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Effects of Pellet and Mash Diets of Mesquite Fruit (*Prosopis juliflora*) on Performance, Energy and Protein Efficiency Ratio and Intestinal Morphology of Broiler Chickens

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Abstract

The primary aim of this study was to assay the influence of pellet and mash diets supplemented with different levels of mesquite fruit on performance, energy and protein efficiency ratio, carcass characteristics, and intestinal morphology of broiler chickens. In this study, a total of 560 one-day-old (mixed sex) Ross 308 were distributed in a completely randomized design with 7 treatments, 4 replicates, and 20 chicks per replicate. Seven iso-caloric and iso-nitrogenous diets including a control diet (mash form without mesquite fruit), and pelleted and mash diets, consisting of three levels of mesquite fruit (3, 6, and 9%) were adjusted. The results exhibited that mesquite fruit contained a high percentage of dietary fiber. The results also showed that pelleted and mash diets containing different levels of mesquite caused a significant difference in feed intake, body weight gain, and feed conversion ratio in starter and grower periods. At the finisher period, there was a significant difference between the experimental treatments in terms of feed intake and body weight gain, but there was no significant difference in feed conversion ratio. Experimental treatments also caused a significant difference in energy and protein efficiency ratio in the starter and grower periods. Dietary treatments also exhibited a significant difference in the relative weight of breast and intestine, but no effect was found on carcass yield and relative weight of other internal organs. The findings revealed that pelleted and mash diets containing different levels of mesquite fruit did not show significant differences in morphological traits of the intestine. Taken together, our results suggested that, the use of mesquite fruit in pelleted diets can have positive effects on the performance of broilers.

Introduction

Due to the shortage of the main ingredients of poultry diets in Iran, especially corn and soybean meal, which are often imported at high cost from other countries, the use of local ingredients is necessitous to offset some of the feed requirements of poultry. One of the most important species resistant to the drought that has high salinity tolerance potential and nitrogen fixation in the soil is the mesquite (*Prosopis juliflora*) plant (Toky *et al*., 1992). The fruits of this tree are similar to beans and contained nearly 18–20 seeds. The high nutritional value of mesquite fruit comes from a pod containing seeds that is a valuable source of energy and protein (Silva, 1986). Overall, reports of the chemical composition and nutritional value of mesquite pod exhibit that the pods are a good source of energy and protein, and their composition varies depending on the plant growth area (Silva, 1986; Sharma and Dakshini, 1998). Tannins are important compounds found in all parts of the mesquite plant (Aminzadeh *et al*., 2012) and its amount was reported between 0.7 and 2.6% by Ruiz-Nieto *et al*. (2020). These components have anti-nutritional effects and produce complex, low digestible compounds with protein, starch, digestive enzymes, vitamins, and minerals. So that one gram of tannin per kg of broiler feed reduces the growth rate and increases feed conversion ratio (FCR; Mc-Cann *et al*., 2006).

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Chaudhary *et al*. (2005) studied the effect of corn replacing mesquite pod (0, 10, 20, and 30%) on broiler performance. They revealed that the appropriate replacement level was 20%, which significantly increased body weight and improved FCR at 28 days of age compared to the control group. In another experiment, replacement of mesquite up to 10% level in laying hens diet did not have any negative effect on performance, although, at higher levels, it reduced egg weight, egg percentage and increased FCR (Norouzi *et al*., 2013).

Nowadays, grinding and pelleting are applied to increase the nutritional value of various nutrients in poultry nutrition (Azarbaijani, 1995). The beneficial effects of pelleting diets on poultry performance have been reported by many researchers (Moritz *et al*., 2003; Abdollahi *et al*., 2013). Pellet-fed birds had better weight gain and higher feed intake (FI) than the birds fed the mash diets, also, pelleting diets improved the FCR at the finisher period as well as the whole rearing period (Hooshmandi *et al*., 2017). Pelleting diets increases live body weight and feed efficiency compared to mash feeds. This performance improvement is due to increased FI. Pellet-fed birds also consume less energy to act of eating, so the energy available for growth will increase (Ebrahimi *et al*., 2010). Feed processing has a great effect on improving poultry performance. Moreover, among the feed processing methods, pelleting has received more attention than another process (mash and crumble) due to its effect on improving production efficiency and weight gain (Chewning *et al*., 2012). Feeding broilers with pelleted diets have been reported to reduce heat increment, and increase energy intake for production purposes, and ultimately improve body weight gain (BWG) of birds (Bennett *et al*., 2002; Latshaw and Moritz, 2009; Abdollahi *et al*., 2011). Gastrointestinal functions were influenced by any changes in the microscopic and macroscopic structures of feed. The physical form of feed has a major impact on poultry performance, intestinal health, and digestion process, which can exert its effects via alteration of digestive coefficient, change in intestinal pH, and excessive uptake in the upper gastrointestinal tract (Hetland *et al*., 2002; Amerah *et al*., 2007). Unfortunately, little information is available on the feeding value of mesquite fruit and its possible use as a feedstuff in various types of diet (mash and pellet). Hence, this study was conducted to investigate the effect of pellet and mash diets supplemented with different levels of mesquite fruit on performance, energy and protein efficiency ratio, carcass characteristics, and morphology of the small intestine in broilers.

Materials and Methods

Sampling and plant preparation

All procedures were endorsed by the Institutional Animal Care and Use Committee of Animal Science Research Institute, I.R of Iran (Karaj). At first, the fruits of several different mesquite trees were collected in Khuzestan province. After that, samples were dried under shade at room temperature for 72 h and then powdered. These powders were mixed and the main sample was obtained from them.

Broilers and experimental design

The experiment was done using 560 one-day-old (mixed sex) Ross 308 in a completely randomized design with 7 treatments, 4 replicates, and 20 chicks per replicate. The control diet (mash form without mesquite fruit), and pelleted and mash diets, each containing 3, 6, and 9% levels of mesquite were adjusted. Before adjusting the experimental diets, the chemical composition of mesquite fruit was determined according to AOAC (2005) and the concentration of non-starch polysaccharides in mesquite fruit was analyzed based on Kalantar and Yaghobfar (2016). The total amount of phenolic and tannin compounds was determined according to Makkar (2003). The energy content of the samples (4 replicates) was also determined by the methods described in Yaghobfar and Boldaji (2002). All diets were fed in the mash and pellet forms and a 3-phase feeding program was employed with a starter (1- 10 d), grower (11- 24 d), and finisher (25- 42 d) phases. The composition of experimental diets was presented in Table 1. The rearing management of birds was done according to the standards prescribed in Ross 308 guidelines (Aviagen, 2014).

Growth performance

Productive performance traits including FI, BWG, and FCR were periodically determined by recording daily mortality in chickens.

Carcass characteristics

To specify the carcass characteristics, two birds per replicate were randomly selected and sacrificed at 42 d of age. Weighting was performed using digital scales with an accuracy of one gram for whole carcass and 0.01 gram for carcass components. At first, empty body weight (without skin) was recorded to determine carcass yield, and then weights of different parts of the carcass including thigh, breast, heart, spleen, liver, gallbladder, whole intestine as well as abdominal fat pad were measured to determine the relative weight of these organs. Finally, these values were expressed as a percentage of live body weight.

Table 1. Ingredients and nutrient compositions of experimental diets in different periods (%DM).

Ingredients (% diet)	Starter (d 0 -10)				Grower (d 11 - 24)				Finisher (d 25 - 42)			
Ingredients (% diet)	Control	3% mesquite	6% mesquite	9% mesquite	Control	3% mesquite	6% mesquite	9% mesquite	Control	3% mesquite	6% mesquite	9% mesquite
Corn	57.29	54	54	54	57.38	58	55	55	62.50	64	63	60
Soybean meal (44%)	37	38.86	35.92	33	35.92	35	35	32	30.50	29	27	27
Soybean oil	2	1	1	1	3.40	1	1	1	4	1	1	1
Mesquite fruit	0	3	6	9	0	3	6	9	0	3	6	9
Oyster shell	0.8	0.50	0.50	0.5	0.7	0.5	0.51	0.56	0.65	0.53	0.50	0.50
Dicalcium phosphate	1.71	1	1	1	1.50	1	0.98	1	1.30	0.98	1	0.96
Common salt	0.22	0.30	0.30	0.28	0.20	0.20	0.31	0.31	0.20	0. 35	0.35	0.30
DL-methionine	0.27	0.50	0.48	0.42	0.20	0.48	0.40	0.33	0.20	0.30	0.32	0.42
L-lysine HCL	0.21	0.34	0.30	0.30	0.20	0.32	0.30	0.30	0.15	0.50	0.33	0.32
Mineral and vitamin premix[†]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.34	0.50	0.50
Calculated analyses												
Metabolizable energy (kcal/kg)	3000	2980	2980	3000	3100	2990	3000	2980	3190	3000	2980	3000
Crude protein (%)	22.03	23.21	22.96	22.32	21.50	21.55	21.48	21.51	19.45	19.44	19.28	19.31
Methionine (%)	0.58	0.86	0.85	0.87	0.50	0.84	0.86	0.83	0.48	0.82	0.81	0.80
Methionine+ Cystine (%)	0.9	1.21	1.10	1.20	0.81	1.17	1.16	1.15	0.77	1.11	1.10	1.08
Lysine (%)	1.28	1.48	1.46	1.50	1.25	1.39	1.36	1.33	1.08	1.24	1.21	1.20
Threonine (%)	0.74	0.88	0.9	2.01	0.72	0.86	0.84	0.83	0.64	0.78	0.76	0.74
Calcium (%)	0.96	0.62	0.62	0.58	0.86	0.58	0.58	0.58	0.76	0.57	0.56	0.54
Available phosphorous (%)	0.45	0.38	0.38	0.36	0.41	0.36	0.37	0.36	0.37	0.35	0.35	0.35
Sodium (%)	0.19	0.15	0.15	0.14	0.18	0.14	0.14	0.14	0.16	0.14	0.14	0.14

[†]Mineral and vitamin premix provided per kilogram of diets: 99.2 mg manganese, 85 mg zinc, 50 mg iron, 10 mg copper, 0.2 mg selenium, 13 mg iodine, 44,000 IU vitamin A, 7,200 IU vitamin D3, 440 IU vitamin E, 40 mg vitamin K, 70 mg cobalamine, 65 mg thiamine, 320 mg riboflavin, 290 mg Pantothenic acid, 1220 mg niacin, 65 mg pyridoxine, 22 mg biotin and 270 mg of choline chloride.

Energy and protein efficiency ratio

At the end of each rearing period, required values for energy and protein efficiency indices were calculated according to the following formulas (Kamran *et al*., 2008):

Protein consumed (g)= feed consumed in each period (g) × feed protein in each period.

Energy consumed per period (kcal)= feed consumed in each period × diet energy in each period.

Energy efficiency= weight gain (g) / total metabolizable energy consumed.

Protein efficiency= weight gain (g) / protein consumed (g).

Intestinal morphology

For intestinal morphology measurements, two birds per pen were sacrificed by cervical dislocation at the end of the experiment. Then 2 cm tissue segments from the jejunum (taken from between the bile duct and Meckel's diverticulum), were obtained and fixed in 10% buffered formalin for 24 h, and after that formalin was renewed. samples were dehydrated by transmitting via a series of alcohols with an enhancement of concentrations, located into xylol, and embedded in paraffin. Eventually, a microtome was applied to make 6 cuts that were stained with hematoxylin-eosin. The depth of crypts was taken from the valley between individual villus to the basolateral membrane and villus height was calculated from the tip of the villi to the valley between individual villus. The values of the villus height, crypt depth, and villus width were measured 5 times from different villus and crypts per slide (Yaghobfar *et al*., 2006). Achieved data was applied to calculate the villus height per crypt depth ratio.

Statistical Analysis

The experimental design was completely randomized, and all data were analyzed by ANOVA using the GLM procedures of SAS statistical software (SAS, 2004). Treatments were compared using Duncan's test, and the differences were separated at the statistical level of $P < 0.05$.

Results and Discussion

Nutritional value

The proximate analysis of mesquite fruit (DM basis) and concentration of non-starch polysaccharides are shown in Tables 2 and 3, respectively. This sample was also contained a high percentage of non-fibrous carbohydrates (NFC) (42.28%), non-starch polysaccharides (NSP) (31.4%), hemicellulose (12.6%), cellulose (20.4%), and a high percentage of dietary fiber (37.6%). Also, the amount of tannin in this sample was 6.39 mg/g. Results fall within the range of mesquite fruit values previously reported by some researchers (Askari, 2005; Alemzadeh *et al*., 2015; Dashtban *et al*., 2016).

Table 2. Chemical composition (%), gross energy and metabolizable energy (kcal/kg), and tannin (mg/g) of mesquite fruit (% DM)

Nutrient	Dry matter	Crude protein	Crude fiber	Ether extract	Gross energy	Metabolizable energy	Tannin	NDF[1]	ADF[2]	ADL[3]
Amount	76.79	12.37	25.2	2.35	4183	3515	6.39	39.2	26.6	6.2

[1]NDF: neutral detergent fiber; [2]ADF: acid detergent fiber; [3]ADL: acid detergent lignin.

Table 3. The concentration of non-starch polysaccharides of mesquite fruit (%DM)

Nutrient	Cellulose[1]	Hemi-cellulose[2]	Total carbohydrate[3]	NSP[4]	NFC[5]	Dietary fiber[6]
Amount	76.79	12.37	2.35	4183	3515	6.39

[1]Cellulose:ADF-ADL; [2]Hemi-cellulose: NDF-ADF; [3]Total carbohydrate: [100-(CP+EE+Ash+Moisture)]; [4]NSP; ADL+ Crud fiber; [5]NFC: [100-(CP+EE+Ash+NDF)]; [6]Dietary fiber: ADL+Total NSP.

Growth performance

As shown in Table 4, there was a significant difference in regards to FI between the experimental treatments (mash and pellet diets containing different levels of mesquite) at various stages of rearing ($P<0.05$). The highest daily feed consumption in the starter phase was observed in the chicks fed the pelleted diet containing 6% mesquite fruit, which was not significantly different from the birds fed the control and mash diets containing 3% mesquite fruit. But there was a significant difference between pellet diets containing 3 and 9% mesquite and also mash diets containing 6 and 9% mesquite fruit ($P < 0.05$). Also, in the grower phase, chickens fed the pelleted diet containing 3% level of mesquite had the lowest FI, which was significantly different from other experimental groups ($P < 0.05$). Birds fed the pelleted diet containing 9% level mesquite had the highest daily FI in the finisher phase, which was not significantly different from the birds receiving a pelleted diet containing 3% level mesquite. Also, the lowest FI in the finisher phase was observed in the birds fed the diets containing 6 and 9% levels of mesquite ($P < 0.05$).

As depicted in Table 4, there was a significant difference between the experimental treatments regarding the daily weight gain ($P < 0.05$). In the starter phase, the highest daily gain was related to the birds fed the pellet diet containing 9% level mesquite, which was not significantly different from those receiving pelleted and mash forms of the diet containing 6% level mesquite fruit, At this phase, the

lowest BWG belonged to the control group ($P < 0.05$). Also, during the grower phase, chickens fed pelleted diets containing 3, 6, and 9% levels mesquite fruit and those fed mash diet containing 3% level mesquite fruit had the highest daily BWG, which showed a significant difference with other experimental treatments ($P < 0.05$). Birds fed the pelleted diet containing 9% level mesquite had the highest daily gain in the finisher phase, which was not significantly different from those fed pellet diets containing 3 and 6% levels mesquite ($P < 0.05$).

At the starter phase, birds fed pelleted and mash diets containing 3, 6, and 9% levels mesquite showed a significant difference in FCR compared to control birds (Table 4). The lowest FCR in the starter phase was related to the chicks maintained on mash diets containing 6% level mesquite fruit as well as pelleted diets containing 9% level of mesquite fruit. The highest value was observed in the control chicks ($P < 0.05$). Also, in the grower phase, the lowest FCR belonged to the birds fed the pelleted diets containing 3% level mesquite fruit, which was significantly different from other groups ($P < 0.05$). There were no statistically significant differences between experimental treatments in the finisher phase. Although the results exhibited that pelleted diets containing 3, 6, and 9% levels of mesquite fruit produced lower FCR compared to mash diets with the same levels of mesquite fruit.

It was reported that supplementation of mesquite fruit powder significantly affected FI and BWG, somewhat FI and BWG of broiler chickens receiving 5% mesquite powder were significantly decreased compared to the control group (Dashtban *et al*., 2016), which did not match with our results. In the mentioned experiment, FCR was also significantly increased in the treatment with 5% mesquite powder. Some researchers attribute the negative effects of using this plant in animal nutrition to factors such as the presence of trypsin inhibitor, large amounts of the tannins, and other phenolic compounds found in the pods which suppressed the appetite of the animals to the diet (Ruiz-Nieto *et al*., 2020). In another study, the effect of replacing corn with *Prosopis juliflora* pod at levels (0, 10, 20, and 30%) on broiler performance was investigated.

The results of this study revealed that the appropriate replacement rate was 20% so that at 28 days of age, the 20% replacement level significantly increased BWG and improved FCR compared to the control group (Chaudhary *et al*., 2005). In another project, replacing mesquite up to 10% in laying hens diet had no negative effect on performance. However, at higher levels, it reduced egg weight, and egg production and also increased FCR (Norouzi *et al*., 2013). Silva *et al*. (2002) used levels of 0, 5, 10, 15, 20, 25, and 30% of mesquite pod in pelleted and mash diets in laying hens. They reported that 30% of the mesquite pod compared to the control group reduced egg weight and egg mass and also increased FCR. In another experiment, the researchers found that broilers that fed pelleted diets had 25% more weight, 15% more FI, and 10% higher FCR when compared to chickens fed mash diets. It seems the obtained results for weight gain is due to increased Nitrogen storage and metabolizable energy of pelleted diets compared to mash form, as feed pellets increase Nitrogen storage and metabolizable energy content (Hussar and Robblee, 1962). Pellet-fed birds had higher BWG and higher FI than those fed mash diets, while pellets improved FCR at the finisher and whole rearing periods (Hooshmandi *et al*., 2017). Pelleting diets increases live body weight and feed efficiency compared to mash feed. This performance improvement is due to increased FI. Ebrahimi *et al*. (2010) reported that birds using pelleted diets consumed less energy to eat, and thus the available energy for growth was increased. Feeding chickens with pelleted diets have been reported to reduce incremental heat production, increase energy intake for production purposes, and ultimately improve BWG (Bennett *et al*., 2002; Latshaw and Moritz, 2009; Abdollahi *et al*., 2011). These findings were in good agreement with the results of our experiment.

Energy and protein efficiency ratio

According to Table 5, during the starter and grower periods, the indexes of energy and protein efficiency ratio were statistically influenced by the experimental diets (pellet and mash diets containing different levels of mesquite) ($P < 0.05$). In the starter period, the lowest energy and protein efficiency ratio belonged to the control group and the highest values related to chicks fed either mash diet containing 6% level mesquite and pelleted diets containing 9% level mesquite fruit ($P < 0.05$). Also, during the grower phase, the chicks fed pellet diets containing 3% level mesquite had the highest energy and protein efficiency ratios, which were significantly different from other groups ($P < 0.05$). There was no statistical difference between experimental treatments in the finisher period. The results also exhibited that pelleted diets containing 3, 6, and 9% levels mesquite fruit had higher energy and protein efficiency ratios compared to mash form of diets with the same levels of mesquite and also control group (Table 5). In another experiment, supplementation of mesquite powder in the diet significantly reduced the energy and protein efficiency ratio in 29-42 days compared to the control birds (Dashtban *et al*., 2016), which did not match the results of the present study. There is an opinion that high levels of tannin in the fruit of the mesquite (including anti-nutritional compounds) decrease the digestibility of the protein (De Oliveira Moraes *et al*., 2016). Tannins have a high affinity for binding to proteins, thereby affecting hydrogen, hydrophobic, and covalent bonds, possibly reducing energy consumption and specific amino acids (Ozdal *et al*., 2013).

Table 4. Effect of pellet and mash diets supplemented with different levels of mesquite fruit on growth performance of broiler chickens

Treatment	Starter (1-10 d)			Grower (11–24 d)			Finisher (25–42 d)		
	BWG (g/b/d)	FI (g/b/d)	FCR (g/g)	BWG (g/b/d)	FI (g/b/d)	FCR (g/g)	BWG (g/b/d)	FI (g/b/d)	FCR (g/g)
Control	23.80^{d}	29.00^{abc}	1.22^{a}	47.01^{b}	81.17^{a}	1.33^{a}	59.71^{bc}	170.95^{bc}	1.83
Pellet-3P	29.13^{bc}	28.77^{bc}	0.99^{c}	48.20^{a}	62.54^{b}	1.01^{b}	61.58^{ab}	174.57^{ab}	1.67
Mash-3P	29.00^{bc}	29.61^{ab}	1.02^{b}	48.39^{a}	86.21^{a}	1.29^{a}	57.23^{bc}	167.83^{c}	1.88
Pellet-6P	29.75^{ab}	30.12^{a}	1.01^{bc}	48.34^{a}	87.54^{a}	1.32^{a}	61.72^{ab}	172.18^{bc}	1.79
Mash-6P	29.25^{abc}	27.75^{c}	0.95^{d}	46.94^{b}	84.64^{a}	1.30^{a}	56.90^{c}	160.14^{d}	1.82
Pellet-9P	30.33^{a}	28.38^{bc}	0.94^{d}	48.83^{a}	94.36^{a}	1.37^{a}	64.71^{a}	179.07^{a}	1.78
Mash-9P	28.25^{c}	28.37^{bc}	1.00^{bc}	44.85^{c}	85.71^{a}	1.38^{a}	55.30^{c}	160.76^{d}	1.89
SEM	0.34	0.40	0.01	0.23	4.61	0.05	1.40	1.83	0.05
P-value	<0.0001	0.014	<0.0001	<0.0001	0.008	0.005	0.004	<0.0001	0.083

Control (mash form without mesquite), Pellet-3P: Pellet diet contains 3% mesquite, Mash-3P: Mash diet contains 3% mesquite, Pellet-6P: Pellet diet contains 6% mesquite, Mash-6P: Mash diet contains 6% mesquite, Pellet-9P: Pellet diet contains 9% mesquite, Mash-0P: Mash diet contains 9% mesquite.

[a-d] Means within the same column with different superscripts differ significantly ($P < 0.05$).

SEM: standard error of the means.

Table 5. Effect of pellet and mash diets supplemented with different levels of mesquite fruit on energy and protein efficiency ratio

Treatment	Energy efficiency ratio (g/kcal)			Protein efficiency ratio (g/g)		
	1-10	11-24	25-42	1-10	11-24	25-42
Control	27.54^{d}	18.09^{b}	11.72	3.57^{d}	2.34^{b}	1.52
Pellet-3P	34.00^{b}	28.05^{a}	11.84	4.40^{b}	3.64^{a}	1.53
Mash-3P	32.86^{c}	18.83^{b}	11.44	4.26^{c}	2.44^{b}	1.48
Pellet-6P	33.14^{c}	18.53^{b}	12.03	4.29^{bc}	2.40^{b}	1.56
Mash-6P	35.38^{a}	18.61^{b}	11.92	4.58^{a}	2.41^{b}	1.54
Pellet-9P	35.87^{a}	17.37^{b}	12.13	4.65^{a}	2.25^{b}	1.57
Mash-9P	33.42^{bc}	17.56^{b}	11.54	4.33^{bc}	2.28^{b}	1.49
SEM	0.27	2.17	0.23	0.03	0.28	0.03
P-value	<0.0001	0.041	0.38	<0.0001	0.041	0.39

Control (mash form without mesquite), Pellet-3P: Pellet diet contains 3% mesquite, Mash-3P: Mash diet contains 3% mesquite, Pellet-6P: Pellet diet contains 6% mesquite, Mash-6P: Mash diet contains 6% mesquite, Pellet-9P: Pellet diet contains 9% mesquite, Mash-0P: Mash diet contains 9% mesquite.

[a–c] Means with no common superscript within each column are significantly different ($P < 0.05$).

SEM: standard error of the means.

Carcass characteristics

Based on the results shown in Table 6, carcass yield and the relative weight of some internal organs were not statistically affected by the experimental treatments. However, there was a significant difference between the experimental groups in terms of the relative weight of the breast and intestinal weight ($P < 0.05$). Dashtban *et al*. (2016) reported that supplementation of mesquite powder did not affect carcass yield and the relative weight of internal organs, but the relative weight of the breast in the control birds was significantly different from the other groups, which was in line with the results of the present study. Mabray and Waldroup (1981) and Leenstra and Cahaner (1991) also reported that type of diet (pelleted and mash) did not affect the abdominal fat pad, which was consistent with the results of our survey. Hooshmandi *et al*. (2017) declared that feeding birds with pelleted ration significantly increased the relative weight of the breast and abdominal fat and decreased the relative weight of the liver and gallbladder. Furthermore, Amerah *et al*. (2007) reported that the relative weight of the intestine in the birds which fed a pelleted diet containing wheat grain was lower than those receiving a mash diet. This indicates a general response of the digestive and absorptive capacity of the gastrointestinal tract to nutrients absorbed by the pelleted diets.

In other words, in the present experiment, the viscosity created by the presence of non-starch polysaccharides as well as anti-nutritional compounds such as tannins, especially in mash form of diets, increased the thickness of the intestinal mucous layers and, as a barrier, reduced the contact between digestive enzymes and substrates. This, in turn, increases intestinal enzyme activity and significantly changes intestinal function and ultimately increases the relative weight of the whole intestine.

Intestinal morphology

As shown in Table 7, the morphological characteristics of the intestine (villus height and width, crypt depth, and villus height to crypt depth ratio) were not influenced by the experimental treatments. The use of pelleted diets compared to mash diets increased villus height, villus height to crypt depth ratio, and decreased crypt depth (Hooshmandi *et al*., 2018), which was not in line with the results of the present study. Feeding birds with pelleted diets containing wheat grain has been stated to increase villus height and decrease crypt depth compared to mash diets. This indicates a general response of the digestive and absorptive capacity of the gastrointestinal tract to nutrient absorption by the pelleted feed (Amerah *et al*., 2007).

In accommodate our findings, Rezaian *et al*. (2007) reported that birds fed pelleted diets showed a significant decrease in villus width and crypt depth compared to birds fed mash diets, but villus height and villus height to crypt depth ratio were not affected by treatments. The researchers also stated that with increasing mash form of the diet, the height of villus in the jejunum and ileum was increased (Choi *et al*., 1986; Nir *et al*., 1994), which was following the results of the present experiment. As well as, Parsons *et al*. (2006) demonstrated that feed form had no significant effect on intestinal morphology. Lack of significant effect of feed form on intestinal morphology indices may be related to the non-significant effect of feed on intestinal villus height. Feed form has a major impact on bird performance, intestinal health, and digestion process, which can be affected by changes in digestive coefficient, intestinal pH, and excessive retention in the upper part of the gastrointestinal tract (Hetland *et al*., 2002; Amerah *et al*., 2007).

Table 6. Effect of pellet and mash diets supplemented with different levels of mesquite fruit on carcass traits and the relative weight of some internal organs of the broiler chickens (% of live body weight)

Treatments	Carcass yield	Spleen	Gallbladder	Heart	Whole intestine	Abdominal fat	Liver	Back	Thighs	Breast
Control	36.73	0.11	0.07	0.51	5.35^{ab}	1.20	2.09	22.87	18.43	24.20^{abc}
Pellet-3P	39.78	0.09	0.11	0.49	5.66^{ab}	1.58	2.49	21.91	18.42	26.69^{a}
Mash-3P	35.73	0.11	0.11	0.54	7.08^{a}	1.76	2.29	20.00	21.22	22.36^{bc}
Pellet-6P	38.54	0.10	0.15	0.58	5.17^{ab}	1.43	2.33	19.11	20.01	25.70^{ab}
Mash-6P	35.65	0.11	0.19	0.65	3.99^{b}	0.56	2.48	20.72	17.70	21.15^{c}
Pellet-9P	37.26	0.16	0.14	0.55	5.33^{ab}	0.64	3.23	21.48	20.84	23.79^{abc}
Mash-9P	36.65	0.12	0.12	0.56	7.23^{a}	0.64	2.76	21.5	17.97	22.94^{bc}
SEM	1.47	0.02	0.03	0.07	0.63	0.31	0.37	1.32	1.10	1.08
P-value	0.44	0.41	0.14	0.76	0.03	0.07	0.46	0.52	0.19	0.04

Control (mash form without mesquite), Pellet-3P: Pellet diet contains 3% mesquite, Mash-3P: Mash diet contains 3% mesquite, Pellet-6P: Pellet diet contains 6% mesquite, Mash-6P: Mash diet contains 6% mesquite, Pellet-9P: Pellet diet contains 9% mesquite, Mash-0P: Mash diet contains 9% mesquite.

[a–c] Means with no common superscript within each column are significantly different ($P < 0.05$).

SEM: standard error of the means.

Table 7. Effect of pellet and mash diets supplemented with different levels of mesquite fruit on jejunal morphology characteristics at 42 d of age

Treatment	Morphology parameters (μm)			
	Villus height	Villus width	Crypt depth	Crypt depth/ villus height
Control	1403.00	180.33	116.67	12.24
Pellet-3P	1455.30	217.00	109.00	13.30
Mash-3P	1477.00	159.67	108.00	13.71
Pellet-6P	1138.70	179.33	118.00	9.57
Mash-6P	1163.00	172.67	108.00	10.86
Pellet-9P	1330.30	187.67	113.67	11.67
Mash-9P	1477.70	189.33	122.33	12.09
SEM	0.18	15.23	5.42	1.57
P-value	0.69	0.30	0.42	0.58

[1]Control (mash form without mesquite), Pellet-3P: Pellet diet contains 3% mesquite, Mash-3P: Mash diet contains 3% mesquite, Pellet-6P: Pellet diet contains 6% mesquite, Mash-6P: Mash diet contains 6% mesquite, Pellet-9P: Pellet diet contains 9% mesquite, Mash-0P: Mash diet contains 9% mesquite.
SEM: standard error of the means.

Conclusion

The results of the present survey revealed that broilers fed pelleted diets containing 9% mesquite fruit, especially at the grower and finisher periods, had the highest daily FI and BWG. Also, in the finisher period, birds fed diets containing pelleted mesquite fruit had higher energy and protein efficiency ratio compared to birds receiving mash feed. On the other hand, the experimental treatments caused a significant difference in the relative weight of the breast as well as the total weight of the intestine but did not affect the carcass yield and the relative weight of the other carcass components. The results also, demonstrated that the pelleted and mash feeds containing different levels of mesquite did not show a significant difference in morphological traits of the intestine. Eventually, the consumption of pelleted diets containing mesquite in birds improved the performance, which may point to the positive effect of feed processing (pelleting) on reducing the harmful effects of anti-nutritional compounds such as tannins and non-starch polysaccharides in mesquite fruit.

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