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Potential Relevance of Pomegranate (*Punica granatum*) Peel in the Nutrition, Health, and Quality Products of Poultry

Review Article

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ABSTRACT

Poultry farmers constantly source for alternative feed additives for feeding poultry birds to improve the quality and health benefits of their meat and egg. It is common knowledge that synthetic feed additives (antibiotic growth promoters) are accompanied by some limitations. These limitations include amongst others, the detrimental residual effects accompanying the consumption of the meat and egg products of poultry birds fed antibiotic growth promoters. Also, they cause resistance to some bacteria both in poultry and humans. Recently, increased efforts have been put into utilizing plant-based feed additives in the nutrition of poultry birds, due to their minimal toxicity concerns and holistic functional attributes. Pomegranate is an important fruit that cannot be overlooked among the spectrum of natural feed additives. The potential of pomegranate fruit peel to replace in-feed antibiotic growth promoters in poultry nutrition is quite promising. The current review provides an overview of the usefulness and potential utilization of pomegranate peel as a natural and alternative growth promoter in the nutrition of poultry birds. The pomegranate fruit peel promotes growth, stimulates immune responses, enhances the shelf-life of meat, improves egg quality, increases nutrient release. It also improves bone quality, and ensures the release of odorous gases from poultry manure, which may be linked to its rich antioxidant and bioactive phenol and tannin constituents. Tannin is one of the anti-nutrients that limits the performance of poultry when it is included in the diet. Despite huge benefits of pomegranate inclusion in poultry performance, its tannin content may be a source of worry and these concerns needs to be addressed through further research in order to maximize the full potentials of pomegranate. However, pomegranate shows potential to provide nourishment to poultry birds and positively enhance the health indicators of human consumers of the products (meat and egg).

KEY WORDS antioxidant, digestibility, eggs, fatty acid, gas emission, meat.

INTRODUCTION

One of the most important sectors in livestock industry of any country is poultry. Farmers are always passionate to supply consumers with quality food including the meat and eggs. The widely used livestock product is poultry and they are cheaper sources of protein (Centingul *et al.* 2019). Although, science contributed immensely to the development of the poultry sector but there are some limitations in quality (Oyeagu *et al.* 2023). Poultry farmers need a better and quality meat and egg production. Unfortunately, antibiotic additives may satisfy the farmers' needs with regards to yield but they (antibiotic) cause resistance to gut microbes and deposit their residue in poultry products (meat and eggs) which also causes resistance to some bacteria in humans. The antibiotic resistant bacteria retards poultry productivity and the contaminated products (meat and eggs) increases health risk to consumers. However**,** plant-based feed additives are naturally occurring growth enhancers and prophylactics that improves the productive capacity of broiler birds and quality of their meat (Shang *et al*. 2014; Mir *et al*. 2017). In addition to growth promotion, plant-based feed additives such as pomegranate, add value to poultry products for instance, meat and eggs (El-Nashi *et al*. 2015). Pomegranate processing industry generates a significant number of by-products (leave, seeds, peels) which are left as waste to decompose in the environment. The by-products are rich in nutrients and could potentially be used as additives in livestock diets (Lioliopoulou *et al.* 2023). The by-products are rich in polyphenols (phenolic acids, tannins and flavonoids, particularly anthocyanins) and utilising them in livestock feeding will reduce environmental pollution and production cost as well as improves animal health and production (Akhtar *et al.* 2015).

Earlier studies showed that pomegranate addition in feed improved the health of the birds and the quality of their products (Lioliopoulou *et al.* 2023). It was reported that pomegranate showed a positive effect on the immune system of birds, their performance, meat and egg quality and enhanced intestinal microflora (Rajani *et al*. 2011; Ahmed *et al*. 2015; Bostami *et al*. 2015; Hamady *et al*. 2015; Seleh *et al*. 2017; Seleh *et al*. 2018; Akuru *et al*. 2021b). Moreover, there are studies where gas emissions were reduced as well as the incidence of ascites (Rajani *et al*. 2011; Bostami *et al.* 2015). The replacement of yellow corn with pomegranate peel powder at 7.5% level improved the production and physiological parameters and jejunum morphology (Abbas *et al.* 2017). These beneficial outcomes are due to the antioxidant, antibacterial, antiviral, and anti-inflammatory properties which the additives possess (Pagliarulo *et al*. 2016). Pomegranate (*Punica granatum*) is a deciduous and ornamental plant named among the *Lythraceae* family and which is indigenous to Central Asia. Pomegranate fruit is highly nutritious, has high economic value and contains several active components with potent pharmacological benefits (Holland *et al*. 2009; Fawole and Opara, 2013). The economic and medicinal value of the pomegranate is not limited to the edible portions (seed). The non-edible parts (such as the peel) also have promising applications which have not been maximally explored. Pomegranate enhances growth, meat quality, immune functions, and other productive parameters in broiler birds, owing to the rich amounts of polyphenols that it contains.

Therefore, this review provides scientific evidence on the nutritional, phytochemical and medicinal properties of pomegranate fruit peel and its utilization in the nutrition of poultry birds, with the aim of increasing awareness on the economic value of pomegranate peel which is an underutilized fruit waste. Also, the limitations of pomegranate use in poultry production was highlighted which will trigger questions for further research.

Pomegranate

Origin and taxonomy

Pomegranate is one of the first five fruits that were cultivated alongside figs, dates, olives, and grapes. Pomegranate became domesticated as far back as 3000-4000 BC in the Northern part of Iran and the Northern Himalayans of India (Lye, 2008). Pomegranate is indigenous to Central Asia, but is now widely grown in many diverse climes, including the tropical and sub-tropical regions of the world. The tree adapts to a wide range of soil and climatic conditions (Holland *et al*. 2009). Pomegranate has over 500 varieties, indicating a wide genetic diversity. According to IPGRI (2001), fifty out of this number is grown for profit-making purposes.

Pomegranate was originally thought to be a member of the *Punicaceae* family, however, through recent molecular studies, it is now considered to belong to the *Lythracae* family (Graham *et al*. 2005; Kandylis and Kokkinomagoulos 2020). The *Punica* genus included two species, with the names of *P. granatum* and *P. protopunica* Balf (Guerrero-Solano *et al*. 2020).

The former is prevalent in the Socotra Island of the Arabian Peninsula and it is the only analogous relative of *P. granatum* (Guerrero-Solano *et al*. 2020). Pomegranate was originally called *Malum punicum*, which means the apple of Carthage. However, the name *Punica granatum* was given to the fruit by Linneaus, where *granatum* means seed and the name *Punica* comes from a feminized Roman name, Carthage. Table 1 summarizes the taxonomic classification of the pomegranate fruit.

Production and economic value

In general, there are about 300000 hectares of land used for pomegranate cultivation worldwide with a yield of 3 million metric tons (Venkitasamy *et al*. 2019). Of this amount, India is the most important producer (0.81 metric tons), while the southern hemisphere contributed 10% of the pomegranate fruit. Major producers of pomegranate are India, Iran, and California, with South Africa, Israel, Argentina, Brazil, Peru, and Chile, being recognized as other important producers. Pomegranates produced in South Africa amounted to 5547.1 tons in 2018 (POMASA, 2018).

Table 1 Taxonomic classification of Pomegranate (*Punica granatum*)

Kingdom	Plantae
Sub-kingdom	Tracheobionta (vascular plants)
Super-division	Spermatophyta (seed plants)
Division	Magnoliophyta (flowering plants)
Class	Magnoliopsida (Dicotyledons)
Sub-class	Rosidae
Order	Myrtales
Family	Punicaceae, formerly, Lythraceae, currently
Genus	Punica L. (pomegranate)
Species	*Punica granatum* L. *Punica protopunica Balf*

Source: (USDA, 2014).

The increase in production and consumption in the world is driven by two major factors; the high nutritional value of pomegranate and the multiple articles that have been published on pomegranate over the years (Melgarejo *et al.* 2020). Figure 1 shows the pomegranate tree with ripe fruits, and a cut pomegranate fruit containing seeds and other internal components.

Nutritional composition of pomegranate peel

Pomegranate peel contains appreciable amounts of crude fibre (β-glucans), essential and non-essential amino acids, proteins, carbohydrates, ash, fatty acids, vitamins, minerals, organic acids (malic, acetic, lactic, fumaric, citric, oxalic, tartaric, ascorbic etc.) and other important nutrients (Hassan *et al.* 2012; Fawole and Opara, 2013). A summary on the nutrient composition of pomegranate peel powder is shown in Table 2.

Bioactive polyphenols of pomegranate peel

Pomegranate peel has rich polyphenol content, which is beneficial in oxidative health of poultry. These include flavonoids like flavonols, and anthocyanins, hydrolyzable tannins such as ellagitannins and simple phenolic acids (Bassoli *et al.* 2008; Abid *et al.* 2017; Khalil *et al.* 2017; Chukwuma *et al.* 2020; El-Hadary and Taha, 2020). The tannins in pomegranate are medicinally useful. Pomegranate peel possesses higher total phenolic content and antioxidant activity than the seed and pulp of the pomegranate fruit and as such might be regarded as a richer source of natural antioxidants (Li *et al.* 2006).

The main phenolic acids reported in pomegranate peel are gallic acid, caffeic acid, vanillic, ferulic, cinnamic and p-coumaric (Singh *et al.* 2018; Bar-Ya'akov *et al.* 2019; Chukwuma *et al.* 2020; Pirzadeh *et al.* 2020), which are natural antioxidants. Dietary supplementation of pomegranate peel inhibits bone lytic disease and osteoporosis in laying birds, which may be attributed to the presence of caffeic acid in the peel (Ang, 2009; Mbikay, 2012).

The peel supported bone growth and development and reduced overall incidence of tibia deformities in laying birds (Ang, 2009; Mbikay, 2012). Pomegranate peel contains flavonoids such as quercetin, catechin, hesperidine, epicatechin, rutin, luteolin, kaempferol and anthocyanidins (Bassoli *et al.* 2008; Abid *et al.* 2017; Khalil *et al.* 2017; El-Hadary and Taha, 2020), which protect against oxidative damage of biological molecules. Pomegranate peel makes up about 30% of the total anthocyanins present in the fruit (Romeo *et al.* 2015). Anthocyanidins in pomegranate peel gives it its reddish/purple colour (Ben-Simhon *et al.* 2015). Anthocyanidins have several biological functions and play essential roles in therapeutic and preventive disease measures (Williamson, 2017; Pirzadeh *et al.* 2020), and have been linked to the ability of pomegranate peel to activate endogenous antioxidant enzyme (Ahmadipour *et al.* 2021). Dietary flavonoids, including anthocyanidins have also been linked to several health benefits in poultry nutrition, such as performance, blood constituents, carcass composition and small intestinal morphology (Changxing *et al.* 2018; Prihambodo *et al.* 2021). Cyanidins, delphinidi and pelargonidin are some of the reported anthocyanidins in pomegranate peel (Zhao *et al.* 2013).

The tannins in pomegranate are mainly the condensed tannins and the hydrolysable tannins. The hydrolysable tannins make up nearly 85% of the overall tannins in pomegranate peel (Bar-Ya'akov *et al.* 2019). The ability of pomegranate peel to enhance nutrient digestibility and overall growth performance in poultry birds has been linked to the presence of tannins (Sarica and Urkmez, 2016; Ahmadipour *et al.* 2018). Pomegranate peel has also been shown to possess antimicrobial property due to its tannin contents, thus leading to reduced emission of odorous gases from manure of birds fed pomegranate peel-based diets (Ahmed and Yang, 2017; Ahmadipour *et al.* 2021). Proanthocyanidins are the predominant condensed tannins in pomegranate peel, whereas ellagitannins are the main hydrolysable tannins (Turrini *et al.* 2015; Singh *et al.* 2018).

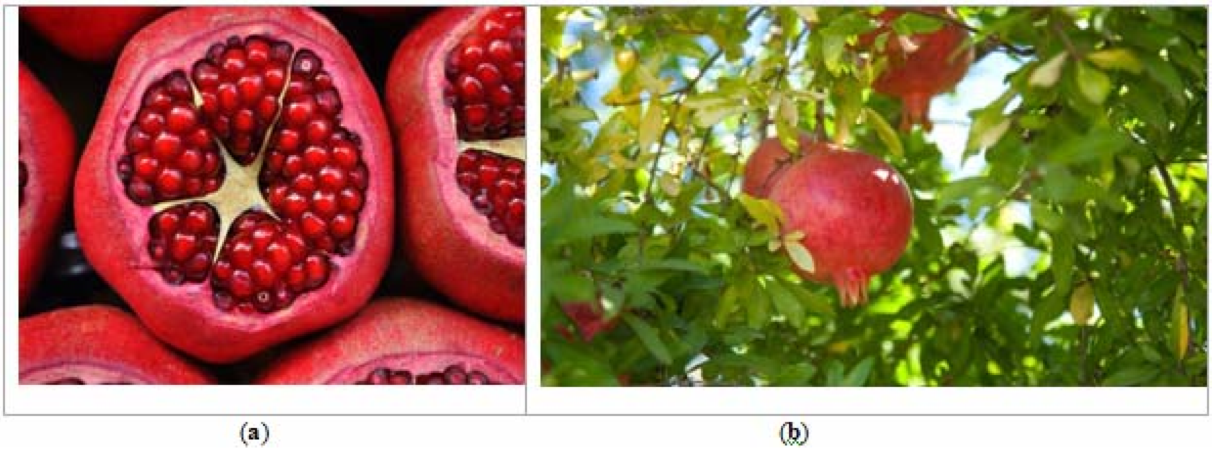

Figure 1 (**a**) Pomegranate fruit with seed, peel, and other components (**b**) Pomegranate tree with ripe fruits

The ellagitannin content of pomegranate peel is responsible for its immunomodulatory, antioxidant and antimicrobial properties (Seeram *et al.* 2008; Joseph *et al.* 2012). Sorrenti *et al.* (2019) reported that punicalagins are the predominant ellagitannins in pomegranate peel and makes up about 47% of the total amounts of phenols in the extract of pomegranate peel. It was also found that ellagic acid and its derivatives make up about 30% to 40% of the total phenolics in the peel (Sorrenti *et al.* 2019). Other minor phenolics such as punicalin, granatin B and gallic acid account for about 3% of phenolics in the peel (Sorrenti *et al.* 2019). The punicalagin, punicalins, gallic acid and ellagic acids in pomegranate peel have been reported to exert beneficial effects including, antimicrobial, anticarcinogenic, cardioprotective, antimicrobial, antidiabetic, and anti-inflammatory properties amongst others (Alexandre *et al.* 2019; Gullon *et al.* 2020).

Upon ingestion, the ellagitannins in pomegranate are degraded by gut microbes into ellagic acids which are smaller phenolic compounds. The ellagic acids are then absorbed into blood circulation pathways whereas ellagitannins are metabolized into urolithins (Sorrenti *et al.* 2019). There is evidence that ellagitannins and the resultant ellagic acid inhibits the activation of inflammatory pathways, including NF-kB system and mitogen-activated protein kinases (Ahmed *et al.* 2005; Afaq *et al.* 2005; Larrosa *et al.* 2009). The cardioprotective and antimicrobial effects of pomegranate peel has been attributed to punicalagins constituent, while its ellagic acid constituent has been linked to cholesterol lowering properties (Somparn *et al.* 2018; Wang *et al.* 2018). Ellagic acid promoted cholesterol removal in oxidized LDL-induced foam cells (Park *et al.* 2011).

These results provide new information that ellagic acid downregulated macrophage lipid uptake to block foam cell formation of macrophages and boosted cholesterol removal in lipid-laden foam cells (Park *et al.* 2011).

Previous reports have shown that punicalagin inhibits the growth of harmful microbes such as *E. coli, S. aureus* etc., as the population of beneficial microbes (*Lactobacilli* and *Bifidobacterium*) increased (Bialonska *et al.* 2009; Wang *et al.* 2018). In heat stressed quail birds, ellagic acid supplementation reduced lipid peroxidation, increased gut microbes, and improved shell weight, thus promoting growth and egg quality (Mutlu and Guler, 2021). The polyphenols present in pomegranate peel appears influential in its benefits on poultry nutrition and health as discussed below, and thus may be a promising additive in poultry feed (Ahmed *et al.* 2015; Hamady *et al.* 2015).

The role of pomegranate peel in poultry bird nutrition and health

Table 3 summarizes the beneficial role of pomegranate peel in the nutrition and health of some poultry birds.

Effects on nutrient digestibility, growth and performance

Pomegranate peel (PP) enhances the growth of beneficial gut microbes, improves the activity of endogenous pancreatic and small intestinal digestive enzymes, prevents the harmful impact of free radicals on intestinal enterocytes; and thereby increase nutrient digestion and absorption (Reddy *et al.* 2014; Kishawy *et al.* 2019). Also, pomegranate peel decreases the population of harmful gut microbes, inhibits pathogenic microbial metabolism and the activities of harmful microbial enzymes, prevents oxidative phosphorylation (Viuda-Martos *et al.* 2010b) and thereby ensure overall improvement in bird's performance. Authors reported that pomegranate peel powder (PPP) and pomegranate peel extract (PPE) had enriching effect on the performance of broiler birds (Ahmed *et al.* 2015; Hamady *et al.* 2015; Sarica and Urkmez, 2016; Ahmadipour *et al.* 2018; Kishawy *et al.* 2019; Abdel-Basset *et al.* 2020).

Table 2 Proximate and nutrient composition of pomegranate peel powder

Parameters	Concentration
Dry matter[1, 2]	30.57-95.44 g/100 g
Crude protein[2, 3, 4, 5, 6]	2.56-8.72 g/100 g
Ether extract[2, 3, 4, 5]	1.27-9.40 g/100 g
Crude fibre[2, 3, 4, 5]	10.50-21.00 g/100 g
Ash[2, 3, 4, 5]	2.12-5.49 g/100 g
Moisture[2, 3, 4, 5]	4.00-12.48 g/100 g
Carbohydrate[2, 3, 4, 5]	77.4-80.50 g/100 g
Neutral detergent fibre[1, 7]	17.83-29.36 g/100 g
Acid detergent fibre[7]	14.55-19.22 g/100 g
Acid detergent lignin[7]	3.90-4.29 g/100 g
Nitrogen[3]	1.39 g/100 g
Nitrogen-free extract[1, 7]	75.54-76.09 g/100 g
Organic matter[7]	95.80-96.57 g/100 g
Energy[3, 7]	2825-4287 Kcal/kg
Total sugar[8, 9]	17.70-81.62 g/100 g
Reducing sugar[9]	4.34 g/100 g
Glucose[8]	7.3-27.94 g/100 g
Fructose[8]	7.8-32.79 g/100 g
Total solid[9]	94.50 g/100 g
Total saturated fatty acids[7]	23.04 g/100 g
Total monounsaturated fatty acids[7]	20.76 g/100 g
Total polyunsaturated fatty acids[7]	56.20 g/100 g
Total unsaturated fatty acids[7]	76.96 g/100 g
Omega-6 fatty acids (n-6)[7]	20.72 g/100 g
Omega-3 fatty acids (n-3)[6]	35.48 g/100 g
n6 /n3 (%)[6]	0.58 g/100 g
Thiamine[6]	0.14 mg/100g
Riboflavin[6]	0.09 mg/100g
Ascorbic acid[6]	13.26 mg/100 g
alpha-Tocopherol[6]	4.13 mg/100 g
Retinol[6]	0.18 mg/100 g
Calcium[6]	342 mg/100 g
Phosphorus[6]	120.00 mg/100 g
Potassium[3, 6]	150-1000 mg/100 g
Sodium[6]	68-110 mg/100 g
Iron[3, 6]	6.05-6.11 mg/100 g
Manganese[3, 6]	0.45-0.86 mg/100 g
Zinc[3, 6]	0.4-1.08 mg/100 g
Magnesium[6]	56.00 mg/100 g
Copper[6]	0.65 mg/100 g
Selenium[6]	1.07 mg/100 g
Histidine[6, 7]	0.23-7.56 g/100 g
Arginine[6, 7]	0.19-8.23 g/100 g
Methionine[6, 7]	0.03-3.02 g/100 g
Threonine[6, 7]	0.26-2.12 g/100 g
Lysine[6, 7]	0.74-7.23 g/100 g
Leucine[6, 7]	0.23-7.16 g/100 g
Valine[6, 7]	0.16-5.33 g/100 g
Isoleucine[6, 7]	0.13-3.51 g/100 g
Phenylalanine[6, 7]	0.27-7.14 g/100 g
Serine[6, 7]	0.20-3.02 g/100 g
Glycine[6, 7]	0.46-12.41 g/100 g
Proline[6, 7]	0.17-3.22 g/100 g
Tyrosine[6, 7]	0.72-2.02 g/100 g
Aspartic acid[6, 7]	0.34-8.11 g/100 g
Glutamic acid[6, 7]	0.57-13.52 g/100 g
Cystine[6, 7]	1.02 g/100 g
Alanine[6, 7]	5.05 g/100 g
Total essential amino acids[7]	51.30 g/100 g CP
Total non-essential amino acids[7]	48.37 g/100 g CP

CP: Crude protein.
[1] Kushwaha *et al*. (2013); [2] Saleh *et al*. (2017); [3] Abbas *et al*. (2017); [4] Thorat *et al*. (2018); [5] Ullah *et al*. (2012); [6] Akuru *et al*. (2021b); [7] Omer *et al*. (2019); [8] Spilmont *et al*. (2015); [9] Middha *et al*. (2013).

Table 3 Beneficial effects of pomegranate peel supplementation on the nutrition and health of poultry birds

S/N	Treatment sample	Dietary inclusion levels or dose of administration	Beneficial effects	Implication or potential relevance	References
Broiler birds					
1.	Peel pomace	5 and 10 g/kg of raw and fermented pomace	• Raw PP and FP reduced MDA levels, VH and VH/CD ratio • Higher CD was recorded at 5 g/kg (raw) and 10 g/kg (FP)	Raw PP and FP have antimicrobial and antioxidant effects	Gungor *et al.* (2021)
2.	PPP	2, 4, 6 and 8 g/kg	• PPP supplementation increased AFBW and ADWG at 2 and 4 g/kg • FCR and PER were improved at 4 g/kg PPP inclusion • Thigh, spleen, and gizzard weights were increased at 4 g/kg • Breast weight and breast meat's CAT enzyme activity were increased at 8 g/kg addition of PPP • AST concentration was decreased at 4 g/kg PPP • Higher apparent nutrient digestibility coefficients were recorded at 4 g/kg PPP inclusion	PPP supplementation improved in broiler diets improved the growth, carcass and organ indices, nutrient digestibility, serum lipid profile and meat's antioxidant enzyme activity in the birds	Akuru *et al.* (2021b)
3.	Peel	48 g/kg	• Decreased AST, ALT, MDA and LDL-C levels • Enhanced SOD, GPx and TAC activities • Reduced Hb, RBC and PCV levels • MDA levels in meat was decreased • Enhanced IgG, IgM and total immunoglobulin concentrations was recorded at 40 g/kg diet	Overall, the positive effects of pomegranate peel on performance, blood and meat quality of broilers were noted.	Ghasemi-Sadabadi *et al.* (2021)
4.	Peel	25, 50, 75 and 100 g/kg	• Hepatic CAT and SOD was upregulated • Circulatory MDA levels were decreased • Serum TG and cholesterol levels were reduced at 7.5 and 10 g/kg • Abdominal fat deposition decreased at 7.5 and 10 g/kg • Reduced heart weight and right-total ventricular weight ratio • Mortality from pulmonary hypertension was reduced	Pomegranate peel has antioxidant, antihyperlipidemic and hypotensive properties at 7.5 and 10 g/kg inclusion levels	Ahmadipour *et al.* (2021)
5.	PPE	0.3 and 0.6 g/kg	• BW, FI and FCR were unaffected • Relative bursa weight was increased • Abdominal fat levels were decreased • Decreased serum cholesterol and LDL-C concentrations • LDH and AST activities were reduced • Oxidative state of stored meat was improved • VH and CD/VH of jejunum were increased	Pomegranate peel has growth promoting, carcass modifying, hypolipidemic and immune enhancing attributes	Abedi *et al.* (2019)
6.	PPE	10, 20 and 40 mg/100 g concentration	• 40 mg/100 g PPE reduced excretion of fecal oocyte • Pathological lesions due to coccidiosis were reduced at this level • Caecal life of the parasite was eliminated at 40 mg/100 g PPE	PPE can be employed in the adjunct therapeutic control of coccidiosis in broiler and poultry	Talkhonche and Moghtadiee (2019)
7.	PPE infusion in drinking water	50 mL/L distilled water of 50 g/L infusion	• Pomegranate peel infusion enhanced antioxidant capacity of meat. This was seen in the higher ferric reducing antioxidant power, total flavonoid, and phenolic contents and decreased TBARS concentrations	Infusing pomegranate peel in the drinking water of birds has potential to extend storage capacity of the meat	Ghosh *et al.* (2021)
8.	PPE	10, 20 and 40 mg/100 g concentration	• At 40 mg/100 g dietary PPE: • Reduced intestinal lesions • PPE reduced oocyte per gram • Depressed growth traits • Can result in liver damage	Pomegranate peel extract has anticoccidia properties but should not be included at a rate where it impairs growth and liver functions	Khorrami *et al.* (2022)
9.	Pomegranate peel polyphenol extract	0.05 and 0.1 g/kg	• Pigmentation of skin and shank increased • Decreased serum corticosterone levels	Supplementing polyphenols extracted from pomegranate peel in broiler diets can enhance their growth production under heat-stressed conditions	Gopi *et al.* (2020)

Continuation of table 3

S/N	Treatment sample	Dietary inclusion levels or dose of administration	Beneficial effects	Implication or potential relevance	References
Laying hens					
10.	PPP	2, 4 and, 6 g/kg	• Non-dietary treatment effects on at 60th week of age • Supplementation of PPP increased the concentrations of total protein, glucose, albumin, globulin, cholesterol, LDL-C, HDL-C and TG at 72nd week of age	Pomegranate peel powder enhances lipid profile of laying hens	Jabber *et al.* (2021)
11.	PPP	20 and 40 g/kg	• Decrease in dexamethasone induced oxidative stress on BW and egg production • Reduced plasma cholesterol, TG and MDA levels • Levels of SOD, CAT and GSH-Px were increased	4% pomegranate peel powder (PPP) ameliorates the harmful effects of oxidative stress during the pre-peak period of laying	Eid *et al.* (2021)
Japanese quails					
12.	PPP	10 and 15 g/kg	• PPP inclusion improved body weight gain and egg quality traits • PPP inclusion decreased plasma total lipids, total cholesterol, LDL-C, HDL-C, uric acid, creatinine, AST, and ALT • At 10 g/kg, PPP increased eviscerated carcass weight • PPP addition lowered plasma thiobarbituric acid levels at 15 g/kg	PPP dietary supplementation can enhance the performance and physiology of quails, and extend the storage potential of the meat	Yassein *et al.* (2015)
13.	PPP	20, 50 and 75 g/kg	• Increased feed intake at 75 g/kg PPP inclusion • Improvement in FCR and egg quality parameters were observed • At 50 g/kg PPP, the concentrations of cholesterol, TG, glucose, and other serum lipids were decreased • Higher VH:VD ratio was recorded at 50 and 75 g/kg dietary levels • Interestingly, females had higher weight, villus length and CD compared to male quails	Supplementation of pomegranate peel powder enhances growth, physiology, and gut health of Japanese quails	Abbas *et al.* (2017)
14.	PPE	0.2 g/kg	• Supplementing reduced crude protein diet with 0.2 g/kg PPE led to: • Increased PCV levels • Decreased serum H/L ratio • Increased liver CAT and GSH-Px activities • Increased levels of plasma uric acid • Decreased MDA concentration in meat	Pomegranate peel has more potential to reduce heat stress in Japanese quails compared to α-tocopherol acetate	Senay *et al.* (2019)
15.	PPP	10 and 15 g/kg	• Higher dressing percentage, liver percentage and heart percentage were recorded at 10 and 15 g/kg dietary levels • Highest revenue, net return and lower cost-benefit ratio was recorded at 10 g/kg inclusion level	Pomegranate peel powder can modify carcass traits and increase revenue in poultry enterprise	Hamad and Kareem (2019)
16.	PPP	30, 60 and 90 g/kg diet	• There was interaction between genotype and PPP levels in growth, egg quality and gene expression • 90 g/kg inclusion of PPP enhanced growth performance, fertility, hatchability, and egg quality traits • Dietary PPP at 90 g/kg reduced blood urea and AST levels and improved mRNA expression of FSHR and LH-β genes • Increased net returns were recorded at 60 and 90 g/kg inclusion of PPP	Pomegranate peel powder has growth promoting effect in addition to its ability to improve egg quality and lipid profile traits and increase economic returns	Kamel *et al.* (2021)

PP: pomegranate pomace; FP: fermented pomace; MDA: malondialdehyde; VH: villus height; VH/CD: villus height: crypt depth; CD: crypt depth; PPP: pomegranate peel powder; AFBW: average final body weight; ADWG: average daily weight gain; FCR: feed conversion ratio; PER; protein efficiency ratio; CAT: catalase; AST: aspartate aminotransferase; ALT: alanine aminotransferase; LDL-C: low-density lipoprotein cholesterol; Hb: haemoglobin concentration; RBC: red blood cell count; PCV: packed cell volume; IgG: immunoglobulin G; IgM: immunoglobulin M; SOD: superoxide dismutase; TG: triglyceride; BW: body weight; FI: feed intake; LDH: lactose dehydrogenase; TBARS: thiobarbituric reactive acid reactive substances; PPE: pomegranate peel extract; HDL-C: high-density lipoprotein cholesterol; GSH-Px: glutathione peroxidase; H/L: haematocrit/lymphocyte ratio; mRNA: messenger ribonucleic acid; FSHR: follicle-stimulating hormone receptor; LSH-β genes: luteinizing hormone subunit beta genes.

Other reports prove that the inclusion of PPP in poultry diets had no effect on growth parameters of birds (Rama Rao *et al*. 2019). This positive effect on growth may perhaps be to reduced dietary tannin levels and improved feed palatability (Hamad and Kareem, 2019). Furthermore, other reports prove that the inclusion of pomegranate peel in animal diets depressed broiler growth (Rajani *et al*. 2011; Saleh *et al*. 2017). For example, Saleh *et al*. (2017) reported that 1-3 g/kg pomegranate pomace inclusion reduced the body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR) of broiler birds. Rajani *et al*. (2011) also reported that 15 g/kg PP supplementation depressed body weight and FI in broilers. The depressed growth performance may be due to high inclusion levels of the peel powder or heat stress (Goni *et al*. 2007).

Medicinal plants improved growth in broiler birds by regulating cacal nutrient digestion, decreasing bacteria colony counts and associated fermentation products (Murugesan *et al*. 2015). Rezvani and Rahimi (2017) reported that PPE supplementation at 4 g/kg enhanced nutrient digestibility in broiler birds. Akuru *et al*. (2021a) also reported that 2 g/kg and 4 g/kg PPP inclusion in broiler diets increased the digestibility of dry matter, ether extract, ash, acid detergent fibre, neutral detergent fibre and nitrogen-free extract. The improvement in nutrient digestibility may be attributed to the rich tannin content, which is modulates digestive secretions, improves enzymatic functions, promote growth of beneficial gut bacteria, thereby enhancing growth in broilers (Murugesan *et al*. 2015). The *in vitro* study of Pérez-Vicente *et al*. (2002) reported that anthocyanins (bio-active) from the pomegranate juice influenced gastrointestinal digestion.

Effect on carcass and portion yield characteristics

Poultry carcass is the body of any slaughtered poultry after bleeding and dressing. In recent years, due to the increased demand for secondary processed broiler meat products, i.e., portions, broilers are expected to possess high slaughter yields and desirable carcass conformation (Owens *et al*. 2010).

Reports showed that PPP and PPE supplementation at 4g/kg and 30ml/L respectively increased the carcass and portion yield parameters of chicken (Hamady *et al*. 2015; Al-Shammari *et al*. 2019; Abdel-Baset *et al*. 2020), other reports showed that PPP and PPE did not influence carcass parameters (Sarica and Urkmez, 2016; Kishawy *et al*. 2019). The improvement of PPP and PPE on carcass yield may be due to the correct inclusion level used which will maximize the functioning of the bio-active compound (anthocyanins) that increased digestion of diets (Pérez-Vicente *et al*. 2002) for higher yield.

Effect on immune function

Immunoglobulins (i.e., antibodies) are glycoproteins synthesized by plasma cells that specifically recognize, bind to, and obliterate antigens, for instance, viruses, bacteria etc. (Zaib *et al*. 2016). Immunoglobulin M (IgM) and immunoglobulin A (IgA) are involved in maintaining the immune functions of broiler birds, whereas immunoglobulin G (IgG) hinders the adherence and penetration of microbes on the mucosal epithelial lining (Mahmoud *et al*. 2020).

Ahmed and Yang (2017) reported that pomegranate-by product (peel and seed) diets increased the serum IgA and IgG concentrations in broiler birds. Sharifian *et al*. (2019) reported a linear increase in the primary total and secondary total anti-sheep RBC in broiler birds fed PPE supplemented diets. Rama Rao *et al*. (2019) reported that although the addition of 250 mg/kg and 500 mg/kg of PP had no impact on the cellular immune response of broiler birds, their humoral immune response was improved. The findings of Kumar and Neeraj (2018) were however contrary to these findings. The contradiction may be due to different inclusion levels pomegranate by-products employed by different authors. The authors noted that PPE supplementation had no noticeable effect on the humoral and cellular immune responses of broiler birds reared under summer conditions. Sharifian *et al*. (2019) also observed a linear increase in the primary IgM response with 2 g/kg supplementation of pomegranate seed cake. Administering urea-treated PPP at 5 g/kg in broiler diets increased the primary total, IgM and IgG anti-sheep RBC responses, coupled with increased secondary total and IgG anti-sheep RBC responses (Hosseini-Vashan *et al*. 2020). Abdel-Basset *et al*. (2020) also reported an increase in the IgM and lysozyme levels in broiler birds upon receiving varying dietary levels of PPP. The positive effects of pomegranate peel on immunomodulatory function have been linked to its polyphenolic and tannin constituents (Labsi *et al*. 2016).

As in other avian species, lymphoid organs such as the bursa of Fabricius, spleen and thymus are the main site for the development and differentiation of immune cells, as well as antibody production in broiler birds (Ahmed and Yang, 2017; Hosseini-Vashan *et al*. 2020). Increase in the weight of immune organs often indicates higher immune capacity in the birds. In other words, birds that are exposed to stressful conditions have decreased lymphoid organ weights, compromised immunity, and are more prone to diseases (Heckert *et al*. 2002). The findings of Akuru *et al*. (2021a) revealed that PPP inclusion at 4 g/kg enhanced bird's spleen weight. The reports of Hosseini-Vashan (2020) revealed that the dietary urea-treated pomegranate peel increased the immune response indices of broiler birds and it also improved the relative bursa weights of the birds.

According to Ahmed and Yang (2017), dietary inclusion of pomegranate by-product increased the weight of the spleen and bursa of Fabricius in broilers but had no effect on the relative weight of the liver. Al-Ghousein and Beitawi, (2009) reported that broiler birds fed nutritive diets usually have increased gastrointestinal tract segments length. Nonetheless, there are reports that dietary PPP and PPE had no effect on the organ (heart, gizzard, liver) weights and intestinal tract length parameters of broiler birds (Sarica and Urkmez, 2016; Sharifian *et al*. 2019; Al-Shammari *et al*. 2019; Abdel-Baset *et al*. 2020). Pomegranate peel has been shown to activate both humoral and cellular immune responses in broiler birds (Abdel-Basset *et al*. 2020). According to Rama Rao *et al*. (2019), the immune-stimulatory effect of pomegranate peel is linked to its polyphenol (ellagitannin) constituents that can increase the composition of beneficial gut microflora, resulting in strengthened immune function. Pomegranate peel contains PSP001 which is a polysaccharide compound, which increases its ability to stimulate the growth of normal lymphocytes (Joseph *et al*. 2012).

Effect on haematology and biochemical parameters

Haematological parameters such as white blood cell, red blood cell count (RBC), haemoglobin concentration (Hb), packed cell volume (PCV) is used to ascertain the toxic effect of dietary treatments (Oloruntola *et al*. 2016). For instance, low Hb and PCV values suggests anaemia condition in the birds whereas high RBC levels suggests the birds' ability to withstand respiratory stress (Chukwuebuka and Chinenye, 2015). There are very few existing literatures on the dietary effects of PPP and PPE on the haematological parameters of broiler birds. According to Ghasemi-Sadabadi *et al*. (2021), the supplementation of 8% pomegranate peel in broiler diets led to a decrease in RBC, Hb and PCV concentrations. Perricone *et al*. (2020) reported that dietary PPE improved RBC's antiradical capacity, suggesting that PPE inhibits the activities of reactive oxygen species (ROS). The decrease in the haematological parameters at high inclusion level of pomegranate peel may be associated with the high tannin concentrations in the peel which decreased the bioavailability of iron (Kumar and Neeraj, 2018). Tannins are known to decrease the availability and concentrations of iron in animal models due to their anti-nutrient properties (Delimont *et al*. 2017).

Serum-biochemical tests are used to determine the body's nutrient metabolic rate and to highlight any change caused by intrinsic and extrinsic factors (Hu *et al*. 2016). Alanine aminotransferase (ALT), aspartate aminotransaminase (AST) and alkaline phosphatase (ALP) are liver enzymes used to assess hepatocellular injury (Kroliczewska *et al*. 2017). There are reports that PPP and PPE decreased the serum AST, ALT and ALP levels in birds (Sharifian *et al*. 2019; Abdel-Basset *et al*. 2020; Hosseini-Vashan *et al*. 2020; Akuru *et al*. 2021a). Similarly, the hypocholesterolemic and hypolipidemic effects of PPP and PPE have also been reported (Ahmed *et al*. 2015; Kishawy *et al*. 2019; Sharifian *et al*. 2019; Adel-Basset *et al*. 2020; Hosseini-Vashan *et al*. 2020). The hepatoprotective effects of pomegranate peel may be due to the flavonoids and quercetin in it, while its cholesterolemic effect may be as a result of ellagic acid content (Somparn *et al*. 2018). Serum protein concentrations on the other hand are used to indicate the functional status of hepatocytes, whereas urea and creatinine levels reflect the condition of the kidney (Tothova *et al*. 2019). Sharifian *et al*. (2019) reported that dietary PPE increased plasma protein levels in birds, while the reports of Abdel-Baset *et al*. (2020) showed that plasma urea and creatinine levels decreased upon supplementing broiler diets with 2, 3 and 4 mg/kg PPP.

Effects on meat quality

Nowadays, emphasis is on how to modify the physicochemical attributes of poultry meat to increase its quality (Mir *et al*. 2017). The pH of meat affects the colour, tenderness, cooking loss, drip loss, shelf-life, and other physicochemical properties, whereas meat colour is the most important attribute that determines the acceptance or rejection of meat (Shang *et al*. 2014). Meat colour and pH are highly correlated, thus, meat with low pH will be lighter, less red, and more yellow, whereas meat with high pH will be darker (Lawrie and Ledward, 2006). Pomegranate peel enhances meat pH and colour owing to the rich carotenoids (β-carotene), tannin and phenols contents which confers it with water-binding and antimicrobial effects (Hughes *et al*. 2014). Inclusion of 2-4 g/kg PPP increased the pH and redness and reduced lightness and yellowness values in a 3-month stored broiler meat (Abdel-Baset *et al*. 2020).

Cooking loss in meat is the amount of water lost during cooking due to the denaturation of muscle proteins which reduces the structural composition of the tissues (Honikel, 2004). On the other hand, drip loss is important in assessing meat quality because high exudate loss reduces the quality of the saleable meat (Thema *et al*. 2009). Cooking loss and drip loss are inversely correlated; hence, increase in drip loss causes a concomitant decrease in cooking loss (Thomas *et al*. 2004). Pomegranate peel can reduce meat's drip and cooking losses because it contains phenols which endows it with antioxidant and water-binding properties (El-Nashi *et al*. 2015). There are reports that PPP and PPE decreased the drip and cooking losses of stored broiler meat (Al-Qazzez, 2014; Sarica and Urkmez, 2016). On the other hand, tenderness is the most crucial attribute that is linked with consumer satisfaction in relation to the tastiness of meat (Destefanis *et al*. 2007). The inclusion of PPP (1-3%) in 12-day stored meat product improved the tenderness and other sensory attributes leading to improved acceptability (El-Nashi *et al*. 2015).

Effect on antioxidant capacity

Biological systems are exposed to oxidative stress when their endogenous defence mechanisms are overwhelmed by excessive free radical production. In meat producing animals this overpowering effect is linked to diet and breed differences, coupled with inappropriate pre-slaughter handling techniques. Oxidative stress affects deoxyribonucleic acid, proteins and lipids and is responsible for numerous degenerative diseases in animals (Xing *et al*. 2019). Interestingly, there are several enzymatic and non-enzymatic antioxidant compounds that protect cells and tissues from oxidative damage and stress caused by the harmful impact of free radicals (Halliwell and Gutteridge, 2007). Pomegranate peel exerts antioxidant scavenging capacity against superoxide and hydroxyl radicals through the activation of antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px), reduced glutathione (GSH) amongst others (Wang *et al*. 2011). The ability of pomegranate peel to scavenge for free radicals has been attributed to its polyphenolic and anthocyanidin contents (Ahmadipour *et al*. 2021). According to Saleh *et al.* (2017), the activities of SOD and GSH-Px in the plasma of broiler birds were not influenced by dietary PPP and PPE. Ghosh *et al*. (2019) reported increased concentrations of serum GSH and CAT activity when pomegranate peel was infused in the drinking water of broiler birds.

Lipid peroxidation is the major cause of postmortem deterioration in stored and processed meat products, thus lowering meat's sensorial, nutritional and storage potentials (Estevez, 2015). Xiong (2000) reported that meat is prone to lipid peroxidation due to increased amounts of unsaturated fatty acids, pigments, transition metals and oxidoreductase enzymes. Malonaldehyde (MDA) occurrence in meat which is induced by reactive oxygen species is a key indicator of lipid peroxidation (Schwarz *et al*. 2009). Pomegranate peel prolongs the shelf-life of stored meat and meat products due to its polyphenols and tannin contents (Chukwuma *et al*. 2020). Ahmed *et al*. (2015) reported that dietary PPP inclusion delayed the onset of lipid oxidation in 7-day stored broiler meat. Dietary supplementation of 0, 250, 450 and 650 mg/kg PPE reduced the MDA contents of broiler breast meat that were stored for 60 days (Sharifian *et al*. 2019). Other studies have also shown that pomegranate peel powder (PPP) and pomegranate peel extract (PPE) inclusion decreased MDA contents of stored broiler breast and thigh meat (Saleh *et al*. 2017; Abdel-Baset *et al*. 2020; Ghosh *et al*. 2020; Ghosh *et al*. 2021; Hosseini-Vashan *et al*. 2020).

Lipid oxidation is one of the main process that cause deterioration of poultry product (meat and egg) quality and shelf-life, causing adverse effects on organoleptic properties and nutritional value Lioliopoulou *et al*. (2023). Malondialdehyde (MDA) has been implicated as the main product to evaluate lipid peroxidation. According to *in vivo* study of Lioliopoulou *et al.* (2023), MDA levels were reduced in egg at 5% pomegranate peel by-product (PPB) inclusion in laying hens. It may be due to the antioxidants inherent in pomegranate peel which is made up of mainly flavonoids and hydrolysable tannins. Other *in vivo* studies showed that pomegranate could be used as a natural food preservative due to its antioxidant make-up as it reduces lipid peroxidation in meat and egg yolk.

Effects on fatty acid composition

The fatty acid composition of broiler meat is a good indicator of the dietary fat content. Replacing dietary saturated fatty acids (SFA) with higher intake of monounsaturated fatty acid (MUFA) and polyunsaturated fatty acids (PUFAs) reduces coronary heart disease risk due to reduced low-density lipoprotein cholesterol (Siri-Tarino *et al*. 2010).

The fatty acid contents of feeds can be manipulated to increase broiler meat's PUFA concentration and lower the omega 6 (n-6): omega 3 (n-3) ratios (Raes *et al*. 2004). Meat with a PUFA:SFA ratio above 0.7 and n-6: n-3 ratio below 0.5 is healthy. Kishawy *et al*. (2019) reported that feeding broilers with 0.1% PPE increased the concentrations of α-linoleic fatty acids in the meat.

Ahmed *et al*. (2015) reported lower n-6/n-3 ratio and higher PUFA/SFA in the breast and thigh meat of broiler birds fed pomegranate by-product supplemented diets. The improvement in PUFA long chain n-3 in the breast meat of broilers is linked to the presence of polyphenols in pomegranate peel which is responsible for its antioxidant property. On the other hand, the decrease in n-6/n-3 by pomegranate peel extract and pomegranate powder shows its cardioprotective effects on human consumers of broiler meat (Krauss *et al*. 2001) owing to its ellagitannin, ellagic acid, anthocyanidin and flavonoid contents (Wang *et al*. 2018).

Lioliopoulou *et al*. (2023) reported no major changes in egg yolk fatty acid profile among treatments, except for the n-6:n-3 ratio, which was significantly increased by the higher PPB inclusion level at 5%. The n-6:n-3 fatty acid ratio in the diet is an important factor for consumer health, as it is more important for the fat and cholesterol metabolism than absolute n-6 or n-3.

According to Kostogrys *et al.* (2017), higher concentrations of punicic acid from pomegranate seed oils in diets of laying hen increased the proportions of saturated fatty acids and decreased the proportions of monounsaturated and polyunsaturated fatty acids. Elsewhere, the consumption of pomegranate juice by women increase in total MUFA content and a numerical increase of n-6:n-3. The latter authors postulated that polyphenols could prevent fatty acid oxidation, and as a result affect the fatty acid profile, by protecting especially unsaturated fatty acids which are prone to free radical damage. It is plausible that a similar mechanism may have occurred in the study of Liolioupoulou *et al.* (2023), as the MDA levels were significantly lower in the 5% PPB group, in which the n-6:n-3 ratio was also found to be higher.

Effects on gut histology

The gastrointestinal tract (GIT) is one of the largest immunological organ in the body due to its digestive, absorptive, and protective functions (Choct, 2009). The epithelial layer of the small intestine is made up of finger-like protrusions known as villi that protrude into the intestinal lumen. The villi play an essential role in small intestinal nutrient absorption, in that an increase in its length increases the surface area and absorptive capacity of the small intestine. Near the villi are indentations known as crypt that extend into the connective tissues (Choct, 2009). An increase in crypt depth (CD) and a decrease in villi height (VH) results in higher GIT secretions, increased proneness to diseases and reduced performance (Choct, 2009). Sharifian *et al.* (2019) reported that dietary PPE increased the VH and CD in the jejunum of broiler birds. Pomegranate peel has protective effects on the GIT due to the presence of polyphenols that endows it with antibacterial property (Fawole *et al.* 2012). More studies are needed to further validate these claims.

Effects on bone morphometric characteristics and mineral composition

Bone is a unique and metabolically active organ with continuous turnover and precise remodelling action. Bone health is dependent on the balance between osteoclasts and osteoblasts in bone resorption and formation. The functioning of both processes is controlled by hormonal, immune, gastrointestinal, gut microbiota, and physiological systems (Collins *et al.* 2016). Selection of fast-growing broiler birds with improved efficiency and meatiness has welfare and economic implications. This is because birds with skeletal defects cannot readily access feed and water, are easily emaciated, and dehydrated leading to poor flock uniformity (Talaty *et al.* 2009). Although, there are existing reports on the dietary effects of PPP and PPE on bone morphometric and mineral indices of broiler birds, however plants with flavonoids contents such as pomegranate peel are known to have bone sparing attributes (Mbikay, 2012). The acetone extract of PPE is reportedly rich in caffeic acid which inhibits bone lytic diseases and osteoporosis (Mbikay, 2012; Chukwuma *et al.* 2020).

Similarly, bone is an important source of minerals necessary to meet bird's metabolic needs (Swiatkiewicz *et al.* 2018). Calcium (Ca) and phosphorus (P) are principal inorganic components of the bone that confers it with strength, hardiness, and health (Penido and Alon, 2020). Feeding broilers with diets that has imbalanced proportions of Ca and P decreases growth performance and nutrient digestibility. Hence, bone condition and the bioavailability of Ca and phosphorus are directly related at tissue level (Shaw *et al.* 2010). Bone length, weight and breaking strength are used to assess tibia strength while bone ash parameters on the other hand are used to evaluate the bioavailability of Ca, P, and other minerals (Swiatkiewicz *et al.* 2018). Higher bone length shows high amount of vitamins C, D and K in the bone which is needed for the uptake of calcium and for bone formation. Increase in breaking strength is an indication of bone rigidity, whereas higher bone weight:length index is a pointer to the denseness of the bone structure which shows an increase in the availability of Ca and P (Swiatkiewicz *et al.* 2018). Ahmed *et al.* (2015) reported that dietary PPP (0.5%, 1% and 2%) had no effect on the calcium content but increased the proportions of sodium and iron in the breast meat of broiler birds. Pomegranates are packed with essential vitamins and minerals that make them an ideal treat for your chickens. They contain vitamins A, C, E, and K; potassium; magnesium; iron; and calcium – all of which are important components of a healthy chicken diet (El-Hadary and Taha, 2020). Pomegranates are packed with vitamin C, which helps keep your chickens healthy and strong (Eid *et al.* 2021). Vitamin C helps boost their immune systems, as well as helps them fight off any infections or diseases they may encounter. It can also help to keep their feathers looking glossy and healthy (Eid *et al.* 2021).

Effect on odorous gas emission

The emission of odours from livestock farms is a major issue that rural and urban dwellers grapple with daily. The release of odour from livestock farms stem from the large amounts of ammonia, hydrogen sulphide and volatile organic compounds produced (Wang *et al.* 2021). Odorous compounds are produced when unutilized dietary nutrients are converted by microbes coupled with the anaerobic secretion of endogenous products in the gastrointestinal tract (Le *et al.* 2005). The emission of faecal noxious gases in broilers depends on their nutrient use and gut microbial composition. Hence, limiting odour emission in broiler houses is possible when there is improvement in nutrient utilization of the birds, in addition to proper handling of faecal matter. Management of the poultry house is very important to reduce the odour. Poultry houses should be managed properly in terms of humidity, ventilation and stocking density and the bedding should be between 70mm and 100mm deep, depending on the type of material used (Garcês *et al.* 2013). Again, birds should also receive a high-quality diet to prevent a built up of high moisture levels in order to prevent accumulation of odours. In other words, there is need to ensure adequate nutrient supply and use such that the birds are not fed more than required to avoid feed wastage (Ferket *et al.* 2002). Thus, manipulating the diet fed to birds with feed additives enhances their gut microbiota composition and content of fresh manure produced, thus reducing the amount of odour formed in the manure during storage (Le *et al.* 2005).

Majority of the nitrogen in the feed that is not utilized by poultry birds are excreted as uric acid with urine and converted to ammonia by microbial urease enzymes that are found in the faeces (Such *et al.* 2023). Compounds rich in tannins have been shown to reduce the excretion of urine nitrogen and the activity of urease enzymes in animal excreta (Powell *et al.* 2011). According to Whitehead *et al.* (2012), tannins are potent at reducing hydrogen sulphide emissions from animal waste by the anaerobic reduction in the metabolic activity of bacteria with sulphate reducing ability. Not so much work has been done to determine the dietary effects of pomegranate peel on noxious gas emission from broiler excreta. Nevertheless, Ahmed and Yang (2017) reported a significant reduction in hydrogen sulphide and methanethiol emissions in the excreta of broiler birds fed pomegranate by-product diets. Pomegranate peel has antimicrobial property due to the copious amounts of hydrolysable tannins that it contains. This enables pomegranate peel to reduce ammonia emissions from broiler faeces due to the decrease in the concentration of gut and ureolytic bacteria in the excreta such as *E. coli*, *Pseudomonas* spp. Klebsiella spp. etc. coupled with the decrease in the activity of faecal urease enzymes (Ahmed and Yang, 2017). Thus, pomegranate peel supplementation in broiler birds has multifunctional benefits, in that it improves the bird's performance and immunity, enhances the concentration of gut microbiota, and offers a safe environment to the bird (Murugesan *et al.* 2015; Kishawy *et al.* 2019).

Effect on egg quality

Egg quality change is directly linked to the carbon dioxide loss through the shell pores in freshly laid eggs during storage (Centingul *et al.* 2019). Egg quality parameters can be controlled by plant-based supplementation and the use of herbs in diets increases the quality of eggs during and after storage. Scientists have recorded positive effects of herbal extracts and oils on performance parameters as well as egg quality and production (Rahman *et al.* 2017; Khan *et al.* 2012). Research studies on dietary pomegranate seed pulp (15%) and pomegranate seed oil fed laying hens showed increased egg production and improvement of several egg quality traits such as, egg weight, yolk colour, yolk Fe content, yolk punicic acid and conjugated linoleic acid percentage (Saki *et al.* 2014; Abbas *et al.* 2017; Kostogrys *et al.* 2017; Saki *et al.* 2019). Some bio-active compounds are highly effective in preventing or treating chronic diseases such as cardiovascular diseases, diabetes, and cancer. It is essential to enrich the eggs with bio-active compounds by changing the diet of chickens (Kostogrys *et al.* 2017). One of the bio-active components used in trials is conjugated linoleic acid (CLA), which has numerous health benefits. Pomegranate is rich in the CLA isomer known as punicic acid (Centingul *et al.* 2019), and CLA is readily incorporated into egg yolk (Windisch *et al.* 2008). Eggs are used to enhance human nutrition and several trials have shown that the exogenous use of CLA containing feeds affects the sensory properties as well as egg shelf life (Manterys *et al.* 2016). Conjugated linoleic acid improves the texture of the yolk and the yolks were relatively difficult to brake using an Instron because it has a rubbery and elastic texture (Centingul *et al.* 2019). There are other reports that showed that CLA addition to diets of laying hens negatively affects egg quality (Kim *et al.* 2007; Franczyk-Zarow *et al.* 2008). These controversies in performance may be due to different inclusion levels by different researchers.

Limitations of pomegranate on the performance of poultry

Plant bioactive substances and their constituents are known to have medicinal abilities (Okuda and Ito, 2011; Sultana *et al.* 2012). The use of plants such as pomegranate as an alternative treatment to improve the health of animals has been referred to as naturopathy and tannins are a potentially useful compound since they have been widely recognized for their positive effects in livestock, particularly ruminants because their system can handle high tannin level. Even though they offer antibacterial (McRae and Kennedy, 2011), anti-inflammatory (Azimi *et al.* 2012), and antiviral (Marzoni *et al.* 2020) effects, plants containing tannins have not been widely used as feed additives in poultry because they lack the capacity of handling higher tannin level (Hidayat *et al.* 2021). Most of the feed ingredients such as sorghum and barley contain tannins and tannins are synthesised by green plants in different levels and qualities. Dietary inclusion of tannins up to 3% improved the gut health and digestive performance of chicken (Gambacorta *et al.*

2016; Farahat *et al*. 2017; Huang *et al*. 2018). Unlike in ruminant animals, the bioactivities of tannins in poultry have not been fully investigated (Huang *et al*. 2018). However, previous studies have found inconsistent results: Some studies showed a positive effect of dietary tannins with regards to improved performance, digestibility (Tandiang *et al*. 2014), and organ health (Moyle *et al*. 2012), whereas other studies have reported negative effects due to their addition (Hidayat *et al*. 2021).

Tannins are classified as "antinutritional factor" for poultry with negative effects on feed intake, nutrient digestibility, and production performance (Redondo *et al*. 2014).

Currently, most researchers have revealed that some tannins can improve the intestinal microbial ecosystem, enhance gut health, and hence increase productive performance when applied appropriately in poultry diets (Liu *et al*. 2012; Chamorro *et al*. 2015; Bilic-Šobot *et al*. 2016). Strong protein affinity is a well-recognized property of plant tannins, which has successfully been applied to monogastric animals' nutrition. Limitations of dietary high tannin on poultry performance have been reported by many scientists (Ebrahim *et al*. 2015). The limitations of tannins are related to their protein-binding capacity and reduction in protein, starch, and energy digestibility (Houshmand *et al*. 2015; Tapiwa, 2019). Hassan *et al*. (2003) and Ravindran *et al*. (2006) reported that dry matter intake, bodyweight, feed efficiency and nutrient digestibility were reduced when broiler chickens were fed diets with tannins, whilst Ebrahim *et al*. (2015) showed that body weight gain and feed intake decreased. However, Antongiovanni *et al*. (2015) and Chamorro *et al*. (2015) reported no effects on growth performance and on egg weight, shell thickness and yolk color of layers. Although, several studies showed that low concentrations of tannins improved feed intake, health status, nutrition digestibility, and performance in poultry (Maertens and Štruklec, 2006; Brus *et al*. 2013; Huang *et al*. 2018). More research is needed to overcome the negative effect of tannin in poultry diet.

CONCLUSION

Pomegranate peel has antioxidant property that enables it to scavenge free radicals and prevent several degenerative diseases. Pomegranate peel is a veritable natural growth promoter that improves the growth of broiler and laying birds, owing to the rich content of bioflavonoids and tannins with varying degrees of biological activities. Similarly, there is the tendency for a reduction in tibia-linked deformities when pomegranate is fed to broiler birds leading to enhanced slaughter and carcass conformation. More so, pomegranate peel has the potential to enhance the blood biochemical constituents of broiler birds and thereby help them to fight diseases. Pomegranate peel also delays the onset of lipid rancidity in meat and egg during storage, resulting in enhanced meat and egg quality parameters. Hence, the utilization of pomegranate peel in poultry bird feeding is beneficial to the birds and human consumers of the derived meat and eggs. Additionally, utilizing pomegranate peel as a feed resource in poultry nutrition will potentially address the menace of environmental pollution of underutilized fruit wastes. These wastes contain some antinutrients such as tannins which has negative effects on monogastric, especially poultry. Further research is needed with regards to manipulation of diets to maximize the full potential of pomegranate by-products on poultry.

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