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Flavonoids: Polyphenolic compound for the improvement of poultry and its products

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Abstract
Flavonoids (also named as bioflavonoids) are naturally occurring secondary plant metabolites found in all plant species and known to exhibit a number of benefits. Due to their possible role in health promoting and preventing from chronic diseases, they could be known as "functional ingredients" and "health promoting biomolecules". Flavonoids have shown various biological effects including antibacterial, antiviral, gut modulatory, antioxidant, hepatoprotective, hypocholesteremic and immunomodulator activities. Many evidences confirms that phytochemicals like flavonoids could improve genomic stability and cellular integrity by reducing oxidative stress at cellular level. Because of these biological effects flavonoids can eventually decreases risk of infectious diseases and could increase animal's performance. Dietary supplementation with flavonoids could be used as a plan to improve and enhance meat and egg quality in commercial poultry, in addition to other positive effects on poultry health like it can improve meat's shelf- life, sensorial and technological attributes, thus positively affecting consumers' preference for purchasing. In poultry diets, several studies confirmed the effective role of flavonoids on growth performance, carcass yield, meat and egg quality, oxidative status and other productive performance parameters. Today, poultry production is moving toward incorporating a range of naturally bioactive-based products as additives in ration in order to satisfy consumer awareness and demands.

Keywords: flavonoids, poultry, growth promoting, antioxidant, gut modulatory, immunomodulatory, lipid metabolism

Introduction
Poultry products i.e. meat and eggs have been key sources of protein and other essential nutrients for humans. These are relatively easily available and less costly than other conventional sources. Eggs in particular have become a go to kind of food in modern households which are the by-product of modernization and urbanization centered on the individualistic fast paced urban lifestyle. The demand for these types of foods is likely to increase as the global population increases [4]. The presence of undesirable antibiotic residues in poultry products and environmental combination has largely added to the public concern regarding antibiotic use in feed [20]. Today, poultry production is moving toward incorporating a range of naturally bioactive-based products as additives, in order to satisfy consumer awareness and demands [5].

In poultry diets, several studies confirmed the effective role of flavonoids on growth performance, carcass yield, meat and egg quality, oxidative status and other productive performance parameters [9]. Flavonoids (also named as bioflavonoids) are secondary plant metabolites found in all plant species and known to exhibit a number of benefits. Many evidences confirm that phytochemicals like flavonoids could improve genomic stability and cellular integrity by reducing oxidative stress at cellular level.

Poultry meat is more prone to oxidative deterioration due to its high polyunsaturated fatty acids (PUFA) content when compared with other species meat having a lower PUFA content [28]. Lipid oxidation rate can be decreased by incorporating herbs and botanicals having antioxidant properties in broiler diet and thus, increasing poultry product's shelf life [2]. Antioxidative properties of plants are accredited to compounds such as ?-tocopherol, ascorbic acid, ?-carotene, various other flavonoids, and phenolic compounds [24]. Because of these biological effects flavonoids can eventually decreases risk of infectious diseases and could increase animal's performance [21]. Flavonoid tends to activate appetite mechanism in birds and contributes to gastrointestinal microflora balance [8]. It has been observed that combined use of many flavonoids or combinations with other botanicals had improved efficacy and therefore, suggests synergism [15].

The absorption of flavonoids mainly depends on their physical and chemical properties like molecular size, solubility, configuration and lipophilicity. According to various rodent studies, primarily ileum was seen to be responsible for the absorption of flavonoids, followed by the jejunum and duodenum. The best absorption occurs at pH 5.0 to 6.8 [18]. Flavonoid's glycosylated forms are absorbed more actively compared to aglycone forms. After absorption from small intestine (mainly the jejunum and ileum segments) flavonoids can be conjugated with glucuronic acid and O-methylation or sulphate ester formation may occur. As a result, no free flavonoid aglycones are observed in the circulation or urine, except avanols. Both the unabsorbed parts of flavonoids from small intestine, and the absorbed flavonoids secreted with bile, will pass through further degradation processes in colon by micro-organisms, which will break down the ring structure of flavonoids [13]. Two gut regions i.e. lower parts of GIT, liver, kidneys and colon [13] are involved for metabolism of flavonoids.

Classification of major flavonoids and their food source [27]

Class	Representative examples	Food sources
Flavones	Luteolin, apigenin, diosmetin, chrysin, myrecetin	Red pepper, parsley, celery, thyme
Flavonols	Quercetin, rutin, myricetin, kaempferol	Onions, grapes, tea, kale, broccoli, apples, cherries, fennel, sorrel, berries, red wine
Flavanones	Naringenin, hesperidin	Citrus fruits, tomatoes, prunes
Isoflavones	Genistein, daidzein, formononetin, glycitein	Soybean, soya foods, legumes
Flavanols/ Catechins	Epicatechin, gallocatechin	Tea, red wine, chocolate, apples, pears, grapes, peaches, cocoa
Flavanonols	Taxifolin	Red wine, red onion, vinegars, cocoa
Anthocyanidins	Pelargonidin, malvidin, cyanidin	Plums, apples, eggplant, berries, cherries, grapes

Biological effects of flavonoids

Studies have shown that flavonoids are anti-inflammatory, antioxidant, antibacterial, antiviral, antiallergic, hepatoprotective, anticarcinogenic, antithrombotic and immunomodulator activities in a number of in vitro and animal model studies. Various effects of flavonoids are shown in Figure 1 and Figure 2 [14]

Fig 1: Biological effects of flavonoids

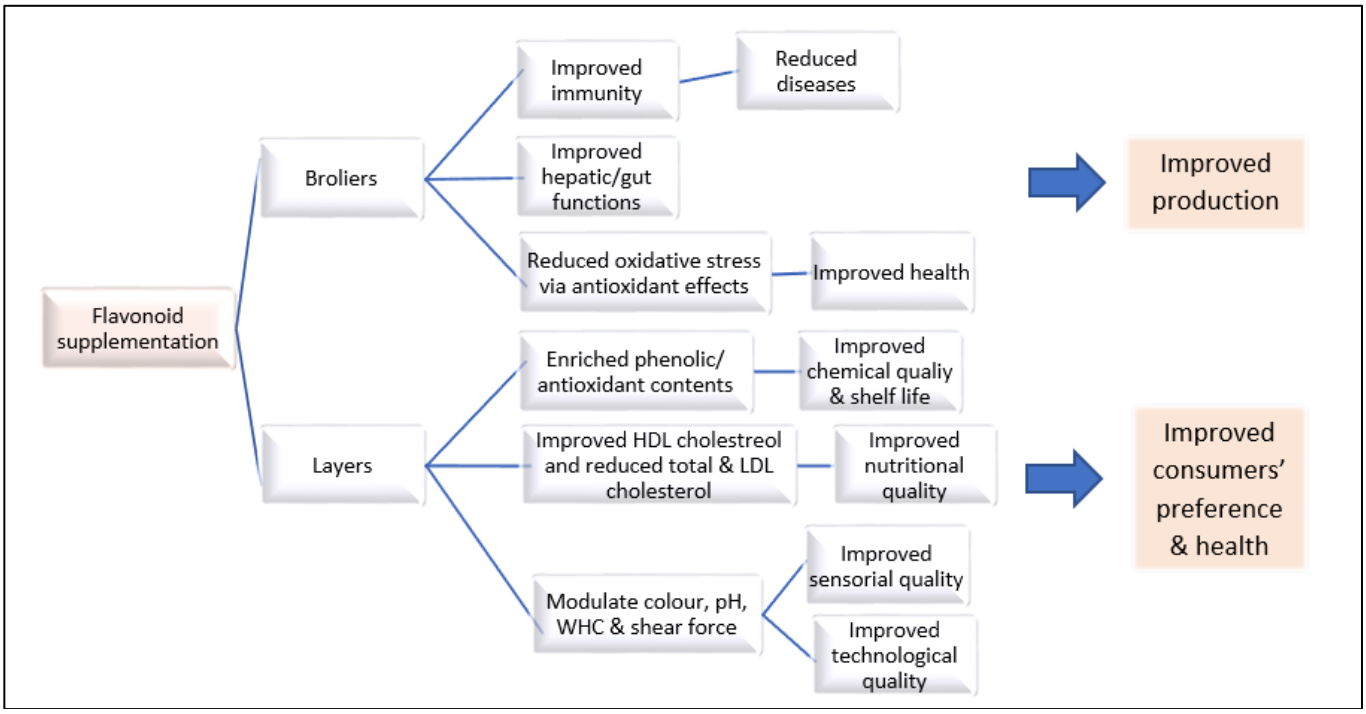

Fig 2: Positive effects of flavonoid supplementation on chicken health and product quality [14]

Growth promoting activity of flavonoids

Antibiotics were previously used as a growth promoter but recently it has been prohibited worldwide and raised concerns over food safety, environmental contamination and general health risks. This has eventually triggered producers and animal scientists to recognize alternative supplements that could be used to enhance animal growth, immunity and their product quality. Generally, flavonoids supplementation in broiler chickens has potential to improve their growth performance [29]. The effect of alfalfa (Medicago sativa) flavonoids on broiler performance was investigated by [22]. They observed no significant differences for Body weight at 21 d of age, average daily gain (ADG) from 0 to 21 d, feed to gain ratio (F: G) from 0 to 21 d and 0 to 42 d between the treatments, but broilers supplemented with basal diet+15 mg flavonoids/kg diet had significantly (P<0.05) increased ADG and BW at 42 d of age than broilers fed with basal diet. They concluded that possible reason for growth increment could be that flavone can upregulate the combination of growth hormone and hepatic growth hormone receptor and then result in increase of insulin-like growth factor concentration and hence promotes the animal growth. Additionally, isoflavone can promote protein synthesis in muscle and thus, induce growth performance [16]. Recently, [11] had investigated the growth performance of broiler chickens supplemented different levels of Rutin (flavonol glycoside). The broiler chicks were fed basal diet supplemented with 0 (control), 0.25, 0.50 or 1.00 g Rutin powder/kg feed. Supplementing highest level of Rutin (1.00 g/kg) showed significantly (P<0.05) increased body weight, weight gain, protein efficiency ratio and lowered feed conversion ratio (FCR) compared to the other groups. However, no effect was observed on either feed intake or relative growth rate.

Antioxidant activities of flavonoids

Physiological stress results from reactive oxygen species (ROS) production leading to shifts in oxidative balance and causes cell damage. Antioxidative mediators are essential as they decrease lipid peroxidation, improve organoleptic characteristics and nutritional value of eggs and meat, and can increase product's shelf life [6]. Studies have shown that flavonoids can prevent cellular injury (because of free radicals) by various mechanisms such as direct scavenging of reactive oxygen species (ROS), antioxidant enzymes activation, metal chelating activity, inhibition of oxidases, reduction of α-tocopheryl radicals, mitigation of oxidative stress caused by nitric oxide and increase in antioxidant properties of low molecular antioxidants [25].

Synthetic antioxidants, butylated hydroxy toluene and butylated hydroxy anisole have long been used to control lipid oxidation in stored meat and meat products, but concern over their use has created a necessity for alternative natural antioxidants. A study was conducted by [16] to examine the effects of genistein and hesperidin (purified bioflavonoids), as potential replacements to plant/herbs or synthetic antioxidants. They observed that T-AOC level was significantly (P<0.05) higher for all dietary levels, even lowered level of combined genistein and hesperidin (5 mg/kg) resulted in to increased plasma T-AOC activity [8]. Studied the effect of hesperidin flavonoid by supplementing it in laying hens with 1 or 3 g/kg of feed. They reported that dietary hesperidin supplementation can significantly (P<0.05) improve oxidative stability of both fresh and stored eggs. Probable explanation of reduced MDA values is supplementation of hesperidin and/or its metabolites can leads to inhibition of chain reactions in hen's metabolism and could reduce oxidation products in yolk. Thus, further enhance egg antioxidative potential.

Recently, the antioxidant capacity of broiler chickens fed Rutin (0.25, 0.50 and 1.00 g rutin/kg diet) was studied by [11]. The higher levels of rutin supplementation (0.50 and 1.00 g/kg) significantly (P<0.05) increase SOD, CAT, and GSH-Px activity and reduced MDA concentrations thereby indicating rutin's ability to transfer electrons, activating antioxidant enzymes and thus, reducing oxidative stress. Similarly [30], studied effect of flavonoid baicalein on the antioxidant capacity of broiler chickens at levels of 100 and 200 mg/kg. The results indicate that GSH-Px, SOD, and CAT (oxidative parameters) activity in the serum had increased with the supplementation of baicalein (as a feed additive).

Gut modulatory activity of flavonoids

In recent studies, many researchers have stated the gut modulatory effects of flavonoids present in herbal plants, in various farm animal species and poultry. They suggested antioxidant potential of polyphenols and could modulate functional architecture of small intestine for maximum absorption of nutrients [1]. The effect of supplementation of quercetin on cecal microflora populations in laying hens was studied by [19]. They observed significant (P<0.05) decrease in total aerobes and coliforms population, and increase in Bifidobacteria population as increasing level of quercetin. Observations reveal that quercetin can act as metabolic prebiotic and exert significant effect on intestinal environment by modulating cecal microflora population. The individual and combined effects of genistein (an isoflavone) and hesperidin (a flavanone) on intestinal morphometry in lipopolysaccharide (LPS)-challenged broiler chickens was investigated by [17]. Villus length, crypt depth, villus width, and villus length/ crypt depth ratios (intestinal morphometry parameters) were improved in both LPS-unchallenged and -challenged groups. Notable increase indicate the potential of supplements to improve gut morphology.

Immunomodulatory activity of flavonoids

All vertebrates possess developed immune system that protects the animal from infectious agents present in environment (e.g., viruses, bacteria, fungi etc.). In all taxa of vertebrates, phytochemicals with antioxidant properties such as flavonoids are identified to improve their immune response [14, 12] addressed the IgY antibody increasing effects of quercetin supplemented in broilers, that showed the potential of quercetin, supplemented at 0.5 and 1.0 g/kg feed, to promote broilers' humoral immune responses. They found that in a dose-dependent manner dietary quercetin enhances humoral immune response. Similarly, [17] verified that citrus and soy flavonoids containing 1:4 of genistein and hesperidin can significantly improve the immunity of LPS-challenged broilers.

Genistein and hesperidin are naturally occurring flavonoids and are abundant in soy and citrus fruits, respectively and have potential to improve immunity by altering phagocytic activity of mononuclear cells in a dose- dependent manner. Phagocytosis results into increase in oxygen consumption which leads to abundant production of reactive oxygen species (ROS) like superoxide anion, responsible to damage internal organs and decrease immune cell functions. ROS are tend to be neutralized by bioflavonoids [26, 5] conducted a study to investigate supplementation effect of Grape Seed Extract (GSE) at various levels to check humoral immune response against Newcastle disease virus vaccines. Significant elevation was observed in antibody titer against Newcastle disease virus vaccines in 28 and 35 day-old broiler chickens supplemented with GSE or BHT (Butylated hydroxy toluene). As GSE had provided higher response, the immunomodulatory function could be attributed to its antioxidant and free radical scavenging properties, responsible to increase integrity and proliferation of B-lymphocytes and its differentiation into antibodies producing plasma cells (10). So, GSE could be used as feed additive in broiler chickens and can increase vaccination effectiveness.

Effect on lipid metabolism

The fatty acid profile of meat and eggs could be altered by flavonoid supplementation in the poultry by reducing cholesterol and triglyceride content [14]. In a recent study of [30] on the effect of the flavonoid baicalein as a feed additive for broiler chickens. As Total Cholesterol, LDL-C, HDL-C, and Triglycerides levels can reflect the lipid metabolism, while assessing the lipid profile in serum of broiler chicken, they found that baicalein supplementation exerted no significant effect on HDL-C level but significantly decreased TC, LDL-C, and TG level. According to them, this might be due to the improvement in body's internal environment by baicalein, which leads to improvement in lipid profile of broilers. Similarly, [11] had evaluated the effect of rutin (flavonol glycoside) supplementation (found in apples, citrus fruits, berry, black teas, passion flower and buckwheat) on lipid metabolism of broiler chickens. They found that rutin supplementation had failed to affect high-density lipoprotein cholesterol concentration; however reduction in total cholesterol, triacylglycerol and low-density lipoprotein cholesterol levels were observed, mainly for the 0.5 and 1.0 g/kg diets.

Conclusions

Flavonoids serve a multiplicity of functions as feed additive in poultry diet. Dietary supplementation with flavonoids could be used to improve meat and egg quality in commercial poultry, in addition to other positive effects on poultry health like it can improve meat's shelf- life, sensorial and technological attributes, thus positively affecting consumers' preference for purchasing. Evidences suggest that phytochemicals like flavonoids could decrease oxidative stress at cellular level and can improve genomic stability and cellular integrity. Flavonoids can also improve immunity and gut functions that eventually reduce the risk of infectious diseases and could increase animal performance. Hence, the flavonoid compounds, both in purified and phytoextracts-form could be the potential supplements to improve poultry production. However, there are great variation in supplemental dosages, probably because of the heterogeneity of different molecular structures of different compounds that ultimately affect their biological activities. Thus, further studies are necessary to determine optimal doses for each class/compound of flavonoid family.

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