The Open Agriculture Journal

Content list available at: https://openagriculturejournal.com

REVIEW ARTICLE

Mushroom Supplementation in Promoting Health and Performance of Poultry: Review

Assen Ebrahim Seid[1,*]

[1]*Department of Animal Science, Aksum University, P.O. Box 314, Aksum, Ethiopia*

Abstract:

This review paper aims to update and discuss the latest data available with respect to the effects of mushrooms in promoting the health and performance of broiler and layer chickens. Most studies proved that different preparations of mushrooms from diverse mushroom species improved feed utilization efficiency, growth rate, egg production, and quality traits. Mushroom supplementation decreased the count of pathogenic bacteria (*Clostridium spp*., *Coliforms*, and *E.coli* and increased that of beneficial ones (*Lactobacillus spp*. and *Bifidobacterium*) in both broiler and layer chickens. Inclusion of different preparations (powders, extracts, leftovers, *etc*.) of mushrooms resulted in lower cholesterol and other lipid metabolites in poultry meat and eggs. Some studies reported no significant effect of mushroom on the performance of broiler and layer chickens, however, it is concluded that mushrooms, in various forms, could be included in poultry diets without any harmful effect on their health. Further research works are also suggested to investigate the opportunities for making mushrooms part of the compound poultry feed ingredients in countries like Ethiopia.

Keywords: Broiler, Feed additives, Layers, Mushrooms, Poultry, Chickens.

Article History	Received: February 10, 2023	Revised: April 18, 2023	Accepted: May 15, 2023

1. INTRODUCTION

Feed constitutes the major input that decides the profit margin in the poultry industry [1 - 3]. In economic terms, feed cost accounts for 60-75% of the total cost of poultry production [4]. The poultry industry is also under increasing pressure to produce good quality and high quantitative products for consumers [5]. Therefore, there is a need for new intensive techniques to allow efficiency and augment poultry productivity. In this view, feed additives (antibiotics, probiotics, organic acids, essential oils, prebiotics, enzymes, *etc*.) help in improving the efficiency of feed utilization and thus reducing the high cost of feed [6].

The use of antibiotics in poultry feed as a growth promoter has been beneficial in the improvement of production parameters and disease prevention [7]. However, the continuous and over application of in-feed antibiotics in poultry production has created public and animal health hazards because of concern over the development of antibiotic resistant bacteria [8 - 11]. Removal of antibiotics as growth promoters has then led to animal performance problems, feed conversion ratio, incensement, and a rise in the incidence of certain animal diseases [12]. Consequently, there has been a growing interest in finding viable phytogenic or plant-derived replacements of antibiotics in poultry feed for production enhancement and disease prevention [13, 14]. Natural materials have been considered as safe feed additives to improve the efficiency of feed utilization and growth performance of poultry [15 - 17]. Recently, mushrooms have been investigated as safe alternative natural products to be included in poultry diets [18].

Traditionally, mushrooms have been grown for human food as well as pharmacological purposes in different countries [19]. Medicinal mushrooms are an increasing focus of research due to their capacity to exert growth-promoting, antioxidant, immunostimulatory, antimicrobial, anti-inflammatory, hypo-cholesterolemic and probiotic activity [20, 21]; thus can be used effectively as an alternative to antibiotic growth promoters for poultry [22]. Although the mushroom has long been cultivated and utilized in different parts of the globe, there has been poor consumption habits in Ethiopia. In recent years, there has been a growing demand for mushrooms by consumers, particularly in urban areas of the country [23], and more people started involving in mushroom cultivation business. Nevertheless, incorporating mushrooms in a commercial poultry diets has not received much attention in Ethiopia in particular and Africa in general. It also was reported that in spite of the medicinal and nutritional values of

* Address correspondence to this author at the Department of Animal Science, Aksum University, P.O. Box 314, Aksum, Ethiopia; Tel: +251936652658; E-mail: hassenwukro@yahoo.com

different edible mushrooms, utilization is limited for animal production globally [24]. Studies have been conducted to evaluate the effect of including various mushroom preparations (extracts, powders, leftovers, *etc*.) in poultry diets. The objective of this review was, therefore, to update and discuss the latest scientific information available with respect to some medicinal mushrooms such as Flammulina *velutipes*, *Pleurotus ostreatu*s, *Lentinus edodes* and *Agaricus bisporus* proven to be effective in promoting the health and performance of broiler and layer chickens.

2. METHODOLOGY

This review paper attempted to collect and synthesize information from different source materials, mainly journals, from previous research works on the effects of common mushrooms on the health and performance of both broiler and layer chickens.

3. REVIEW

3.1. Nutrient Composition and Functional Components of Mushrooms

The constituents of commonly used mushrooms in the poultry rations are presented in Table **1**. The highest crude protein (23.0%) and the lowest crude fiber (7.8%) have been reported in the fermented mycelium of Flammulina velutipes mushroom, followed by *Pleurotus ostreatus* powder. In another study conducted to evaluate the constituents of nine mushroom species, the crude protein content ranged from 16.47% in P. eryngii to 36.96% in P. ostreatus (black oyster) [25]. The presence of higher crude protein content in *Flammulina velutipes* mushrooms suggests its potential to be used as a protein source feed ingredient. Most of the mushroom preparations had CP content higher than maize grain (8.5%) [26], which is the most commonly used conventional feed ingredient in poultry rations. The value for crude fiber was higher in the stalk part of Flammulina velutipes (Table **1**). Some findings have also shown high levels of dietary fibre (24.47–46.62%) [25]. With respect to energy content, mushrooms have been reported to be low calorific values [27]. The ether extract value ranged from 1.5 percent in the stalk waste of Flammulina velutipes to 3.8 percent in the waster medium of *Cordyceps militaris mushroom.* The variability in the nutrient composition could be attributed to the differences in strain, substrate development stage [28], climatic condition, and part of the mushroom used. Vargas-Sánchez *et al*. [29] reported about 3.9 and 7.9 g kg^{-1} of lysine and methionine, respectively, in *Pleurotus ostreatus* mushroom powder. Eun-Ju *et al*. [30] have reported about 4.1, 5.1 and 0.3 g kg^{-1} of lysine, cysteine and methionine in ethanolic extracted *Lentinula edodes* mushrooms, respectively. Consumption of mushrooms helps in obtaining all amino acids considered to be essential for simple stomached animals' nutrition like chickens [25]. Pathania *et al*. [31] reported that mushrooms are also rich in vitamin B12 and folic acid, which are uncommon in vegetables.

In addition to the proximate constituents of mushrooms, different functional or active components are found in mushrooms fruiting bodies and mycelium [35]. The major functional components of mushrooms with their mode of action on broiler and layer chickens are summarized in Table **2**. The beta-glucan is the main polysaccharide and bioactive component in medicinal mushrooms. It is recognized as potent immunological stimulators in animal cells, and the contents of β-glucan ranged from 1.58 to 16.91 mg g^{-1} of dry matter among the nine edible mushrooms [25]. It has also been reported that different medicinal mushrooms are rich in phenolic compounds, especially phenolic acid, which is the major naturally occurring antioxidant component found in mushrooms to help improve the antioxidant status of chickens [36].

Table 1. Chemical composition (%DM) of some mushroom species used in different experiments on broiler and layer chickens.

Species	Part Used	Chemical Composition						References
		DM	CP	EE	CF	Ash	ME (MJ/kg)	
Flammulina velutipes	Stalk waste	85.3	12.8	1.5	20.2	8.4	15.2	[19]
Pleurotus ostreatus	Powder	93.0	21.7	2.3	ND	6.6	7.9	[32]
Flammulina velutipes	Fermented mycelium	89.5	23.0	2.6	7.8	6.8	ND	[33]
Pleurotus ostreatus	Vegetative Mature *P. ostreatus*	16.6	22.6	5.0	16.3	8.2	ND	[34]

Abbreviations: CF=crude fiber; CP=crude protein; DM=dry matter; EE= ether extract; ME=metabolizable energy; ND=not determined

Table 2. Some functional components of mushrooms with their mode of actions and roles on broiler and layer chickens.

Functional Components	Mode of Actions and Roles	References
Polysaccharides such as β-glucans and mannans	Increasing immune response by improving the growth of beneficial microbial population(lactobacilli) and inhibiting harmful biota of gastrointestinal tract, and hence; improving digestibility, feed conversion ratio and performances Resistant to birds' digestive enzymes, aiding in the increase of faeces volume and intestinal mobility. Lowering cholesterol through reducing the absorption or increasing excreta	[19,25,37,38]

(Table 2) contd.....

Functional Components	Mode of Actions and Roles	References
Phenols	Improving the antioxidant status of chickens by Increasing serum antioxidant enzyme activities	[36]
Selenium	Improving the antioxidant status of chickens by Increasing serum antioxidant enzyme activities	[36]
Vitamin C	Improving the antioxidant status in chickens	[21]
Dietary fiber	Lowering cholesterol level both in chicken meat and eggs through increasing bile acid excretion and affecting lipid synthesis Promoting defecation and improves gut flora	[19,39,40]

Fig. (1). Some commonly used mushrooms in poultry rations. (**a**) *Flammulina velutipes*, (**b**) *Pleurotus Ostreatus*, (**c**) *Lentimus edodes*, and (**d**) *Agaricus bisporus*.

3.2. Effects on Gut Health and Immunity

Experiments using different types and forms of mushrooms on gut health and immunity of broiler and layer chickens produced promising results. Mahfuz *et al*. [24] reported that winter *Flammulina velutipes* (Fig. **1**) stalk helps to control pathogenic bacteria as well as increased beneficial bacteria in the cecum to keep sound gut health in layer chickens. Willis *et al*. [41] have shown that broiler chickens receiving *Lentinula edodes* extract had a significant increase in the population of bifidobacteria in the fecal samples than the control (no additive). Similarly, dietary spent mushroom (Cordyceps militaris) substrate resulted in significantly higher numbers of *lactobacillus spp*., and *Bifidobacterium* in the cecum and decreased numbers of *Clostridium spp., Coliforms*, and *E.coli* compared to the control group [42]. Supplementation of broiler chicken's diets with Reishi, *Ganoderma lucidum*, Fungus Myceliated Grain (FMG) at 5% level of inclusion had significantly more oocysts shed in the fecal droppings at 49 days of age than any other treatment [20]. The observed improvement in the intestinal health of chickens is attributed due to the presence of biologically active compounds such as fibre, glucans, phenols, and other active ingredients in mushrooms [18, 43].

Results from Mahfuz *et al.* [24] suggested that supplementation of *Flammulina velutipes* mushrooms (3-5%) in laying hens' diet decreased the count of pathogenic bacteria (*Clostridium spp*., *Coliforms*, and *E.coli* and increased that of beneficial ones (*Lactobacillus spp*. and *Bifidobacterium*). These strong antimicrobial effects of mushrooms might be due to the ability to change cell membranes and cause ion leakage, thus making microbes less virulent [44]. In another study, Mahfuz *et al*. [19] demonstrated that feeding *F. velutipes mushroom* stalk waste at 2% level can be an effective way of improving the immunity in broilers. It has also been demonstrated that broilers experimentally challenged with *Eimeria* were more responsive to treatment with mushroom FMG than those who obtained a natural infection [45]. A trial conducted [46] using Eimeria-infected chickens showed that mushroom extract-fed group showed a significant development of gastrointestinal tract (GIT) compared with the non-fed group. Polysaccharides from medicinal mushrooms generally do have bioactive effects, and hence, these polysaccharide extracts might increase the activity of intestinal microflora and fermentation end-products such as volatile fatty acids (VFA) and increased proliferation of GIT [38]. According to Muthusamy *et al*. [47], the polysaccharides, especially ß-glucan substances, extracted from mushrooms had significant immune stimulatory functions in broiler chickens. A significant higher antibody response against Newcastle disease and infectious bursal disease was noted in *Flammulina velutipes* mushroom stalk waste fed broiler chickens and concluded that feeding. *Velutipes* stalk waste at a 2% level can be an effective way of improving the immunity in broilers Mahfuz *et al*. [19]. According to Abou-Zeid *et al*. [18], *Pleurotus ostreatus* mushrooms could be safely used in broiler feeding as natural feed additives at 2 g kg^{-1} diet with superior effects on their immune response.

3.3. Effects on Broiler Performance

Most findings highlighted the positive growth performances of broilers supplemented with various forms of mushrooms. Polysaccharide extracts of two mushrooms (*Lentinus edodes* and *Tremella fuciformis*) inclusion prompted the growth performance, feed intake and feed conversion ratio of broiler chickens compared to the control group, but were not significantly different from those fed with antibiotic treatment group (20 mg kg^{-1}, virginiamycin (VRG) [38]. Giannenas *et al*. [37] have also found increased performance of broiler chickens fed with 10 and 20 g kg^{-1} of an edible *Agaricus bisporus*. In a study with Japanese quails, Asadi- Dizaji *et al*. [32] found that supplementation with mushroom (*Agaricus. bisporus)* at 2% significantly increased ($p<0.05$) weight gain and feed intake compared to the control. The possible mechanisms regarding mushrooms include changes in the intestinal microbiota, increased nutrient digestibility, increased feed intake and absorption, enhanced nitrogen absorption, improved immune response, and antioxidant activity [48]. In another study conducted to evaluate the feeding of four medicinal mushrooms *via* fungus myceliated grain (FMG), reduced performance was observed in broiler chickens fed Reishi (*Ganoderma lucidum*) and Oyster (*Pleurotus ostreatu*s) FMG supplemented diets compared with those fed diets supplemented with *Lentinus edodes* FMG [20]. Dietary inclusion of five levels (0, 0.5, 1.0, 1.5, and 2.0 g kg^{-1} of diet) of edible mushroom powder (*Agaricus bisporus*) positively affected broiler weight gain and feed conversion ratio [49]. According to Abou-Zeid *et al*. [18], *Pleurotus ostreatus* mushrooms could be safely used in broiler feeding as natural feed additives at 2g kg^{-1} diet with superior effects on their productive performance.

An increase in daily body weight gain of broilers fed with *Agaricus bisporus* mushroom was also noted by Guimarães *et al*. [50]. Daneshmand *et al*. [51] however found negative effects following administration of oyster mushroom powder (2 g kg^{-1}) in male broiler chickens. It has also been documented that dried *P. ostreatus* (oyster mushroom) waste at 1% negatively affected body weight gain and feed conversion ratio of broiler chickens should be added (a feed additive for broiler chickens, which might be due to the high fibre contents in the mushroom additive) [52]. Replacement of *Pleurotus ostreatus*-colonized substrate in standard diet (100-200g kg^{-1}) of broiler chickens has been found to be effective for improving body weight, feed intake and feed conversion ratio [53]. It has been reported that the improved growth and feed utilization efficiency of birds supplemented with natural materials is due to their appetite and digestion stimulating properties [54 - 56]. No significant differences were observed in daily body weight gain, feed intake, and feed conversion ratio when *F. velutipes* mushroom stalk waste was incorporated at 1 and 2% in broiler rations [19]. In another experiment, *Agaricus bisporus mushroom* powder and flavophospholipol inclusion, as individual factors, produced positive effect on weight gain and feed conversion ratio of broiler chickens [50]. The observed variation between results on broilers growth performance could be attributed to the difference in the type of mushroom species used, forms offered (powder, extracts, leftover, *etc*.), supplement dose, and may partly be due to the difference in the type of broiler breeds under investigation.

3.4. Effects on Laying Performance and Egg Quality Traits

Unlike broiler chickens, studies are limited regarding the effects of feeding different forms of mushrooms on laying performance and egg quality parameters. Hwang *et al.* [57] reported that dietary supplementation with shiitake (*Lentinula edodes)* mushroom powder up to 0.5% positively affects egg production, egg quality, and fatty acid composition of eggs. It was observed that feeding *F. velutipes* mycelium had no adverse effects on egg production percentage, feed intake, and feed conversion ratio in laying hens, but the egg weight was found greater ($p < 0.05$) in the 1% and 3% mushroom-fed groups than the control diets [32].

Recently, Karaalp *et al.* [22] evaluated the effects of supplementing apple cider vinegar (ACV) and feed mushroom (*Agaricus bisporus*) stalk separately and in combination on performance and certain egg characteristics. Their study found a lack of significant effect of dietary treatments on any performance criteria, and physical external and external egg quality characteristics. Another study by Yoshida *et al*. [58] demonstrated that supplementation of fermented mushroom bed (*Flammulina velutipes*) in a laying hen diet (3%) improved egg production and decreased damaged eggs due to broken/ soft shells by one-sixth than the control group, which might be associated with the potentials of mushroom in reducing stress conditions. Hens fed dietary spent mushroom (*Cordyceps militaris)* substrate had higher egg weight and feed conversion ratio than non-supplemented group ($p<0.05$), but hen-day egg production and feed intake were not affected by treatment groups [42, 59]. Kim *et al*. [60] also reported a lack of difference in egg production, egg mass, egg weight, feed conversion ratio, feed intake, and most internal and external egg quality parameters, but significantly heavy egg yolks were reported for laying hens fed fermented spent mushroom(*Hypsizygus marmoreus)* substrate in corn-soy based experimental diet. It has also been observed that the inclusion of the dried edible portions of the fruiting body of *Cordyceps militaris* mushrooms could be employed as a new feed additive that offers potential benefits for elevating egg mass and producing lower cholesterol eggs [39]. The improvement in egg production parameters with phytogenic feed additives may be due to the provision of certain functional compounds that improve digestion and absorption of nutrients in the digestive tract [61].

3.5. Effects on Blood Biochemistry

Blood biochemical parameters reflect the health [61] of an animal and are vital indicators of the physiological and nutritional status of an organism as well as the quality of feed [62]. Dietary supplementation of *Flammulina velutipes* stalk waste at 1 and 2% level of inclusion resulted in significantly lower total cholesterol and high density lipoprotein cholesterol than the control diets [19]. The cholesterol concentration of egg yolk significantly decreased in egg laying chickens supplemented with shiitake (0.5%) compared to the control group (basal diet with no shiitake mushroom) [32]. Conversely, Mužić *et al*. [63] reported no effect of Shiitake (*Lentinus*

edodes) mushroom on the cholesterol content of egg yolk. Daneshmand *et al*. [52] found that inclusion of 2 g kg^{-1} oyster mushroom power significantly reduced the high density lipoprotein concentration than the probiotic treatments in the 42 days intervention time, whereas this level of inclusion did not bring significant change in the other lipid parameters when compared to the control and probiotic treatments. In hens, dietary spent mushroom supplementation decreased total cholesterol, LDL-cholesterol, and triglycerides ($P<0.05$) in laying hens [59]. Shah *et al*. [64] reported the anti-cholesterol property of mushrooms. Other studies also proved that phytogenic feed additives such as garlic, fenugreek, coriander, and garden cress are effective in lowering cholesterol concentration in broiler and layer chickens [65 - 68]. Ming-Yei *et al.* [69] indicated that both enoki mushrooms (*Flammulina velutipes*) extract and powder, at 3% level of inclusion, are capable of reducing the level of total cholesterol, triglycerides, low-density lipoprotein cholesterol and high density lipoprotein cholesterol in the serum and liver of the hamsters. In the layer rations, supplementation of *Pleurotus eryngii* mushrooms resulted in significantly low serum triglycerides and serum cholesterol compared to the control fed group [33]. Schneider *et al*. [70] observed that groups that received oyster mushroom soup showed a significant reduction in triacylglycerol concentrations and oxidized low density lipoprotein levels in humans. Addition of edible mushroom (*Agaricus bisporus*) powder showed an overall decrease in blood lipid metabolite profiles of broiler chickens fed for a period of 42 days [50]. Sogunle *et al*. [27] also suggested that the administration of oyster mushroom in water and feed at 15 ml/liter and 750 ppm, respectively, could be adopted in cockerel chickens' for improved blood lipid profile. Beta-glucan and its derivatives in medicinal mushrooms had cholesterol lowering effects by reducing the absorption or increasing faecal excretion [71]. Feeding mushrooms may also involve suppression of endogenous cholesterol biosynthesis by inhibiting the 3-hydroxy-3- methylglutaryl coenzyme A (HMG-CoA) reductase activity, which is the rate-limiting enzyme of cholesterol biosynthesis [72].

3.6. Hazards of fungal feed additives

It has been known for a long time that it is hazardous to eat or use as feed some of the larger fungi species, *i.e.*, mushrooms. This might be due to the fact that several mycotoxins can be produced by hazardous fungi [73]. Fortunately, various enzymes produced by mushrooms contribute to an antifungal activity [74] and can also act to decrease the toxicity of mycotoxins [73]. Previous research works demonstrated positive health and performance upon feeding different forms of mushrooms in both broiler and laying poultry [11, 19, 25, 59]. The potential of mushroom-forming fungi for the mitigation of mycotoxin contamination in cereal products has also been reviewed by Savoie *et al*. [74]. The same authors further suggested that through proper storage conditions (including rapid drying and crushing), the risk of mycotoxins in the mushroom can be minimized.

CONCLUSION

A number of findings confirmed that inclusion of different forms of mushrooms in the diets of both broiler and layer chickens had the potential to produce desired quality and quantity of poultry products without the using antibiotics. Yet, the potential of different mushroom spices has been untapped. Hence, this requires concentrated efforts for wider utilization of mushrooms as safe natural alternative to antibiotic growth promoters. Taking the manifold benefits of mushrooms into account, there is a need to exploit their potential beyond human consumption in Ethiopia as well. Further research is also suggested to investigate the opportunities for making mushroom part of the compound poultry feed ingredients.

CONSENT FOR PUBLICATION

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

[1] Sugiharto S, Ranjitkar S. Recent advances in fermented feeds towards improved broiler chicken performance, gastrointestinal tract microecology and immune responses: A review. Anim Nutr 2019; 5(1): 1-10. [http://dx.doi.org/10.1016/j.aninu.2018.11.001] [PMID: 30899804]

[2] Mohammed A, Worku Z. Effect of garlic powder (*allium sativum*) on performance of broiler chicken. Livest Res Rural Dev 2019; 2(4): 31.

[3] Kalia S, K Bharti V, Gogoi D, Giri A, Kumar B. Studies on the growth performance of different broiler strains at high altitude and evaluation of probiotic effect on their survivability. Sci Rep 2017; 7: 46074. [http://dx.doi.org/10.1038/srep46074] [PMID: 28397871]

[4] Ojewola GS, Udom SF, Ojewola GS, Udom SF. Chemical evaluation of the nutrient composition of some unconventional animal protein sources. Int J Poult Sci 2005; 4(10): 745-7. [http://dx.doi.org/10.3923/ijps.2005.745.747]

[5] Abd El-Hack ME, Samak DH, Noreldin AE, El-Naggar K, Abdo M. Probiotics and plant-derived compounds as eco-friendly agents to inhibit microbial toxins in poultry feed: A comprehensive review. Environ Sci Pollut Res Int 2018; 25(32): 31971-86. [http://dx.doi.org/10.1007/s11356-018-3197-2] [PMID: 30229484]

[6] Karangiya VK, Savsani HH, Patil SS, *et al.* Effect of dietary supplementation of garlic, ginger and their combination on feed intake, growth performance and economics in commercial broilers. Vet World 2016; 9(3): 245-50. [http://dx.doi.org/10.14202/vetworld.2016.245-250] [PMID: 27057106]

[7] Alloui MN, Agabou A, Alloui N. Application of herbs and phytogenic feed additives in poultry production-A Review. Glob J Animal Sci Res 2014; 2(3): 234-43.

[8] Edens FW. An alternative for antibiotic se in poultry: Probiotics. Rev Bras Cienc Avic 2003; 5(2): 75-97. [http://dx.doi.org/10.1590/S1516-635X2003000200001]

[9] Dibaji SM, Alireza S, Seidavi A. Effect of dietary inclusion of the synbiotic biomin imbo on broilers' some blood metabolites. Res Opin Anim Vet Sci 2012; 2: 10-3.

[10] Zeryehun T, Asrat M, Amha N, Urge M. Effects of supplementation of different levels of garlic (*llium sativum*) on selected blood profile and immunity of white leghorn chicken. Biotechnol Anim Husb 2017; 33(3): 333-48. [http://dx.doi.org/10.2298/BAH1703333Z]

[11] Mahfuz S, Piao XS. Application of moringa(*moringa oleifera*) as

natural feed supplement in poultry diets. Animals 2019; 9(7): 431. [http://dx.doi.org/10.3390/ani9070431] [PMID: 31323953]

[12] Wierup M. The swedish experience of the 1986 year ban of antimicrobial growth promoters, with special reference to animal health, disease prevention, productivity, and usage of antimicrobials. Microb Drug Resist 2001; 7(2): 183-90. [http://dx.doi.org/10.1089/10766290152045066] [PMID: 11442345]

[13] Khan RU, Naz S. The applications of probiotics in poultry production. Worlds Poult Sci J 2013; 69(3): 621-32. [http://dx.doi.org/10.1017/S0043933913000627]

[14] Kumar M, Kumar V, Roy D, Kushwaha R, Vaswani S. Application of herbal feed additives in animal nutrition - a review. Int J Livest Res 2014; 4(9): 1. [http://dx.doi.org/10.5455/ijlr.20141205105218]

[15] Daneshmand A, Sadeghi GH, Karimi A. The effects of a combination of garlic, oyster mushroom and propolis extract in comparison to antibiotic on growth performance, some blood parameters and nutrients digestibility of male broilers. Rev Bras Cienc Avic 2012; 14(2): 141-7. [http://dx.doi.org/10.1590/S1516-635X2012000200009]

[16] Adil S, Qureshi S, Pattoo RA. A review on positive effects of fenugreek as feed additive in poultry production. Int J Poult Sci 2015; 14(12): 664-9. [http://dx.doi.org/10.3923/ijps.2015.664.669]

[17] Attia G, El-Eraky W, Hassanein E, El-Gamal M, Farahat M, Hernandez- A. Effect of dietary inclusion of a plant extract blend on broiler growth performance, nutrient digestibility, caecal microflora and intestinal histomorphology. Int J Poult Sci 2017; 16(9): 344-53. [http://dx.doi.org/10.3923/ijps.2017.344.353]

[18] Abou-Zeid AE, EL-Damarawy SZ, Mariey YA, Kayed AS. Effect of using yeast (saccharomyces cerevisiae) and mushroom (pleurotus ostreatus) as natural feed additives on productive and immune response of broiler chicks. animal and poultry prod. Mansoura Univ 2019; 10(5): 149-55. [http://dx.doi.org/10.21608/JAPPMU.2019.43015]

[19] Mahfuz S, He T, Liu S, Wu D, Long S, Piao X. Dietary inclusion of mushroom (*flammulina velutipes*) stem waste on growth performance, antibody response, immune status, and serum cholesterol in broiler chickens. Animals 2019; 9(9): 692. [http://dx.doi.org/10.3390/ani9090692] [PMID: 31533253]

[20] Willis WL, Wall1 DC, Isikhuemhen OS, *et al.* Effect of level and type of mushroom on performance, blood parameters and natural coccidiosis infection in floor-reared broilers. Open Mycol J 2013; 7(1): 1-6. [http://dx.doi.org/10.2174/1874437001307010001]

[21] Bederska-Łojewska D, Świątkiewicz S, Muszyńska B. The use of basidiomycota mushrooms in poultry nutrition—a review. Anim Feed Sci Technol 2017; 230: 59-69. [http://dx.doi.org/10.1016/j.anifeedsci.2017.06.001]

[22] Karaalp M, Aksakal V, Beyza S, *et al.* The effect of apple cider vinegar and mushroom stem supplementation on laying hens. Indian J Anim Res 2018; 52(10): 1457-61. [http://dx.doi.org/10.18805/ijar.B-768]

[23] Dawit A. Wild Mushrooms and Mushroom Cultivation Efforts in Ethiopia. Addis Ababa, Ethiopia: Addis Ababa University 2014.

[24] Mahfuz SU, Hui S, Zhongjun L. Improved production performance and health status with winter mushroom stem (*flammulina velutipes*) in laying chicken. Int J Poult Sci 2017; 16(4): 112-7. [http://dx.doi.org/10.3923/ijps.2017.112.117]

[25] Bach F, Helm CV, Bellettini MB, Maciel GM, Haminiuk CWI. Edible mushrooms: A potential source of essential amino acids, glucans and minerals. Int J Food Sci Technol 2017; 52(11): 2382-92. [http://dx.doi.org/10.1111/ijfs.13522]

[26] Mosebework K, Tegene N, Ajebu N. Effect of replacing maize (*zea mays L.*) with orange fleshed sweet potato tuber (*ipomoea batatas*) on performance of cobb 500 broiler chickens. J Agric Res Technol 2018; 13(5)

[27] Sogunle OM, Labinjo OS, Olanite JA, Adebowale AA. Growth performance and blood profile of cockerel chickens on administration of oyster mushroom (pleurotus ostreatus) in water and feed. Arch Zootec 2019; 68(261): 24-30. [http://dx.doi.org/10.21071/az.v68i261.3935]

[28] Mattila P, Salo-Väänänen P, Könkö K, Aro H, Jalava T. Basic composition and amino acid contents of mushrooms cultivated in finland. J Agric Food Chem 2002; 50(22): 6419-22. [http://dx.doi.org/10.1021/jf020608m] [PMID: 12381127]

[29] Vargas-Sánchez RD, Torrescano-Urrutia GR, Ibarra-Arias FJ, Portillo-Loera JJ, Ríos-Rincón FG, Sánchez-Escalante A. Effect of dietary supplementation with *pleurotus ostreatus* on growth performance and meat quality of japanese quail. Livest Sci 2018; 207: 117-25. [http://dx.doi.org/10.1016/j.livsci.2017.11.015]

[30] Choi EJ, Park ZY, Kim EK. Chemical composition and inhibitory effect of lentinula edodes ethanolic extract on experimentally induced atopic dermatitis *in vitro* and *in vivo*. Molecules 2016; 21(8): 993. [http://dx.doi.org/10.3390/molecules21080993] [PMID: 27483228]

[31] Pathania S, Sharma N, Gupta D. A study on cultivation and yield performance of oyster mushroom (*Pleurotus ostreatus*) on Wheat straw mixed with horticultural waste (apple pomace) in different ratio and their nutritional evaluation. Int J Curr Microbiol Appl Sci 2017; 6(8): 2940-53. [http://dx.doi.org/10.20546/ijcmas.2017.608.353]

[32] Asadi-Dizaji A, Habib AS, Shaddel-Tili A, Maheri-Sis N, Jamshid GG. Effect of common mushroom (*agaricus. bisporus*) levels on growth performance and carcass yields of japanese quails (*coturnix coturnix japonica*). Bull EnvPharmacol Life Sci 2014; 3(7): 1-5.

[33] Lee SB, Im J, Kim S-K, *et al.* Effects of dietary fermented *flammulina velutipes* mycelium on performance and egg quality in laying hens. Int J Poult Sci 2014; 13(11): 637-44. [http://dx.doi.org/10.3923/ijps.2014.637.644]

[34] Majesty M, Ijeoma E, Winner K. Prince nutritional, anti-nutritional and biochemical studies on the oyster mushroom, pleurotus ostreatus. EC Nutrition 2019; 14(1): 36-59.

[35] Mahfuz SU, Long SF, Piao XS. Role of medicinal mushroom on growth performance and physiological responses in broiler chicken. Worlds Poult Sci J 2020; 76(1): 74-90. [http://dx.doi.org/10.1080/00439339.2020.1729670]

[36] Mahfuz S, Piao X. Use of medicinal mushrooms in layer ration. Animals 2019; 9(12): 1014. [http://dx.doi.org/10.3390/ani9121014] [PMID: 31766523]

[37] Giannenas I, Tontis D, Tsalie E, Chronis EF, Doukas D, Kyriazakis I. influence of dietary mushroom agaricus bisporus on intestinal morphology and microflora composition in broiler chickens. Res Vet Sci 2010; 89(1): 78-84. [http://dx.doi.org/10.1016/j.rvsc.2010.02.003] [PMID: 20207382]

[38] Guo FC, Kwakkel RP, Williams BA, *et al.* Effects of mushroom and herb polysaccharides, as alternatives for an antibiotic, on growth performance of broilers. Br Poult Sci 2004; 45(5): 684-94. [http://dx.doi.org/10.1080/00071660400006214] [PMID: 15623224]

[39] Wang CL, Chiang CJ, Chao YP, Yu B, Lee TT. Effect of cordyceps militaris waster medium on production performance, egg traits and egg yolk cholesterol of laying hens. J Poult Sci 2015; 52(3): 188-96. [http://dx.doi.org/10.2141/jpsa.0140191]

[40] Simpson HL, Campbell BJ. Review article: Dietary fibre-microbiota interactions. Aliment Pharmacol Ther 2015; 42(2): 158-79. [http://dx.doi.org/10.1111/apt.13248] [PMID: 26011307]

[41] Willis WL, King K, Iskhuemhen OS, Ibrahim SA. Administration of mushroom extract to broiler chickens for bifidobacteria enhancement and Salmonella reduction. J Appl Poult Res 2009; 18(4): 658-64. [http://dx.doi.org/10.3382/japr.2008-00101]

[42] Arjin C, Yachai M, Tapingkae T, Udnoon P, Tapingkae W. Effects of dietary spent mushroom (*Cordyceps militaris*) substrate supplementation on productive performance and cecal microflora of laying hens. Khon Khan Agriculture Journal 2016; 44: 647-53.

[43] Adams S, Che D, Hailong J, *et al.* Effects of pulverized oyster mushroom (*Pleurotus ostreatus*) on diarrhea incidence, growth performance, immunity, and microbial composition in piglets. J Sci Food Agric 2019; 99(7): 3616-27. [http://dx.doi.org/10.1002/jsfa.9582] [PMID: 30628086]

[44] Suganya T, Senthilkumar S, Deepa K, Muralidharan J, Gomathi G, Gobiraju S. Herbal feed additives in poultry. Int J Sci Environ Technol 2016; 5(3): 1137-45.

[45] Willis WL, Wall DC, Isikhuemhe OS, *et al.* Effect of different mushrooms fed to eimeria-challenged broilers on rearing performance. Int J Poult Sci 2012; 11(7): 433-7. [http://dx.doi.org/10.3923/ijps.2012.433.437]

[46] Guo FC. Mushroom and herb polysaccharides as alternative for antimicrobial growth promoters in poultry. PhD Thesis. Wageningen University 2003.

[47] Muthusamy G, Joardar SN, Samanta I, Isore DP, Roy B, Maiti K. ß-glucan from edible mushroom (*Pleurotus florida*) enhances mucosal immunity in poultry. Adv Anim Vet Sci 2013; 1(4): 116-9.

[48] Kiczorowska B. Kiczorowska, Samolińska W, Ridha A, Al-Yasiry M, Kiczorowski P, Winiarska-Mieczan A. The natural feed additives as

immunostimulants in monogastric animal nutrition -A Review. Ann Anim Sci 2017; 17(3): 605-25.
[http://dx.doi.org/10.1515/aoas-2016-0076]

[49] Shamsi S, Seidavi A, Rahati M, Nieto JA. Edible mushroom powder (*Agaricus bisporus*) and flavophospholipol improve performance and blood parameters of broilers. Rev Colomb Cienc Pecu 2015; 28(4): 291-302.
[http://dx.doi.org/10.17533/udea.rccp.v28n4a01]

[50] Guimarães JB, dos Santos ÉC, Dias ES, Bertechini AG, da Silva Ávila CL, Dias FS. Performance and meat quality of broiler chickens that are fed diets supplemented with *Agaricus brasiliensis* mushrooms. Trop Anim Health Prod 2014; 46(8): 1509-14.
[http://dx.doi.org/10.1007/s11250-014-0655-9] [PMID: 25169695]

[51] Daneshmand A, Sadeghi GH, Karimi A, Vaziry A. Effect of oyster mushroom (*Pleurotus ostreatus*) with and without probiotic on growth performance and some blood parameters of male broilers. Anim Feed Sci Technol 2011; 170(1-2): 91-6.
[http://dx.doi.org/10.1016/j.anifeedsci.2011.08.008]

[52] Fard SH, Toghyani M, Tabeidian SA. Effect of oyster mushroom wastes on performance, immune responses and intestinal morphology of broiler chickens. Int J Recycl Org Waste Agric 2014; 3(4): 141-6.
[http://dx.doi.org/10.1007/s40093-014-0076-9]

[53] Mateus S, Alberton L, Valle J, Linde G, Colauto N. Effect Of Pleurotus Ostreatus Colonized Substrate On Broiler Chicken Growth.

[54] Mellor S. Antibiotics are not the only growth promoters. World Poult 2000; 16(1): 14-5.

[55] Jang IS, Ko YH, Kang SY, Lee CY. Effect of a commercial essential oil on growth performance, digestive enzyme activity and intestinal microflora population in broiler chickens. Anim Feed Sci Technol 2007; 134(3-4): 304-15.
[http://dx.doi.org/10.1016/j.anifeedsci.2006.06.009]

[56] Windisch W, Schedle K, Plitzner C, Kroismayr A. Use of phytogenic products as feed additives for swine and poultry1. J Anim Sci 2008; 86(14)(Suppl. 14): E140-8.
[http://dx.doi.org/10.2527/jas.2007-0459] [PMID: 18073277]

[57] Hwang JA, Hossain ME, Yun DH, Moon ST, Kim GM, Yang CJ. Effect of shiitake [*Lentinula edodes* (Berk.) Pegler] mushroom on laying performance, egg quality, fatty acid composition and cholesterol concentration of eggs in layer chickens. J Med Plants Res 2012; 6(1): 146-53. [http://dx.doi.org/10.17582/journal.pjz/2020.52.1.255.262].

[58] Yoshida S, Mitani H, Kamata M, *et al.* Effect of dietary fermented mushroom bed on egg production in laying hens. Biosci Biotechnol Biochem 2017; 81(11): 2204-8.
[http://dx.doi.org/10.1080/09168451.2017.1383846] [PMID: 29144889]

[59] Arjin C, Tapingkae W, Tapingkae T, Udnoon P, Yacha M. . Effects of Dietary Spent Mushroom (Cordyceps militaris) Substrate Supplements on Productive Performance and Egg Yolk Cholesterol of Laying Hens The 4th National Animal Science Conference of Thailand. [http://doi.org/10.13140/RG.2.1.4247.0569]

[60] Kim SC, Moon YH, Kim HS, *et al.* Effect of dietary fermented spent mushroom (*Hypsizygus marmoreus*) substrates on laying hens. Journal of Mushroom 2014; 12(4): 350-6.
[http://dx.doi.org/10.14480/JM.2014.12.4.350]

[61] Alagawany M, Abd El-Hack M. The effect of rosemary herb as a dietary supplement on performance, egg quality, serum biochemical parameters, and oxidative status in laying hens. J Anim Feed Sci 2015; 24(4): 341-7.
[http://dx.doi.org/10.22358/jafs/65617/2015]

[62] Babatunde GM, Fajimi AO, Oyejide AO. Rubber seed oil versus palm oil in broiler chicken diets. Effects on performance, nutrient digestibility, haematology and carcass characteristics. Anim Feed Sci Technol 1992; 1992(35): 133-46.

[63] Mužić S, Janječić Z, Mesarić M, Svalina K. Cholesterol content and quality of eggs from hens fed feed mixture supplemented with Lentinus edodes mushroom. Stockbreeding 2005; 59(4): 271-9.

[64] Shah MZ, Ashraf M, Ishtiaq MC. Comparative study on cultivation and yield performance of oyster on Different Substrates (Wheat Straw, Leaves, Saw Dust). Pak J Nutr 2004; 3: 158-60.
[http://dx.doi.org/10.3923/pjn.2004.158.160]

[65] Chowdhury SR Sr, Chowdhury SD, Smith TK. Effects of dietary garlic on cholesterol metabolism in laying hens. Poult Sci 2002; 81(12): 1856-62.
[http://dx.doi.org/10.1093/ps/81.12.1856] [PMID: 12512577]

[66] Hosseinzadeh H, Qotbi A, Ahmad A, Seidavi A, Norris D, Brown B. Effects of Different Levels of Coriander (Coriandrum sativum). Seed Powder and Extract on Serum Biochemical Parameters, Microbiota, and Immunity in Broiler Chicks, The Scientific World Journal 2014.
[http://dx.doi.org/10.1155/2014/628979]

[67] Mamoun T, Mukhtar A, Mohamed HT. Effect of Fenugreek seed powder on the Performance Carcass Characteristics and Some Blood Serum Attributes. Adv Res Agric Vet Sci 2014; 1: 6-1.

[68] Shawle K, Urge M, Animut G. Effect of different levels of Lepidium sativum L. on growth performance, carcass characteristics, hematology and serum biochemical parameters of broilers. Springerplus 2016; 5(1): 1441.
[http://dx.doi.org/10.1186/s40064-016-3118-0] [PMID: 27652017]

[69] Mingr Yei, Wen-Ching K, Li-Yun L. Hypolipidemic and antioxidant activity of enoki mushrooms (Flammulina velutipes). BioMed Res Int 2014.
[http://dx.doi.org/10.1155/2014/352385]

[70] Schneider I, Kressela G, Meyer A, Krings U, Berger RG, Hahna A. Lipid lowering effects of oyster mushroom (*pleurotus ostreatus*) in humans. Jfuncfood 2011; 3(1): 17-24.
[http://dx.doi.org/10.1016/j.jff.2010.11.004]

[71] Alam N, Yoon KN, Lee TS, Lee UY. Hypolipidemic activities of dietary *pleurotus ostreatus* in hypercholesterolemic rats. Mycobiology 2011; 39(1): 45-51.
[http://dx.doi.org/10.4489/MYCO.2011.39.1.045] [PMID: 22783072]

[72] Asadi-Dizaji A, Shahryar HA, Maheri-Sis N. Effect of levels of oyster mushroom (*pleurotus ostreatus*) on performance and blood biochemical characteristics in japanese quails (*coturnix coturnix*). Iran J Appl Anim Sci 2017; 7(4): 687-9.

[73] Chuang WY, Hsieh YC, Lee TT. The effects of fungal feed additives in animals: A review. Animals 2020; 10(5): 805.
[http://dx.doi.org/10.3390/ani10050805] [PMID: 32384791]

[74] Savoie JM, Mata G, Atanasova Penichon V, Foulonge-Oriol M. Using mushroom-forming fungi in preventing and reducing mycotoxins in cereal products. Scientia Fungorum 2019; 49e1256
[http://dx.doi.org/10.33885/sf.2019.49.1256]