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Beneficial and adverse effects of medicinal plants as feed supplements in poultry nutrition: a review

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ABSTRACT

Medicinal plants exhibit colossal impact on poultry industries by improving its performance and productivity. However, some of these plants show adverse influence too by decreasing egg production percentage, egg mass, and microbiota counts. Green tea, nettle, pennyroyal, yarrow, and alfalfa in the form of seed, powder, and extract had vast potentiality to improve immunity, reduce the growth of pathogenic microbes, and improve the viable counts of lactic acid bacteria. Lavender, Alfalfa, and Nettle powder were able to improve egg yolk color. Furthermore, ginger reduced fat content in meat and increased color intensity. Flax seed increased alpha linolenic acid content in tissue, and increased n-3 fatty acid content in breast as well as thigh tissue. Physiological assessment showed that green tea, lavender, nettle, pennyroyal, and yarrow improved poultry immunity. Lavender and nettle improved internal organ traits. Interestingly, the use of flaxseed improved quail egg hatchability. Plants metabolites, particularly carvacrol and thymol showed its pivotal role as natural growth promoters by affecting growth performances, nutrient bioavailability, and immunity of broiler chickens. Additionally, in recent years, micro-encapsulation or nano-encapsulation of plant extracts and its metabolites improved growth performances of broiler chickens, thereby suggested wide utilization of this technique as a potential alternative to antibiotic growth promoters in future. This review sheds a light on beneficial as well as no adverse effects of some of the direct-fed important medicinal plants and its metabolites in poultry nutrition in order to suggest its key role in future poultry enterprise.

KEYWORDS

Adverse effect; beneficial effect; medicinal plants and metabolites; micro-encapsulation; poultry nutrition

Introduction

Antibiotics have so far been the most cost-effective way to maintain feed efficiency and health status in monogastrics like poultry.[1] However, with human practices constantly changing or constantly influenced, these are bound to change with time circumstances that come due to its usage. Hence, the renewed and deliberate interest in the use of herbs and different plant products is an interesting development in modern poultry production. This is in alignment with the 'clean' production practice in millennial farming. This intensified effort in search for alternatives to synthetic drugs[2] came about as a result of negative effect of synthetic on poultry and consumers health and the rising cost of the use of drugs in poultry production. This is because the use of feed antibiotics has led to antimicrobial resistance due to 'familiarity' with the drugs,[2,3] thus, necessitating the ban on its usage in Europe and America and the recommended ban on the use of medically important antibiotics in poultry industries.[4]

Several herbs such as black cumin seed, moringa, pawpaw seed, green tea, lavender, garlic, neem, essential oil etc. have been used in poultry such as quail, broiler, turkey, and pullets as alternative to antibiotics and growth promoter. These herbs are used not only as alternative to antibiotics and growth promoters but also as antiviral, anticocidiosis, antiparasite, and immunomodulatory agents.[5] It can also reveal beneficial, toxic or lethal effect[6] depending on the quantity of usage. The antibiotics' function is based on the bioactive components in them[2] such as isothiocyanates, thymoquinone, allicin, and azadirachtin while the

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Table 1. Effect of green tea supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Broilers	Increased performance and health.	Seidavi et al.[9]
Powder	Broilers	Improved performance and economic parameters.	Saraee et al.[10]
Powder	Broilers	Increased non-intestinal bacteria, inhibiting growth of pathogens, improving performance, and reducing mortality.	Seidavi and Simões[11]
Powder	Broilers	Reduced abdominal fat in carcasses and causing weight loss.	Saraee et al.[12]
Powder	Broilers	Increased resistance to avian flu.	Seidavi et al.[13]
Powder	Quails	Lower blood lipids and cholesterol.	Karimi and Pazoki[14]
Extract	Broilers	Improved the immune system, decreased total cholesterol, and increased concentration of serum biochemical parameters.	Song et al.[15]
Extract	Broilers	Increased antibody titer against Newcastle disease virus.	Farahat et al.[16]
Extract	Broilers	Reduced malondialdehyide content and increased the expression of interleukin-6 and gamma interferon liver genes.	Alimohammadi Saraei et al.[17]
Powder	Broilers	Decreased the abdominal fat content and some lipid metabolites.	Liu et al.[18]
Powder	Broilers	Affected the gut microbiota.	Chen et al.[19]
Powder	Broilers	Reduced the body weight gain during their early age, increased the body weight gain during the late stage, induced *Lactobacillus* proliferation, and inhibited *E. coli* proliferation in the ileum and cecum.	Chen et al.[20]
Powder and extract	Broilers	Decreased carcass traits and performances.	Jelveh et al.[21]
Powder	Broilers	Decreased the egg production.	Xia et al.[22]
Powder	Broilers	Decreased body weight gain, cecum, and small intestine weight.	Hrnčár and Bujko[23]
Powder	Broilers	Decreased LDL, LDL/HDL ratio, and performance.	Alimohammadi Saraei et al.[24]
Extract	Broilers	Black cumin seed alone, or with artemisia leaf, improved health, but green tea extract negatively affected feed intake.	Khalaji et al.[25]

growth promoting is based on the ability of these plants to aid feed intake, increase feed digestibility through digestive enzyme stimulation, and prevent colonization of pathogens in the gut;[7] or perhaps, influence the development of the gut villi to aid absorption. This review highlights not only the beneficial impact but also detrimental effect of some of the direct-fed important medicinal plants on poultry nutrition.

Green tea (*Camellia sinensis* L.)

Phytoconstituents

Leaves of green tea (Family – Theaceae) have been used for beverages in China, Japan, and some other countries for thousands of years, even more in the form of black tea than as green tea. This plant contains polyphenol components such as epiphanolategalate, tannin, caffeine, theophylline, and theobromine.[8]

Beneficial and adverse effects in poultry nutrition

In the poultry industry, it is important to pay attention on the growth performances and immune system. This can be achieved via nutritional manipulation by supplementing green tea as feed additives (Table 1). The effects of a diet that included fish oil [1.5 and 2% weight by weight (*w/w*)] and green tea powder 1 and 1.5% (*w/w*) as supplements on the immunity of broiler chickens were demonstrated.[9] The additives exhibited beneficial effects on the immune system of the chickens. In this very study, hemorrhagic responses to Flu and Newcastle disease were improved. In another study, the addition of fish powder (1–2% *w/w)* and green tea (1 and 1.5% *w/w*) as supplements in the diet of broiler chickens improved the carcass weight. Rate of passage of feed through the digestive tract was reduced by increasing digestion, absorption, and efficiency of diet utilization.[10] In addition, researchers determined the effect of diets containing fish oil (1.5 and 2% *w/w*) and green tea powder (1 and 1.5% *w/w*) as supplements on gizzard, ileal, and cecal microflora in broiler chickens.[11] These diets did not have a significant effect on cecal microflora, especially at low levels; but if the combination was used for 42 days, it effectively inhibited the growth of pathogens by increasing non-intestinal bacteria, which improved performance and reduced mortality. Furthermore, researchers examined the effects of dietary supplementation of different levels of green tea powder (1 and 1.5% *w/w*) and fish oil (1.5 and 2% *w/w*) on carcass characteristics in broiler chickens. The combination resulted in lower abdominal fat in the carcass, as well as weight loss, because it led to a higher oxidation rate of lipid in the body.[12] Moreover, the effect of green tea powder (0.25–1.0% *w/w*) was examined on the immunological parameters of broiler chickens supplemented with green tea powder which led to increased resistance to Flu.[13]

Hematological and serum biochemistry parameters are very important measurements when using herbs in livestock. This is meant to access the internal health of livestock in a noninvasive manner. Study revealed the effects of green tea powder (1.5% *w/w*) on blood

parameters, egg quality, carcass quality, and growth performances in Japanese quail fed with or without added cholesterol.[14] Results showed that the addition of green tea powder into the diet of Japanese quail did not reduce blood lipid and cholesterol levels, but led to increase the body weight gain. The effects of dietary supplements including microencapsulated *Enterococcus faecalis* (1 g/kg of diet) and tea extract (300 and 500 mg/kg of diet) on growth performance, immune system, and biochemical parameters of broiler chickens were investigated.[15]

Another study determined the effect of green tea extract (GTE; 125, 250, 500, 1000, and 2000 mg/kg) on the growth performance, serum lipid profile, liver glutathione-reduced, thigh muscle malondialdehyde, and humoral immune response against Newcastle disease virus vaccines of broiler chickens from hatching to 42 d of age. Results showed no significant difference among treatments in the measured growth performance parameters (body weight, average daily gain, average daily feed intake, and feed conversion ratio) and serum lipid profile. Further, the intake of GTE significantly increased the liver glutathione-reduced level compared to the control. The supplementation of GTE decreased malondialdehyde level of meat tissue. In addition, GTE supplementation increased the specific antibody titer against Newcastle disease virus vaccines at 28 and 35 d of age in broilers.[16]

The effect of GTE (0.5 and 1 g/kg of diet) on growth performance, carcass characteristics, blood biochemical parameters, oxidative stability of meat, and expression of interleukin-6 genes and interferon gamma in broiler chickens was determined. The extract showed significant influence on liver enzyme ($p < 0.05$) and reduced malondialdehyide content produced in the drumsticks of broiler chickens ($p < 0.05$). Plant compounds increased the expression of interleukin-6 and gamma interferon liver genes.[17]

Researchers evaluated the impact of waste powder of green tea (0.25–1% *w/w*) on the growth performance, carcass characteristics, blood parameters, and lipid metabolites of growing broilers (chicks). The powder revealed positive influence on growth performance, carcass characteristics, blood parameters, and lipid metabolites of growing broilers. The supplementation of green tea powder (GTP) decreased the abdominal fat content and some lipid metabolites of broiler chicks. Findings concluded that dietary green tea can be used not only to reduce abdominal fat and lipid metabolites but also induce antioxidants.[18]

The influence of diet supplementation with GTP on the chicken gut microbiota was assessed. The gut microbiota compositions were determined using 16S rDNA sequencing. A higher abundance of potentially pathogenic *Gallibacterium* was found in the chicken gut when the diet was supplemented with GTP. These results indicated that GTP can greatly affect the gut microbiota of chickens by changing their compositions.[19]

In another study, the supplementation of GTP (1% *w/w*) reduced the body weight gain of broiler during their early age (days 0–21) but increased the body weight gain during the late stage (days 21–42) of production. The feed conversion ratio was unaltered upon addition of GTP. The leg muscle was proportionally high and abdominal fat was proportionally low in the supplemented group. The lightness value, the shear force, and the calcium content of the supplemented group were reduced in the breast meat. Dietary supplementation of GTP induced *Lactobacillus* proliferation, inhibited *Escherichia coli* proliferation in the ileum and cecum. Thus, study suggested that GTP could be used as ideal feed additive for improving meat color and *Lactobacillus* proliferation for broiler production.[20]

Besides the above-mentioned studies, there are few recent reports which revealed the adverse impact of green tea as feed supplements on diversified parameters of poultry. The comparative effects of GTE and GTP on performance of broilers were determined.[21] Feed intake and body weight gain were suppressed ($p < 0.05$) by GTP supplementation ($p < 0.05$). The relative weights of carcass, breast, and drumstick were significantly ($p < 0.05$) decreased due to the addition of GTP. According to the authors, differences in the polyphenol content of the extract (10.2%) and powder (14.9%) might be the prominent reasons for reduced performance results.

The effects of GTP (1–3% *w/w*) supplementation on egg production and egg quality in hens were investigated.[22] Results suggested that 1% (*w/w*) GTP supplementation had little effect on egg production and feed conversion, but high amounts of GTP (>2% *w/w*) treatment significantly ($p < 0.05$) decreased the egg production performance. Thus, GTP treatment significantly changed the nutritional composition of eggs.

The effect of different levels of green tea in powder form as feed additives on productive performance, carcass parameters, and organs in broiler chickens was determined.[23] Results indicated that the supplementation of different levels (0.5–1.5% *w/w*) of green tea decreased the body weight gain and recorded lower body weight in 21 days of age compared with control

Table 2. Effect of lavender supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Extract	Broilers	Due to antioxidant activity, it can be used as a growth promoter and can prevent liver damage.	Küçükyilmaz et al.[27]
Powder	Broilers	Increased feed intake, body weight gain, and feed conversion ratio. Decreased jejuna crypt depth and increased villous height:crypt depth ratio.	Salajegheh et al.[28]
Essential oil	Broilers	Improved weight gain and feed conversion ratio. Reduced the growth of pathogens and increased the counts of lactic acid bacteria.	Adaszynska-Skwirzynska and Szczerbinska[29]
Essential oil	Broilers	Increased superoxide dismutase activity in serum and liver and glutathione peroxidase activity in serum, reduced concentrations of malondialdehyde in the serum, and inproved body weight gain.	Barbarestani et al.[30]
Powder	Broilers	Decreased carcass, breast, thigh, wings, neck, gizzard weights, and counts of cecal *Lactobacillus* spp.	Mokhtari et al.[31]

group. The cecum and small intestine weights were significantly ($p \leq 0.05$) decreased in chickens fed diets containing 0.5% (*w/w*) green tea supplement compared to 1 and 1.5% (*w/w*).

The influence of the dietary supplementation of fish oil (0, 15, or 20 g/kg of diet), GTP (0, 10, or 15 g/kg of diet), or their factorial treatment arrangements on selected blood chemical components in 42 days old broiler chickens was investigated.[24] The GTP at 15 g/kg of diet caused a significant increase in plasma uric acid content, but in combination with fish oil, the plasma uric acid content was lower than with 15 g of GTP alone. The GTP at 15 g/kg of diet caused a significant ($p < 0.05$) reduction in plasma low density lipoprotein (LDL), which was attributed to a significant ($p < 0.05$) decrease in plasma LDL/high density lipoprotein (HDL) ratio. In general, performance traits of broilers fed GTP with and without fish oil decreased, which was attributed to the decrease in feed intake and decreased energy and protein efficiencies.

Researchers used black cumin seeds (BCS), artemisia leaf (AL), and green tea as phytogenic products in broiler diets and studied their effects on the performance, blood components, immunity, and intestinal bacterial population.[25] Results showed that BCS alone, or with AL, improved health of broiler chickens, but green tea had a negative effect on feed intake; therefore, suggested that it could not be used as a good alternative to commercial mannan-oligosaccharide.

*Lavender (*Lavandula stoechas *L.)*

Phytoconstituents

Lavender (Family – Lamiaceae) is a perennial plant, revealing bitter taste and a pleasant smell. The essence of this plant contains some compounds such as acetate lanalil, butyric acid, propionic acid, valeric acid, free linalool, and grambol.[26]

Beneficial and adverse effects in poultry nutrition

Table 2 summarizes the beneficial and detrimental impacts of lavender on poultry nutrition. Researchers reported the effects of lavender extract (24 and 48 mg/kg of feed) on growth performance, carcass quality, and antioxidant status of broiler chickens.[27] A total of 405 day-old chicks (Ross-308) were allocated to the three dietary treatments, each with three replicate pens with 45 birds per pen. After the first 21-day feeding period, the body weight of chicks fed 24 mg of lavender extract/kg of feed was higher ($p < 0.01$) than 48 mg of lavender extract/kg of feed treatment, but only slightly higher than that of the untreated group. Diets with 24 and 48 mg of lavender extract tended to increase final body weight of birds at 39 days old. No differences were observed for feed intake, feed conversion ratio, and mortality among treatments. Percentage of spleen weight of birds fed 24 mg of lavender extract/kg of feed was lower ($p < 0.05$) than for those who received 48 mg of lavender extract/kg of feed. However, it was similar to that of the control group. Birds fed diets supplemented with 24 and 48 mg lavender extract/kg of feed had breast meat with higher brightness and higher concentration of superoxide dismutase compared with birds that did not receive lavender extract. Authors concluded that the extract of this plant could be used as a growth promoter in broiler chickens and prevented liver damage due to its antioxidant activity.

Researchers evaluated the effects of lavender powder as an herbal feed additive on growth performance, carcass traits, meat quality, jejunal histomorphology, and ileal microbial population in broiler chickens.[28] Results showed that lavender powder (1% level) significantly ($p < 0.05$) increased feed intake during the finisher and entire rearing periods. Also, body weight

Table 3. Effect of nettle supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Laying hens	Increased food intake, production percent, and special weight. Decreased total cholesterol, triglycerides, and LDL concentration.	Hosseini-Mansoub[32]
Powder	Broilers	A mixture of nettle, *Mentha pulegium* and *Thymyus vulgaris* improved performance and quality of carcass.	Ali[33]
Powder	Broilers	Reduced serum cholesterol and triglyceride levels, and improved immune system.	Safamehr et al.[34]
Powder	Laying hens	Effective in achieving desired yellow color in egg yolks, without adverse effects.	Loetscher et al.[35]
Extract	Broilers	Improved internal organs, but no change in performance.	Keshavarz et al.[36]
Extract	Broilers	Positive effect on body weight gain.	Kwiecień and Winiarska-Mieczan[37]
Extract	Broilers	Overexpression (target gene/β-actin as the arbitrary unit) of catalase (*CAT*) and superoxide dismutase 1 (*SOD1*) genes in the liver and lung.	Ahmadipour and Khajali[38]
Extract	Broilers	Improved body weight gain and feed conversion efficiency.	Meimandipour et al.[39]
Powder	Quails	Reduced egg yolk cholesterol, serum cholesterol, and serum triglyceride levels.	Moula et al.[40]

gain and feed conversion ratio improved during the grower, finisher, and entire rearing periods. Lavender powder significantly ($p < 0.05$) decreased jejunal crypt depth and increased villas height: crypt depth ratio with respect to the control. Authors suggested that lavender powder can be used to improve growth performances and meat quality in the broilers.

Authors evaluated the growth performance, selected biochemical blood parameters, and the microbiota of ileal digesta in broiler chickens provided with drinking water containing an addition of natural lavender essential oil (LEO).[29] The analyses revealed that the addition of LEO had a positive effect on body weight gain in the second period of rearing (d 22–24). Treatment broilers (LEO1-42 and LEO22-42) weighed on average 6.35% more compared to the control ($p < 0.01$). Addition of LEO positively affected body weight gains and feed conversion ratio ($p < 0.01$) in the second period of rearing (d 22–24). No differences were found between the groups feed intake, water intake, survival rate, and blood biochemical parameters ($p > 0.05$). The addition of LEO to drinking water had a positive impact on the gut microflora of the ileum in terms of reduced counts of pathogenic microorganisms (*E. coli* and coliform) as well as increased counts of probiotic bacteria ($p < 0.01$).

Effects of supplementation of varied levels (300 and 600 mg/kg of substrate) of LEO supplementation on growth performance and physiological characteristics of broiler chickens was estimated.[30] Results showed that treatments had no significant ($p > 0.05$) effect on feed intake at any stage of the study. In addition, no effect of treatments was observed on body weight gain and feed conversion ratio over the starter period (d 0–21). However, broiler chickens fed with LEO_{600} exhibited greater body weight gain and showed reduced feed conversion ratio during grower period (d 21–42). Further, the dietary supplementation of LEO increased superoxide dismutase activity in serum and liver and glutathione peroxidase activity in serum, but reduced concentrations of malondialdehyde in the serum ($p < 0.05$).

Based on the previous investigations, the supplementation of lavender into the feed revealed its adverse impact in poultry nutrition too. The effects of lavender essence (100 to 800 mg/kg of feed) on carcass characteristics and cecal microflora of broiler chickens were evaluated.[31] Birds given 400 mg of lavender/kg of feed had lower ($p < 0.05$) carcass, breast, thigh, wings, neck, and gizzard weights than birds from the other groups. Broilers fed 600 mg of lavender/kg of feed had lower ($p < 0.05$) counts of cecal *Lactobacillus* spp. than other groups.

*Nettle (*Urtica dioica *L.)*

Phytoconstituents

Nettle (Family – Urticaceae) is widely found in different parts of the world and is used for health improvement. Analysis showed that it contained more than 50 different chemical compounds, including starch, gum, albumin, sugar, and resin. It also contained histamine, acetylcholine, choline, and serotonin.[32]

Beneficial effects in poultry nutrition

The beneficial effects of nettle on poultry nutrition are described in Table 3. The effects of nettle (0.75–2% *w/w*) on performance, egg quality, blood biochemical, and immunity parameters of laying hens were evaluated.[32] Results showed that using this medicinal plant with different level had significant ($p < 0.05$) effects on performance, blood parameters, and egg quality but did not show significant ($p > 0.05$) effects on the immune system of laying hens. The highest

food intake, production rate, and body weight gain were seen in the treatment group. Also, the serum total cholesterol, triglycerides, and LDL concentrations were significantly ($p < 0.05$) reduced in treatment group compared to the control group.

The effect of nettle (0–2% *w/w*) on carcass characteristic of male broilers was evaluated.[33] According to the findings, the highest and the lowest intestine percentage (5.26 and 3.91%) were observed in control and third experiment groups, whereas the highest and the lowest gizzard percentage (2.9 and 2.44%) were observed in second and control groups. The highest and the lowest percentage of liver (3.85 and 2.87%) were observed in groups fifth and third. Author suggested that nettle could effectively improve the carcass characteristics of broilers.

The medicinal effects of nettle (0.5–2% *w/w*) on growth performance, immune response, and serum biochemical parameters of broiler chickens were determined.[4] Results showed that the supplementation of 1% (*w/w*) nettle increased body weight of broilers at 42 days of age ($p < 0.05$). Feed conversion ratio of broiler chickens fed diets containing 1% (*w/w*) of nettle significantly ($p < 0.05$) improved in comparison to the control group at 0–21 and 0–42 days of age. Serum triglyceride and cholesterol concentrations were significantly ($p < 0.05$) decreased in broilers fed 1% (*w/w*) nettle diet. Feeding diets containing different levels of nettle did not show significant effect on carcass yield in comparison to control. None of the immune related parameters was statistically different among the treatments. Findings indicate that nettle supplementation at 1–2% (*w/w*) can be used as growth promoters in broiler diets. The effects of nettle (6.25–25 g/kg of feed) in the diet of laying hens to add natural color to the yolk were assessed.[35] Study showed that nettle is an effective tool to achieve optimal yellow yolk color, without any side effects. The growth performance, blood metabolites, antioxidative stability, and carcass characteristics of broiler chickens fed a diet containing nettle powder or extract (5 and 10 g/kg of feed) were examined.[36] Results showed that carcass internal organs such as liver, bile sac, gizzard, proventriculus, and lungs weight were affected by different level of nettle powder and extract ($p < 0.05$). The blood metabolites indicated that the use of nettle powder or extract decreased aspartate aminotransferase (AST) in birds ($p < 0.05$). However, blood parameters such as alkaline phosphatase (ALP), alanine transaminase (ALT), glucose, cholesterol, and triglyceride were not influenced by dietary treatments. Thiobarbituric acid reactive substances (TBARS), as an indicator for meat lipid oxidation after storage, were not affected by supplementing nettle powder or extract in broiler diets. Study concluded that the inclusion of 10 g of nettle essential oil/kg of diet probably can induce internal organs potential. Previous report also revealed that nettle extract (2% *w/w*) had a positive effect on body weight gain of broiler chickens.[37]

Nettle at various levels (0.5–1.5% *w/w*) was supplemented into the diet of broiler chickens to investigate the antioxidant gene expression and pulmonary hypertensive responses. Findings showed a significant relative overexpression (target gene/β-actin as the arbitrary unit) of catalase (CAT) and superoxide dismutase 1 (SOD1) genes in the liver and lung of the chickens fed nettle. Lipid peroxidation was significantly suppressed after supplementing nettle. These birds also had significantly ($p < 0.05$) higher serum nitric oxide concentrations than those in the control group. Feeding nettle at 1 and 1.5% (*w/w*) also attenuated the right ventricular hypertrophy. In addition, supplementation of nettle upregulated hepatic and pulmonary antioxidant genes.[38]

In another study, a significant effort was undertaken to depict the impact of extracts of nettle root (0.02–0.05% *w/w*) on performance of broiler chickens. Results showed that that the extract improved body weight gain and feed conversion efficiency. Findings concluded that the extract can be used as a substitute for antibiotics in the diet of broiler chickens.[39]

Authors evaluated the effects of dietary supplementation of stinging nettle powder (SNP) on laying performance, egg quality, and some selected serum biochemical parameters of Japanese quails.[40] One hundred and forty-four 10-wk-old Japanese quails were divided into three dietary treatment groups (basic diet without SNP [SNP0], SNP0 with 3% SNP [SNP3], SNP0 with 6% SNP [SNP6]) with 4 replicates for a rearing period of 12 wk. Results showed that daily feed intake was not statistically ($p > 0.05$) different among the groups. The mean number of eggs laid ranged from 65 to 69 with laying rates from 76.8 to 82.1%. The rate of cracked eggs was not significantly ($p > 0.05$) different among the groups and ranged from 1.6 to 1.9%. The egg weight was similar, and the feed conversion ratio was closer among the groups. The egg yolk cholesterol, serum cholesterol, and serum triglyceride levels in the SNP6 group were significantly reduced ($p < 0.001$) compared to those of the SNP0 group. Serum Ca, P, and Mg were not significantly ($p > 0.05$) influenced by the supplementation. In conclusion, the supplementation of SNP to

Table 4. Effect of pennyroyal supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Broilers	Improved performance and characteristics, probably due to antibacterial and antifungal properties, and decreased harmful microbial population in the intestine.	Goodarzi and Nanekarani[42]
Powder	Broilers	Positive effect on performance and carcass characteristics.	Nobakht et al.[43]
Powder	Broilers	Reduction in *E. coli* and increase in lactic acid bacteria. Improved feed conversion.	Erhan et al.[44]
Extract	Broilers	Improved immune response to Newcastle disease.	Mahdavi et al.[45]
Extract	Laying hens	Improved feed conversion rate, egg production, egg weight, and shell strength.	Aydın et al.[46]
Essential oil	Japanese quail	Improved feed conversion ratio and reduced serum triglycerides level.	Dehghani et al.[47]
Extract	Laying hens	Improved the performance, decreased the blood parameters, and increased the lymphocyte of laying hens.	Paymard et al.[48]
Powder	Laying hens	Alone, or in combination with probiotics showed adverse effects on the performance of laying hens.	Arjomandi et al.[49]
Powder	Broilers	No positive effect on growth performance.	Ghalamkari et al.[50]

the Japanese quail diet at the level of 6% reduced Japanese quail egg yolk cholesterol, serum total cholesterol, and serum triglyceride levels and did not negatively influence Japanese quail performance. Considering the prior investigations, the utilization of nettle as feed supplement did not exhibit adverse impact on the growth performances, immunological parameters, blood parameters, and serum biochemical parameters of poultry.

Pennyroyal (Mentha pulegium *L.*)

Phytoconstituents

Pennyroyal is a medicinal plant from the family Lamiaceae. The most important compounds of pennyroyal essence are trans-caryophyllene, eucalyptol, germacrene-D, and viridiflorol.[41]

Beneficial and adverse effects in poultry nutrition

Table 4 illustrates the beneficial and adverse effects of pennyroyal powder or extract on poultry nutrition. The effects of pennyroyal powder (1–3% *w/w*) as an alternative to antibiotics for broiler chickens were investigated.[42] Results concluded that the supplementation of 2% *w/w* of pennyroyal improved performance (body weight gain, feed conversion, and breast percentage) and carcass characteristics, probably due to antibacterial and antifungal properties of pennyroyal compounds.

The effects of different levels (0.5–2% *w/w*) of pennyroyal powder on performance (body weight, feed intake, and feed conversion), carcass and giblet characteristics (abdominal fat, gizzard, breast, thigh, and liver weights), hematological parameters (glucose, cholesterol, triglyceride, albumin, uric acid, heterophil, lymphocyte, and heterophil/lymphocyte) of broiler chickens were demonstrated.[43] There were significant ($p < 0.05$) differences between treatments on performance, carcass traits, and blood biochemical parameters of broilers. The overall results showed that the use of 0.5% *w/w* of pennyroyal in the diets of broilers had positive effects on their performances and carcass traits.

In another study, the effects of dietary pennyroyal levels (0, 0.25, or 0.5% *w/w*) on the growth performance and bacteria count in the jejunum of broilers were investigated.[44] The average final body weights and body weight gains were similar in all groups. The gain-to-feed ratios for 0, 0.25, and 0.5% *w/w* dietary pennyroyal were 1.5, 1.5, and 1.41, respectively. The supplementation of pennyroyal reduced *E. coli* count and increased the lactic acid bacteria count of the jejunum ($p < 0.01$). In conclusion, dietary supplementation of pennyroyal improved feed conversion ratio and lactic acid bacteria count, as well as decreased *E. coli* count of the jejunum in broilers.

Authors investigated the effects of different levels (0.5–2% *w/w*) of pennyroyal extract on the immune function of broiler chickens.[45] During hemaggultination inhibition test (antibody levels against Newcastle virus vaccine), the extract did not show statistical significance ($p > 0.05$) in different treatment groups. Regarding heterophil: lymphocyte ratio, the additive did not show statistical significance ($p > 0.05$) in different treatment groups. However, pennyroyal (1% *w/w*) showed the best performance in comparison with the other groups and found improvements in immune response against Newcastle disease.

The supplementation of pennyroyal extract at different levels (0, 32.5, 65, and 130 mg/kg of extract) into the diets of laying hens improved feed conversion rate, egg production, egg weight, and shell strength. On the other hand, the additive revealed no effect on feed intake, rates of albumen, specific gravity, and some serum parameters of laying hens.[46]

Table 5. Effect of ginger supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Extract	Broilers	A mixture of ginger, fennel, and anis extracts reduced fat content of meat and increased the color intensity.	El-Deek et al.[52]
Extract	Broilers	Improved physiological functions and lipid profile.	Saeid et al.[53]
Extract	Broilers	Decreased the breast and thigh malondialdehyde and increased muscle, reduced glutathione serum interferon gamma, and interleukin 2 levels.	Zidan et al.[54]
Extract	Broilers	Improved growth.	Ebrahimnezhad et al.[55]
Powder	Broilers	Improved performance, carcass, and blood parameters.	Barazesh et al.[56]
Powder	Broilers	Feed conversion ratio was lowered.	George et al.[57]
Extract	Broilers	Reduced microbial population in the gastro-intestinal tract.	Ofongo-Abule and Ohimain[58]
Powder	Broilers	Reduced gizzard weight and abdominal fat, and increased *Lactobacillus* count.	Qorbanpour et al.[59]
Extract	Laying hens	Increased egg weight, egg quality, and antioxidant status.	Wen et al.[60]
Essential oil	Japanese quail	Increased egg weight and reduced serum and cholesterol level.	Herve et al.[61]
Powder	Broilers	Inhibited pathological bacteria in broiler's gut.	Huthail Najib et al.[62]
Powder	Broilers	Increased body weight, gain in body weight, performance index, and carcass characteristics.	Rio et al.[63]
Extract	Laying hens	Improved plasma superoxide dismutase activity and reduced malondialdehyde content.	An et al.[64]

In another report, pennyroyal essential oil at varied levels (200, 300, and 400 ppm/kg of diet) showed significant improvement in feed conversion ratio of Japanese quail. Organs weight was not significantly ($p < 0.05$) affected by the experimental treatments. Serum triglycerides level was decreased in the groups that received diets supplemented with different levels of essential oils. Findings suggested that plant essential oils can be used as ideal replacement of antibiotic growth parameters without affecting quail's health.[47]

The effect of different levels (0.5–1.5% *w/w*) of pennyroyal extract on performance, egg traits, blood biochemical (triglyceride, albumin, total protein, and uric acid content), and immunity parameters (hetrophil and lymphocyte) of laying hens was investigated.[48] Pennyroyal significantly ($p < 0.05$) affected the performance, egg traits, blood biochemical, and immunity parameters of laying hens. Pennyroyal powder at 1.5% *w/w* concentration enhanced the performance, decreased the blood parameters, and improved the lymphocyte of laying hens. Results showed that varied doses of pennyroyal powder and extract could alter the egg traits, blood biochemical parameters, and immunity of laying hens.

Researchers investigated the effects of probiotics (1 and 2% *w/w*) and pennyroyal powder (1 and 2% *w/w*) on the performances (average egg weight, egg production percentage, egg mass production, feed intake, and feed conversion ration) of laying hens.[49] Results showed that pennyroyal, alone or in combination with probiotics, had undesirable effects on performances of hens.

The effects of pennyroyal (5 and 10 g/kg of feed) on performance (body weight, feed intake, and feed conversion ration), carcass as well as some internal organ traits (abdominal fat, gizzard, cecum, and small intestine weights), and immune responses (influenza, new castle, and sheep red blood cells) on broiler chickens were assessed.[50] Results indicated that the performance, internal organ weights, and carcass characteristics were not significantly ($p > 0.05$) nfluenced by the dietary treatments at day 42. Humoral immune responses were not affected by dietary treatments. Results of this study showed that the inclusion of pennyroyal powder had no positive influence on growth performance of broiler chickens.

*Ginger (*Zingiber officinale *Roscoe)*

Phytoconstituents

Ginger (Family – Zingiberaceae) is widely used as therapeutic agent since ancient period. Ginger contains several active compounds including gingerol, shogaols, gingerdiol, and gingerdione.[51]

Beneficial effects in poultry nutrition

The beneficial impact of ginger in poultry nutrition is exhibited in Table 5. Study investigated the effect of ginger extract at the concentrations of 0.05 and 0.1% *w/w* on performance (initial body weight, body weight, and total feed intake), carcass as well as some internal organ traits (abdominal fat, heart, liver, spleen, and pancreas), and meat quality of broiler chickens.[52] Results showed significant ($p < 0.05$) improvement in the performances while no significant ($p > 0.05$) effect on carcass traits was estimated. Additionally, the plant decreased meat fat level and substantially increased color intensity.

Authors investigated the usage of different levels such as 0.4 and 0.6 g of aqueous extract of ginger/kg

of diet on blood parameters and lipid profile of the broiler chickens.[53] Result showed significant ($p > 0.05$) difference in the glucose and uric acid contents between treatments. However, albumin and globulin contents were not significantly affected ($p < 0.05$). Serum HDL-cholesterol, LDL-cholesterol, and very low-density lipoprotein (VLDL)-cholesterol level revealed no significant ($p > 0.05$) difference between treatments but serum cholesterol level was a significantly ($p < 0.05$) lower in the 0.4 and 0.6 g of aqueous extract of ginger/kg of feed. Findings of the research study indicated that the ginger infusion at the rate 0.4 and 0.6 g/kg of feed improved the blood parameters and lipid profiles in broiler.

The effects of ginger extract (5–15 g/kg of feed) as feed additive on growth performance, immunity, and antioxidant status in broiler chickens were determined.[54] The overall body weight gains and feed conversion ratio of birds treated with feed additive were significantly ($p < 0.05$) increased. In addition, ginger significantly ($p > 0.05$) decreased the levels of serum total cholesterol and triacylglycerol. Moreover, the supplementation of ginger significantly ($p < 0.05$) decreased the breast and thigh malondialdehyde and significantly ($p < 0.05$) increased muscle, reduced glutathione serum interferon gamma, and interleukin 2 levels.

Researchers studied the effect of ginger (5, 10, 15, 20, and 25 g/kg of feed) on growth performance (body weight gain, feed intake, and feed conversion ratio), carcass as well as internal organs characteristics (relative weights of carcass, liver, abdominal fat, fat around gizzard, and intestinal), and blood biochemistry (glucose, triglycerides, globulin, cholesterol, albumin, and cholesterol) parameters in broiler chickens.[55] Results showed that the growth performance was significantly ($p < 0.05$) improved in the ginger treated broilers compared to the not supplemented controls. In addition, carcass characteristics and blood biochemistry parameters were not significantly ($p > 0.05$) altered except relative weight of eviscerated carcass and blood LDL.

The effect of ginger powder (0.5–1.5 g/kg of feed) on performance (feed intake, weight gain, and feed conversion ratio), carcass characteristics (thigh, breast, liver, gizzard, abdominal fat, and spleen weights), and blood parameters (glucose, triglyceride, cholesterol, LDL, and HDL) in broiler chickens (Ross) in a completely randomized design was demonstrated.[56] Results showed that increasing levels of ginger powder caused a significant ($p < 0.05$) reduction in food intake and weight gain in broilers. The carcass traits were not significantly ($p > 0.05$) affected. Further, the blood parameters of glucose, HDL, and LDL levels treated with 1.5 g of ginger powder/kg of feed showed no significant ($p > 0.05$) difference compared to control, while, the supplementation of ginger powder showed non-significant ($p > 0.05$) reduction in cholesterol and triglycerides content.

The effect of feeding ginger (2–6 g/kg of feed) at graded levels on growth and performance characteristics of broiler chickens was assessed.[57] Feed conversion was significantly reduced with respect to the control group, which can be attributed to the active ingredients in ginger that result in stable intestinal flora. In another study, authors examined the antimicrobial effects of fresh ginger root extract fed to broiler chickens.[58] One week later, the microbial population, particularly *Salmonella* sp., *Lactobacillus* sp., and *E. coli* in the gastrointestinal tract were reduced. Authors recommended that the use of ginger for the control of infection is plausible but its use must be modified to prevent killing of beneficial microbes in the broiler gastrointestinal tract.

Male broiler chickens fed with 0.15, 0.2, and 0.25% (*w/w*) of ginger powder showed no significant effect on growth traits and carcass characteristics, whereas a significant reduction in gizzard weight and abdominal fat compared to the control group was estimated. *Lactobacillus* counts in ileal content of birds fed 0.2 and 0.25% (*w/w*) ginger were higher compared to the other treatments.[59] In another study, the dietary supplement of ginger (100 g/kg of diet) increased egg weight, egg quality, and antioxidant status of laying hens.[60]

Herve et al.[61] evaluated the impacts of ginger rhizome essential oil (50 to 150 µL/kg of body weight) on growth and laying performances, cholesterol status, and serum metabolites in Japanese quail. Results showed that the additive had no significant ($p > 0.05$) impact on feed intake, live and body weights gain, feed conversion ratio, egg production, and weekly mass of eggs. Likewise, the oral administration of ginger rhizomes essential oil had no significant effects ($p > 0.05$) on liver, intestine, heart, and gizzard relative weights as compared to the control. Egg weight markedly ($p < 0.05$) increased in Japanese quails treated with ginger rhizomes essential oil. The serum and cholesterol level reduced significantly ($p < 0.05$) with 100 and 150 µL/kg body weight of ginger rhizomes essential oil compared to control group.

In another investigation, 10, 20, and 30 g/kg of ginger root powder did not affect growth performance and immune response of broiler chickens. However,

Table 6. Effect of yarrow supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Broilers	Reduced serum lipid levels and increased immune response. Reduced the population of pathogenic bacteria in the gastro-intestinal tract, and improved intestinal and overall health.	Yakhkeshi et al.[68]
Powder	Broilers	Lack of mortality and absence of pathological lesions at autopsy suggested that yarrow was useful in poultry nutrition.	Makinia[69]
Powder	Broilers	Improved feed conversion rates, gastrointestinal tract weight, and lactobacilli counts.	Norouzi et al.[70]
Powder	Broilers	No positive effect on growth performance.	Toghyani et al.[71]

ginger powder revealed significant ($p < 0.05$) inhibitory effect on pathological bacteria in broiler's gut.[62] Rio et al.[63] assessed the effect of dietary supplementation of ginger powder (7.5 g/kg of diet) on performance of broiler chicken. Findings showed that the dietary supplementation of ginger powder had significant ($p < 0.05$) effect on the performance in terms of body weight, gain in body weight, performance index, and carcass characteristics.

An et al.[64] investigated the effect of ginger extract (0.1% *w/w*) on production performance, antioxidant ability, and immunity of laying hens. Ginger extract significantly ($p < 0.05$) enhanced laying rates and daily egg weight and reduced the ratio of feed to egg of the hens. The extract did not change glutathione peroxidase activity and total antioxidant capacity but improved plasma superoxide dismutase activity and reduced malondialdehyde content. Further, the ginger extract did not affect the serum total protein content, albumin, and globulin, but significantly ($p < 0.05$) altered lysozyme activity and plasma prostaglandin content.

In spite of limited adverse effect of ginger on poultry nutrition, feeding ginger to the chickens led to edema, necrosis, and inflammation. All phytobiotics have toxic properties and their toxicity is determined by dosage and duration of feeding.[65] Feeding these substances at higher doses causes congestion, edema, inflammation, and necrosis.[66]

*Yarrow (*Achillea millefolium *var. occidentalis)*

Phytoconstituents

Yarrow is a wild and herbaceous plant of family Asteraceae. Volatile oil, polyphenols, some types of flavors, lactone betains, acetylene compounds, resin, tannin, achilles, phosphate, nitrate, and potassium salts of organic acids are important constituents of its floral branches.[67]

Beneficial and adverse effects in poultry nutrition

The beneficial and adverse impacts of yarrow powder are summarized in Table 6. Previous study depicted the effect of yarrow powder (1.5 and 3 g/kg of feed) on the performance (feed intake, weight gain, and feed conversion ratio), gastrointestinal characteristics (duodenum, jejunum, and ileum) immune response (total titer, IgG, IgM, bursa, and spleen), blood parameters (triglyceride, cholesterol, HDL, and LDL), and microbial population (total aerobic, lactic acid bacteria, and total coliforms) of broiler chickens. Yarrow increased the growth performances and decreased the level of serum lipids. Further, it increased the immune response in broiler chickens and reduced the population of pathogenic bacteria in the gastrointestinal tract, which can help improve intestinal health and chicken health.[68] The effects of yarrow (1% *w/w*) as a growth stimulant for broilers were demonstrated.[69] The group fed yarrow had no mortality or pathological lesions, concluding that the supplementation of yarrow powder in the diet of broiler chickens will be very useful in poultry nutrition in future.

The effect of increasing dietary levels (0.5–1.5 g/kg of feed) of yarrow herb powders on the growth performance (feed intake, average daily weight gain, and feed conversion rate), carcass traits (breasts and drumsticks), and ileal microbiota (*Lactobacillus* sp. and *E. coli*) of broilers was determined.[70] Results showed significant differences ($p < 0.05$) between treatments in the starting (d 1–21) and growing (d 22–42) periods, and in the average feed intake in the starting period. Yarrow supplementation resulted in better-feed conversion rates ($p < 0.05$) than the control treatment for all the periods. No significant differences ($p > 0.05$) were found in the final body weight or in most of the carcass traits at 42 days of age. The gastrointestinal tract weight, relative to body weight, increased ($p < 0.05$) due to yarrow supplementation, compared with the control treatment. At 42 days of age, the yarrows supplementation slightly increased lactobacilli and decreased *E. coli* counts.

Researchers demonstrated the influence of yarrow (5 and 10 g/kg of diet) in comparison with a probiotic supplement on the performance (body weight, daily feed intake, and feed: gain ratio), humeral immunity

Table 7. Effect of flax supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Seeds	Broilers	Increased alpha-linolenic acid in tissues.	Mridula et al.[74]
Seeds	Quails	Best performance, highest egg yield, and best hatchability.	Szczerbinska et al.[75]
Seeds	Broilers	Increased n-3 fatty acids in breast and thigh tissues.	Shen et al.[76]
Seeds	Broilers	Erythrocyte deformation did not change but total saturated fatty acids in the erythrocyte membrane reduced.	Bond et al.[77]
Powder	Broilers	Reduced blood protein and increased liver enzymes.	Al-Nawass[78]
Seeds	Broilers	No impact on number of fertile eggs, post-hatch mortality, and fertility rate.	Saber and Kutlu[79]
Oil	Broilers	Reduced feed conversion ratio, abdominal fat percentage, total triglycerides, $CD4^+$ T lymphocyte count, $CD4^+$:$CD8^+$ ratio, and total cholesterol in blood. Increased cardiac glutathione peroxidase.	Huo et al.[80]
Seeds	Broilers	Increased average body weight and reduced ether extract content and energy digestibility of the diets. Increased the iron content in drumstick muscles.	Zając et al.[81]
Seeds	Broilers	Reduced weight gain and increased feed conversion ratio. Reduced the levels of saturated fatty acids, monounsaturated fatty acids, and increased polyunsaturated fatty acids.	Zhaleh et al.[82]
Seeds	Laying hens	Increased yields of omega-3 eggs as well as improved health of layer birds.	Khan[83]
Seeds	Peking ducks	Decreased growth performance, body weight, and body weight gain.	Shahid et al.[84]

(Newcastle disease, Influenza, sheep red blood cells, H/L, and A/G), and blood parameters (albumin, globulin, triglyceride, total cholesterol, red blood corpuscles or RBC, white blood corpuscles or WBC, and hemoglobin) in broiler chickens.[71] Results showed that the body weight of broilers significantly ($p < 0.05$) decreased using 10 g of yarrow/kg of feed. Feed intake and feed conversion were not affected by dietary treatments. Most of the blood parameters were not statistically ($p > 0.05$) affected by dietary treatments. No significant impact of additive was observed on humoral immune responses. Results suggested that the addition of yarrow powder had no positive influence on growth performance and failed to elevate immune responses thus, it could not be considered as a natural growth promoter for broiler chicks.

Flax (Linum usitatissimum *L.*)

Phytoconstituents

Flax (Family – Linaceae) is unique among the vegetable oil seeds as its essence contains large amounts of oil, with a high percentage of α-linolenic acid.[72] Traditionally, ground flax is used to produce oil for industrial use and as a protein supplement in the feeding of birds. In birds, the characteristics of meat and fat are directly affected by the source of dietary fat. Omega-3 fatty acids are known to increase in egg and meat of poultry fed with flax supplementation.[73]

Beneficial and adverse effects in poultry nutrition

Table 7 illustrates the beneficial and detrimental effects of flaxseeds and powder on poultry nutrition. The growth performance (live weight, feed intake, feed conversion ratio, and energy efficiency ratio), carcass characteristics, and meat quality of broilers fed diets with flaxseed (5–15 g/kg of feed) were demonstrated.[74] Among the treatments, birds of 5 and 10 g of flaxseed/kg of feed meal groups had significantly ($p < 0.05$) better feed conversion ratio, protein efficiency ratio, and energy efficiency ratio compared to those of the 15 g of flaxseed/kg of feed meal group. The carcass characteristics data indicated a significant ($p < 0.05$) reduction in the eviscerated weight and breast yield at 15 g of flaxseed/kg of feed meal in the diet as compared to other dietary groups. However, the alpha-linolenic acid content in both breast and thigh meat was higher with an increasing level of flaxseed meal in the diets without affecting the sensory acceptability of meat. Findings suggested that up to 10 g of flaxseed/kg of feed meal may be used in broiler diet to enhance the alpha-linolenic acid content in the broiler meat.

In another study, researchers demonstrated the effects of flaxseeds (4 and 7 g/kg of feed) as dietary supplementation on performance (egg weight, egg laying performance, feed intake, and feed utilization) and reproduction (fertilization rate and hatchability rate) of quails.[75] Results showed the best performance and the highest fertility of eggs in quails that received 4 g of flaxseeds/kg of diet. On the other hand, the highest rate of hatching was obtained when the diet was supplemented with 7 g of flaxseeds/kg of feed.

The effect of diets containing various levels (12 and 14 g/kg of diet) of flaxseed on carcass characteristics and fatty acid deposition was investigated in broiler chickens. Flaxseed resulted in increased levels of omega-3 fatty acids in broiler breast and thigh meat.[76] Previous study investigated the effect of flaxseed (10–30 g/kg of diet) on the growth of broiler chickens, erythrocyte deformability, and fatty acid composition

of membranes.[77] Deformability of erythrocytes did not change, but the percentage of total saturated fatty acids in erythrocyte membranes was reduced. This was probably due to the presence of unsaturated fatty acids in flaxseed powder. The effect of different levels (12–16 g/kg of diet) of gold flax powder on some blood biochemical parameters (serum protein, albumin, globulin, ALT, AST, and ALP) in male and female broiler chickens was investigated.[78] Results showed that the supplementation of flaxseed powder at higher concentrations in the diet reduced blood protein and increased liver enzymes.

In another recent study, the effect of different dietary fatty acid (omega-3 and omega-6) sources containing 2% *v/w* (volume by weight) flaxseed was determined on reproductive performance of female broiler breeders and growth performance and carcass traits of their progeny.[79] Findings revealed that the inclusion of different fatty acid sources in female broiler breeders diet had no significant impact ($p > 0.05$) on number of fertile eggs, post-hatch mortality, and fertility rate. The study concluded that 2% (*v/w*) flaxseed oil in broiler breeders' diet could reduce late embryonic mortality. On the other hand, the other reproductive traits of parents and growth and carcass characteristics of progeny were not affected.

The supplementation of 5% (*v/w*) flaxseed oil into the feeding diet of broilers significantly ($p < 0.05$) reduced feed conversion ratio. Meanwhile, the apparent total tract nutrient digestibility of crude fat in treatment groups was increased. The flaxseed supplemented group revealed decreased ($p < 0.05$) abdominal fat percentage, total triglycerides, $CD4^+$ T lymphocyte count, $CD4^+$:$CD8^+$ ratio, and total cholesterol in blood. On the other hand, flaxseed treatments increased cardiac glutathione peroxidase ($p < 0.05$). Findings suggested that addition of flaxseed to the standard corn-soybean meal diet not only improved feed efficiency as well as cardiac glutathione peroxidise activity but also affected the T lymphocytes ratio of broilers.[80]

The addition of 15% (*w/w*) of flaxseed to iso-caloric and iso-nitrogenous diets of broiler chickens increased ($p < 0.05$) average body weight and reduced ($p < 0.05$) ether extract content and energy digestibility of the diets. Moreover, a high proportion of muscles and low abdominal fat content ($p < 0.05$) was noted in broilers fed flaxseed diets. The treatments with the oil seeds reduced the ether extract content and the calorific value of breast and drumstick muscles. The flaxseeds increased the iron content in drumstick muscles. In addition, the hemoglobin level was declined ($p < 0.05$) due to the supplementation of flaxseed. Overall, the study revealed that flaxseed can be utilized as good dietary components with positive impact on the dietary value of poultry meat.[81]

Researchers compared the effect of corn-soybean meal finisher diets containing flaxseeds (5, 10, and 15% *w/w*) on pellet quality, performance, n-3 fatty acids, and oxidative stability of meat in broiler chickens.[82] Birds fed diet containing 15% (*w/w*) flaxseed showed significantly ($P < 0.05$) lower weight gain and higher feed conversion ratio. The addition of flaxseed reduced the levels of saturated fatty acids, monounsaturated fatty acids, and increased polyunsaturated fatty acids, particularly the n-3 fatty acids in meat. Findings summarized that the supplementation of 15% (*w/w*) flaxseeds to finisher diet can increase n-3 fatty acids and lipid peroxidation in meat, while reducing growth performance of broiler chickens. In another study, the supplementation of flaxseed cake (2% *w/w*) with pyridoxine resulted in better yields of omega-3 eggs as well as improved health of layer birds.[83]

Despite the pivotal potency of flaxseed in poultry nutrition, the effect of the duration of a flaxseed diet on Peking duck's growth performance, gene expression, and fatty acid profile of the meat was studied.[84] Results showed that the growth performance of the ducks decreased with flaxseed diet's duration. Both body weight and body weight gain decreased linearly. Further, the expression of lipin-1 gene (LPIN-1) and fatty acid desaturase 2 (FADS2) linearly increased in ducks fed flaxseed.

*Alfalfa (*Medicago sativa *L.)*

Phytoconstituents

Alfalfa (Family – Fabaceae) is an important ingredient used to feed a variety of animals. It is known as the king of medicinal herbs due to the presence of variety of vitamins, minerals, and proteins. It is an important source of various minerals and vitamins, flavonoids, phenolic acid, xanthophylls, zanotophils, carotenoids, and other nutrients.[85]

Beneficial and adverse effects in poultry nutrition

Table 8 summarizes the beneficial and adverse impacts of alfalfa on poultry nutrition. Study investigated the nutritional effects of low-fiber alfalfa (15% *w/w* of diet) on production characteristics and egg quality in laying hens.[85] There was a positive effect on production characteristics, yolk color, and yolk percentage. Results suggested that the supplementation of

Table 8. Effect of alfalfa supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Laying hens	Positive effect on yolk quality and production parameters.	Laudadio et al.[85]
Extract	Broilers	No effect on feed intake but may have decreased abdominal fat and increased immunity.	Dong et al.[86]
Extract	Broilers	Increased activity of liver enzymes.	Pour[87]
Meal	Broilers	Reduced average body weight, lowered cumulative feed consumption, and increased adjusted feed conversion.	Gulizia and Downs[88]
Meal	Broilers	Reduced feed conversion ratio, mortality, abdominal fat yield, and yolk cholesterol content. Increased breast muscle contents of inosine monophosphate, total amino acids, essential amino acids, non-essential amino acids, delicious amino acids, yolk protein, albumen protein, and yolk color.	Zheng et al.[89]
Extract	Laying hens	Deteriorates the performance and shell quality.	Englmaierová et al.[90]

low-fiber alfalfa meal in the laying-hens diet can positively influence yolk quality without adversely affecting productive traits.

The effect of polysavone, a natural extract from alfalfa on deposition of abdominal fat and immunity of broiler chickens was determined.[86] Polysavone had no significant ($p > 0.05$) effect on feed intake, body weight, or feed: gain ratio in the experimental period, and it decreased the abdominal fat weights at 5 and 6 wk of age. Polysavone improved ($p < 0.05$) the relative thymus and spleen weights at 6 wk of age and the bursa weights at 4 and 5 wk of age compared with the control group. At 4 and 6 wk of age, the proliferation of T and B lymphocytes in the polysavone group was significantly greater ($p < 0.05$) than that of the control group. When birds were of 4 and 5 wk of age, polysavone resulted in a significant increase ($p < 0.05$) in serum anti-Newcastle disease virus hemagglutination inhibition antibody titer. These results showed that polysavone may decrease abdominal fat deposition and enhance immunity without an adverse effect on the performance of broiler chickens. The use of alfalfa ethanol extract (0.1 and 0.15 g/kg of feed) as potent replacement of antibiotics in poultry was studied and determined its effect on the body weight gain and liver enzymes in broiler chickens.[87] The extract increased the activity of liver enzymes as well as body weight gain, thereby suggesting the potency of alfalfa extract during the growing period of poultry.

The effect of dietary supplementation of alfalfa meal (7.3% *w/w*) on broiler performance and organ parameters was evaluated. Birds fed with alfalfa meal showed lower average body weight, lower cumulative feed consumption, and a higher adjusted feed conversion. Additionally, minimal treatment effects were reported on organ parameters.[88] In another investigation, the supplementation of alfalfa meal in diet of chickens showed lower ($p < 0.05$) feed conversion ratio, mortality, abdominal fat yield, and yolk cholesterol content, and higher ($p < 0.05$) breast muscle contents of inosine monophosphate, total amino acids, essential amino acids, non-essential amino acids, delicious amino acids, yolk protein, albumen protein, and yolk color. Additionally, the supplementation of alfalfa meal induced the proliferation of beneficial bacteria and inhibited potential pathogens.[89]

In contrary to the previous reports, researchers demonstrated the performance characteristics and egg quality of laying hens due to the supplementation of dehydrated alfalfa (DA; 40 g/kg of diet).[90] Findings showed that the addition of DA deteriorates the performance and shell quality.

Dill (Anethum graveolens *L.*)

Phytoconstituents

Dill (Family – Apiaceae) can be used as a growth stimulator in poultry diets. Glycosides, saponins, tannins, terpenoids, steroids, flavonoids, phlobatannin, cardiac glycoside, anthraquinone, gallic acid, catechin, chlorogenic acid, luteolin, and epicatechin are some of the important constituents of dill.[91]

Beneficial effects in poultry nutrition

The beneficial impact of dill on poultry nutrition is expressed in Table 9. It is investigated the effect of different levels (200–600 g per ton of diet) of dill seeds on performance (body weight, feed conversion ratio, and carcass traits), some biochemical parameters (triglycerides, cholesterol, HDL, and LDL) of the blood, and intestinal microbial populations (*E. coli* and *Klebsiella* sp.) in broiler chickens.[92] Results showed that dill has the potentiality to improve the performance, reduce cholesterol and triglycerides, and lower the microbial counts.

The effect of different doses of hemp seed alone or in combination with dill seed (0.3 g/kg of diet) against antibiotic growth promoter was studied on performance, serum biochemicals, and gut health of broiler chickens over a period of 42 days.[93] The performance traits like feed intake, body weight gain and feed

Table 9. Effect of dill supplementation in poultry nutrition.

Form	Animal	Summary of findings	References
Powder	Broilers	Improved performance.	Rahimian et al.[92]
Seeds	Broilers	Reduced serum lipids like triglyceride, LDL, and total cholesterol concentration. Reduced coliform count in cecum and jejunum.	Vispute et al.[93]
Powder	Broilers	Improved some of physiological traits.	Hammod et al.[94]
Powder	Broilers	Increased the feed intake and HDL, and decrease the percentage of inner fat.	Bahadori et al.[95]
Seeds	Quails	Improved growth performance, efficiency of feed utilization, and behavior of quails.	Rafiei-Tari et al.[96]
Essential oil and powder	Broilers	Improved serum biochemistry and enhanced the antioxidant status.	Mohammadi[97]
Essential oil	Laying hens	Reduced serum cholesterol and triglycerides concentration. Improved some production performance and antioxidant enzyme activity.	Torki et al.[98]

conversion ratio and carcass traits like cut-up parts, giblets, and abdominal fat yield remained unaffected due to dietary treatments for overall trial period. Serum protein concentration remained unchanged, whereas significant ($p < 0.05$) reduction in serum lipids like triglyceride, LDL, and total cholesterol concentration was noticed due to dietary inclusion of seeds. Serum enzymes like AST and ALT concentrations depleted significantly ($p < 0.05$) treated groups, however, alkaline phosphatase levels were unaffected. Coliform count in cecum and jejunum reduced linearly ($p < 0.01$) due to seed inclusion, whereas dose-dependent proliferation of lactobacilli was evident ($p < 0.01$) in cecum and jejunum of treated birds. No effect was observed on the villus height and crypt depth of the jejunal mucosa. In conclusion, drill seeds positively altered the serum lipid profile of the birds and improved gut health as well, thereby enhanced overall performance of broiler chickens.

Researchers determined the effect of adding dill leaves powder in the diets of broiler on some physiological properties (hemoglobin, RBC, packed cell volume or PCV, total protein, albumin, globulin, glucose, and cholesterol).[94] Results showed a significant ($p < 0.05$) effect of dill supplementation on PCV while no significant ($p > 0.05$) effects on hemoglobin, globulin, red blood cells, total protein, glucose, and cholesterol were reported.

The effect of dill powder in diet on blood parameters, performance, and carcass characteristics in broiler chicken was studied.[95] The treatments had no significant ($p > 0.05$) effects on feed conversion ratio. The percentage of thigh was significantly ($p < 0.05$) higher in treatment groups than that of control. The use of the highest level of dill powder in diet significantly ($p < 0.05$) had lower percentage of inner fat than control group. Dill powder had no significant ($p > 0.05$) effect on glucose, triglyceride, and HDL level. Results showed that the use of dill powder could increase the feed intake and HDL and decrease the percentage of inner fat in broiler chickens.

The additional effects of dill seed (3 g/kg of diet) on serum lipids (HDL, LDL, and VLDL), carcass characteristics (breast weight, leg weight, and liver weight), and growth performance (body weight gain, feed intake, and feed conversion ratio) were investigated in Japanese quails.[96] The body weight gain of seed-fed birds was intermediate ($p > 0.05$). Birds that received diet containing seed consumed significantly ($p < 0.05$) lower feed compared to two other groups. Over the experimental period, feed conversion ratio was significantly ($p < 0.05$) improved in the group that received 3 g of dill seed/kg of diet compared to other treatments ($p < 0.05$). Carcass weight and carcass components were not positively influenced by the dietary treatments ($p > 0.05$). Dill seed-fed birds showed significantly ($p < 0.05$) lower VLDL and triglyceride serum compared to control group. Furthermore, feeding dill seed significantly ($p < 0.05$) decreased the testosterone level of serum as compared to the control birds. Taken together, these results suggest the beneficial effects of dill seed on growth performance, efficiency of feed utilization, and behavior of quails; thus, it can be considered as a potential natural growth promoter for quails breeding.

Mohammadi[97] demonstrated the effect of dill essential oils and powders (0.5–1.0%) on biochemical, hematological, and oxidative stress factors in broilers chickens. Results showed significant ($p < 0.05$) variations in the serum cholesterol and triglyceride levels in supplemented groups. The plant powder revealed no significant effect on glucose levels. Heterophil and lymphocyte counts were significantly ($p < 0.05$) different too between groups. Moreover, the additive varied significantly ($p < 0.05$) the activities of glutathione peroxidase, superoxide dismutase, and catalase. Findings concluded that the supplementation of dried powders improved serum biochemistry and enhanced the antioxidant status.

Essential oil of dill (15 mL/100 kg of diet) showed significant effect on egg index of laying hens under heat stress condition. Birds fed with dill essential oil

Table 10. Phytocompounds as feed additives in poultry nutrition.

Phytocomponents	Animal	Summary of findings	References
Cinnamaldehyde	Broilers	Reduced *Clostridium* count in the small intestine as well as cecum and increased the villus height and antibody titer against Newcastle disease vaccine.	Pathak et al.[99]
Carvacrol	Broilers	Improved daily body weight gain and feed conversion ratio.	Jamroz and Kamel,[109]
Thymol and carvacrol	Broilers	Increased efficiency of feed utilization.	Lee et al.[110]
Carvacrol	Broilers	Reduced feed intake and weight gain. Improved feed conversion.	Jaafari et al.[111]
Carvacrol, thymol, and organic acids	Broilers	Improved live body weight, feed consumption, feed efficiency.	Lee et al.[112]
Carvacrol	Broilers	Improved body weight gain and reduced oocyte shedding, gut lesions, and gene expression of pro-inflammatory cytokine during coccidiosis.	Lillehoj et al.[113]
Carvacrol	Broilers	Reduced lipid oxidation and microbial counts in chicken patties. Improved shelf life and quality of poultry meat.	Kim et al.[114]; Akalin and Incesu,[115]
Carvacrol	Broilers	Showed antimicrobial properties against *E. coli* and *Salmonella* sp.	Burt et al.[116,117]
Carvacrol and eugenol	Broilers	Reduced the viability of *Salmonella* Enteritidis and *C. jejuni* counts.	Johny et al.[118]
Carvacrol	Broilers	Lipid oxidation inhibition.	Luna et al.[119]
Carvacrol	Broilers	Induced immune responses.	Botsoglou et al.[120]
Thymol + carvacrol	Broilers	Increased weight gain and improved feed conversion. Decreased digesta viscosity and serum total cholesterol.	Hashemipour et al.[121]
Thymol + carvacrol	Broilers	Decreased feed intake, total saturated fatty acids, and heterophil to lymphocyte ratio. Increased weight gain and feed efficiency, superoxide dismutase and glutathione peroxidase activities, total polyunsaturated fatty acid, digestive enzymes, and immune response.	Hashemipour et al.[122]
Thymol + carvacrol	Broilers	Increased final body weight, average daily gain, feed efficiency, retention of dry matter, protein and energy, total volatile fatty acid, and acetate levels. Reduced digesta viscosity in jejunum and ileum, total cholesterol, total protein, and albumin content.	Hashemipour et al.[123]
Capsicum oleoresin, carvacrol, and cinnamaldehyde	Broilers	Improved sensory, physical, and chemical properties in breast meat and leg meat.	İpçak and Alçiçek,[124]
Lycium barbarum polysaccharides	Broilers	Improved growth performance, digestive enzyme activities, antioxidant capacity, and immune function.	Long et al.[125]
Carvacrol and thymol	Broilers	Improved performance and reduced the total bacterial count.	Reis et al.[126]
Carvacrol, cinnamaldehyde, and *Capsicum oleoresin*	Broilers	Improved productive performance variables, final body weight, and weight gain. Exhibited potent immunomodulatory effect.	Awaad et al.[127]

exhibited lower serum cholesterol and triglycerides concentration under thermo-neutral and heat stress condition ($p < 0.05$). Study concluded that the addition of dill essential oil improved some production performance and antioxidant enzyme activity (glutathione peroxidase) in heat-stressed laying hens.[98]

In view of the prior studies, there is no report suggesting the adverse impact of drill in poultry nutrition.

Phytocompounds as feed additives

Plants constitute plethora of compounds that have beneficial influence on the broiler's growth, productivity, and metabolism. As a matter of fact, these natural additives serve as potential alternative to synthetic products. The prime focus of this alternative strategies has been to prevent the pathogenicity of microbiota and modulate the microbial ecosystem of the gut so that the overall status of health and immunity improves, thus leading to an enhanced performance of broilers.[99] Plethora of studies showed that feeding poultry with antioxidant components will enhance the oxidative properties of products.[100,101] Butylated hydroxytoluene (a widely used synthetic antioxidant compound) has revealed potential toxicity and adverse effects on animal nutrition.[102] Biological properties of medicinal plants, particularly Oregano (*Origanum compactum*; an aromatic plant) are generally attributed to its two main components: carvacrol and thymol.[103] Carvacrol and thymol have obtained 'generally recognized as safe' status by the Food and Drug Administration.[104] Carvacrol, a monoterpenoid phenol predominantly present in *Nigella sativa*, *O. compactum*, *Monarda didyma*, *Origanum dictamnus*, *Origanum microphyllum*, *Origanum onites*, *Origanum scabrum*, *Origanum vulgare*, *Thymus glandulosus*, and *Satureja hortensis*[105,106] have pronounced bioactivities on poultry metabolism[107] and exhibit antioxidant activities on poultry meat when supplemented in the feed. In addition, carvacrol acts as natural antioxidant by reducing lipid peroxidation. Likewise, thymol is a phenolic compound which is used as natural growth promoters too.[108]

Several studies demonstrated the supplementation of carvacrol and thymol as feed additives to depict their impact on poultry nutrition (Table 10). Daily body weight gain and feed conversion ratio were improved by 8.1 and 7.7%, respectively due to the addition of carvacrol at 300 mg/kg of diet in poultry.[109] Lee et al.[110] observed increased efficiency of feed utilization because of the addition of thymol and carvacrol. Likewise, Hernandez et al.[128] estimated enhanced performance of broiler fed with thymol and carvacrol. Jaafari et al.[111] observed reductions in feed intake and weight gain but improvement in feed conversion of female broilers fed with 200 ppm of carvacrol. Additionally, the supplementation of carvacrol decreased plasma concentration of triglyceride without affecting plasma content of cholesterol. Lee et al.[112] observed non-significant impact of carvacrol, thymol, and organic acids on live body weight, feed consumption, feed efficiency, and ileal content of microbiota of broiler chickens. Supplementation of 5.0 ppm of carvacrol into the diet of broilers improved body weight gain and reduced oocyte shedding, gut lesions, and gene expression of pro-inflammatory cytokine during coccidiosis.[113] Moreover, lipid metabolism, estrogen, and androgen metabolism in intestinal intraepithelial lymphocytes were maintained in broilers. Feeding chickens with 5.0 ppm carvacrol/kg of diet up-regulated genes associated with the metabolic and endocrine system such as protease serine 3 (PRSS3) and selenoproteinX, 1 (SEPX1).[113] Previous studies reported that the supplementation of carvacrol not only reduced lipid oxidation and microbial counts in chicken patties but also improved shelf life and quality of poultry meat.[114,115] Carvacrol supplementation exhibited antimicrobial properties against *E. coli* and *Salmonella* sp. in chickens.[116,117] Johny et al.[118] postulated that carvacrol and eugenol reduced the viability of *Salmonella* Enteritidis and *C. jejuni* counts in chicken cecal to <1.0 log10 cfu/ml at 50 and 75 mM and 20 and 30 mM, respectively. Luna et al.[119] demonstrated lipid oxidation inhibition trait of carvacrol similar to synthetic antioxidants and suggested the application of carvacrol as ideal natural additives in poultry industries for improving their growth performances. Botsoglou et al.[120] observed induced immune responses of chickens fed with carvacrol. Lillehoj et al.[113] demonstrated that feeding birds with diets constituting carvacrol, thymol, cinnamaldehyde, capsicum, and oleoresin enhanced the immune response in chickens and reduced microbial infections. The supplementation of cinnamaldehyde into the diet reduced the *Clostridium* count in the small intestine as well as cecum and increased the villus height and antibody titer against Newcastle disease vaccine in broilers chicken.[99]

Hashemipour et al.[121] evaluated the impact of thymol + carvacrol on performance, digesta viscosity, and some blood metabolites of broilers fed diets supplemented with carboxy methyl cellulose (CMC). The addition of 2% (*w/w*) CMC decreased ($p < 0.05$) body weight gain by 2.2% and increased feed conversion ratio by 2.3%. Carboxy methyl cellulose significantly increased the digesta viscosity and decreased serum total cholesterol, but showed no influence on triglyceride, pH, HDL, and LDL. Thymol + carvacrol significantly increased ($p < 0.05$) body weight gain and improved feed conversion ratio ($p < 0.05$) by the addition of 100 and 200 mg/kg of thymol + carvacrol, respectively. Inclusion of thymol + carvacrol at levels of 100 and 200 mg/kg of the diets decreased digesta viscosity and serum total cholesterol ($p < 0.05$) and also increased AST at a 200 mg/kg of thymol + carvacrol without any effect on creatine kinase. Thymol + carvacrol significantly ($p < 0.05$) improved total protein, albumin and globulin content ($p < 0.05$).

In another study, Hashemipour et al.[122] evaluated the influence of an equal mixture of thymol and carvacrol (60, 100, and 200 mg/kg of diet) on performance, antioxidant enzyme activities, fatty acid composition, digestive enzyme activities, and immune response in broiler chickens. The supplementation of thymol + carvacrol linearly decreased ($p < 0.05$) feed intake but the body weight gain and feed efficiency were increased ($p < 0.05$) at 200 mg/kg of additive. The additive linearly increased ($p < 0.05$) superoxide dismutase and glutathione peroxidase activities and reduced ($p < 0.05$) malondialdehyde content. Total saturated fatty acids were decreased ($p < 0.05$) and total polyunsaturated fatty acid were linearly increased ($p < 0.05$) in serum. The addition of thymol + carvacrol also increased digestive enzymes (trypsin, lipase, and protease) activities. In addition, thymol + carvacrol increased hypersensitivity response and IgG anti-sheep red blood cell titers, and decreased heterophil to lymphocyte ratio compared with the control group without affecting haematological parameters and lymphoid organ weight.

Feed supplementation of an equal mixture of thymol + carvacrol (100 and 200 mg/kg of diet) was also investigated on performance, nutrient retention, volatile fatty acid profiles, cecum microbial ecosystem, serum parameters, and characteristics of gastrointestinal tract of broilers. Birds fed with thymol + carvacrol showed increased ($p < 0.01$) final body

Table 11. Micro-encapsulation of plants and its components in poultry nutrition.

Plants and phytocomponents	Animal	Summary of findings	References
Aloe vera, dill, and nettle roots	Broilers	Improved body weight gain and feed conversion efficiency.	Meimandipour et al.[39]
Eucalyptol and eugenol	Broilers	Showed strong antioxidant and antimicrobial properties.	Scherer et al.[130]
Organic acids and essential oil	Broilers	Improved performances and gut microflora.	Gauthier et al.[131]
Organic acids and essential oil	Broilers	Reduced intestinal and fecal pathogenic microbial counts.	Mitsch et al.[132]
Organic acids and essential oil	Broilers	Lowered pH of stomach.	Desai et al.[133]
Organic acids and essential oil	Broilers	Inhibited the growth of pathogens.	Mroz[134]
Organic acids and essential oil	Broilers	Improved digestive enzymes activities.	Yang et al.[135]
Organics acids and essential oils	Broilers	Improvement in the growth performance in the final growth stage as well as some morphological gut traits and reduction in *C. perfringens* count in ileum.	Stamilla et al.[136]
Garlic and *Phyllanthus niruri* L.	Broilers	Improved live weight gain and feed evaluation.	Natsir et al.[137]
Turmeric extract	Broilers	Reduced meat cholesterol.	Sundari et al.[138]
Organics acids and essential oils	Broilers	Improved weight gain.	Lippens et al.[139]
Organic acid mixture and medium chain fatty acid	Broilers	Improved the intestinal microflora and digestibility.	Lee et al.[140]
Camellia oleifera seed extract	Broilers	Positive impact on average body weight, serum IgA level, antioxidant activity, and *E. coli* K88-challenged broiler chickens.	Dong et al.[141]

weight, average daily gain, and feed efficiency. The inclusion of thymol + carvacrol reduced digesta viscosity in jejunum and ileum, increased ($p < 0.05$) retention of dry matter, protein and energy, increased ($p < 0.01$) total volatile fatty acid and acetate levels, and reduced butyrate ($p < 0.01$). The additive reduced *E. coli* as well as *Clostridium perfringens* and increased *Lactobacilli* counts in birds fed with 200 mg/kg of diet. The supplementation of thymol + carvacrol decreased ($p < 0.05$) total cholesterol, total protein, and albumin content. In addition, the dietary supplementation of additive affected carcass relative weight as well as jejunum and ileum relative lengths.[123]

The addition of 150 mg/kg of *Capsicum oleoresin*, carvacrol, cinnamaldehyde or their mixture altered the sensory, physical, and chemical properties in breast meat and leg meat of broilers.[124] In another study, the supplementation of *Lycium barbarum* polysaccharides improved growth performance, digestive enzyme activities, antioxidant capacity, and immune function of broilers. Findings suggested that *Lycium barbarum* polysaccharides at 2000 mg/kg of diet may be exploited as a promising feed additive for broilers.[125] The use of carvacrol and thymol was considered as a pronounced alternative for increasing broilers performance and reducing the total bacterial count in the broiler chickens.[126] Awaad et al.[127] determined the effect of a mixture of carvacrol, cinnamaldehyde, and *Capsicum oleoresin* on productive performance and immune response in broiler chickens. Results showed improvement in the productive performance variables, final body weight, and weight gain as compared with the control birds. In addition, the additives exhibited potent immunomodulatory effect (potentiated immune response) and improved gut integrity.

Micro-encapsulation of feed additives

Despite the versatile applications of plants and their components as direct-fed supplements in poultry industries, it is considered to reveal its beneficial aspects with certain limitations. Sensitivity of bioactive components of plants to peroxidation and oxidation damage, hydrophobicity, and volatile nature of compounds are important limitations of direct usages. Moreover, the supplementation of plants extracts at high doses reduces the palatability and feed intake.[39] Recently, micro-encapsulation or nano-encapsulation has gained scientific attention as alternative concept to harness the potential of plants in poultry industries. Microencapsulation is a technique in which tiny particles or droplets are surrounded by a coating wall, or are embedded in a homogeneous or heterogeneous matrix, to form small capsules.[129] This method enables the protection and controlled release of diversified bioactive agents. In general, microcapsules are tiny particles ranging from 1 and 1000 µm comprising a bioactive agent surrounded by a natural or synthetic polymeric membrane.[130] Studies investigated in the past few years evidenced the magnificent role of micro-encapsulated plants metabolites as dietary supplements in poultry industries (Table 11).

Microencapsulated organic acids and essential oil, alone or mixed, as feed additive in broiler chickens improved performances and gut microflora[131], reduced intestinal and fecal pathogenic microbial counts[132], lowered the pH of stomach[133], inhibited the growth of pathogens[134], and improved digestive enzymes activities.[135] Scherer et al.[130] evaluated the effect of microencapsulated eucalyptol and eugenol in broiler chickens diet as alternative growth promoters for avilamycin. The eugenol showed strong antioxidant property while both the eugenol and eucalyptol exhibited antimicrobial activities. No significant

($p > 0.05$) difference was observed in the growth performance of broilers when eucalyptol (500 mg/kg of diet) or eugenol (500 mg/kg of diet) were used. Findings suggested that the microencapsulated phytotherapic agents are promising alternative to the growth promoter in broilers.

Effects of nano-encapsulated extracts (0.02, 0.025, and 0.05% *w/w*) of aloe vera, dill, and nettle roots were investigated on performance, carcass traits, and serum immunoglobulin (IgM and IgY) concentrations in broiler chickens. Increasing the concentration of nano-encapsulated herbal extracts improved body weight gain. However, nano-encapsulated dill extract showed significantly ($p < 0.05$) higher body weight gain. The addition of nano-encapsulated nettle extract in diet significantly ($p < 0.05$) improved feed conversion efficiency. Findings concluded that the nano-encapsulation of plant extracts could improve growth performance of broiler chickens.[39] Stamilla et al.[136] observed improvement in the growth performance in the final growth stage as well as some morphological gut traits and reduction in *C. perfringens* count in ileum due to the supplementation of micro-encapsulated blends of organics acids and essential oils as a feed additive in broiler chicken. The capsular forms of garlic and *Phyllanthus niruri* L. mixture encapsulated by arabic gum revealed promising effects on live weight gain and feed evaluation of broiler.[137] In another study, the encapsulation of turmeric extract reduced meat cholesterol of broiler chicken to improve food digestibility.[138] Likewise, the encapsulated forms of various essential oils and organic acids improved weight gain of broiler chickens.[139] The micro-capsulated organic acid mixture and medium chain fatty acid positively affected the intestinal microflora and digestibility.[140] Similarly, the dietary supplementation of micro-encapsulated *Camellia oleifera* seed extract exhibited positive impact on average body weight, serum IgA level, antioxidant activity, and *E. coli* K88-challenged broiler chickens.[141]

Conclusions

Green tea, flaxseed, lavender, nettle, and yarrow are capable of improving poultry production. On the other hand, nettle, lavender, ginger, flax seed, and alfalfa have the potentiality to improve the animal product quality which are beneficial to producer as well as consumers. Considering the prior findings, these medicinal plants can certainly be considered for utilization in poultry nutrition as direct feed supplements in the form of powder, extracts, and seeds. In addition, certain plant metabolites, particularly carvacrol and thymol exhibited its potentialities as natural antioxidants or growth promoters with beneficial aspects toward feed efficiency, nutrient bioavailability, immunity, oxidative status, egg quality parameters, and productive performances. Most importantly, considering the natural growth promoter ability of micro-encapsulated plant extracts or its metabolites in broiler chickens, this technique can certainly be utilized as a potential alternative to antibiotic growth promoters in future. Exploring the nutritional, pharmacological, and biological properties of plants metabolites and its encapsulated forms may play crucial role in poultry industries.

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