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Application of fruit wastes in broiler diets: their effects on performance, immunity and cecal bacteria

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Abstract This experiment was conducted to investigate the effect of dietary inclusion of natural fruit wastes, including apple pulp powder (APP), lemon pulp powder (LPP), and pomegranate peel powder (PPP), on the performance, immunity status, some cecal bacteria count, and carcass characteristics in broilers. A total of 260 male and female Ross 308 broiler chicks were distributed in a completely randomized design among 5 experimental treatments with 4 replicate pens of 13 birds each. The control group was fed a basal diet without any additive, while groups 2-5 were fed the same basal diet supplemented with antibiotics, 2% APP, 2% LPP, and 2% PPP, respectively. Birds were reared under the same management conditions for 42 days. The results indicated that all of the additives caused greater body weight gain (BWG) during the grower period (d 11-24; P<0.05). Addition of antibiotics and LPP had a similar growth-promoting effect on overall BWG (d 1-42). Supplementation of the diet with PPP during the starter and all of additives during the grower period resulted in better feed conversion ratio (FCR) compared to that of the control group. Feeding birds with antibiotics, APP and LPP improved overall FCR compared to the control group. The additives did not affect the weight of spleen and bursa of Fabricius, concentration of total, Y, and M immunoglobulins as well as the carcass characteristics (P>0.05). The lower count of cecal *Escherichia coli* was determined in APP group (P<0.05). In conclusion, APP, and LPP had similar growth-promoting activity as antibiotics. The inclusion of APP beneficially influenced the cecal bacteria balance. These positive effects suggested that APP, LPP, and PPP could be considered as suitable alternatives to feed antibiotics, resulting in a better food safety and less environmental pollution.

Keywords: apple, broiler, lemon, performance, pomegranate

Introduction

As a by-product of fruit processing industry, large quantities of fruit waste are produced in the world, annually (Georganas et al., 2023). Because of the environmental and economic concerns, proper management of these wastes is of great importance. Thus, it is necessary to find a suitable solution for this problem. Application of fruit wastes in animal nutrition is among suggested strategies (Azizi et al., 2018). In literature, fruit wastes have been used in different forms in poultry, nutrition. Because of the valuable nutrients (essential amino acids, vitamins, minerals and fiber), fruit wastes have potential to be used as replacements for expensive common feed ingredients in poultry diets, leading to lower feed cost (Mnisi et al., 2022; Sosnówka-Czajka et al., 2023). On the other hand, they are rich in different bioactive substances, particularly phenolic compounds with antioxidant, antiviral, antibacterial, anti-inflammatory, and immune-stimulating properties (Mnisi et al., 2022). By considering the prohibition of using chemical antibiotics growth promoters as well as consumers' concerns regarding the safety of animal-origin foods, using fruit wastes in poultry nutrition as natural, and safe feed additives for replacement of antibiotics has been received more interest in recent years (Erinle and Adewole, 2022). Taken together, proper application of these by-products could result in safer poultry products, better waste management, environmental benefits as well as lower costs of diets and production (Azizi et al., 2018; Mnisi et al., 2022).

Apple, lemon and pomegranate are important fruits throughout the world. In apple processing industry, 25-30 % of fruit weight is remained as a pomace (Sosnówka-Czajka et al., 2023). It contains high levels of carbohydrates, crude fiber and minerals. Additionally, it is rich in bioactive compounds including phenols, flavonoids and flavan-3-ols with strong antioxidant, antimicrobial and anticancer properties (Erinle and Adewole, 2022; Mnisi et al., 2022). Beneficial consequences of dietary application of up to 5 % apple by-products on reducing oxidative stress (Azizi et al., 2018) and 3 or 6 % apple pomace on improvement of serum and tissue antioxidant activity in broilers have been indicated (Colombino et al., 2020a).

Lemon is one of the most important species of citrus. Due to the presence of different nutrients (9.42% protein, 4.98% fat, 6.26% ash, 15.18 % fiber and considerable levels of minerals and vitamins) as well as bioactive substances particularly phenols, it has beneficial influences on poultry health (Janati et al., 2012; Akbarian et al., 2013). It was reported that dietary supplementation with lemon peel essential oil improved the growth performance and gut health of broilers during summer (Sahu et al., 2019).

Iran is the world's third producer of pomegranate with 915,000 tons (Mnisi et al., 2022). This fruit is consumed fresh or processed to produce different products. Processing of pomegranate produces a large quantity of wastes. Considerable levels of protein, peptides and polysaccharides as well as polyphenols (tannins, flavonoids, phenolic acid, gallic acid, ellagic acid, punicagal and punicagalin) are available in pomegranate peel (Hosseini-Vashan and Raei-Moghadam, 2019; Smaoui et al., 2019). Previous findings indicated that dietary inclusion of pomegranate by-products had beneficial consequences on performance (Ahmadipour et al., 2021), intestinal bacteria (Gungor et al., 2021), immunity response (Hosseini-Vashan and Raei-Moghadam, 2019) and antioxidative capacity (Gungor et al., 2021) in broiler chickens. Considering the importance of fruit waste management and possible beneficial effects on broiler health and performance, the objective of the current study was to investigate whether apple, lemon and pomegranate wastes can act as natural alternatives to replace chemical antibiotics in broilers diets.

Materials and methods

Birds, diets and experimental design

The experiment was conducted at the Research Farm of Yasouj University, Yasouj, Iran. A total number of 260 one-day-old male and female Ross 308 broiler chicks was purchased from a commercial hatchery and transported to the rearing facilities. On arrival time, they were randomly divided into 5 experimental groups with 4-floor pen replicates of 13 birds each. During the rearing period, the first group was fed with a basal diet without any additive and served as the control, second group was fed with a basal diet supplemented with antibiotic (50 g/t, Erythromycin) and birds in groups 3 to 5 received the same basal diet supplemented with 2% apple pulp powder (APP), lemon pulp powder (LPP) or pomegranate peel powder (PPP), respectively. The dietary inclusion level of fruit wastes was based on the previous findings. Experimental diets and water were provided *ad libitum* throughout the rearing period. All birds were reared under the same management conditions during the 42 d of the experiment.

Fruit wastes, obtained from fruit juice factories in Yasouj city, Kohgiloyeh and Boyer Ahmad province, Iran, were air-dried in a shaded area at room temperature, ground into the powdered form and added to the experimental diets in the required amounts. Isonitrogenous and isoenergetic starter (d 1-10), grower (d 11-24) and finisher (d 25-42) diets were formulated to meet or exceed Ross 308 nutrient recommendations (Table 1).

Measurements and sample collection

Body weight and feed intake were measured at the end of the starter, grower and finisher periods of the experiment. Using this data, BWG and FCR were calculated for each experimental period as well as the overall period (d 1-42). At the end of the rearing period (d 42), one bird from each pen was selected based on the pen average live weight and slaughtered by cervical dislocation. Immediately after removal of the digestive system, weights of the carcass, breast, thighs, wings and liver were determined and expressed as the relative weight of the final live body weight (%). Also, the length of different parts of the small intestine (duodenum, jejunum and ileum) was measured.

The immunity status was evaluated by injection of sheep red blood cells (SRBC) into the wing vein at 28 and 35 d of age. Blood was collected and the antibody response to SRBC was measured at 42 d of age (Nelson et al., 1996). Additionally, the relative weight of the spleen and bursa of Fabricius were calculated.

After slaughtering the birds, digesta samples were collected from the cecum, put in sterile tubes and sent to the Microbiology Lab. Population of *Lactobacillus* and *Escherichia coli* were measured after serial dilution (from 10^{-1} to 10^{-9}) of each sample. Eosin Methylene Blue (EMB) and De Man, Rogosa, and Sharpe (MRS) agar were used as media to differentiate *Escherichia coli* and *Lactobacillus,* respectively. After incubation of media under standard conditions, the count of bacteria was measured and expressed as colony forming unit (CFU) per gram of digesta.

Table 1. Ingredients and composition of the experimental diets fed to broilers

Ingredient (%)	Starter (d 1-10)	Grower (d 11-24)	Finisher (d 25-42)
Corn grains	45.24	54.82	66.42
Soybean meal	44.05	36.17	28.03
Calcium carbonate	1.26	1.15	1.00
Dicalcium phosphate	1.63	1.48	1.15
Vegetable oil	6.43	5.15	2.20
Vitamin premix[2]	0.25	0.25	0.25
Mineral premix[3]	0.25	0.25	0.25
Salt	0.46	0.39	0.35
DL-Methionine	0.36	0.26	0.25
L- Lysine	0.07	0.08	0.10
Calculated nutrient composition			
ME (kcal/kg)	2912	2912	3100
Crude protein (%)	22.32	19.73	19.00
Calcium (%)	0.94	0.84	0.86
Available phosphorus (%)	0.47	0.42	0.43
Sodium (%)	0.20	0.17	0.18
Methionine + Cysteine (%)	1.05	0.93	0.89
Lysine (%)	1.40	1.24	1.13

[1] The vitamin premix supplied the following per kilogram of diet: vitamin A (retinol acetate), 8,000 IU; vitamin D_3, 1,000 IU; vitamin E (dl-α-tocopherol), 30 IU; vitamin K_3, 2.5 mg; vitamin B_1, 2 mg; vitamin B2, 5 mg; vitamin B_6, 2 mg; vitamin B_{12}, 0.01 mg; niacin, 30 mg; d-biotin, 0.045 mg; vitamin C, 50 mg; d-pantothenate, 8 mg, folic acid, 0.5 mg.
[2] The mineral premix supplied the following per kilogram of diet: Mn, 70 mg; Fe, 35 mg; Zn, 70 mg; Cu, 8 mg; I, 1 mg, Se, 0.25 mg; Co, 0.2 mg.

Statistical analysis

General Linear Models (GLM) procedures of SAS software (SAS, 2005) was used for data analysis. The means were compared by the Duncan’s multiple range test. The level of significance was set at $P<0.05$.

Results

During the starter period, dietary inclusion of antibiotic had no effect on BWG (Table 2; P>0.05), while during the grower and finisher as well as the overall periods of the study, feeding with this additive resulted in a greater BWG than the control group. Moreover, during the starter period, birds in LPP and PPP groups gained more weight than those in the control group. Grower BWG was greater in all additive groups compared to the control group (P<0.05). Birds were fed the diet containing antibiotic had a greater finisher BWG than other groups. Dietary inclusion of APP, LPP and PPP did not change the overall BWG (d 1-42) but birds consuming the antibiotic had greater BWG than other groups except for LPP diet.

The experimental treatments had no effect on the starter, grower, finisher, and also overall feed intake. The starter FCR was better in birds that received PPP compared to the control group. Feeding the birds with all additives resulted in a better grower FCR than the control group, while the finisher FCR was remained unaffected. Compared to the control treatment, dietary inclusion of antibiotic, LPP, and APP improved the overall FCR.

The immunity parameters (Table 3), including lymphatic organs (spleen and bursa of Fabricius) weight as well as the concentration of total, Y, and M immunoglobulins, were not influenced by the treatments (P>0.05).

Table 4 indicates that using antibiotic, PPP, and LPP did not change the number of cecal harmful bacteria (*Escherichia coli*) while APP reduced the population of these bacteria (P<0.05). In addition, different additives did not affect the population of intestinal *lactobacillus*.

Table 2. Effects of experimental diets on performance traits (body weight gain, feed intake and feed conversion ratio) in broilers at different phases of the experiment

Traits	[1] Experimental diets					SEM	P-value
	Control	Antibiotic	Pomegranate	Lemon	Apple		
Body weight gain (g)							
d 1-10	128[c]	135[bc]	149[a]	148[ab]	132[c]	3	0.008
d 11-24	572[d]	794[a]	637[c]	738[ab]	701[b]	19	0.000
d 25-42	1277[bc]	1359[a]	1209[b]	1269[bc]	1200[b]	21	0.100
d 1-42	1977[b]	2289[a]	1996[b]	2156[ab]	2033[b]	36	0.009
Feed intake (g)							
d 1-10	186	190	190	192	187	1	0.420
d 11-24	1027	1111	1091	1081	1007	15	0.240
d 25-42	2339	2453	2324	2359	2285	25	0.300
d 1-42	3552	3754	3606	3634	3479	37	0.230
Feed conversion ratio							
d 1-10	1.464[a]	1.405[ab]	1.276[b]	1.301[ab]	1.419[ab]	0.027	0.040
d 11-24	1.794[a]	1.400[c]	1.712[b]	1.464[c]	1.434[c]	0.043	0.000
d 25-42	1.835	1.806	1.921	1.860	1.912	0.020	0.310
d 1-42	1.798[a]	1.641[b]	1.805[a]	1.686[b]	1.712[b]	0.019	0.003

a,b:Within rows, means with common superscript(s) are not different (P>0.05).
[1]Control: basal diet without any additive, Antibiotic: diet containing 50 g/ton antibiotic (erythromycin), Apple, Lemon, Pomegranate: diet containing 2 % apple pulp powder, 2 % lemon pulp powder, 2 % pomegranate peel powder, respectively.
SEM: Standard error of the mean

There was no effect of the experimental treatments on carcass yield and relative weight of breast, and thighs (P>0.05; Table 5). Additionally, wing weight was not different between the control and additives treatments. However, higher wing weight was observed in APP than LPP or antibiotics groups. The experimental treatments did not impact on the liver weight and length of different parts of the small intestine at 42 d of age (P>0.05).

Table 3. Effects of experimental diets on immunity status in broilers at 42 d of age

Parameter	[1] Experimental diets					SEM	P-value
	Control	Antibiotic	Pomegranate	Lemon	Apple		
Spleen weight (% BW)	0.126	0.127	0.146	0.134	0.141	0.01	0.970
Bursa of Fabricius weight (% BW)	0.191	0.174	0.159	0.186	0.143	0.008	0.320
Total Ig	2.7	2.4	2.5	2.6	2.8	0.06	0.070
IgY	1.7	1.6	1.8	2.1	1.7	0.10	0.510
IgM	1	0.8	0.7	0.5	1.1	0.11	0.520

a,b:Within rows, means with common superscript(s) are not different (P>0.05).
[1]Control: basal diet without any additive, Antibiotic: diet containing 50 g/ton antibiotic (erythromycin), Apple, Lemon, Pomegranate: diet containing 2 % apple pulp powder, 2 % lemon pulp powder, 2 % pomegranate peel powder, respectively.
SEM: Standard error of the mean

Table 4. Effects of experimental diets on intestinal bacterial count (CFU) in broilers

Parameter	[1] Experimental diets					SEM	P-value
	Control	Antibiotic	Pomegranate	Lemon	Apple		
Escherichia coli	9.1^{a}	8.4^{a}	8.5^{a}	8.5^{a}	7.6^{b}	0.15	0.0130
Lactobacillus	7.2	7.2	6.9	7.6	6.6	0.19	0.570

a,b:Within rows, means with common superscript(s) are not different (P>0.05).
[1]Control: basal diet without any additive, Antibiotic: diet containing 50 g/ton antibiotic (erythromycin), Apple, Lemon, Pomegranate: diet containing 2 % apple pulp powder, 2 % lemon pulp powder, 2 % pomegranate peel powder, respectively.
SEM: Standard error of the mean

Table 5. Effects of experimental diets on the relative weight (% body weight) of carcass components and small intestinal length (cm) at 42 d of age in broilers

Parameter	[1] Experimental diets					SEM	P-value
	Control	Antibiotic	Pomegranate	Lemon	Apple		
Carcass	64.0	64.0	64.0	61.1	64.4	0.63	0.570
Breast	21.3	21.4	22.1	22.0	22.0	0.33	0.960
Thighs	19.1	19.2	19.3	19.0	19.0	0.18	0.660
Wings	5.5^{ab}	5.3^{b}	5.7^{ab}	5.2^{b}	5.9^{a}	0.09	0.040
Liver	2.56	2.72	2.15	2.65	2.83	0.08	0.070
Length of different parts of the small intestine (cm)							
Duodenum	32	33	30	35	30	0.79	0.250
Jejunum	85	86	96	89	89	0.96	0.540
Ileum	78	87	95	91	85	2.01	0.070

a,b:Within rows, means with common superscript(s) are not different (P>0.05).
[1]Control: basal diet without any additive, Antibiotic: diet containing 50 g/ton antibiotic (erythromycin), Apple, Lemon, Pomegranate: diet containing 2 % apple pulp powder, 2 % lemon pulp powder, 2 % pomegranate peel powder, respectively.
SEM: Standard error of the mean

Discussion

Supplementation with the antibiotics, APP, LPP, and PPP improved the BWG during some periods of the rearing period, while feed intake was remained unaffected, meaning that supplemented groups were more efficient in converting feed into the BWG than the control group. Based on the findings of the current experiment, it could be concluded that APP and LPP wastes have the potential to be used as safe and natural growth promoters to replace in-feed chemical antibiotics in broiler diets.

There are some reports on the growth-promoting activity of apple, lemon and pomegranate by-products. Apple pomace has beneficial effects on the physiological processes of the birds (Sosnówka-Czajka et al., 2023).

Also, it can improve the gut microbiome and intestinal health of chickens (Jackson et al., 2022), causing better performance. Furthermore, polyphenols in apple can capture free radicals, change signal transduction in cells and tissues as well as regulate gene expression in animals (Asgary et al., 2018). On the other hand, environmental stressors have negative consequences on poultry performance (Bartlett and Smith, 2003) which could be alleviated by using antioxidants such as phenol compounds (Brisibe et al., 2009). In this regard, dietary application of up to 5 % apple by-products reduced the oxidative stress in broilers (Azizi et al., 2018). Probably, these mechanisms can explain the improved performance of broilers fed apple pomace in the current study.

Recently, Hafeez et al. (2023) found that dietary supplementation with 3 and 6 g/kg lemon peel powder beneficially influenced performance and intestinal histology and alleviated the detrimental consequences of coccidiosis in broilers challenged with *E. tenella.* Nobakht (2013) found that dietary inclusion of 1.5, 3 and 4.5 % dried lemon pulp resulted in a greater feed intake and body weight gain of broilers. Moreover, feeding phenols rich-lemon extract improved the antioxidant activity and metabolic functions in broilers under the hot conditions (Akbarian et al., 2015).

Dietary supplementation with 0.2 % fermented or unfermented pomegranate peel also had beneficial consequences on the performance and intestinal microbiota of broilers challenged with avian pathogenic *Escherichia coli (*Xu et al., 2024). Hosseini-Vashan and Raei-Moghadam (2019) found that rearing broilers under the heat stress conditions negatively influenced their performance, immunity, and antioxidant capacity, which was decreased by dietary inclusion of 7 and 10 % pomegranate pulp. Due to the presence of phenolic compounds, particularly elagic acid and tannins in pomegranate pulp, it has antioxidant activity, which can alleviate the adverse effects of heat stress. In another study, feeding broilers with 7.5 g/kg pomegranate peel resulted in a better FCR (Ahmadipour et al., 2021). In addition to antioxidant and antimicrobial activities, pomegranate peel improves the functions of digestive enzymes and has beneficial effects on intestinal bacteria and thereby nutrient absorption resulting in a better feed utilization in broilers (Akuru et al., 2021).

However, there are inconsistencies in the literature concerning the growth-promoting activity of apple, lemon and pomegranate wastes. In a recent study, dietary inclusion of 3 % apple pomace did not affect the performance of broilers (Sosnówka-Czajka et al., 2023). Also, in some other studies (Heidarisafar et al., 2016; Colombino et al., 2020b; Jackson et al., 2022), using apple by-products did not result in a better performance of broilers. Moreover, dietary supplementation with 5, and 10 g/kg pomegranate pomace (Gungor et al., 2021) or 2, 4, 6, and 8 g/kg pomegranate peel powder (Akuru et al., 2021) did not change the growth performance of broilers. Akbarian et al. (2013) found that dietary supplementation with 200 and 400 mg/kg lemon peel extract had no beneficial effect on the performance of broilers reared under high ambient temperatures. Interestingly, in some studies feeding with fruit waste deteriorated the broiler performance. For example, the diets containing 1, 2, and 3 g/kg of pomegranate pomace (Saleh et al., 2018), 12, 16, and 20 % apple pulp (Aghili et al., 2019) or 2.5 -12 % dried lemon pulp (Basir and Toghyani, 2017) adversely affected the broiler performance. The presence of high levels of polyphenols (Saleh *et al*. 2018) or lower digestibility of nutrients due to higher dietary fiber content (Mourao et al., 2008) could be accounted as possible reasons for impaired broiler performance.

Different factors can influence the efficacy of fruit by-products on broiler performance including: the form, type and dietary inclusion level (Sosnówka-Czajka et al., 2023), level and composition of the active components in by-products, basal diet, rearing conditions and physiological state of the bird (Akbarian et al., 2013), pharmacokinetics, metabolism, compounds bioavailability, stage and species of the experimental animal and duration of the experiment (Mahfuz et al., 2021), antinutritional factors present in fruit waste (Erinle and Adewole, 2022). In addition, concentration of phenolic compounds in fruits can be influenced by different factors such as variety, growing region, maturation and climatic conditions (Hosseini-Vashan and Raei-Moghadam, 2019). Therefore, inconsistency in animal performance could be attributed to the all above-mentioned factors.

Furthermore, it is emphasized that the number of broilers used in the current study was not large enough for obtaining a more clear effect of the additives. A previous finding has also suggested that larger numbers of broilers should be used for the better understanding of the consequences of apple, blackcurrant, and strawberry pomaces in broilers (Colombino et al., 2020a).

We found no significant differences in immunity parameters (spleen and bursa of Fabricius weight and blood immunoglobulins) between experimental groups. Similarly, in a previous study, 5 and 10 g/kg pomegranate pomace did not affect the spleen weight (Gungor et al., 2021). In another study, different levels of dried lemon pulp did not change the immune cells (Nobakht, 2013). Conversely, in the study of Hosseini-Vashan and Raei-Moghadam (2019), feeding with pomegranate pulp resulted in greater relative weight of the spleen and bursa of Fabricius as well as greater titers of total and IgM antibodies against SRBC and New castle disease virus. Additionally, Aghili et al. (2019) reported that dietary inclusion of up to 12 % apple pomace increased antibody titers against SRBC, Newcastle and influenza in broilers. Akbarian et al. (2015) found that dietary inclusion of 400 mg/kg lemon peel extract increased the bronchitis antibody titers in heat stressed- broilers. In another study, lower levels of antibodies against SRBC and influenza were observed in broilers fed with lemon pulp which indicates that high levels of lemon pulp can impair the immunity responses (Basir and Toghyani, 2017).

In our experiment, the antibiotic erythromycin at 50 g/t, did not change the population of *Escherichia coli* and *lactobacillus* in cecum, while APP reduced the number of *Escherichia coli*. It should be mentioned that rearing conditions plays an important role in the response of broilers to different feed additives such as antibiotics. The absence of a challenging environment will limit the response of the animals to the dietary application of antibiotic growth promoters (Morales-Lopez et al., 2009). In a previous study, dietary supplementation with 2 antibiotics (virginiamycin or bacitracin) and a prebiotic did not change the performance traits, carcass characteristics as well as the population of cecal *E. coli* and *Campylobacter* at 14 and 24 d in broilers. As the experiment was conducted under the clean and hygienic conditions, it was suggested that under such conditions, feed additives were not needed to obtain maximum growth (Baurhoo et al., 2009). Morales-Lopez et al. (2009) observed that feeding antibiotic (avilamycin)-supplemented diet did not influence the performance and antibody response to Newcastle disease virus; this was hypothesized to be related to the absence of a real microbial challenge.

There is little data on the effects of apple, lemon and pomegranate waste on the gut bacteria in broilers. In a previous study, the intra-amniotic injection of soluble extracts of apple pomace on d 17 of incubation positively influenced the cecal bacterial population and broiler health (Jackson et al., 2022). In another study, a greater count of *Lactobacillus* and lower count of *Escherichia coli* were observed in the cecum of broilers that were fed with lemon essential oils at 35 d of age (Elbaz et al., 2022). Xu et al. (2024) found that dietary inclusion of 0.2 % fermented or unfermented pomegranate peel had favorable effects on the intestinal microbiota in broilers challenged with *Escherichia coli.* A previous finding indicated that birds fed a diet with 10g/kg pomegranate pomace had the lower count of cecal *Colstridium perfringens* but *Escherichia coli, Enterococcus* spp., *Lactobacillus* spp., *S. aureus* and *C. jejuni*, were not influenced by pomegranate pomace (Gungor et al., 2021).

Phenolic compounds can inhibit Gram-positive and Gram-negative bacteria. Different mechanisms have been suggested for their antibacterial activity including denaturation of cellular protein causing in cell death, decrease in ATP production, increase in the permeability of the inner bacterial membrane, and inhibition of the DNA gyrase that is involved in bacterial DNA and RNA synthesis. Additionally, due to the lipophilic nature of phenolic compounds, they can influence the lipid bilayer in bacterial cell membrane and mitochondria, thereby causing disturbance in normal cell functions (Mahfuz et al., 2021).

In our study APP, LPP and PPP did not impact on the carcass traits or the small intestine length in broilers. In agreement with these findings, dietary inclusion of 3 % apple pomace had no effect on the carcass yield, breast muscle, leg muscle, abdominal fat and liver weight of broilers (Sosnówka-Czajka et al., 2023). Also, Colombino et al. (2020a) reported that carcass traits (dressing, liver, breast, thigh, abdominal fat) were not influenced by dietary inclusion of 3 and 6 % dried apple pomace. Nobakht (2013) found that carcass yield, breast, thigh and liver weight were not influenced by 1.5, 3 and 4.5 % dried lemon pulp but abdominal fat was decreased in broilers fed with 3% dried lemon pulp. In another study, lemon pulp did not affect the carcass yield, abdominal fat, small intestine length, but liver weight was heavier in the lemon pulp group (Basir and Toghyani 2017). In the study of Hosseini-Vashan and Raei-Moghadam (2019), the carcass, breast and thigh relative weights were not influenced by 4, 7 and 10 % pomegranate pulp in heat stressed-broilers. In another study, dietary inclusion of 2.5, 5, 7.5 and 10 g/kg pomegranate peel did not affect the carcass yield while 7.5 and 10 g/kg peel reduced the percentage of abdominal fat in broilers (Ahmadipour et al., 2021).

Determination of nutrient composition and also bioactive compounds in the apple, lemon, and pomegranate wastes is recommended for future studies. Moreover, further studies, using larger number of broilers, are needed for clear understanding of the effects of fruit wastes on broilers.

Conclusions

In conclusion, dietary inclusion of APP and LPP at 2 % improved the overall FCR in broilers. This effect was similar to that produced by the dietary inclusion of erythromycin at 50 g/t. Thus, these fruit pulps have the potential to serve as effective, natural and safe feed additives to replace the conventional antibiotics, resulting in safer and healthier products and less environmental and economic concerns regarding fruit waste management.

Conflict of interests

There is no conflict of interest

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