterols, and volatile organic compounds, which are considered as relevant responsible agents for their healthy activities including antitumor, immunomodulating, antioxidant, radical scavenging, antihypercholesterolemia, antiviral, antibacterial, hepatoprotective, and antidiabetic effects [5]. Thus, numerous studies have revealed that different mushroom species are beneficial for the prevention and treatment of several chronic diseases, such as cancer, cardiovascular diseases, diabetes mellitus and neurodegenerative diseases [6–9]. In the light of the emerging literature, the objective of this review is to compile the more recent information about the benefits associated to the consumption of edible mushrooms on human health.

Cancer disease

Cancer is one of the main causes of death worldwide. Evidences from a large number of scientific publications show that mushrooms, and more specifically their polysaccharides, could play an important role in prevention and treatment of this disease [6,7••]. Thus, Zhang *et al.* have demonstrated that a higher dietary intake of mushrooms decreased breast cancer risk in pre- and postmenopausal Chinese women [10]. Recently, results from a meta-analysis of observational studies also suggested that a greater mushroom intake may be inversely associated with risk of breast cancer, which need to be confirmed with large-scale prospective studies further [11].

Several studies and clinical trials have evidenced that the preventive effects on cancer could be mediated by the immunomodulatory capability of mushrooms. Thus, it has been established that some of their polysaccharides would activate the innate immune system and exert antitumor activity by accelerating the host's defense mechanisms. Mushrooms polysaccharides can inhibit tumor growth by stimulating the immune system via effects on natural killer cells, macrophages and via T cells and their cytokine production [7••]. In the same line, a double-blind placebo-controlled human clinical trial

Table 1

Evolution of mushrooms and truffles production (tons) during 2004–2014 as documented by FAO (World Mushrooms & Truffles: Production, 1961–2014; United Nations, FAO, FAOStat)

Country	2004	2009	2014	Rate of increase
China	3 360 496	4 680 720	7 634 959	2.3
USA	387 601	371 844	432 100	1.1
UK	74 000	69 400	94 857	1.3
Belgium	42 380	41 792	41 754	0.9
France	165 466	113 851	108 540	0.7
Denmark	10 946	9500	10 113	0.9
Germany	50 000	52 200	59 923	1.2
Italy	94 152	720 100	600 114	6.4
Spain	138 782	131 000	149 854	1.1
Poland	150 000	204 886	254 221	1.7
Netherlands	260 000	230 000	310 000	1.2
Iran	25 000	60 000	80 239	3.2

investigated the potential of *Pleurotus cornucopiae* to up-regulate of the immune system. After consuming this mushroom extract for 8 weeks, the results clearly suggested that *P. cornucopiae* had the potential to enhance the immune system, through Th1 phenotype potentiation as the macrophage-IL-12—IFN-γ pathway, leading to the activation of the cell-mediated immune system as exemplified by up-regulation of natural killer cell activity [12]. The study by Dai *et al.* [13] has also established that a regular intake of *L. edodes* resulted in improved human immunity function, as seen by increased cell proliferation and activation and the higher levels of secretory immunoglobulin A produced.

Among the polysaccharides, β-glucans are known to be the most effective compounds to exert the anti-tumorigenic effects via enhancement of cellular immunity. Relevant effects using grifolan, a β-glucan extracted from *Grifola frondosa*, have been reported in gastrointestinal, lung, liver and breast cancers [14]. Grifolan is a macrophage activator that increases cytokine production, augments the expression of IL-6, IL-1 and tumor necrosis factor-alpha (TNF-α) of macrophages. Some authors have proposed that the induction of this proinflammatory cytokine response is the responsible for the antitumor activity [7••], since inflammation could help to isolate the tumor. However, other authors have evidenced that a grifolan containing extract increased the production of both stimulatory (IL-2) and suppressive (IL-10) cytokines in a clinical trial with 34 postmenopausal breast cancer patients, free of disease after initial treatment [15]. Therefore, the clinical effect of the balance of these cytokines and the mechanism by which it happens is still unknown. Further studies are needed to understand the role of grifolan in the activation of the immune system and in the cancer prevention.

Beside the capacity of mushrooms polysaccharides to prevent cancer by activating the immune system, it is also known that they have a direct antitumor activity against various synergetic tumors, and avoid tumor metastasis. Their activity is especially beneficial when used in conjunction with chemotherapy [5]. Thus, *L. edodes* polysaccharides have been used in clinical practice with other conventional forms of cancer treatment such as chemotherapy and surgery. Ren *et al.* [16] found that a combination of *L. edodes* polysaccharide with 5-fluorouracil, a chemotherapeutic drug, could significantly reduce the tumor weight and volume in H22-bearing mice.

On the other hand, fungal lectins have also attracted considerable attention due to their antitumor, antiproliferative and immunomodulatory activities. Lectins from mushrooms display antiproliferative potential by cross-linking cell surface glycoconjugates or through immunomodulatory effects [17••].

Metabolic syndrome

Metabolic syndrome is a medical condition characterized by central obesity, hyperglycemia, hypercholesterolemia and hypertension. Edible mushrooms, their extracts, polysaccharide fractions and isolated compounds possess hypoglycemic, cholesterol and triglyceride lowering ability, hypotensive effects, as well as weight managing activity [8]. The most active compounds are β-glucans as well as lectines and small compounds such as eritadenine, triterpenes, sterols and phenolic compounds [8].

Obesity and hyperlipidemia

Several studies have been carried out about the effect of mushrooms on hyperlipidemia and obesity. *L. edodes* has been associated with antihyperlipidemia activity and preventing body weight gain as shown in the following studies. Rats fed a high fat diet enriched with *L. edodes* significantly lowered plasma triacylglycerol (TAG) and fat deposition by −55% and −35%, respectively, compared to rats fed with high fat diet without the *L. edodes* [18]. In a later study by the same research group, where authors wanted to identify the mechanism on how high-dose *L. edodes* prevents obesity, the authors discovered an undesirable increase of TAG in the liver, rather than in adipose tissue [19]. Eritadenine, a component of *L. edodes*, is effective in lowering dyslipidaemia by decreasing the concentration of phosphatidylcholine (PC) and increasing the concentration of phosphatidylethanolamine (PE) in the liver [20]. PC is an important phospholipid for lipoprotein assembly and secretion from the liver. Adding eritadenine to the rat diet significantly decreased the level of plasma TAG but increased the concentration of TAG in the liver. However, when the eritadenine was given concurrently with choline supplementation did not significantly increase liver total fat, liver TAG and liver weight; PC deficiency could be prevented by the addition of choline chloride (8 g choline chloride/kg) [20].