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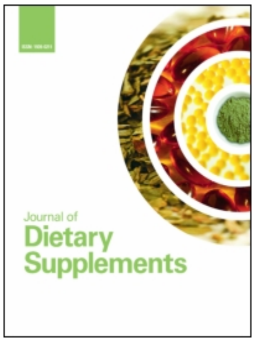

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ARTICLE

Role of Mushroom as Dietary Supplement on Performance of Poultry

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ABSTRACT

The objective of this review is to summarize the effect of commonly used mushrooms (particularly *Pleurotus ostreatus* or oyster mushroom, *Agaricus bisporus* or Button mushroom, *Lentimula edodes* or shiitake mushroom, and *Ganoderma lucidum* or reishi mushroom) in poultry diets on performance of broilers and layers. It can be concluded from different studies that mushrooms and their polysaccharides can play important roles in poultry production: (1) Polysaccharides in mushrooms may act as immune enhancers or immunomodulators and show antibacterial, antiviral, antiparasitic bioactivities; (2) phenolic compounds of mushrooms may act as antioxidants; (3) mushrooms in broiler's diet may be used as growth promoters as an alternative to antibiotics; (4) mushrooms in the diet may improve egg production and quality; (5) mushrooms may be used as a safe and effective alternative for inducing molt, enhancing immunity, reducing *Salmonella* growth, and returning to egg production. Further studies are needed to investigate the effects of mushrooms to improve productive performance in chickens and to illuminate the possible modes of action related to the gut ecosystem and the immune response.

KEYWORDS
antioxidant; broiler growth; egg production; egg quality; immunity; mushroom

Introduction

Extensive use of antibiotic growth promoters in the poultry industry has resulted in the rapid appearance of antibiotic-resistant forms of microorganisms. Once antibiotic resistance is established in bacterial population, it is maintained for long periods of time (Newman, 2002). Due to these adverse effects, Europe banned the use of antibiotics as growth promoters in animals in 1999 (European Commission/Scientific Steering Committee 1999). However, the removal of antibiotics as growth promoters has led to an increase in enteric problems in birds. So there is a need to search for natural products that could substitute for antibiotic growth promoters and have no adverse effects.

Mushrooms are fruiting bodies of fungi that are known to offer several benefits such as fast growth, improved health, and increased resistance to and protection from pathogens (Guo, Savelkoul, Kwakkel, Williams, & Verstegen, 2003). This fungal kingdom possesses certain

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natural advantages in terms of their dietary superiority over the rest of the vegetarian platter: (a) good protein content (20%–30% of dry matter) with all the essential amino acids, making them capable of substituting for meat; (b) chitinous wall to act as a source of dietary fiber; (c) high vitamin B content; (d) low fat content; and (e) virtually no cholesterol (Ghorai et al., 2009). Total lipid content varies between 0.6% and 3.1% of the dry weight in the commonly cultivated mushrooms, and at least 72% of the total fatty acids were unsaturated in the four tested mushroom varieties: *Lentinus edodes, Volvariella volvacea, Agaricus bisporus L., and Pleurotus Sajor Caju* (Huang, Yung, & Chang, 1985); linoleic acid accounted for 76%, 70%, 69%, and 63%, respectively, of total fatty acids in these tested mushroom varieties.

Moreover, mushrooms are a rich source of natural antibiotics. The cell surfaces of mycelia secrete antibiotics, known as exudates, most of which are secondary metabolites (Willis et al., 2009). Some of these antibiotics and enzymes target specific microbes. The presence of essential nutrients, which are nutritional requirements of poultry, implies mushrooms could be utilized as a feed supplement to improve growth performance and health of poultry.

Mushroom are the source of numerous well-studied preparations with proven pharmacological properties. In addition to glycogen-like polysaccharides, (1–4)-, (1–6)-α-D-glucans, and antitumor polysaccharides, (1–3)-, (1–6)-β-bonded heteroglucans, heterogalactans, heteromannans, xyloglucans, and lentinan have been identified in mushrooms (Hobbs, 2000). Lentinan stimulates various kinds of NK cell-, T cell-, B cell-, and macrophage-dependent immune reactivity. Mushrooms also contain various biologically active compounds such as gallic acid, protocatechuic acid, chlorogenic acid, naringenin, hesperetin, and biochanin-A (Alam et al., 2008, 2010). Presence of sugars and indigestible crude fiber, fractions of carbohydrates or polysaccharides, and low fat play a beneficial role in the digestive tract of chickens, thereby increasing growth of nonpathogenic bacteria such as *Bifidobacterium* species (Sundu, Kumar, & Dingle, 2006). Mushrooms and herb polysaccharides have been used as immune enhancers or immunomodulators and show antibacterial, antiviral, antiparasitic, and anticarcinogenic bioactivities (Guo et al., 2003). In addition, mushroom polymers (β-glucans) may trigger the stimulation of immune cells in animals and humans by binding to other receptors such as Dectin-1 (Rowan, Smith, & Sullivan, 2003). Oyster mushrooms (*Pleurotus ostreatus*) are known to have antioxidant and immunomodulatory effects (Elmastas, Isildak, Turkekul, & Temur, 2007) and have been shown to improve growth, immunity, and intestinal health in poultry (Daneshmand et al., 2012; Giannenas et al., 2010a; Guo et al., 2003). In a layer experiment, Cho et al. (2010) concluded that fermented spent mushroom substrates could be used as a resource in laying hen feed at 5% to 15% without adversely affecting egg-related performance and egg quality.

The objective of the present review is to determine the effect of dietary mushroom on performance of broilers and layers in addition to finding the possible mechanism for its potential to enhance performance in chickens.

Mushroom as immunomodulator

The immune status of the host is known to play an important role in resistance to various infections. The immunoactive components in plants and fungi include polysaccharides, glycosides, alkaloids, volatile oils, and organic acids, of which polysaccharides are considered to be the most important (Guo et al., 2004). Polysaccharides may act as immune enhancers or immunomodulators, and these components may display antimicrobial activity (Kitandu & Juranová, 2006). Generally, polysaccharides could affect both innate and adaptive immunity, including cellular and humoral responses (Guo et al., 2004). The mushroom and herb polysaccharides may enhance cellular and humoral responses of chickens. Therefore, they could play an important role in strengthening the birds' defense systems against invasion by infectious organisms. However, the immune mechanisms affected by the mushroom and herb polysaccharides, and other parameters such as growth and health, have not been thoroughly investigated in chickens. Both in vitro and in vivo studies have demonstrated that (1–3)-β-/(1–6)-β-D-glucan promoted immune enhancement, thereby supporting the innate immune system against bacterial, viral, fungal, and parasitic infections. These effects are achieved by activating macrophages, T-helper and natural killer cells that also involve the differentiation and proliferation of T-lymphocytes (Willis et al., 2013). Lee et al. (2010) reported that in vitro culture of chicken spleen lymphocytes with extracts of milk thistle, turmeric, and shiitake and reishi mushrooms induced significantly higher cell proliferation compared with the untreated control cells. Stimulation of macrophages with extracts of milk thistle and shiitake and reishi mushrooms, but not turmeric, resulted in robust nitric oxide production to levels that were similar to those induced by recombinant chicken interferon-γ. All extracts uniformly inhibited the growth of chicken tumor cells in vitro at the concentration of 6.3 through 100 mg/ml. Finally, the levels of mRNAs encoding interleukin- (IL-) 1β, IL-6, IL-12, IL-18, and TNFSF15 were enhanced in macrophages that were treated with extracts of turmeric or shiitake mushroom compared with the untreated control. These results documented the immunologically based enhancement of innate immunity in chickens by extracts of plants and mushrooms with known medicinal properties in vitro. In vivo studies are needed to delineate the cellular and molecular mechanisms of action.

Avian coccidiosis is the major parasitic disease of poultry with substantial economic burden to the industry. Coccidiosis is caused by several apicomplexan parasites of the genus *Eimeria* that infect the intestinal tract and are transmitted between birds via ingestion of infective oocysts. Different studies have investigated the immunopotentiating effect of a mushroom on poultry cell-mediated immunity and subsequent protection against coccidiosis. Guo et al. (2004, 2005) demonstrated the protective effects of mushrooms and their polysaccharide extracts (*Lentinus edodes* and *Tremella fuciformis*) against *Eimeria tenella* infection. Dalloul, Lillehoj, Lee, Lee, & Chung (2006) investigated the immunopotentiating effect of a mushroom lectin extracted from mushroom (*Fomitella fraxiena*) on poultry cell-mediated immunity and protection against coccidiosis. When extract injected into 18-day-old chicken embryos followed by a posthatch oral *E. acervulina* challenge infection, lectin treatment significantly protected chickens against weight loss associated with coccidiosis. Injecting embryos with lectin also resulted in significant reduction in oocyst shedding as compared with the control saline-injected birds. Their results from utilizing the mushroom lectin included effective growth promotion and immune stimulation in poultry with coccidiosis. In a recent study conducted by Willis et al. (2012), four different medicinal mushrooms (shiitake, cordyceps, reishi, and oyster) were utilized for their potential immunomodulating properties in *Eimeria*-challenged broiler chickens. These workers evaluated the effects of feeding 5% each of four different medicinal mushrooms, both singularly and combined, via fungus myceliated grain (FMG) to broilers challenged with *Eimeria* at 14 days of age and reared in battery brooder cages. The major findings in this study demonstrated that broilers fed 5% shiitake via FMG were superior in their performance and *Eimeria* protection as opposed to broilers supplemented with reishi, oyster, or cordyceps or a combination of all four. Cordyceps was found to cause some depression in broiler body weights whether or not the bird was experimentally challenged with *Eimeria* at the time; however, it also showed the ability to significantly reduce oocyst shedding.

Infectious bursal disease (IBD) is caused by a virus that is a member of the genus *Avibirnavirus* of the family Birnaviridae. According to the virus virulence and pathogenicity, IBD causes more severe or less severe lesions on the bursa of Fabricius and other organs such as spleen, thymus, and kidneys and may induce immunosuppression and mortality in birds. Ogbe, Mgbojikwe, Owoade, Atawodi, & Abdu, (2008) supplemented chick diets with wild *Ganoderma* mushroom (*Ganoderma lucidum*) at the rate of 0.05%, 0.1%, or 0.2%. Chicks were vaccinated against IBD at 2 and 5 weeks of age. Each feed treatment lasted for 7 days each time before and after vaccinations. The results showed that in both qualitative and quantitative agar gel precipitation tests, there was positive response in all the vaccinated groups at 6 weeks of age, in which chicks fed 0.2% mushroom diet showed the highest positive response (2.5 log2), followed by 0.1% (2.3 log2) and 0.05% (2.0 log2). There was significant increase in the positive response at 8 to 10 weeks of age in all the groups: 3.8 log2, 3.5 log2, and 3.0 log2, respectively. Selegean et al. (2009) investigated the synergistic relations between extracts (the polysaccharide-containing extracellular fractions [EFs] of the edible mushroom *Pleurotus ostreatus*) and BIAVAC and BIAROMVAC vaccines. In the first experiment, by administrating EFs to unvaccinated broilers, they noticed slow stimulation of maternal antibodies against IBD starting from four weeks post hatching. For the broilers vaccinated with BIAVAC and BIAROMVAC vaccines, a low to almost complete lack of IBD maternal antibodies was recorded. By adding 5% and 15% EFs in the water intake, as compared to the reaction of the immune system in the previous experiment, the level of IBD antibodies was increased. Thus the workers believed that by using this combination of BIAVAC and BIAROMVAC vaccine and EFs, good results may be obtained in stimulating the production of IBD antibodies in the period of the chicken's first days of life, which are critical to broilers' survival.

Newcastle disease (ND) is a contagious, highly fatal viral infection affecting many species of domestic and wild birds worldwide and regarded as an Office Internationale des Epizooties (OIE) list A disease (Office Internationale des Epizooties 2001). This is due to the huge economic impact on the poultry industry precipitated following outbreaks of the disease. The literature found inconsistent effect of mushroom against ND. Toghyani, Mohsen, Abbasali, Ali, and Mehdi (2012) reported that the broiler chickens fed diets containing oyster mushroom powder (1% or 2%) had marginally enhanced antibody titer production against ND and influenza viruses compared to those fed control diets. They explained that substances in mushrooms responsible for up-regulating the immune responses may include polysaccharides, glycosides, alkaloids, volatile oils, and organic acids. Daneshmand et al. (2012) evaluated the combined effects of garlic (3%), oyster mushroom (0.2%), and propolis (0.02%) extract on the antibody response to Newcastle disease vaccine (NDV) in broiler chicks. The extract induced a lower antibody titer to NDV at day 21 of age, but there were significantly ($p < .05$) increased antibody titers at 33 and 42 days of age as compared to the control group. The extract treatment increased antibody response to NDV when compared to the antibiotic group at all sampling intervals. Antibiotic-treated chicks showed similar antibody response to NDV at 21 days of age when compared to the control birds, but inclusion of antibiotic increased ($p < .05$) response at 33 and 42 days of age. In contrast to these studies, Daneshmand, Sadeghi, Karimi, and Vaziry (2011) reported that inclusion of oyster mushroom (0.2%) in the broiler diet decreased ($p < .05$) concentration of antibody titer to NDV at 21 days of age, whereas there was no similar significant effect at days 33 and 42 of age. Kavyani, Zare Shahne, Porreza, Jalali Haji-Abadi, & Landy, (2012) reported that different levels of mushroom (*Agaricus bisporus*) had no effect on antibody titers against NDV. However, the sheep red blood cell (SRBC) antibody titer was significantly greater in birds fed the diet containing 0.3% mushroom than those birds fed diets containing 0.5% mushroom or 0.45% flavophospholipol. *Agaricus bisporus* mushroom is also considered a good source of selenium (Giannenas et al., 2010a). Selenium is important due to its function as an antioxidant in organisms; it neutralizes the free radicals that result from many factors but especially by immune response. So humoral immune activity can be improved by selenium source supplementation (Saad, Gertner, Bona, & Santin, 2009). Recently, Fard, Toghyani, & Tabeidian, (2014) reported that chickens fed diets supplemented with 1% oyster mushroom wastes showed marginal enhancement of antibody titers against influenza disease virus and SRBC; chickens fed 2% oyster mushroom diet showed significantly decreased antibody titer against NDV. Some studies showed that none of the lymphoid organs were affected by mushroom inclusion at either 28 or 42 days of age (Fard et al., 2014; Kavyani et al., 2012; Toghyani et al., 2012).

Mushrooms as antioxidants in poultry diet

The poultry industry would greatly appreciate natural antioxidants that could replace synthetic ones and satisfy consumer demands for food products without residues from substances that have the potential to harm human health. Oxidative damage is associated with free radical formation, and oxidative stress causes health deterioration. Superoxide, hydrogen peroxide, and hydroxyl radicals, which are mutagens produced by radiation, are also byproducts of normal metabolism (Cui et al., 2012). In addition to health deterioration, lipid peroxidation is also a major cause of meat quality deterioration, affecting color, flavor, texture, and nutritional value (Halliwell & Gutteridge, 1999). Synthetic antioxidants are currently approved to control lipid oxidation in foods, but consumer concern over their use (Giannenas et al., 2010a) has created a need and prompted research for alternative antioxidants. Recent research on the potential applications of antioxidants from natural products, for stabilizing foods against oxidation, has received much attention (Yildirim et al., 2012). Mushrooms accumulate a variety of secondary metabolites, including phenolic compounds, polyketides, terpenes, and steroids. Total phenol contents ranged from 9.55 to 16.8 mg/g in different mushrooms (*Cantharellus friessi, Cantharellus subcibarius, Cantharellus cinerius*, and *Pleurotus florida*) (Kumari, Reddy, & Upadhyay, 2011). Phenolic compounds (*Fistulina hepatica*, protocatechuic, p-hydroxybenzoic, p-coumaric, and cinnamic acid) are among the most widely distributed plant secondary products. The ability of these compounds to act as antioxidants has been well established (Yildirim et al., 2012). Polyphenols are multifunctional antioxidants by acting as reducing agents, hydrogen-donating antioxidants, and singlet oxygen quenchers (Punitha & Rajasekaran, 2012). In addition, a mushroom phenolic compound has been found to be an excellent antioxidant and synergist that is not mutagenic (Mitra, Jit, Narayan, & Krishnendu, 2014). Phenolic compounds may act directly as antioxidants or prevent underlying oxidative stress–related pathological conditions such as cancer, heart ailments, diabetes, inflammation, gastric ulcer, hepatic damage, and microbial pathogens (Dasgupta, Debal, Ananya, Anirban, & Krishnendu, 2014).

The literature contains abundant evidence of in vitro antioxidant activity of mushrooms. Some common edible mushrooms have been found to possess significant in vitro antioxidant activity (Kalava & Sudha, 2012; Keleş, İlkay, & Hüseyin, 2011), which was well correlated with their total phenolic content (Gan et al., 2013; Huang, Kim, & Chung, 2011). Various concentrations of methanolic extracts from mushrooms exhibited free radical-scavenging activity (Menaga et al., 2013). However, there is only one in vivo study that showed these effects on broiler chicken. Giannenas et al. (2010a) reported that dietary mushroom (*Agaricus bisporus*) at both inclusion levels (10 or 20 g/kg broiler diet) reduced malondialdehyde production in liver, breast, and thigh tissues and elevated glutathione peroxidase, reduced glutathione, glutathione reductase, and glutathione S-transferase compared with the control treatment, the effects being dose dependent. They also observed an increased activity of the four selenoenzymes in the mushroom-supplemented groups compared with control birds. The high selenium content in mushroom might contribute to this desired property. The data showed that antioxidant protective effect was more pronounced at the higher level of mushroom supplementation. Elevated antioxidant enzyme activities could be due to active induction of glutathione synthetic enzymes due to higher selenium uptake or passive sparing of glutathione by decreasing the oxidative load on the cells. Although the latter seems more plausible because malondialdehyde formation was found to be reduced in mushroom-supplemented groups, additional studies are required to determine which mechanism is responsible. It is possible that the antioxidant properties of mushrooms (Dubost, Ou, & Beelman, 2007) are being used by the cells, thus sparing the intracellular antioxidant systems such as glutathione and glutathione peroxidase. Further research, including dietary supplementation with certain mushroom extracts and specified mushroom constituents during certain periods of feeding, is necessary to elucidate the in vivo regulation of the antioxidant defenses in the liver as well as the response of the system to acute oxidative stress.

Effect of dietary mushroom on broilers' performance

The most commonly used cultivated edible mushrooms in the poultry diet are listed in Table 1 along with their appearance and nutritional properties. The literature shows that different levels of mushrooms or their polysaccharides enhanced the feed efficiency in broilers compared to control diet. Guo et al. (2004) conducted an experiment to evaluate the potential prebiotic effects of mushroom polysaccharide extracts, *Lentinus edodes* (LenE) and *Tremella fuciformis* (TreE), and an herb, *Astragalus membranaceus* (AstE), on growth performance. Three extracts (LenE, TreE, and AstE) were supplemented at inclusion rates of 0.05%, 0.1%, 0.2%, 0.3%, and 0.4% from 7 to 14 days of age and compared with an antibiotic treatment group (0.002% virginiamycin [VRG]) as well as a group of nonsupplemented birds. The results showed that body weight (BW) gain, feed intake, and feed conversion ratio (FCR) of the extract-supplemented groups were not significantly different from those of the antibiotic group. Generally, birds fed with LenE showed higher BW gain and lower FCR from 7 to 28 days of age than those fed with TreE and AstE, and LenE 0.2% was considered the optimal inclusion rate for enhanced broiler growth. In this experiment, a significant effect of both VRG and the extracts on performance was found only in the first two weeks, and especially during the supplemental period. This suggests that possible beneficial effects might have demonstrated antibacterial, antiviral, or antiparasitic activities in chickens when given to the birds for a short period or as an adjuvant of vaccines (Pang, Xie, & Ling, 2000). Until now, the use of polysaccharides of mushroom as growth promoters in poultry has been quite limited. Giannenas et al. (2010a) gave three dietary treatments, a nutritionally balanced basal diet or the basal diet supplemented with 1.0% or 2.0% of dried mushroom (*Agaricus bisporus*), for 6 weeks on an ad libitum basis. Results showed that dietary mushroom inclusion at 2.0% improved both growth performance and feed efficiency compared with control diet at 42 days of age. Willis et al. (2007) evaluated the effect of combined shiitake mushroom (*Lentinus edodes*) extract with probiotics (PrimaLac) on the growth and health of broiler chickens. In trial 1, six dietary treatments were given: (1) control feed + ad libitum tap water, (2) control feed + skip-a-day mushroom water, (3) control feed + ad libitum mushroom water, (4) probiotic feed + ad libitum tap water, (5) probiotic feed + skip-a-day mushroom water, (6) probiotic feed + ad libitum mushroom water. A known weight (100 g) of dried shiitake mushroom was extracted with 1 L of distilled water and kept at 4°C before use as an additive in the water that was given to the chicks starting at day 1 and continuing until day 21. In trial 2, the performance of broilers 3 to 7 weeks

Table 1. Some nutritional properties and benefits of commonly used edible mushrooms in poultry diets.

Scientific name (common name)	Appearance	Nutritional properties	Benefits in poultry	References
Pleurotus ostreatus or *Pleurotus ssp.*(oyster mushroom)	White, gray-brown, or ivory colored and resembles oyster shell-like shape. The white gills run down its short, off-centered white stalk.	Rich in protein, fiber, carbohydrates, vitamins, and minerals. Among thevolatile compounds that constitute edible mushroom flavor, 1-octen-3-ol is considered to be the major contributor.	Supplementation of oyster mushroom (5%) in broiler's diet produced the highest average gain in body weight relative to control group; the ileum relative length at 21 days of age was higher; decreased the high-density lipoprotein concentration of plasma in broilers.	Cohen, Persky, and Hadar (2002) Daneshmand et al. (2011) Willis et al. (2013)
Agaricus bisporus(button mushroom, champignon)	The original wild form bears a brownish cap and dark brown gills but more familiar ones are with a white cap, stalk, and flesh and brown gills.	Fairly rich in vitamins such as vitamin B and minerals such as sodium, potassium, phosphorus, and selenium; raw mushrooms are naturally cholesterol and fat free.	Dietary button mushroom inclusion at 20 g/kg improved both growth performance and feed efficiency of broiler chicks as compared with control diet at 42 d of age. At 30 g/kg diet induced favorable influences on immune responses of broilers without any adverse effects on performance criteria.	Beelman et al. (2003) Giannenas et al. (2010a) Kavyani et al. (2012)
Lentimula edodes (shiitake or shiang-gu)	Dark brown cap with white stalk.	Contains high protein with all essential amino acids; well-known natural source of vitamin D; adenine and choline content effective in preventing the occurrence of cirrhosis of the liver as well as vascular sclerosis.	The average body weight of 49-day-old broilers attained 2.97 and 2.65 kg with supplementation of 5% and 10% shiitake, respectively. Furthermore, shiitake mushroom (0.5%) in layer's diet decreased cholesterol concentration of egg yolk.	Murata et al. (2002) Hwang et al. (2012) Willis et al. (2013)
Ganoderma lucidum (reishi)	Large, hard, and leathery fungus with sessile or stalked basidiocarps having tiny pores under surface.	A good source of crude protein (16.79%) and carbohydrates (63.27%). Glucose accounted for 11% and metals 10.2% of dry mass (K, Mg, and Ca being the major trace components).	The average body weight of 49-day-old broilers attained 2.92 kg with supplementation of 5% or 10% reishi mushroom. Supplementation of reishi mushroom in Lorman brown pullet's diet found an average live body weight of 1.7 kg at 35 weeks of age with a hen-day egg production of 73.8%.	Bao, Wang, Dong, Fang, and Li (2002) Ogbe et al. (2009) Ogbe and Obeka (2013) Willis et al. (2013)

withdrawn from the mushroom extract was evaluated along with the comparative level of fecal bifidobacteria in the control and mushroom extract treatment. Significant differences in female weight gain (treatment 4: 0.62 vs. treatment 1: 0.54 kg) and male spleen weights were observed. In trial 2, significant differences were observed in male weight gain (treatment 2: 2.40 vs. treatment 4: 1.12 kg), male and female fat pads, male bursa weights (treatment 3: 0.15 vs. treatment 6: 0.39), female carcass yield percentage (treatment 1: 77.8 vs. treatment 4: 66.4), and feed consumption and efficiency. Body weights were severely depressed in the male broilers receiving the probiotics feed in treatments 4, 5, and 6 but not in the female broilers. These results indicated that performance differences in gender occurred with additives during different grow-out periods, and mushroom extract promotes bifidobacteria growth in broiler chickens after 4 weeks of withdrawal. This may provide an indication that bifidobacteria proliferation is enhanced with the mushroom extract. As demonstrated by another study (Guo et al., 2004), mushroom and herb extract diets reduced *Bacteroides* spp., *Enterococci*, and *E. coli* numbers, but increased numbers of bifidobacteria and lactobacilli. This shows that probiotics and mushroom extract offered no combination potential for weight gain, which was compromised in this study, but possible health-enhanced characteristics. Similarly, Daneshmand et al. (2011) supplemented a basal diet with 0.2% of oyster mushroom (*Pleurotus ostreatus*) or 0.45% of probiotic, or their combination. Results showed that the inclusion of the oyster mushroom powder decreased feed intake and body weight gain of broiler chicks during 1–21 days of age. Dietary supplementation with mushroom or probiotic decreased bird's body weight during the entire experiment. The combination of mushroom and probiotic had no effect on birds' performance. Inclusion of the probiotic in the diet decreased relative weight of abdominal fat. Mushroom, probiotic, and their combination had no effect on relative lengths of duodenum and jejunum at 21 and 42 days of age. However, ileum relative length at 21 days of age was higher ($p < .05$) in chicks that received oyster mushroom in their diet. Experimental diets did not affect antibody response against Newcastle disease virus, triglyceride, cholesterol, low-density lipoproteins, and very-low-density lipoprotein concentrations of plasma.

Giannenas et al. (2011) investigated the consequences of consumption of *Agaricus bisporus* mushroom on turkey poults fed ad libitum a basal diet supplemented with the dried mushroom at levels of 0%, 1.0%, or 2.0% to 10 weeks of age. The results showed that at 28 days of age, no significant differences of body weight gain and feed-to-gain ratio were noted among treatments. At 56 days of age, the group with the highest level of mushroom presented better ($p < .05$) feed conversion ratio values compared to the control group. At 70 days of age, the group with the highest level of mushroom had better body weight and weight gain values than the low level of mushroom group, which in turn was better than the control group. A similar pattern was found for feed conversion ratio values among the experimental groups. Similar results were obtained by Kavyani et al. (2012), who reported that supplementing the broiler diet with 3.0% mushroom (*Agaricus bisporus*) could induce favorable influences on immune responses of broilers without any adverse effects on performance criteria. Giannenas et al. (2011) also reported that mushroom supplementation resulted in changes of intestinal microbiota and gut morphology. Supplementation increased lactobacilli loads in the ileum, and both lactobacilli and bifidobacteria loads in the caecum, and affected the ratios of *Lactobacillus* spp. to *E. coli* compared to control diet (Giannenas et al., 2010b). It is suggested that the establishment of *Lactobacillus* spp. prevents the colonization of pathogenic bacteria by competitive exclusion (Van Der Wielen, Lipman, Van Knapen, & Biesterveld, 2002). Lactobacilli and bifidobacteria compete against potential pathogens for nutrients and binding sites, thereby reducing the intestinal population of pathogens (Rolfe, 2000). Furthermore, lactobacilli and bifidobacteria produce organic acids and other bactericidal substances (Jin, Ho, Abdullah, & Jalaludin, 1998), all of which can suppress the colonization of the intestine by pathogenic bacteria. It is possible that mushroom fermentable polysaccharides favored the growth of lactobacilli and bifidobacteria populations and inhibited that of *E. coli*. Other researchers (Sims, Dawson, Newman, Spring, & Hooge, 2004; Stanley et al., 2000) have reported that lactobacilli and bifidobacteria bacteria increased in poultry intestinal content when birds were fed specific prebiotics, such as mannan and fructo oligosaccharides, which presumably were high in mushrooms given their high content in sugars. Giannenas et al. (2011) reported that significant increase in duodenal, jejunal, and ileal villus height was noted in birds fed a diet with supplementation of mushroom. The intestinal villous can be regarded as the capacity of the bird to absorb nutrients from the feed. Longer villi are typically associated with excellent gut health and high absorptive efficiency.

Willis et al. (2013) evaluated the feeding of four medicinal mushrooms (shiitake [*Lentinus edodes*], reishi [*Ganoderma lucidum*], oyster [*Pleurotus ostreatus*], and cordyceps [*Cordycepss inensis*]) at two levels (5% or 10%) on broiler production performance. The results showed that the oyster mushroom (5%) group produced the highest average body weight at 3.21 kg, while the cordyceps (10%) group produced the lowest at 2.33 kg. A higher oocyst count and increased heterophil percentage were observed in the reishi (5%) group. Similarly, Toghyani et al. (2012) reported that oyster mushroom powder at an inclusion level of 2.0% had favorable effects on performance criteria of broiler chicks reared to 28 day of age. In contrast to these studies, Fard et al. (2014) reported that inclusion of 1% oyster mushroom wastes had no significant effect on the whole period BW and BW gain of broilers, only marginally increasing these indices. On the contrary, using 2% of mushroom wastes decreased BW. Supplementation of 1% mushroom wastes led to the significant increase of feed intake, while no impact of 2% mushroom wastes was observed. Increased feed intake of chickens using 1% mushroom wastes might be the reason for the insignificant increase in BW of broilers. In addition, the slight improvement of BW through supplementation of 1% mushroom wastes could be explained by the oligosaccharide existence in the mushroom cell wall and its growth promoter role as a prebiotic, which may have positively affected the microflora balance of the intestinal tract (Chou, Sheih, & Fang, 2013). In addition, the decreased BW of chickens fed 2% mushroom wastes in the whole period might have been partially due to the high fiber contents and subsequently reduced nutrient utilization of the chickens. This BW decrease finally led to the higher FCR in this group.

These results indicate that the birds responded differently to the different mushroom species and levels of inclusion in regard to body weight. However, different fungi and levels of their inclusion in the basal feed can impact production performance responses significantly and enhance the overall health of broiler chickens.

Limited evidence exists on the mechanisms through which mushrooms exert their growth-promoting activities. The effect of mushroom polysaccharide extract was more pronounced under disease challenge rather than that under “normal” states. Polysaccharide extracts increased the activity of intestinal microflora and fermentation end products, such as volatile fatty acids, and increased proliferation of the gastrointestinal tract.

Effect of dietary mushroom on layers’ performance

There is limited information on the effects of mushrooms and their extracts on layer performance and egg quality characteristics. Ogbe et al. (2009) reported that Lorman brown pullets fed diets with the supplementation (0.1% or .2.0%) of *Ganoderma* mushroom recorded an average live body weight of 1.3 kg, and by 35 weeks of age their average weight was 1.7 kg/bird with a hen-day egg production of 73.8%. Although feed intake did not show significant difference in all the groups, the feed-to-gain ratio was better in birds fed a diet with 0.2% mushroom (3.3) than in those fed 0.1% or 0.05% mushroom (3.4 or 3.5) or control (3.6), which showed that supplementation with mushroom resulted in better feed efficiency in pullets. They further reported that hen-day (% of laid eggs per bird/day) and hen-housed (number of eggs laid per bird/day) egg production were 72.1% and 270, respectively. The eggs laid by pullets fed mushroom-supplemented diets were large brown eggs; the egg weight was recorded as 0.1 kg and egg shape index was 85.7. In another study, Hwang et al. (2012) reported that egg production was significantly increased by the shiitake mushroom supplementation (0.25% or 0.5%) compared to the control, but other laying parameters were not affected. The results indicated that Haugh unit was significantly increased in both shiitake groups, but a thinner egg shell was observed in the shiitake 0.25% group and thicker egg albumen in the shiitake 0.5% group compared to the control group. Dietary addition of shiitake mushroom did not induce any effect on sensory evaluation of eggs. Among the fatty acid composition of egg yolk, linoleic acid and total n-6 and polyunsaturated fatty acid contents were increased, whereas palmitoleic acid and α-linolenic acid were decreased in the shiitake 0.5% group. Cholesterol concentration of egg yolk was significantly decreased in the shiitake 0.5% group compared to the control group.

Molting in poultry is used to rejuvenate hens for a second or third laying cycle. Feed withdrawal was once the most effective method used for molt induction; however, it has been phased out due to food safety and animal welfare concerns. In some studies, mushrooms were used as a safe and effective alternative for inducing molt, enhancing immunity, reducing *Salmonella* growth, and returning to egg production. Willis et al. (2008) evaluated the efficiency of medicinal mushroom (shiitake) and pokeweed extract combined with alfalfa on the induction of a molt, weight loss, *Salmonella* population, and postmolt egg production in older hens. The results indicated that body weight loss, ovary regression, and return to egg production were not adversely affected by the two extracts utilized in this experiment. A greater decrease in the natural *Salmonella* population in the ceca and crop was obtained with the combination of full-fed alfalfa plus mushroom extract in molting hens, and it induced a comparable molt with feed withdrawal. The mechanism is not clear regarding the combined effect of alfalfa and mushroom extract to decrease the *Salmonella* population. A possible explanation could come from the work of Hinton et al. (2000). They indicated that feed withdrawal purges the crop of fermentable carbohydrates that lactic acid–producing bacteria require for growth and lactic acid production. This action generally allows an increase in the numbers of Salmonellae and other Enterobacteriaceae. The polysaccharides provided by the mushroom extract could have optimized this process. There was also a significant reduction of *Salmonella* in the crop with the combination of alfalfa meal plus pokeweed. Willis et al. (2009) evaluated the use of feeding fungus-myceliated (FM) sorghum grain on molt induction, postmolt production, *Salmonella*, and humoral immunity response in laying hens. The results showed that egg production for the FM group ceased completely by day 5, whereas hens in the FM + alfalfa group ceased egg production by day 6. The percentage of body weight loss decreased significantly in FM group (35%) and FM + alfalfa group (37%) than control group (57%). Return to egg production differed between treatments with higher production beginning in the FM group and ending in the FM + alfalfa group. However, no differences in antibody production could be attributed to the supplementation of fungus-myceliated grain.

This was the first report concerning the effect of fungal-based supplement on humoral immune response in molting layer hens. The reason the results from this study did not show any humoral immunity enhancement responses may be the low inclusion levels of the meal form of fungus-myceliated sorghum grain. The results suggest that some *Salmonella* invasion in the organs was reduced by the FM diet alone and in combination with the alfalfa meal. The reduction observed in the crop and ceca was not as great as that observed in a previous experiment conducted by Willis et al. (2008). This is expected because in the previous study a concentrated liquid extract from the shiitake mushroom was utilized.

Conclusions

Summarizing the published data presented in this review article, it can be concluded that mushrooms and their polysaccharides can play important roles in poultry production. Mushrooms in broilers' diet may be used as growth promoters instead of antibiotics. The effect of mushroom polysaccharide extract was more pronounced under disease challenge rather than that under "normal" states. The use of mushroom in layer diets is beneficial in improvement of egg production and quality. Mushrooms may be used as a safe and effective alternative for inducing molt, enhancing immunity, reducing *Salmonella* growth, and returning to egg production. Further studies are needed to investigate the effects of mushrooms to improve productive performance in chickens and to illuminate the possible modes of action related to the gut ecosystem and immune response.

Declaration of interest

The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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