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Evaluation of Inferior Quality Pellets on the Growth Performance, Carcass Parameters, and Digestive Organs of Broiler Chickens

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ABSTRACT

Feed form can affect broiler performance. However, it has not been conclusively demonstrated whether the improved growth performance is due to processing (conditioning or pelleting), the physical form of the feed, or a combination of these factors. This study was conducted to investigate the effects of feed form on the growth performance, carcass and cut yields, small intestinal segment lengths, and weights and ratios of several visceral organs in broiler chickens. A total of 450 14-day-old male Ross 308 broilers were weighed and randomly allocated to five treatments, each with nine replicates, using a randomized complete block design. Experimental groups were as follows: 1, mash; 2, conditioned mash; 3, pellet (inferior quality, characterized by low physical integrity; pellet durability index = 51%); 4, the same pellet feed offered at a level equal to the daily mash feed intake of treatment 1; and 5, ground pellet feed. Broilers were fed the same diet formula from 14 to 40 days of age. The results revealed that pellet feed increased feed intake and body weight gain, as well as improved the feed conversion ratio ($p \leq 0.05$). Broilers fed pellet feed at a level equal to the mash feed intake had the highest carcass yield ($p \leq 0.05$). The highest relative weight of the gizzard was observed in broilers fed mash feed ($p \leq 0.05$). The relative lengths of small intestinal segments were reduced in broilers fed pellet feed ($p \leq 0.05$). Based on these results, it can be concluded that the superior performance of pellet feed is mainly attributable to the increased feed intake associated with the pellet form, rather than to modifications induced by thermal processing.

***Keywords:** broiler; digestive organs; feed form; growth performance; pellet quality*

INTRODUCTION

Poultry feed is available in several forms, including mash and pellets. The pellet form is obtained by compressing mashed feed particles under heat, moisture, and pressure. Pellet feed has several advantages over mash, including reduced feed waste, pathogen sterilization, prevention of ingredient segregation, selective feeding, and improved feed handling (Attar *et al.*, 2019). Furthermore, increased feed intake, higher live weight gain, and improved overall feed utilization have led to the widespread adoption of pelleted diets (Abdollahi *et al.*, 2018). This improvement in broiler performance is believed to be related to the increased starch and protein digestibility owing to hydrothermal processing, which facilitates starch gelatinization and partial protein denaturation (Oliveira *et al.*, 2022). However, some reports have indicated that frictional heat and mechanical shear generated in the die hole are responsible for substantial gelatinization, rather than conditioning (Boroojeni *et al.*, 2016; Iravani *et al.*, 2024).

Several studies have suggested that improvements in broiler performance are attributable more to the physical form of the diet than to chemical changes occurring during feed processing, thereby emphasizing a significant relationship between pellet physical integrity and performance (Svihus *et al.*, 2025). The benefits of using intact pellets on broiler performance stem from a reduction in the time required for feed consumption, leading to greater feed intake and longer resting times (Iravani *et al.*, 2024). However, no consensus has been reached regarding the optimal pellet durability index (PDI) for broiler nutrition, as Svihus *et al.* (2025) suggested that broilers can tolerate a higher proportion of fines than what is currently suggested by industry recommendations (Aviagen, 2025). This questions the necessity of producing good-quality pellets (>92% PDI) (Vallejo-Sartorius *et al.*, 2019) instead of normal (65%–87% PDI) and even inferior quality (<65% PDI) (You *et al.*, 2025).

As multiple factors contribute to the increased broiler performance, previous research has not conclusively demonstrated whether improved growth performance is owing to processing (conditioning or pelleting), the physical form of the feed, or a combination of these factors. Furthermore, previous studies have reported no significant differences

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in overall body weight gain and feed conversion ratio (FCR) (Lemons *et al.*, 2019) or carcass yield (Massuquetto *et al*., 2020) across varying pellet qualities. However, others continue to attribute the advantages of pellet form and high pellet quality to growth performance and economics in broiler production, thereby warranting further investigation. Therefore, in this study, pellet quality was reduced to address this issue. Additionally, unlike previous studies, we included five different feed forms: mash, conditioned mash, intact pellets, pellets offered at a level equal to the mash feed intake, and ground pellet feed adjusted to the mean particle size of the mash. This design enables a thorough evaluation of the effects of processing, feed form, and other relevant factors. Herein, we aimed to evaluate the effects of different feed forms on growth performance, carcass and cut yields, and digestive organs in broilers fed maize–soybean-based diets.; thereby contributing to the optimization of broiler feeding strategies.

MATERIALS AND METHODS

All the experimental procedures were approved by the Ankara University Animal Experiments Local Ethics Committee (approval number: 2021-15-134).

Birds, Housing, Experimental Design, and Diets

A total of 450 one-day-old male Ross 308 broilers were fed on a crumble starter diet (mean particle size: 975 µm) based on maize–soybean meal for 14 days. On day 14, birds were weighed and randomly allocated to five treatments, each with nine replicates: 1) mash; 2) conditioned mash; 3) pellet (inferior quality, characterized by low physical integrity; PDI = 51%); 4) the same pellet feed offered at a level equal to the daily mash feed intake in treatment 1; and 5) ground pellet, across a total of 45 broiler chicken battery cages (each 90 cm × 85 cm) with a stocking density of 13 birds per square meter, equipped with plastic wire mesh, nipple drinkers, and feeders in a randomized complete block design.

The dietary feeds were prepared from a common experimental maize–soybean diet (Table 1), formulated according to the recommendations for Ross 308 broilers (Aviagen, 2019), and administered from 14 to 40 days of age. After grinding in a hammer mill (6-mm screen) and mixing in a horizontal ribbon mixer for 210 s, a portion of the mash feed (treatment 1) was removed from the mixer outlet. At the same feed mill, an experimental pellet feed of intentionally inferior quality (target PDI: 40–65%) was produced based on prior experience with pellet quality, diet type, and conditioning and pelleting parameters. The rest of the mash feed was conditioned for 90 s with steam at 4.2 atm and 110 °C (feed temperature at the outlet of the conditioner was 67 °C). Subsequently, a portion of the conditioned mash feed was collected from the conditioner outlet (treatment 2). Subsequently, the conditioned feed was placed on a clean floor and cooled to room temperature using high-capacity ventilation fans. For pellet-feed treatments (pellets 4.0 mm in diameter and 10 mm in length), the conditioned feed was passed through a pellet die with 4.0 mm holes, with a feed temperature at the pellet-die outlet of 81 °C and then cooled to 20 °C in a vertical cooler. For the ground pellet treatment, a portion of the cooled pellet feed was ground using a mill. The ground pellets and mash feed from each 50-kg bag were sieved and compared. Based on the sieve analysis results, the grinding settings were adjusted to ensure that the mean particle size matched that of the mash feed.

Table 1. Ingredients and composition of the experimental diet (14-40 days) (as-fed basis, g/kg, unless otherwise stated)

Ingredients	Composition
Maize	510.17
Soybean meal	289.47
Wheat	80.00
Full-fat soybean	50.00
Meat and bone meal	20.27
Red dog	10.89
Soybean oil	10.00
Sepiolite	5.00
Limestone	11.56
Sodium bicarbonate	1.50
Sodium chloride	1.46
Choline chloride (60%)	0.34
Vitamin premix[a]	1.00
Mineral premix[b]	1.00
Liquid MHA[c] (88%)	3.46
L-Lysine sulphate (62.4%)	2.83
L-Threonine	0.70
Carbohydrase and protease multienzyme[c]	0.25
Phytase[d]	0.10
Total	1000.00
Calculated values	
Crude protein	198.0[e]
Metabolisable energy (MJ/kg)	13.1
Ether extract	67.9[e]
Crude fibre	27.2[e]
Crude ash	60.7[e]
Calcium	10.0
Available phosphorus	4.4
Dietary electrolyte balance, mEq/kg	257
SID[f] Met	6.0
SID Met+Cys	9.2
SID Lys	11.6
SID Thr	8.0
SID Val	9.2

Note: [a] Supplied per kg of diet: 10000 U vitamin A, 4500 U vitamin D3, 65 mg vitamin E, 2.8 mg vitamin B1, 6.5 mg vitamin B2, 3.2 mg vitamin B6, 0.017 mg vitamin B12, 3.5 mg vitamin K3, 18 mg pantothenic acid, 55 mg niacin, 0.18 mg biotin,1.9 mg folic acid. [b] Supplied per kg of diet: 80 mg manganese (Mn oxide); 70 mg iron (Fe sulphate monohydrate); 80 mg zinc (Zn oxide); 14 mg copper (Cu sulphate pentahydrate); 1 mg iodine (Ca iodate); 0.15 mg selenium (Na selenite); 35 mg magnesium (Mg oxide); 0.70 mg molybdenum (Na molybdate). [c] Methionine hydroxy analog. [d] Avizyme® 1505X, 250g/ton, supplied per kg of diet : 2300 U xylanase, 400 U amylase and 4000 U protease. [d] Axtra® PHY 10000 TPT, 100g/ton, supplied per kg of diet, 1000 FTU phytase. [e] Analysed values. [f] standardized ileal digestible

Feed (except in treatment 4) and water were provided *ad libitum* during the trial. Daily feed allocation for treatment 4 was calculated based on the daily mash feed intake in treatment 1. Treatment 4 pellet feed allowance for the following day was calculated based on the mash feed intake of the previous day, while adjusting for the estimated daily increase in intake and a safety margin. The calculated amounts were weighed and offered daily at the same time. During the experiment, all birds were exposed to the photoperiods of 23, 22, and 20 h with fluorescent illumination (30 lx for the first 7 days, decreased to 20 lx) at 7, 14, and 40 days of age, respectively. The temperature of the poultry house was set at 33 °C for the first 3 days, then gradually decreased to approximately 23 °C by the end of the third week and was maintained until the end of the study using automated heating, cooling, and ventilation systems.

Analysis of Feeds

Proximate analysis (AOAC, 2005) was performed on a common experimental diet, and bulk density (ASAE, 2016) was assessed for each feed form. The PDI (Thomas & van der Poel, 1996) was determined using a Holmen NHP100 pellet durability device. Sieve analysis was performed on each bag of mash, conditioned mash, and ground pellet diets (ASAE, 1995), and the geometric mean diameter of each feed was calculated. The bulk density and analysis results are presented in Table 2, and the particle size and distribution of the different treatments are presented in Table 3.

Table 2. Bulk density and pellet durability index (PDI) of experimental feeds produced with different processing methods

Feeds	Bulk density[a] (kg/m³)	PDI[b] (%)
Mash	681±2.0	-
Conditioned mash	687±2.0	-
Pellet	683±4.5	51±0.5
Ground pellet	671±3.3	-

Note: [a]Each value represents the mean of 5 replicate samples. [b]Pellet durability index was assessed with 13 replicates using Holmen NHP100 (TekPro Ltd, Norfolk, UK) pneumatic pellet tester set at 60 mbar forced air with 30 s run time.

Growth Performance

At the beginning of the experiment (day 14), broiler live weight and the amount of feed provided were measured, and on days 28 and 40, live weight, remaining feed, and the amount of feed provided for the following period were measured and recorded. Following the start of experimental feeding (day 14), body weight gains (BWGs) for the periods of 14–28, 28–40, and 14–40 days of age were calculated as the differences between the body weight measurements for each period. The feed intake was calculated by subtracting the remaining feed from the amount of feed provided for the respective periods. The mortality rate was recorded daily. The FCRs for the experimental feeding periods of 14–28, 28–40, and 14–40 days of age were calculated from feed intake and BWG, including the weights of dead birds. As the BWGs differed significantly, the adjusted FCR (AdjFCR) was calculated according to the BWG for each treatment using the equation as follows: $AdjFCR = FCR - [(BWGtr - BWGav)/100] \times 0.03$, where BWGtr is the BWG for each treatment, and BWGav is the average BWG across all treatments (Dersjant-Li *et al.*, 2013).

Carcass and Cut Yields, Digestive Organ Weights, and Small Intestine Parts Lengths

At the end of the experiment (day 40), two birds per cage, selected to approximate the mean broiler weights of the respective cages, were euthanized by transection of the jugular vein and defeathered using a rotary picker after bleeding ceased. The carcass, thigh, drumstick, breast (meat with bone in and skin on), abdominal fat, liver (without the gallbladder), and pancreas of each bird were weighed. The contents of the proventriculus and gizzard were removed, and the empty organs were weighed. The small intestine was divided into three standard segments, i.e., duodenum, jejunum, and ileum, and their lengths were measured. Relative

Table 3. Particle size and distribution of experimental feeds produced with different processing methods

Sieve size[a] (mm)	Particle size distribution[b] (%)		
	Mash	Conditioned mash	Ground pellet
3200	1.2±0.23	0.6±0.12	0.0±0.00
2360	4.6±0.34	4.3±0.31	0.1±0.01
1700	9.8±0.51	9.7±0.49	2.3±0.49
1180	13.8±0.47	13.8±0.92	14.0±1.17
850	20.8±0.28	20.0±0.71	28.2±0.68
600	16.7±0.32	16.3±0.80	22.4±1.06
300	14.4±0.58	14.3±0.42	17.4±0.27
150	16.6±1.13	19.0±0.83	14.7±0.53
90	1.9±0.48	2.0±0.32	0.9±0.18
0	0.2±0.04	0.0±0.00	0.0±0.00
	Mean particle size[b] (µm)		
	667.0	669.8	667.5

Note: [a]Sieve size: coarse >850 µm, medium 600-850 µm, and fine <600 µm (Córdova-Noboa *et al.*, 2020). [b]Each value represents the mean of 7 replicate samples.

weights of the carcass, abdominal fat, liver (without the gallbladder), pancreas, proventriculus, and gizzard were calculated as percentages of live body weight. Relative weights of the thigh, drumstick, and breast meat, with the bone in and skin on, were calculated as percentages of carcass weight. The relative lengths of the small intestinal segments were calculated for each bird as centimeters per 100 g of its body weight.

Statistical Analyses

All data obtained were analyzed using the analysis of variance with the general linear model procedure in Minitab (version 16) under a randomized complete block design. Each cage was considered the experimental unit, with nine replicate cages per treatment. When a statistical difference (p≤0.05) was detected among the studied parameters, the means were compared using Tukey's honest significant difference test. Mortality results were analyzed using Fisher's exact test because of the extremely low mortality rate.

RESULTS

Growth Performance

At the beginning of the experiment (day 14), the birds were weighed to confirm that the mean group body weights were similar (mean 432 g, p = 0.888), indicating that the experiment began under comparable initial body weight conditions.

The mean values of feed intake, BWG, FCR, and AdjFCR for the treatments during 14–28, 28–40, and 14–40 days of age are presented in Table 4. The highest feed intake in treatment 3 (pellet) was statistically significant for all analyzed periods of the experiment (p≤0.05). The highest BWGs (p≤0.05) of 1,042, 1,390, and 2,432 g were observed in treatment 3 at 14–28, 28–40, and 14–40 days of age, respectively. The lowest AdjFCRs (p≤0.05) of 1.292, 1.469, and 1.353 were observed in treatment 3 at 14–28, 28–40, and 14–40 days of age, respectively. FCRs showed a similar pattern to those of AdjFCRs. Two chickens died in treatment 3 (2.2% mortality); however, the mortality results were not significant (Fisher's exact test, p = 0.497).

Relative Weights of Carcass and Cuts, Abdominal Fat, Liver, and Pancreas

The relative weights of the carcass, thigh, drumstick, breast, abdominal fat, liver, and pancreas are listed in Table 5. A statistically significant difference in carcass yield was observed between the treatments (p<0.001). The highest carcass yield was obtained in treatment 4 (76.4%), whereas the other treatments exhibited similar yields. Thigh yield in treatment 3 was significantly higher (p≤0.05) than in treatment 1. Treatment 4 resulted in a significant increase (p≤0.05) in the relative weights of abdominal fat and liver tissues compared with those in treatment 1.

Relative Weights of Proventriculus and Gizzard, and Relative Lengths of Small Intestine Parts

The relative weights of the proventriculus and gizzard and the relative lengths of the duodenum, jejunum, ileum, and whole small intestine are presented in Table 6. The relative gizzard weight in treatment 1 was similar to that in treatment 2 (p>0.05) but significantly higher than in the other treatments (p≤0.05). The relative duodenum length was significantly higher in treatment 4 than in treatments 1 and 3 (p≤0.05). In treatment 3, the relative lengths of the jejunum and total small intestine were similar to those in treatment 5 (ground pellet) (p>0.05) and lower than those in the other treatments (p≤0.05).

Table 4. Growth performance of male broiler chickens fed different feed forms and subjected to different feeding programs

Variables	Different feed forms					p value
	Mash	Conditioned mash	Pellet	Pellet, allocated [1]	Ground pellet	
BW (14d)	431±12.3	431±11.8	432±12.6	432±12.0	432±12.6	0.888
BW (28d)	1323±38.7^{bc}	1317±41.2^{c}	1474±44.0^{a}	1374±45.8^{b}	1338±31.9^{bc}	< 0.001
BW (40d)	2543±59.8^{b}	2496±56.8^{b}	2864±67.1^{a}	2572±64.7^{b}	2532±64.9^{b}	< 0.001
BWG[2] (14-28 d)	892±27.0^{bc}	886±30.5^{c}	1042±32.5^{a}	942±35.2^{b}	906±21.1^{bc}	< 0.001
BWG (28-40 d)	1220±24.8^{b}	1179±21.8^{b}	1390±30.3^{a}	1198±22.3^{b}	1193±34.6^{b}	< 0.001
BWG (14-40 d)	2111±48.3^{b}	2064±46.7^{b}	2432±55.2^{a}	2140±54.2^{b}	2100±53.9^{b}	< 0.001
FI[3] (14-28 d)	1274±38.7^{bc}	1288±39.8^{bc}	1381±48.9^{a}	1306±38.2^{b}	1233±31.1^{c}	< 0.001
FI (28-40 d)	1913±39.9^{b}	1895±42.4^{b}	2107±58.9^{a}	1901±41.9^{b}	1835±48.2^{b}	< 0.001
FI (14-40 d)	3187±76.6^{bc}	3182±78.5^{bc}	3488±106^{a}	3207±77.1^{b}	3068±77.9^{c}	< 0.001
FCR[4] (14-28 d)	1.429±0.0063^{ab}	1.456±0.0164^{a}	1.324±0.0135^{d}	1.390±0.0192^{bc}	1.360±0.0115^{cd}	< 0.001
AdjFCR[5] (14-28 d)	1.441±0.0104^{ab}	1.470±0.0221^{a}	1.292±0.0139^{d}	1.387±0.0279^{bc}	1.369±0.0127^{c}	< 0.001
FCR (28-40 d)	1.568±0.0096^{abc}	1.607±0.0202^{a}	1.515±0.0166^{c}	1.587±0.0135^{ab}	1.539±0.0145^{bc}	< 0.001
AdjFCR (28-40 d)	1.573±0.0126^{ab}	1.624±0.0212^{a}	1.469±0.0154^{c}	1.598±0.0136^{ab}	1.552±0.0215^{b}	< 0.001
FCR (14-40 d)	1.509±0.0062^{ab}	1.541±0.0088^{a}	1.432±0.0116^{c}	1.498±0.0087^{b}	1.460±0.0080^{c}	< 0.001
AdjFCR (14-40 d)	1.526±0.0146^{b}	1.572±0.0146^{a}	1.353±0.0070^{d}	1.506±0.0212^{bc}	1.481±0.0188^{c}	< 0.001

Note: [1]Pellet feed offered at a level equal to the daily mash feed intake of treatment 1, [2]BWG: Body weight gain (g), [3]FI: Feed intake (g), [4]FCR: feed conversion ratio, [5]AdjFCR: Body weight gain and mortality weight corrected feed conversion ratio, $AdjFCR = FCR – [(BWG_{tr} – BWG_{av})/100] \times 0.03$, BWG_{tr}: body weight gain for each treatment, BWG_{av}: average body weight gain across all treatments (Dersjant-Li *et al*. 2013). [a-d] Means in a column not sharing a common superscript are significantly different at p≤0.05.

Table 5. Relative weights (weight/body weight, %) of carcass, abdominal fat, liver, pancreas, and yields of carcass parts (weight/carcass weight, %) in male broiler chickens (40 d) fed different feed forms and subjected to different feeding programs

Variables	Different feed forms					p value
	Mash	Conditioned mash	Pellet	Pellet, allocated [1]	Ground pellet	
Carcass	73.8±0.50[b]	73.1±0.65[b]	72.8±0.34[b]	76.4±0.40[a]	72.9±0.58[b]	< 0.001
Thigh	26.5±0.35[b]	27.5±0.34[ab]	28.4±0.26[a]	27.5±0.33[ab]	27.4±0.24[ab]	0.001
Drumstick	13.6±0.21	14.0±0.17	13.6±0.26	14.0±0.20	14.0±0.21	0.405
Breast	35.1±0.44	34.4±0.46	33.9±0.46	34.0±0.38	34.5±0.41	0.25
Abdominal fat	0.82±0.110[b]	1.01±0.073[ab]	1.04±0.060[ab]	1.28±0.061[a]	1.01±0.086[ab]	0.004
Liver	1.92±0.052[b]	2.05±0.075[ab]	2.14±0.065[ab]	2.29±0.058[a]	2.02±0.050[b]	0.001
Pancreas	0.237±0.0096	0.232±0.0094	0.228±0.0097	0.254±0.0132	0.226±0.0105	0.254

Note: [1]Pellet feed offered at a level equal to the daily mash feed intake of treatment 1. [a-c] Means in a column not sharing a common superscript are significantly different at p≤0.05.

Table 6. Relative weights (weight/body weight, %) of proventriculus, gizzard, and relative length (cm/100 g body weight) of small intestine in male broiler chickens (40 d) fed different feed forms and subjected to different feeding programs

Variables	Different feed forms					p value
	Mash	Conditioned mash	Pellet	Pellet, allocated [1]	Ground pellet	
Proventriculus	0.398±0.0126	0.418±0.0182	0.448±0.0165	0.448±0.0185	0.461±0.0202	0.069
Gizzard	1.45±0.042[a]	1.43±0.043[ab]	1.22±0.043[c]	1.29±0.037[bc]	1.22±0.033[c]	< 0.001
Duodenum	1.12±0.026[b]	1.22±0.035[ab]	1.13±0.028[b]	1.26±0.036[a]	1.19±0.029[ab]	0.002
Jejunum	3.22±0.068[a]	3.16±0.107[a]	2.90±0.061[b]	3.27±0.083[a]	3.11±0.079[ab]	0.003
Ileum	3.26±0.105	3.29±0.094	3.03±0.065	3.32±0.095	3.27±0.081	0.054
Small intestine	7.61±0.179[a]	7.67±0.191[a]	7.06±0.126[b]	7.86±0.182[a]	7.57±0.152[ab]	0.002

Note: [1]Pellet feed offered at a level equal to the daily mash feed intake of treatment 1. [a-c] Means in a column not sharing a common superscript are significantly different at p≤0.05.

DISCUSSION

The PDI in the present study was 51%, which is considered indicative of inferior quality based on the <65% threshold proposed by You *et al.* (2025). The ground pellets had a mean particle size and particle size distribution similar to those of the mash feed, thereby demonstrating that the objective of pellet grinding was achieved. The absence of statistically significant differences in feed intake between treatments 1 (mash) and 4 (pellet feed offered at a level equal to the mash feed intake) across all periods confirmed that the intended feed allocation for treatment 4 was largely achieved.

Growth Performance

Nourmohammadi *et al*. (2018) evaluated the effects of the mash and pellet forms of wheat–soybean meal-based diets on broiler chickens and reported that the treatments involving pellet diets increased BWG and decreased FCR compared with those in treatments involving mash diets. The results of the present study are consistent with those previously reported in the literature and further demonstrate that feed intake, BWG, and AdjFCR improved in broilers fed pellet diets, even those with inferior quality (51% PDI). The increase in feed intake was likely owing to the difference in feed form, as evidenced by the findings of this study. Although the feed was produced using the same process, feeding the pellets in ground form resulted in lower feed intake than when using the unground pellet diet. Furthermore, similar feed intakes from ground pellet, mash, and conditioned mash feeds indicate that the physical form of the feed is the primary determinant of feed intake behavior.

Rueda *et al*. (2024) attributed improvements in BWG and FCR to increased nutrient digestibility owing to the pellet feed production process. However, some studies have reported that nutrient digestibility does not improve or diminishes with pellet diets (Abdollahi *et al*., 2011, 2013). Some studies have suggested that feed form is the determining factor. For instance, according to Sellers *et al*. (2017), FCR and BWG are adversely affected when ground pellet percentage is increased from 20% to 50%. Similarly, Lemons and Moritz (2016) reported that increasing the fine-to-pellet ratio from 30% to 60% has adverse effects on BWG and FCR. In the present study, the increased AdjFCR and reduced BWG in the group fed ground pellet feed compared with those in the group fed pellet feed confirmed the effects of the pellet form on these parameters. Pellet feed facilitates feeding, reduces feeding time, increases resting time, and reduces the energy required for feeding activity (Iravani *et al*., 2024). In the present study, the BWG and feed intake of birds fed with ground pellet feed were similar to those of birds fed with mash and conditioned mash feeds, confirming the effects of changes in the pellet form.

The only significant difference observed among the ground pellet, mash, and conditioned mash treatments was in AdjFCR. These differences may be attributed to variations in particle size distribution between treatments. Although the average particle size of the ground pellet feed was similar to the mash feed, the mash and conditioned mash feeds had approximately 15% of the particles on and above the 1,700 μm sieve size, whereas the ground pellet feed had only approximately 2% (Table 3). Particles on 300, 600, and 850 μm sieves made up approximately 51% of the mash and conditioned mash feeds, whereas this ratio was 68% for the ground pellet feed. A more homogeneous particle size distribution in ground pellet feed may have led to more effective enzymatic digestion (Abdollahi *et al*., 2013). Additionally, the potential reduced feed scattering, resulting from selection caused by homogeneous grinding, contributed to the observed differences in AdjFCR. Massuquetto *et al*. (2019) reported that birds fed pellet feed at the same intake level as those consuming mash feed have BWG and FCR comparable to those in birds fed mash feed but lower than those in birds fed with pellets. This result was also observed in the present study, indicating that the advantage of pellets over mash in terms of growth performance is mainly owing to differences in feed intake. Increased activities, such as standing and scavenging (Dixon *et al*., 2022), and elevated plasma corticosterone levels (Yan *et al*., 2021) resulting from restricted feeding may explain why the AdjFCR of birds fed pellets despite having an intake similar to that of birds fed mash was inferior to that of the latter. No specific cause was identified for the deterioration in AdjFCR in birds fed conditioned mash feed at 14–40 days of age compared with that in birds fed unconditioned mash feed; however, it may be related to the conditioning process. According to Boroojeni *et al*. (2016) and Iravani *et al*. (2024), viscosity may have increased owing to conditioning, and this increase may have had a more detrimental effect on the FCR due to non-pelleted feed.

Relative Weights of Carcass and Cuts, Abdominal Fat, Liver, and Pancreas

Massuquetto *et al*. (2020) reported that broilers consuming mash and pellet feeds had similar carcass yields. Lemons and Moritz (2016) reported that broilers fed pellet feed at different fine ratios (30% and 60%) had similar breast yields. The results of the present study on carcass and carcass part yields are consistent with those reported in previous studies. Notably, birds fed pellet feed at a level equal to the mash feed intake had a higher carcass yield than did birds in the other treatments, likely attributable to feed allocation, rather than the feed form. Bordin *et al.* (2021) suggested that restricted feeding increased amino acid absorption and proteolytic enzyme activity. A key pathway for enterocyte amino acid assimilation is mediated by the peptide transporter 1 (PepT1) (Mahdavi *et al*., 2018). Duarte *et al*. (2011) reported that restricted feeding results in a significant increase in *PepT1* mRNA expression in the jejunum of broilers. Aminopeptidase (APN) is an enzyme found in enterocyte brush membranes that plays a crucial role in peptide digestion. According to Duarte *et al*. (2011), restricted feeding increases *APN* mRNA expression levels in the jejunal mucosa by approximately 156%. Similarly, a literature review by Ebeid *et al*. (2022) suggests that feed restriction increases the expression of genes encoding intestinal amino acids and peptide transporters. Evaluation of the aforementioned results indicated that increased carcass yield resulted from improved amino acid utilization under restricted feeding. The pellet diet resulted in a higher thigh yield than that of the mash diet, as reported by Mabelebele *et al*. (2018); however, the exact mechanism behind this observation remains unclear.

Lv *et al*. (2015) reported no significant differences in the abdominal fat ratio between crumble and mash feeds. Similarly, Hamungalu *et al*. (2020) reported that feed form does not affect the relative weight of abdominal fat. The results of the present study are largely consistent with those reported in previous literature; however, they differ in several key aspects. Broilers fed the pellet feed at an intake level equal to that of the mash feed had a higher relative abdominal fat weight than did broilers fed the mash feed. The increased abdominal fat weight associated with pellet feeding has been attributed to increased feed and nutrient intake, resulting in excess energy being stored as abdominal fat (Massuquetto *et al*., 2020). However, this suggestion remains insufficient to explain the observed results, as the intake of the pellet diet was similar to that of the mash diet within the respective treatments. Therefore, the effect of the allocated feeding may underlie this response. Broilers fed mash had continuous access to feed throughout the day; however, when pellet allocation was scheduled based on mash consumption, the feeder remained empty for a certain period, and the broilers were unable to consume feed until the next allocation. This may affect the metabolism and promote the accumulation of abdominal fat. Evidence suggests that blood glucose levels peak immediately after feeding under a restricted feeding regimen, then decrease, and subsequently return to their previous levels (Dixon *et al.*, 2022). Additionally, restricted feeding has been shown to increase lipogenic gene expression (Lunedo *et al*., 2019), supporting this suggestion. The liver findings obtained in this study were consistent with those of abdominal fat. As fatty acids are synthesized in poultry livers (Zaefarian et al., 2019), and liver glycogen reserves are mobilized, especially during starvation (Cai *et al*., 2021). During which the liver must function intensively, which may explain the liver enlargement observed in the present study. No significant effect of feed form on the relative pancreas weight was observed in the present study, consistent with previous studies (Hosseini & Afshar, 2017a; Mahdavi *et al*., 2018).

Relative Weights of Proventriculus and Gizzard, and Relative Small Intestine Parts Lengths

Research on feed form in broiler chickens has generally concluded that feed form affects gizzard weight more than proventriculus weight. Rueda *et al.* (2024) reported no significant differences in proventriculus weight between broilers fed mash or pellet feeds. However, they reported that the gizzard weight-to-live-weight ratio is higher in broilers fed mash diets than in those fed pellet diets. The relative weights of the gizzard have been reported to be 1.13% in birds fed pellet feed and 1.57% in those fed mash feed in a study by Abadi *et al.* (2019). The results of the present study are consistent with those of previous studies, as no significant differences in proventriculus weight were observed between treatments; however, relative gizzard weight was affected by the diet form. Broilers fed the mash diet had a gizzard ratio similar to that of broilers fed the conditioned mash diet but higher than that of broilers fed the pellet diet, pellet feed at a level equal to the mash feed intake, or ground pellet diets. The reduction in the proportion of coarse particles (>2.0 mm) from 1.69% to 0.85% and the increase in the proportion of fine particles (<0.075 mm) from 18.53% to 21.67% are largely attributable to the pelleting process (Abdollahi *et al*., 2014). Similarly, Abdollahi *et al*. (2011) reported that pelleting conditioned mash feed results in a decrease in the proportion of coarse particles (>2.0 mm) and an increase in the proportion of small particles (<0.075 mm). According to previous studies, the reduction in particle size is a result of the narrow distance between the pellet rolls and die, as well as the frictional force generated in the pellet die. This reduction in particle size leads to a decrease in grinding activity in the gizzard and limits its development in broilers fed a pellet diet, as observed in the present study.

There is no consensus regarding the effects of feed form on the length and weight of the small intestine in broilers. Abadi *et al*. (2019) observed no differences between pellet and mash forms in terms of the relative weight of the small intestine. Abdollahi *et al.* (2014), who reported no significant effects of feed form on small intestine weight, reported that the proportional small intestine length of broilers fed pellet feed is approximately 8% shorter than that of those fed mash feed. The proportional small intestine length of these broilers is similar to that of broilers fed ground pellet feed. Naderinejad *et al*. (2016) reported that birds fed pellet feed exhibit an approximately 15% reduction in the relative length of the small intestine compared with that in birds fed mash feed. These results are consistent with those of the present study. In our study, the ratio of small intestine length to live weight was similar to that of the ground pellet, but lower than that of the mash, conditioned mash, and pellet feed when the pellet feed was offered at a level equal to the mash feed intake in broilers consuming pellet feed. These results suggest that physical form is a stronger determinant of the proportional length of the small intestine than conditioning. Data from Abdollahi *et al*. (2011), who investigated the effects of conditioned mash and pellet diets, support this argument. The proportional length of the small intestine of broilers consuming a mash diet conditioned at 75 °C has been reported to increase by approximately 13% compared with that in broilers fed a pellet feed in the respective study. However, it cannot be concluded that pellet diets adversely affect small intestine development and morphology. Rasool *et al.* (2025) reported that a higher villus height-to-crypt depth ratio was obtained with pellet diets than with mash diets. Hosseini and Afshar (2017b) concluded that birds fed pellet and crumble feeds exhibit improved villus height-to-crypt depth ratio in the jejunum compared with those fed mash feed. Therefore, the reduction in the relative length of the small intestine can be attributed mainly to the effect of the pellet form in increasing feed intake and live weight, which becomes more evident when the results of the studies by Abdollahi *et al*. (2013) and Mahdavi *et al*. (2018) are evaluated together. Mahdavi *et al*. (2018) reported that crumble feed decreased the relative length of the small intestine compared to mash feed, and broilers consuming crumble feed were heavier than those consuming mash feed. However, unlike the results of Mahdavi *et al*. (2018), the live weights of broilers fed ground pellets are lower than those of broilers fed mash feed (Abdollahi *et al*., 2013).

CONCLUSION

Pellet feed, even when characterized by inferior quality, improved growth performance. However, when pellet feed was provided at the same intake level as that of mash feed, the differences in BWG or AdjFCR between birds fed pellet or mash feed disappeared. Based on these results, we conclude that the beneficial effects of pellet feed are primarily attributable to the effects of the pellet form on feed intake, rather than to hydrothermal processing. Further research is needed to determine the feed form and pellet quality required for efficient broiler production.

CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding any financial, personal, or other relationships with individuals or organizations related to the material discussed in the manuscript.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

No generative AI or AI-assisted technology was used during the writing process.

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