Review

Potential Effects of Garlic (*Allium sativum L.*) on the Performance, Immunity, Gut Health, Antioxidant Status, and Blood Parameters of Poultry: An Updated Comprehensive Review

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Potential Effects of Garlic (*Allium sativum* L.) on the Performance, Immunity, Gut Health, Antioxidant Status, and Blood Parameters of Poultry: An Updated Comprehensive Review

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Simple Summary: Using antibiotics as growth promoters or antimicrobials is still showing a potential health hazard. Garlic (*Allium sativum* L.) has been extensively used in poultry production systems for several aspects. Therefore, this review article discusses the impact of using garlic as feed additives on performance, immunity, gut health, antioxidant status, and blood parameters of poultry. As a result of the great benefits of feeding garlic on the health of poultry, it has been urged to use it as a potential antibiotics alternative feed additive.

Abstract: The use of antibiotics as growth promotors or for the prevention of some poultry diseases has face global concern and serious criticism. Their addition to poultry feed show hazardous effects including development of antimicrobial resistance and the potential harmful effect on humans' health. To eliminate these threats, there is increasing interest to search for natural alternatives. Plant derivatives such as garlic (*Allium sativum* L.) and its derivatives are nowadays extensively used in poultry production system. Dietary supplementation of broilers and layers with garlic induced improvement of production parameters, carcass quality, and intestinal integrity. Modulation of the immune response against important viral diseases and increasing the immune organs body weight ratio resulting from supplementation of poultry with garlic. Moreover, garlic showed modulation of gut health through the antibacterial and antiparasitic activities. Treatment with garlic also can mitigate the oxidative stress and reduce the free radicals production. Reduction of cholesterol level, but improvement of some liver and blood parameters were also reported following dietary inoculation of garlic. This review was designed to search on the impact of garlic as feed additives on performance, immunity, gut health, antioxidant status, and blood parameters of poultry.

Keywords: *Allium sativum*; meat and egg production; antibodies; antioxidant enzymes; cholesterol

1. Introduction

With the ban of the use of antibiotics as growth promoters in most countries, attention has been focused on finding alternatives without resistance or residues [1]. Through the global trend to go back to nature, the World Health Organization encourages using of natural phytogenic substances to replace or reduce the use of antibiotic growth promotors. Phytobiotics or phytogenic are plant derivatives which have been used as feed additives to improve the health and performance of animals [2]. Over the past decade, this safe source of active ingredients is regarded as an attractive research subject and shows promising results [3]. Herbal plants possess multiple therapeutic properties and different effects.

Garlic (*Allium sativum*) is perennial bulb producing plants that belongs to genus *Allium* in the family *Liliaceae*. Since antiquity, garlic has been grown on a large scale on all countries and widely used as feed additives or growth promoter substance [4]. It has a specific smell and taste, as well as therapeutic activities in alternative medicine [5].

Garlic is estimated to contain almost 33 sulfur compounds (alliin, diallyl sulfides, and allicin), 17 amino acids, essential oils, vitamins (ascorbic acid, ribofavin, niacin, thiamine, and folic acid), minerals (germanium, selenium, phosphates, calcium, and iron), and enzymes [6,7]. The allin and

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alliinase enzymes collaborate to produce allicin [8]. It enzymatically released from precursor form when the garlic bulbs are crushed or destroyed by digestion. Allicin or daily thiosolphinic acid is active inhibitory principle of garlic [9]. Moreover, allicin ingredients can decompose forming many volatile organosulfur compounds with bioactivities [10].

Garlic contains more than two hundred chemical substances that used for prevention and treatment of cardiovascular diseases [11] as well as antioxidants [12], antimicrobial [13,14], anti-inflammatory [15], anti-atherosclerotic, anti-thrombotic, anti-hypertensive, anti-diabetic, and anti-cancer as well as hypoglycemic properties [14,16,17].

Garlic could be given to poultry in the form of powder, aqueous extract, essential oil, and other commercial products either in the feed or in the drinking water. Dietary feeding of poultry on garlic resulted in enhancement in growth performance, gut health, dressing yield, and production cost [18-20], modulation of immunity and blood parameters [12], prevention of bacterial and parasitic infections [21,22], and mitigation of heat stress [23]. Addition of garlic to the feed of broilers has no negative influence due to it does not leave any residue, and the birds' manure does not contaminate the environment. Therefore, products from garlic-consuming animals are safe for consumption.

The objectives of this review was to investigate the findings on the impact of garlic as feed additives on performance, immunity, gut health, antioxidant status, and blood parameters of poultry.

2. The different influences of dietary garlic on poultry health

2.1. Production parameters

2.1.1. Performance

The different effects dietary garlic on the production performance parameters of broilers and layers are presented in Tables (1 and 2). Inoculation of garlic in the diets of birds could enhance the production performance parameters including the feed intake (FI), body weight (BW), body weight gain (BWG), and the feed conversion ratio (FCR) [54]. The mechanism by which the garlic powder can improve these parameters could be related to presence of many organosulfur compounds such as allicin, alliin, ajoene, diallylsulfide, dithiin, and Sallylcysteine [55]. Similarly, the study of Ross et al. [56] demonstrated that the antibacterial compound, dialkylpolysulphide, in garlic plays axial role in improving the BWG in broilers. A combined diet contains garlic and turmeric (10 g/kg each) reduced the pH of the crop, proventriculus, and ceca, and improved digestible and apparent metabolized energy in ileum of broiler chickens [57]. Besides, garlic might increase the enzymes activity of pancreas, which offer a better environment for the digestion and absorption of nutrients [12].

The FI of broilers [58] and layers [46] was increased by increasing the level of garlic powder inoculation in the diet is may be owing of rich aromatic oil content of garlic which enhances digestion.

Table 1. The different effects dietary garlic on the production performance parameters of broilers.

Dose/route	Effects	Reference
Garlic paste (3.8%), solvent fractions, or garlic oil equal to this quantity in feed	No effect on FI	[24]
Garlic 0, 0.01, 0.1 or 1% in meal	No improvement in the performance	[25]
Garlic powder 0.2% and 0.4% of feed	No effects on BWG, FI, FCR, carcass cuts, and visceral organs	[26]
Garlic at 1 kg/ton feed	Enhanced carcass yield	[27]
Garlic 1, 3, and 5% and 3% garlic powder + 200 IU of α-tocopherol/kg of feed	No influence on performance Increased crude protein	[28]

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	Decreased crude fat contents of carcass, the pH, and thiobarbituric acid reactive substances of meat	
Garlic 0.5%, 1.0%, and 3%	Decreased heart weight	[29]
Garlic powder 0.5% of feed	Increased live BWG	[30]
Garlic powder 3% and 5% of diet	Increased breast weight (3%) Low BW (5%)	[31]
A mixture of ginger and garlic (1:1 ratio) 50ml/liter of the drinking water	Improved BW, BWG, FI, and FCR	[32]
Garlic bulb 5, 10, or 15 g/kg meal	Decreased BW (high dose and standard temperature) No effect on the FCR	[33]
The 5 g/kg garlic powder+1 g/kg black pepper powder and 10 g/kg garlic powder+2 g/kg black pepper powder	Improved WG and FCR	[34]
Fresh garlic paste 0.2, 0.4, 0.6, and 0.8%/ liter of drinking water	No effect on BWG or FCR Decreased mortality	[35]
Garlic powder 3% in diet and a mixture of garlic powder 1.5% plus turmeric powder 0.25%	mproved BWG, FI, FCR, performance index, and protein efficiency ratio	[36]
Garlic paste 0.25 % and 0.50% with basal diet	Improved BWG, FCR, and livability No influence on carcass attributes	[37]
Garlic 5g/kg feed, black cumin 5g /kg, or their combination	No difference in BWG, FI, FCR, and relative organ weights	[38]
A basal diet plus 0.25, 0.50, and 0.75 g garlic powder/kg diet	Increased BW and BWG at 21 and 42 days of age High length and average width of small intestine	[12]
Garlic essential oil (200 mg/kg diet) alone/or combination with lemon essential oil (200 mg/kg diet) under heat stress	Enhancement in BW, FCR, carcass dressing, and increasing the digestive enzymes Decreasing mortality rate and abdominal fat content	[23]
Garlic powder 3% of feed	Improved BWG and final BW	[39]

Feed intake= FI; Body weight= BW; Body weight gain= BWG; FCR= Feed conversion ratio.

Table 2. The different effects dietary garlic on the production performance parameters of layers.

Dose/route	Effects	Reference
1 or 3% garlic meal	Decreased egg yolk cholesterol	[40]
Garlic paste (3.8%), solvent fractions, or garlic oil equal to this quantity in feed	No effect on daily FI	[24]
Garlic oil 0.02% in meal	No effect on egg production, egg mass, body weight, feed consumption, and feed efficiency	[41]

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Garlic powder 3% in diet	No differences in color and flavor of eggs No change in yolk cholesterol concentrations	[42]
Sun-dried garlic paste 0, 2, 4, 6, 8, or 10% of diet	No effect on egg weight, egg mass, feed consumption, and feed efficiency among diets or birds' strain Increased Yolk weight with increasing levels of dietary garlic Decreased yolk cholesterol concentrations	[43]
Garlic powder 0, 5, 10, and 15 g/kg feed	Decreased yolk weight	[44]
Garlic powder 0.5 and 10 g/kg feed	Increased egg weight Decreased egg yolk cholesterol triglyceride No effect on performance or egg albumin index, eggshell index, and egg Haugh unit	[45]
Garlic powder 0, 2, 6, or 8% in feed	Increased egg production	[46]
Garlic 2% and fenugreek 2%	No effect on FI, FCR, BW, BWG, egg rate, egg weight, and egg mass Increased yolk weight and color and Haugh units Decreased albumen weight	[47]
Garlic powder 8% in feed	Better egg production No effect on egg mass and egg weight	[48]
Garlic powder 1, 2, and 4% in feed	Increased egg production No effect on egg weight, yolk index, shell weight, shell thickness, yolk weight (1% garlic) Decreased eggshell index and Haugh unit (4% garlic)	[49]
Garlic juice at 0.25, 0.50, and 1%	Improved egg albumin, yolk and shell weight, albumin height, and Haugh unit	[50]
Garlic powder 1%, fenugreek 1%, and garlic powder 1% + fenugreek 0.5%	No effect on laying hens' performance	[51]
Garlic 1, 2, and 3% of ration	No effect on BWG, FCR, egg production, egg mass, albumen weight, albumen height, Haugh unit, yolk index, yolk height, egg weight, fertility, hatchability, embryonic mortality, chick weight and chick visual score, shell thickness, and shell weight An improvement in yolk diameter, yolk weight, chick length and yolk color	[52]
A mixture of lemon, onion, and garlic juice at portions 1.00, 1.00, and 0.125/liter of the drinking water, respectively	Improved FCR Increased number of eggs/hen, percentage of egg production, and egg mass/hen Enhanced yolk color and yolk percentage	[53]

Feed intake= FI; Body weight= BW; Body weight gain= BWG; FCR= Feed conversion ratio.

2.1.2. Intestinal architecture

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The addition of eugenol and garlic tincture could improve the intestinal integrity and enhance the mucin-producing goblet cell numbers as a defensive response to the birds against necrotic enteritis [59]. Administration of garlic increased the villus height and crypt depth but decreased epithelial thickness and goblet cell numbers in the intestine of broiler chickens [60]. Furthermore, the highest capacity of crypt and villi of small intestines was detected following dietary addition of garlic in coccidiosis infected broilers [61]. Allicin can regenerate and improve and the physiological structure epithelium layer of the intestine, increase the crypt's depth and villus height, which eventually support the digestive capacity via increasing the nutrients absorption and assimilation. A longer villi and deeper crypt is considered a sign of a healthy intestine architecture, and consequently a good digestive capacity and the pancreatic enzyme activity. Moreover, the antioxidant characters of garlic can enhanced the overall gut function and improved the nitrogen energy utilization [62]. Yang et al. [63] reported that feeding of broilers on garlic reduces the pH of digesta which was resulted in an increase in the production of the volatile fatty acid and the proliferation of beneficial bacteria. Dietary addition of 0.5% garlic efficiently reduced the systemic hypertension and the prevalence of ascites, but had no negative influences on broilers performance [33]. Inulin component of garlic decreases the digesta pH of birds and increases the volatile fatty acids production which may help in enhancing the beneficial bacterial colonization [64].

Others showed that garlic supplementation has no effect on feed efficiency or growth performance of broilers and layers [41,43,52,65].This discrepancy might be resulted from the differences in the experiment duration, birds' genetic and health status, or the type, processing, and quality of garlic products components.

2.2. Immunity

The effect of garlic on the immunity of birds is illustrated in Table (3). It has been found that the different forms of dietary garlic alone or in combination with other aromatic phytobiotics can enhance the immune response in terms of enhancing the antibody titers against and increasing the immune organ/ body weight ratio [12,23,35].

The improvement in immune response may be related to the characters of biologically active compounds in essential oils as antimicrobial, antioxidant, and anti-inflammatory, which provide essential nutrients the development of the immune cells. In addition, promoting the proliferation of lymphocytes in the primary immune organs and improving intestinal integrity could stimulating the production of immunoglobulin (Ig) such as IgG, IgM, and IgA which is associated with increasing the relative weight of the immune organs. Many immuno-stimulators compounds are present in garlic, including the lectin family, which is known to interact with pathogen recognition receptors on immune cell surfaces [72]. Garlic is one of the impressive conductors of the body's immune system; which stimulates immune function by making macrophages or killer cells more active. Moreover, garlic can improve the humoral immune cell functions via enhancement of the cytokine production and/or antigen presenting cells phagocytic capacity [67]. Dorhoi et al. [73] demonstrated that a high dose of garlic extract (200 mg/ml) on to a macrophage culture of laying chickens could impair the phagocyte function and inhibit phagocytosis, whereas a low dose (50 mg/ml) increased the sheep red blood cell uptake. Inoculation of garlic extract or its protein fraction increased the destruction in peritoneal macrophages and engulfment of parasites in Leishmanial major-infected Balb [74].

An *in-vitro* study showed that garlic extract increased concanavalin A (ConA)-induced splenocytes, thymocytes proliferations, and gene expression of interleukin (IL)-2 and interferon gamma (INF-γ) [75]. Further, addition of garlic extract to a culture augmented the production of IL-2 and IL-12, INF-γ, and tumor necrosis factor α in stimulated splenocytes [76]. Low concentrations of diallyl trisulfide (3-12.5 mg/ml) of garlic increased the proliferative responses in a culture, while higher concentration (50 mg/ml) inhibited T-lymphocyte proliferation in mice [77]. Aged garlic extract stimulated the proliferation and increased activity of T-cells and natural killer cells as well as enhanced phagocytosis and cytokine release [78,79].

Garlic supplementation increased the relative weights of immune organs such as spleen, thymus, and bursa of Fabricius, the white blood cells counts, as well as lymphocytes, splenocyte, and

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thymocyte proliferations [67]. In addition, the titers of antibodies against Newcastle disease virus, sheep red blood cells count, and *Brucella abortus* have been increased following administration of garlic in laying chickens [67].

It has been demonstrated that the anti-oxidative stress of garlic is a potential factor to enhance the immune response [80]. Supplementation with garlic extract at 4 and 8 mg/ml revealed that macrophages may display antimicrobial activity and enhance the production of reactive oxygen species.

Table 3. The effect of dietary garlic on the immune response of poultry.

Dose/route	Type of production	Effects	Reference
Garlic powder 1% or 3% garlic	Broiler chickens	No effect on antibody production against NDV and leukocyte count Enhanced antibodies against NDV, SRBCs, and BA	[66]
Garlic 10 and 30 g/kg diet	White Leghorn chickens	Augmented splenocyte and thymocyte proliferations Reduced $CD4^+$, but increasing $CD4: CD8^-$ lymphocyte ratios and WBCs count Increased relative weights of immune organs (spleen, thymus glands, and bursa of Fabricius)	[67]
Garlic 0.5%, 1.0%, and 3%	Broiler chickens	Lower weights of bursa of Fabricius and spleen	[29]
Garlic powder 0.1%	Broiler chickens	Improved relative weight of bursa of Fabricius without effect on the spleen weight No effect on NDV vaccine (LaSota) antibody response	[68]
Garlic powder 3% and 5% of diet	Broiler chickens	No influence on bursa of Fabricius and thymus weights Decrease spleen weight	[31]
A mixture of ginger and garlic (1:1 ratio) 50ml/liter of the drinking water	Marshal broiler chickens	Increased total protein, albumin, and globulin	[32]
Garlic extract (allicin) 25, 50, 75, or 100 mg/kg diet	Broiler chickens	Increased total protein and albumin concentrations by about 4.7 and 5.9%, respectively (50 mg/kg) No effect on total protein, albumin or globulin concentrations (25, 75, or 100 mg/kg)	[69]
Fresh garlic paste 0.2, 0.4, 0.6, and 0.8%/ liter of drinking water	Broiler chickens	Increased antibody titer against NDV	[35]
Garlic-meal 0.125% of feed.	Broiler chickens	Reducing scores of IBDV signs	[70]

Garlic essential oil 0.06 mL/L drinking water	Broiler chickens	Higher mortality rate High antibody response to IBDV Improved immune organ index, IgM, IgG, and IgA	[71]
A basal diet plus 0.25, 0.50, and 0.75 g garlic powder/kg diet	Broiler chickens	Increasing total protein, globulin, IgM, and IgG Improved liver and immune related organs weight	[12]
Garlic essential oil (200 mg/kg diet) alone/or combination with lemon essential oil (200 mg/kg diet) under heat stress	Broiler chickens	Increasing the relative weight of bursa of Fabricius and the serum antibody titer against NDV No changes in relative weights of spleen and thymus glands, and antibody titer against AIV	[23]

NDV= Newcastle disease virus; AIV= Avian influenza virus; BA= *Brucella abortus*.SRBC= Sheep red blood cells; Ig= Immunoglobulin; CD= Cluster of differentiation; IBDV= Infectious bursal disease virus

2.3. Gut health

2.3.1. Antibacterial

The strong antimicrobial effects of garlic have been reported [37,55,81,82]. It has been reported that garlic extracts exert a differential inhibition between beneficial intestinal microflora and potentially harmful enterobacteria [83]. Garlic could reduce the number of gut pathogenic bacterial populations such as *Escherichia coli* (*E. coli*). Garlic showed an ability to inhibit *E. coli* 10 times greater than that seen in *Lactobacillus casei* [84]. Rahimi et al. [68] demonstrated that *E. coli* count was significantly reduced in the digesta of ileo-cecum of broiler chickens supplemented by a blend of garlic, thyme, and coneflower. Recently, Elbaz et al. [20] (2021) found that garlic treatment could reduce the ileal enumeration of *E. coli* and total coliform, but increase the *Lactobacillus* count. In addition, the positive influences of eugenol and garlic mixture on broilers performance and intestinal health status under necrotic enteritis condition have been reported [82]. Microencapsulated eugenol and garlic tincture modulated the microbiota balance by inhibiting pathogenic while promoting beneficial microbial growth, as well as reduced the severity of the intestinal lesions of broilers with necrotic enteritis [59]. The antimicrobial and the bacteriostatic properties of garlic extract is associated with the presence of allicin active compound [13]. Allicin exhibited bacteriostatic effect on some vancomycin-resistant enterococci. Besides, allicin exhibits SH group reactivity on cysteine residues of pathogen enzymes causing deactivation and suppression of specific thiol-containing enzymes in pathogens [85]. This activity resulted in the inactivation and inhibition of specific thiol-containing enzymes in microorganisms [21,86]. Garlic is a nucleophilic agent that has the ability to counteract the impact of electrophilic substances on microorganisms [87].

2.3.2. Anti-parasitic

The *in-vitro* and *in-vivo* anticoccidial activities of different processed extract forms of garlic have been documented [88-96]. The study of Ali et al. [97] found that supplementing coccidiosis infected broiler chickens with garlic at 15 g/kg feed reduced the oocysts shedding and lesion score, but improved the histopathology of the small intestines. In the same context, continuous feeding of *Eimeria tenella* infected broiler chickens on natural garlic essential oil (0.06 mL/L drinking water) significantly reduced the clinical signs, cecal lesions score, the oocysts shedding, but increased the weight of diseased chickens, and effectively improve the intestinal functions [71]. In comparison with ginger oil, garlic oil (150µL/100 mL) showed superior efficacy against *Eimeria* species infection of

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quails in terms of improved activity level with better health, increased feed intake, and complete recovery from oocysts on day 15 post-infection [98].

Allen et al. [99] reported that the antioxidant properties of garlic causes oxidative stress against parasites and neutralize oxygen reactive species. In furtherance of this, Pourali et al. [100] have owed the anticoccidial activity of garlic to its immunomodulatory activity. Similarly, Kim et al. [101] revealed improved resistance against *Eimeria acervulina* infection in chickens after dietary treatment with garlic metabolites [101]. Propyl thiosulphinate oxide and propyl thiosulphinate active ingredients of garlic reduced the faecal oocysts shedding and enhanced the antibody response against coccidial infection [101]. Likewise, the aqueous garlic extract is rich in phenols, flavonoids, and varying sulphur compounds [14]. The phenolic compounds change the permeability of the cytoplasmic membrane to many cations, inhibit the physiological functions, and consequently resulting in loss of membrane potential, allowing vital cellular substances to leak out, protein and ATP production to be inhibited and cellular death to occur [102].

Allicin induces changes in the intestinal microbiota, exerts antioxidant effect on *Eimeria* oocysts, and stimulates the immunity through enhancing the antibody response which directly destruct sporozoites [54,103]. Additionally, phenolic component in garlic acts on the cytoplasmic membrane of *Eimeria* species and make changes in their cation permeability, leading to the death of *Eimeria* [104]. Further, allicin can interact with the intestinal cytoplasmic membranes and alters cations permeability, resulting in the disruption of vital processes in the parasite cells and, eventually, their death [105]. The ability of allicin and alcoholic garlic extract to eliminate *Eimeria tenella* oocysts makes them superior to chemical disinfectants [22]. *Eimeria* oocysts sporulated in allicin-containing media displayed the lowest *in-vivo* gross lesion score and oocyst count shedding compared to those sporulated in alcoholic garlic extract and potassium hydroxide [22]. Garlic extracts at 360 mg/mL and Allicin at 180 mg/mL significantly decreased the number of oocysts by 73.5 and 88.3%, respectively [22].

Moreover, the garlic crude extract proved great activities against worms and protozoon parasites *Cryptosporidium* spp in different animals' model [106-108].

2.4. Antioxidant status

Garlic exhibited a strong antioxidant activity in birds (Table 4). The imbalance between the oxidation and reduction in the host's cells induces a significant destruction of them with a subsequent oxidative stress. However, the antioxidant enzymes can prevent the free radicals to attack the cell membranes [117]. Essential oils present in different aromatic plants contain several natural antioxidants [12]. Garlic and/or garlic tocopherol induced a much higher antioxidant effect with reducing the free radicals production [12,43], especially in birds under heat stress conditions [23].

Decreased activities of hydroxymethylglutaryl coenzyme A reductase, cholesterol 7 α-hydroxylase, and fatty acid synthetase have been demonstrated after administration of garlic powder polar fractions (garlic equivalent to 1, 2, 4, 6, and 8% fresh garlic paste) [118]. The diallyl polysulfides from an aged garlic extract could protect the cell membranes from lipid peroxidation [119]. Besides, essential oils present in garlic and other plants are able to remove the oxygen free radicals through reducing the level of malondialdehyde (MDA), and enhancing the levels of superoxide dismutase (SOD) and glutathione peroxidase (GPx) [100,120,121].

Table 4. The effect of dietary garlic on the antioxidant status and blood parameters of poultry.

Dose/route	Type of production	Effects	Reference
Garlic paste (3.8%), solvent fractions, or garlic oil equal to this quantity in feed	Broiler chickens Leghorn laying pullets	Decreasing serum cholesterol by 18 and 23% in broilers and Leghorn pullets, respectively	[24]
Garlic oil 0.02% in meal	Babcock B-300 strain of laying hens	No effect on serum cholesterol	[41]

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Garlic 2% in feed	Broiler chickens	Lowering in hepatic cholesterol concentrations	[109]
Garlic 3% in meal	Broiler chickens	Decreased plasma cholesterol and breast and thigh muscle cholesterol	[110]
Garlic powder 3% in diet	Laying hens	No change in serum cholesterol concentrations	[42]
Sun-dried garlic paste 0, 2, 4, 6, 8, or 10% of diet	Hisex Brown, Isa Brown, Lohmann, Starcross, Babcock, and Starcross-579 strains of laying hens	Decreased serum cholesterol concentrations	[43]
Garlic 0, 1, 3, or 5% in meal	Laying hens	No change in HDL level	[111]
Garlic powder 0.5 and 10 g/kg feed	Laying hens	Decreased serum triglyceride	[45]
Garlic 2% and fenugreek 2%	Lohmann Brown laying hens	Increased HDL Reduced serum cholesterol and LDL	[47]
Garlic powder 1% or 3% garlic	Broiler chickens	No effect on leukocyte count	[66]
Garlic powder 10 and 20 g kg^{-1}	Laying hens	Reduced total cholesterol, triglyceride, LDL, and HDL	[112]
Garlic powder 5-20 g kg^{-1}	Broiler chickens	Decreased plasma LDL cholesterol No effect on HDL cholesterol	[113]
Fermented garlic powder 3% in diet	Laying hens	Decreased serum cholesterol	[114]
Garlic powder 1, 2, and 4% in feed	Laying hens	Increased plasma HDL and LDL (1, 2, and 4%).	[49]
Garlic 1, 3, and 5% and 3% garlic powder + 200 IU of α-tocopherol/kg of feed	Broiler chickens	Reduced the total and LDL levels Increased the HDL levels	[28]
A mixture of garlic and thyme powder 0.1 and 0.2 g kg^{-1}	Laying hens	No effect on cholesterol, triglyceride, HDL, and LDL	[115]
Garlic powder 0.1%	Broiler chickens	Decreased triglycerides, total cholesterol, and LDL Increased HDL	[68]
Garlic powder at 0.2% and 0.4% of feed	Cobb broiler chickens	Reduced triglycerides, cholesterol, and LDL Increased HDL	[116]
Garlic powder 3% and 5% of diet	Broiler chickens	Decrease spleen weight, RBCs, WBCs, and packed cells volume	[31]
Garlic powder 1%, fenugreek 1%, and garlic powder 1% + fenugreek 0.5%	Laying hens	Decreased LDL	[51]
Garlic and fenugreek 2%		Beneficial effects on cholesterol metabolism	

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A mixture of ginger and garlic (1:1 ratio) 50ml/liter of the drinking water	Marshal broiler chickens	Increased haemoglobin, packed cell volume, WBCs, RBCs, total protein, albumin, and globulin Decreased cholesterol	[32]
A mixture of lemon, onion, and garlic juice at portions 1.00, 1.00, and 0.125/liter of the drinking water, respectively	Bovan Brown layer chickens	Decreasing total plasma cholesterol content, GPT, GOT, and creatinine	[53]
Garlic 5g/kg feed, black cumin 5g /kg, or their combination	Ross-308 broiler chickens	Increasing total protein Reduced GOT	[38]
Probiotic, citric acid, and garlic supplemented with 0.5 g kg^{-1} multi-strain probiotic mixture, citric acid and garlic powder, respectively. Probiotic-citric and probiotic-garlic groups treated with 0.5 g kg^{-1} multi-strain probiotic mixture, and 0.5 g kg^{-1} citric acid and garlic powder, respectively, while citric-garlic group fed diet with 0.5 g kg^{-1} of citric acid and garlic powder.	Broiler chickens	Decreased cholesterol, triglycerides, and LDL Elevated HDL	[20]
A basal diet plus 0.25, 0.50, and 0.75 g garlic powder/kg diet	Broiler chickens	Increasing RBCs, hemoglobin HDL, SOD, and total antioxidant capacity Decreasing total cholesterol, LDL, GOT, and AMD	[12]
Garlic essential oil (200 mg/kg diet) alone/or combination with lemon essential oil (200 mg/kg diet) under heat stress	Broiler chickens	Reducing MDA, triglycerides, cholesterol, and LDL Increasing HDL, SOD, and GPx	[23]

WBCs= White blood cells; RBCs-= Red blood cells; MDA= Malondialdehyde; GPT= Glutamic-pyruvic transaminase; GOT= Glutamic-oxaloacetic transaminase; HDL= High density lipoprotein; LDL= Low density lipoprotein; SOD= Superoxide dismutase; GPx= Glutathione peroxidase

2.5. Blood parameters

The influence of dietary addition of garlic addition on the different blood parameters of poultry is shown in Table (4).

Many studies showed the hypo-cholesteric effect of garlic in broilers and layers [12,23,51,53,114]. Garlic containing enzymes may have a role in regulating the metabolism of lipid and enhancing enzymes activities that stimulates the biliary cholesterol secretion and lowers the fractional

absorption of dietary cholesterol [20]. Moreover, inhibition of acetyl CoA synthetase and 3-hydroxyl-3-methylglutaryl-CoA reductase enzymes, that are required for cholesterogenesis and the biosynthesis of fatty acids, can reduce the blood cholesterol level [122]. Similarly, the potential effect of garlic on the lipid metabolism in layers may be attributed to depressing of lipogenic and cholesterogenic activity of the liver enzymes such as fatty acid synthase, glucose 6 phosphatase dehydrogenase, and malic enzyme, consequently, the mechanism of hypocholesterol and hypolipid syntheses [50]. Lower serum and liver cholesterol [118] inhibits bacterial growth [123], reduces platelet formation, and decreases oxidative stress [119].

Additionally, the effect of garlic on the hematological parameters such as red blood cells (RBCs) and white blood cells (WBCs) counts, haemoglobin, and packed cell volume have been reported [12,31,32]. The hemolytic bioactives and their metabolites in garlic may be responsible for these effects. Increasing in erythrocytes count with garlic supplementation could be owing to the end--product produced from garlic metabolism possible stimulates the formation and secretion of erythropoietin in the kidney causing synthesis of RBCs [124]. Moreover, addition of garlic extract to laying hens diet could enhance spleen RBCs uptake [73].

3. Conclusion

The supplementation of garlic to broiler and layers poultry species mostly shows improvement in the performance and production efficiency, enhances the immune response, maintains the gut health, reduces the exudative stress, and modulates many important blood parameters. However, the different mode of actions of garlic are is indefinite. Therefore, further studies should focus on establishing the mechanisms of actions of garlic and its derivatives.

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