Effects of feed form and xylanase supplementation on performance and ileal nutrients digestibility of heat-stressed broilers fed wheat–soybean diet

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ABSTRACT

The objective of this experiment was to evaluate the effects of xylanase and feed form on the performance, ileal nutrient digestibility, the gastrointestinal tract measurements, jejunal viscosity, and intestinal morphology of heat-challenged broilers fed wheat-based diets. The experiment was conducted as a $3 \times 2$ factorial arrangement with three feed forms (mash, crumbles, and pellets) and two levels of xylanase (without or with 300 mg/kg). Broilers fed mash had lower average daily feed intake, average daily gain (ADG), carcass weight, carcass yield, abdominal fat percentage, ileal digestibility values of apparent metabolizable energy corrected to zero nitrogen retention (AMEn) and crude protein (CP), villus length, and villus length: crypt depth ratio in the jejunum segment than broilers fed crumbles or pellets. The digestive tract development and crypt depth in the jejunum were lower ($P < .001$) for broilers fed crumbles or pellets than for broilers fed mash. Xylanase significantly increased ADG and ileal digestibility of AMEn, CP, and Ca, but decreased the viscosity of digesta in the jejunum segment. It was concluded that feeding crumbled and pelleted diets may offer a suitable nutritional strategy to improved productive performance in broilers reared under high ambient temperatures.

1. Introduction

Feedstuffs represent approximately 70% of the total production cost and the choice of poultry feeds is, therefore, of extreme economic importance. Poultry feed manufacturers are searching for ways to optimize feed utilization and production efficiency. Because the cost of feed is a substantial portion of producing meat, even small improvements in feed efficiency can increase economic returns. Different types of feed form (mash, crumbles, and pellets) have been involved in broiler production (Abdollahi et al. 2011). A crumble is a type of feed prepared at the mill by pelleting the mixed ingredients and then crushing the pellet to a consistency coarser than mash. This form of feed is very convenient to use and has led to its increased popularity among broiler producers (Cerrate et al. 2009). Pelleting is a common practice used to maximize growth performance and to reduce feed wastage and energy used during feed consumption (Lv et al. 2015). However, pellets or crumbles cost slightly more than the same ration in mash form (Naderinejad et al. 2016). Under commercial conditions, broilers are frequently fed crumbles during the starter phase (1–21 d of age) and then fed pellets to slaughter. However, few studies have been performed to compare performance of heat-challenged broilers fed mash, crumbles, or pellets in the starter period (Xu et al. 2015).

Heat stress (HS) is a critical problem in poultry production systems and has a negative effect on health of bird (Quinteiro-Filho et al. 2010). High ambient temperatures not only cause heavy economic losses to the poultry industry by reducing feed consumption and increasing mortality rate, but also produce inferior meat quality (Chiang et al. 2008). It has been well documented that exposing broilers to continuously high ambient temperatures, especially during the finisher phase, leads to chronic HS and may decrease productive performance (Hosseini et al. 2015). To the best of our knowledge, no information is available concerning the potential effects of diet form and xylanase enzyme in heat-challenged broilers fed wheat-based diets.

There are no studies reported which simultaneously compare feed form and xylanase enzyme in heat-challenged broilers. The main objectives of this study were to evaluate the effects of diet processing methods on broiler performance, ileal nutrient digestibility, digestive tract development, and intestinal morphometry indices as well as possible interactions between diet form and enzyme supplementation.

2. Materials and methods

2.1. Birds and diets

A total of 240 1-d-old (Ross 308) male broiler chicks were randomly assigned to 6 dietary treatments with 5 replicates and 8 chicks per replicate. The experiment was designed according to a $3 \times 2$ factorial arrangement of treatments, and the main factors consisted of feed form (mash, crumbles, and pellets) and xylanase enzyme (0 and 300 mg/kg). There was no
difference in initial BW (43.2 ± 0.2 g) among the treatment groups. The experimental period was divided into grower (1–21 d) and finisher phases (22–42 d). A wheat–soybean meal-based diet was formulated for each phase to meet all nutrient recommendations published in the Ross rearing guideline (NRC 1994; Table 1). In the experiment period, birds were subjected to cyclic HS by exposing them to 33°C for 10 h, from 0700 to 1700 h, and 22°C from 1700 to 0700 h. The lighting programme was 23L:1D during the entire period. Air humidity was kept at 70% throughout the experimental period. The birds were reared in pens (90 × 120 × 70 cm, length × width × height) and given ad libitum access to feed and water. The animal care protocol in this experiment was approved by the Animal Ethics Committee of the University of Birjand, Birjand, Iran.

2.2. Growth performance

Considering pen as the experimental unit, body weight (BW) and feed intake (FI) were recorded weekly. The data were used to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed to gain ratio (FCR) for 1–21 d, 22–42 d, and 1–42 d periods of age. The European Broiler Index (EBI) based on the following equation was also calculated (Euribrid1994):

\[
\text{EBI} = \left( \frac{\text{viability, } \% \times \text{live weight, kg}}{\text{age of slaughter, days } \times \text{FCR, } g/g} \right) \times 100
\]

The mortality rate was recorded up on occurrence.

2.3. Sample collection

At 42 d of age, two birds/replicate were randomly selected and euthanized using sodium thiopental. After evisceration, the carcasses were individually weighed (CW) and the data were expressed as a percentage of live weight (carcass yield; CY). The weight of abdominal fat (AF) also was expressed proportional to carcass weight, and then AF-to-CW ratio was calculated.

The digestive organs of birds were excised, and jejunal digesta samples were collected for viscosity measurement. Jejunal digesta was pooled to obtain a homogeneous mixture, which was then centrifuged at 2150 × g at 4°C for 15 min. The supernatant (0.5 mL) was analysed for viscosity (Waititu et al. 2014). The viscosity of the supernatant was measured with a digital viscometer (Model DV-III, Brookfield Engineering Laboratories Inc., Middleboro, MA). The results of the viscosity measurement are presented in centipoises (cPs). The proventriculus, gizzard, and intestine were cleaned with physiological saline solution, dried with filter paper, and then weighed. Organ relative weight was calculated relative to the total body weight (g/100 g BW). Relative length of duodenum, jejunum, and ileum was also measured (cm/100 g BW).

Fragments of approximately 3 cm in length were obtained from the middle of the duodenum (from the pylorus to the distal portion of the duodenal loop), jejunum (from the distal portion of the duodenal loop to Meckel’s diverticulum), and ileum (from Meckel’s diverticulum to ileocecal junction). These samples were washed with cold PBS and kept in 10% neutral-buffered formalin at 4°C for fixation until the morphometric analysis.

2.4. Apparent ileal digestibility

At day 30 of age, titanium oxide (1 g/kg of diet) was added to all diets for five days as an indigestible marker to determine the effects of feed form and xylanase supplementation on ileal digestibility of CP, Ca, and P. At day 35 of age, 3 birds per replicate (15 chicks per treatment) were randomly selected, weighed, killed, and manually processed to collect the contents of the ileum segment. The ileal samples were placed into plastic containers and freeze-dried. Before the chemical analysis, the samples were ground to pass through a 0.5 mm sieve.

2.5. Chemical analysis

Feed and digesta P concentrations were determined colorimetrically using the molybdo-vanadate method (method 946.06, AOAC International 2000). Concentration of Ca in feed and digesta is determined by Flame Atomic Absorption Spectroscopy (method 968.08, AOAC 2000). The crude protein (CP) content (N × 6.25) in the diet and digesta samples was determined based on the Kjeldahl method (Schneitz et al. 1998). Titanium oxide concentration in digesta and diets was determined according to the procedure described by Lomer et al. (2000) and read on a Varian Inductively Coupled Plasma Mass Spectrometer (Varian Inc., Palo Alto, CA). The apparent ileal digestibility (AID) of nutrient was calculated using the following formula:

\[
\text{AID} = 100 \times \left( \frac{\text{Diet component/Ti}_d}{\text{Diet component/Ti}} - ight)
\]

Where \(\text{Diet component/Ti}_d\) and \(\text{Diet component/Ti}\) are the molar ratios of diet component to titanium in the diet and digesta, respectively.
where \((\text{Diet component}/\text{Ti})_d\) is the ratio of diet component to Ti in the diet, and \((\text{Diet component}/\text{Ti})_i\) is the ratio of diet component to Ti in the ileal digesta.

Gross energy (GE) was determined by using an adiabatic bomb calorimeter (Gallenkamp Autobomb, Loughborough, UK) and was standardized with benzoic acid. The apparent metabolizable energy corrected to zero nitrogen retention (AMEn) values was calculated by subtracting GE excreted (adjusted to zero N balance) from GE intake and dividing this value by DM feed intake. For correction to zero N retention, a value of 36.52 kJ g⁻¹ of nitrogen retained was used (Hill and Anderson 1958). The AME values were calculated following the formula:

\[
\text{AME (MJ/kg)} = \frac{(\text{Feed intake} \times \text{GE}_{\text{diet}}) - (\text{Excreta output} \times \text{GE}_{\text{excreta}})}{\text{Feed intake}}.
\]

2.6. Statistical analysis

In this experiment, pen was considered as the experimental unit and data were analysed as a completely randomized design with 3 × 2 factorial treatment arrangements using the general linear model procedures of SAS (SAS Inst. Inc., Cary, NC). The model included the main effects of feed form, xylanase, and their associated interaction. Level of significance was set at 5% and when a significant effect was indicated, treatment means were separated using Tukey–Kramer’s test.

3. Results

No interactions between feed form and xylanase enzyme were detected for any of the traits studied, and therefore, only main effects are presented. Data on the effects of feed form and xylanase enzyme on growth performance are presented in Table 2.

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For the grower period (1–21 d of age), ADG was higher \((P < .005)\) for broilers fed pellets than for broilers fed crumbles, whereas ADFI was higher for those fed pellets than for broilers fed crumbles, and both were higher than broilers fed mash \((P < .006)\). Also, the FCR was better \((P = .021)\) for chicks fed mash than for broilers fed crumbles, with broilers fed pellets being intermediate. Xylanase supplementation significantly increased ADFI for the grower phase \((P = .041)\). In the finisher phase (from 22 to 42 d of life), ADG and ADFI were higher \((P < .001)\) for chicks fed pellets than for broilers fed crumbles, and both were higher than for broilers fed mash. In this period, the FCR was improved in broilers fed crumbles than those fed pellets \((P = .037)\). For the entire experimental period (1–42 d of age), broilers fed pellets had higher \((P < .01)\) ADG and ADFI than broilers fed crumbles, and both were higher than broilers fed mash, but the FCR was not affected. In addition, ADG of broilers was increased by inclusion of xylanase enzyme for grower and finisher periods \((P < .05)\). The calculated EBI was greater (Figure 1) for the birds fed the crumbled or pelleted diets compared with the mash diet. Moreover, the addition of xylanase increased the EBI \((P < .05)\).

The carcass weight (CW) was higher for broilers fed pelleted diet than for broilers fed crumbled and both were higher than broilers fed mash \((P = .006)\). Carcass yield was higher for chicks fed pellets than for broilers fed mash, with broilers fed crumbles being intermediate \((P = .011)\). In addition, abdominal fat-to-carcass weight ratio (AF:CW) was greater for broilers fed either the crumbled or pelleted diets \((P = .003)\).

The effects of feed form and xylanase supplementation on ileal nutrient digestibility of heat-challenged broilers are summarized in Table 4. Ileal digestibility values of AMEn and CP were higher for broilers when crumbled or pelleted diets were fed \((P < .05)\). Addition of xylanase supplementation to diet significantly increased \((P < .05)\) the ileal digestibility of CP and Ca, and AME of feed.

The relative weight of the gizzard \((P < .001)\) and relative length of the duodenum \((P = .002)\), jejunum \((P = .004)\), and ileum \((P = .002)\) were higher for broilers fed mash than for broilers fed crumbled diet and both were higher than broilers fed pelleted diet (Table 5). The relative intestine weight was lighter for broilers fed pellets than for broilers fed mash or crumbled diets \((P = .002)\). Xylanase decreased the viscosity of jejunal digesta by 1.03 units compared with values in the non-supplemented group \((P = .025)\).

The effects of diet form and xylanase on intestinal morphometry of heat-stressed broilers are shown in Table 6. Villus length (VL) was longer \((P = .021)\), crypt depth (CD) was lower \((P = .017)\), and VL:CD ratio was higher \((P = .022)\) for broilers fed either the crumbled or pelleted diets than those fed the mash diet in the jejunal segment.

4. Discussion

There were no significant interaction effects between feed form and xylanase supplementation \((P > .05)\). Therefore, only the main effects of xylanase supplementation and feed form are discussed.

The effects of feeding crumbles or pellets on performance of broilers have been studied by several researchers (Cerrate et al.
2009; Serrano et al. 2013). The results of the present study are in agreement with data reported by Svhhus et al. (2004) and Abdollahi et al. (2011) who indicated that pelleting improves ADFI and ADG of broilers. The present experiment was conducted on floor pens and feed wastage was not recorded but was assumed to be consumed by the broilers. Visual observation of the floor around the feeders during the experimental period confirmed the lower feed wastage of birds in pens of birds fed crumbles or pellets than in pens fed mash. In addition, pelleting disrupts the physical structure of the ingredients and reduces energy requirements for maintenance, and therefore more energy should be available for growth with pellet than with mash feeds (Naderinejad et al. 2016). In this regard, Latshaw and Mortiz (2009) found that broilers fed pellets spent more time resting and less time eating than broilers fed mash. The birds fed pellets or crumbles eat more feed with less physical activity than those fed mash diet (Lopez and Lesson 2008). Consequently, the broilers fed pellets had higher energy available for production (Latshaw and Mortiz 2009). The higher feed consumption of broilers fed the crumbled or pelleted diets is partly related to their increased palatability. On the other hand, the results of this study indicated that xylanase increased ADG and ADFI of broilers. Arabinoxylans, the major component of soluble non-starch polysaccharides (NSP) in wheat-based diets, increase the digestibility of digesta viscosity of birds. Xylanase supplementation can hydrolyze arabinoxylans and, therefore, releases the enclosed nutrients (Chocht and Annison 1992), resulting in increased nutrients digestion and absorption and consequently increasing broiler growth performance. In heat-challenged birds, more

Table 2. Effects of feed form and xylanase enzyme on average daily gain (ADG), average daily feed intake (ADFI), and feed conversion ratio (FCR) of heat-stressed broilers fed wheat-based diet (n = 5).

| Treatments | ADG (g/d) | ADFI (g/d) | FCR (g/g) |
|------------|-----------|------------|-----------|
|            | 0–21 d    | 22–42 d    | 0–42 d    | 0–21 d    | 22–42 d    | 0–42 d    | 0–21 d    | 22–42 d    | 0–42 d    |
| Mash       | 25.3b     | 59.1h      | 42.2c     | 38.4c     | 114.2b     | 76.3c     | 1.52b     | 2.00a      | 1.85      |
| Mash + xylanase | 27.4b     | 58.7b      | 43.1h     | 40.2b     | 116.4b     | 78.3c     | 1.46b     | 1.96b      | 1.82      |
| Crumble    | 29.5b     | 61.1b      | 45.3b     | 43.2b     | 119.7b     | 81.4b     | 1.47b     | 1.96b      | 1.80      |
| Crumble + xylanase | 28.3ab    | 62.7a      | 45.5b     | 45.8b     | 121.5b     | 83.7b     | 1.62b     | 1.94b      | 1.84      |
| Pellets    | 31.4a     | 62.3a      | 46.8ab    | 48.7a     | 127.6a     | 88.4a     | 1.56b     | 2.05a      | 1.88      |
| Pellets + xylanase | 33.6a     | 64.5a      | 49.1ab    | 49.3a     | 129.5a     | 89.4a     | 1.47b     | 2.01a      | 1.82      |
| SEM        | 0.14      | 0.18       | 0.19      | 0.44      | 1.26       | 0.57      | 0.013     | 0.024      | 0.023     |

Note: Mean values within a column with different letters differ significantly (P < .05).

Table 3. Effects of feed form and xylanase enzyme on carcass weight (CW), carcass yield (CY), and abdominal fat-to-carcass weight ratio (AF:CW) of heat-stressed broilers fed wheat-based diet (n = 5).

| Treatments | CW (g) | CY (%) | AF:CW |
|------------|--------|--------|-------|
|            |        |        |       |
| Mash       | 1096   | 62.30  | 1.64  |
| Mash + xylanase | 1176   | 63.95  | 1.69  |
| Crumble    | 1279   | 66.22  | 2.23  |
| Crumble + xylanase | 1290   | 66.53  | 2.28  |
| Pellets    | 1357   | 68.05  | 2.32  |
| Pellets + xylanase | 1423   | 68.08  | 2.36  |
| SEM        | 14.5   | 2.72   | 0.06  |

Note: Mean values within a column with different letters differ significantly (P < .05).

Table 4. Effects of feed form and xylanase enzyme on ileal digestibility of apparent metabolizable energy corrected to zero nitrogen retention (AMEn), crude protein (CP), Ca, and phosphorus (P) of heat-stressed broilers fed wheat-based diet (n = 5).

| Treatments | AMEn (MJ/kg) | CP (%) | Ca (%) | P (%) |
|------------|--------------|--------|--------|-------|
|            |              |        |        |       |
| Mash       | 11.37        | 80.4b  | 58.1b  | 38.5  |
| Mash + xylanase | 11.61a    | 82.0b  | 58.4a  | 39.4  |
| Crumble    | 11.47        | 80.5b  | 58.4ab | 38.0  |
| Crumble + xylanase | 11.69a   | 84.5a  | 59.3a  | 39.2  |
| Pellets    | 11.42        | 81.8ab | 58.2b  | 37.8  |
| Pellets + xylanase | 11.66a   | 84.4a  | 58.8a  | 39.2  |
| SEM        | 0.08         | 0.14   | 0.38   | 0.32  |

Note: Mean values within a column with different letters differ significantly (P < .05).
energy is expended to adapt to the stressful conditions, therefore less energy was used for growth, leading to the poorer performance. On the other hand, deteriorated performance of broilers exposed to HS can be associated to a poor appetite and lower feed consumption. In this study, crumbled or pelleted diets could compensate for the weight loss due to high ambient temperature.

The authors have not found any research studying the effects of feed form and xylanase on abdominal fat percentage of broilers subjected to HS. Naderinejad et al. (2016) indicated that increasing abdominal fat percentage in birds fed pellet diets was due to the increasing available energy for broilers. The extra energy is deposited as abdominal fat in birds (Lopez and Leeson 2008). In this respect, it has been well demonstrated that the abdominal fat in broiler chickens exposed to high ambient temperatures also was increased (Hosseini et al. 2015). Hence, crumbles and pellets amplified the negative effects of high ambient temperature in this research.

The present data indicated that crumbles and pellets diets increased ileal digestibility of AMEn and CP in heat-stressed broilers fed wheat-based diets. These results are in agreement with reports of Serrano et al. (2013) who found that pelleting increased CP digestibility and AMEn content of the diet compared with mash feeding. In contrast, Abdollahi et al. (2011) indicated that the ileal digestibility of starch was higher for mash than for pellets. It seems that heat and pressure applied during the pelleting process might affect the physical structure of the wheat ingredients, reducing particle size and releasing the encapsulated lipid fractions and increasing nutrient digestibility. Better access to nutrients but lower retention time in the gizzard due to pelleting might neutralize each other and result in different final effect on nutrient digestibility depending on the conditions of the study (Mateos et al. 2012).

### Table 5. Effects of feed form and xylanase enzyme on digestive tract measurements and viscosity of jejunal digesta of heat-stressed broilers fed wheat-based diet (n = 5).

| Treatments | Proventriculus | Gizzard | Intestine | Duodenum | Jejunum | Ileum | Viscosity (cPs) |
|------------|----------------|---------|-----------|-----------|---------|-------|----------------|
|            | Relative weight (g/100 g BW) | Relative length (cm/100 g BW) | | | | | |
| Mash       | 0.51 | 2.17a | 4.4a | 2.96a | 7.48a | 7.82a | 3.87a |
| Mash + xylanase | 0.50 | 2.16a | 4.6a | 2.90a | 7.41a | 7.83a | 2.75b |
| Crumble    | 0.51 | 1.77b | 4.2a | 2.76a | 7.32b | 7.56b | 3.64a |
| Crumble + xylanase | 0.52 | 1.78b | 4.4a | 2.74b | 7.31b | 7.54b | 2.73b |
| Pellets    | 0.52 | 1.64b | 3.8b | 2.61c | 7.11c | 8.29b | 3.76a |
| Pellets + xylanase | 0.51 | 1.65c | 3.6b | 2.62c | 7.09c | 7.31c | 2.72b |
| SEM        | 0.03 | 0.11 | 0.11 | 0.07 | 0.21 | 0.22 | 0.14 |
| Main effect | Feed form | | | | | | |
| Mash       | 0.50 | 2.17a | 4.5a | 2.93a | 7.44a | 7.82a | 3.31 |
| Crumbles   | 0.51 | 1.76b | 4.3a | 2.75b | 7.31b | 7.55b | 3.18 |
| Pellets    | 0.52 | 1.65c | 3.7b | 2.61c | 7.10c | 7.30c | 3.24 |
| Xylanase   | −    | 0.52 | 1.86 | 4.1 | 2.78 | 7.30 | 7.56 | 3.76a |
| +          | 0.51 | 1.87 | 4.2 | 2.75 | 7.27 | 7.57 | 2.73b |
| SEM        | 0.03 | 0.11 | 0.12 | 0.07 | 0.21 | 0.22 | 0.14 |
| P-value    | Feed form | | | | | | |
| Mash       | 0.322 | <0.001 | 0.002 | 0.002 | 0.004 | 0.002 | 0.118 |
| Crumbles   | 0.256 | 0.236 | 0.127 | 0.158 | 0.148 | 0.457 | 0.025 |
| Pellets    | 0.125 | 0.127 | 0.098 | 0.328 | 0.098 | 0.328 | 0.418 |

Note: Mean values within a column with different letters differ significantly (P < .05).

### Table 6. Effects of feed form and xylanase enzyme on intestinal morphology of heat-stressed broilers fed wheat-based diet (n = 5).

| Treatments | Duodenum | Jejunum | Ileum |
|------------|----------|---------|-------|
|            | Villus length | Crypt depth | Ratio | Villus length | Crypt depth | Ratio | Villus length | Crypt depth | Ratio |
| Mash       | 1310 | 182 | 7.19 | 1174bc | 159b | 7.38a | 809 | 153 | 5.29 |
| Mash + xylanase | 1312 | 181 | 7.25 | 1170c | 160bc | 7.31b | 814 | 155 | 5.25 |
| Crumble    | 1310 | 183 | 7.16 | 1177bc | 161bc | 7.31b | 810 | 153 | 5.29 |
| Crumble + xylanase | 1308 | 180 | 7.27 | 1180ab | 162a | 7.28c | 813 | 154 | 5.28 |
| Pellets    | 1307 | 182 | 7.18 | 1181* | 160bc | 7.38b | 812 | 153 | 5.31 |
| Pellets + xylanase | 1311 | 181 | 7.24 | 1182 | 162a | 7.30bc | 813 | 154 | 5.28 |
| SEM        | 1.3 | 0.5 | 0.04 | 1.2 | 1.2 | 0.06 | 5.5 | 1.9 | 0.07 |
| Main effect | Feed form | | | | | | |
| Mash       | 1311 | 181 | 7.22 | 1172b | 159b | 7.37b | 811 | 154 | 5.27 |
| Crumbles   | 1309 | 182 | 7.21 | 1180b | 152b | 7.76b | 812 | 153 | 5.29 |
| Pellets    | 1309 | 181 | 7.22 | 1181* | 153b | 7.72b | 812 | 154 | 5.29 |
| Xylanase   | −    | 1309 | 182 | 7.18 | 1177 | 159 | 7.36 | 810 | 153 | 5.30 |
| +          | 1310 | 181 | 7.25 | 1178 | 160 | 7.30 | 813 | 154 | 5.27 |
| SEM        | 1.3 | 0.5 | 0.04 | 1.2 | 0.2 | 0.06 | 5.5 | 0.2 | 0.07 |
| P-value    | Feed form | | | | | | |
| Mash       | 0.114 | 0.184 | 0.277 | 0.021 | 0.017 | 0.022 | 0.128 | 0.178 | 0.195 |
| Xylanase   | 0.255 | 0.224 | 0.280 | 0.258 | 0.158 | 0.236 | 0.246 | 0.182 | 0.186 |
| Feed form × xylanase | 0.263 | 0.478 | 0.656 | 0.318 | 0.323 | 0.421 | 0.235 | 0.165 | 0.143 |

Note: Mean values within a column with different letters differ significantly (P < .05).
the current study also indicated that xylanase supplementation improved ileal digestibility of CP and Ca, and AME of feed. Positive effects of xylanase on nutrient digestibility have been reported by other authors (Esmaeilipour et al. 2011; Khoramabadi et al. 2014). The NSPs in the cell walls of cereals encapsulate starch and protein and also increase the viscosity of digesta (Abdollahi et al. 2011). The increased CP digestibility with added xylanase in wheat-based diets may be partially due to lowering the endogenous amino acid losses, resulting from the elimination of adverse effects of pentosans in wheat (Esmaeilipour et al. 2011).

The relative weight and length of the different segments of GIT decreased for broilers fed crumbles and pellets than for broilers fed mash. These observations are consistent with data reported by Abdollahi et al. (2011) and Serrano et al. (2013) who demonstrated that pellets reduced the relative weight of the GIT. Serrano et al. (2013) reported greater digestive enzyme activities (amylase, lipase, and chymotrypsin) in broilers fed mash than in broilers fed pellets. Similarly to the results of Serrano et al. (2013) and Abdollahi et al. (2011), the broilers fed pelleted diet had smaller gizzards than those fed crumbled diet and both smaller than broilers fed mash. These results suggest that pelleting decreased particle size of feed and small particles are retained in the gizzard for less time, resulting in less mechanical stimulation and reduced gizzard size (Svihus et al. 2004). Feed form did not affect the viscosity of digesta, but xylanase supplementation significantly decreased the viscosity of digesta. Xylanase reduces the viscosity of digesta by degrading arabinoxylans (Chocht and Annison 1992). Most positive effects of xylanase supplementation on the growth performance of broilers in this research seemed to be related to improved nutrient digestibility and decreased viscosity of digesta.

The feed form influenced the villus length and crypt depth in the jejunum segment. Broilers fed crumbled and pelleted diets had longer villi as well as increased villus length-to-crypt depth ratios than those fed mash. Additionally, the birds fed mash diet had deeper crypts than birds fed crumbles or pellets. With regard to the effect of feed form on the intestinal morphology, the mechanism that leads to the development of longer villi and deeper crypts has not yet been revealed. However, it is known that the feed form plays an important role in maintaining and improving gut health (Montagne et al. 2003). The general assumption exists that an enlargement of the absorptive surface can increase the absorption of nutrients and may lead to an improved growth performance (Gabriel et al. 2007). Montagne et al. (2003) reported that both villus length and crypt depth are important indicators of the digestive health of birds and directly contributed to the increased absorptive capacity of the mucous membrane. Thus, crumbled and pelleted diets stimulated the digestive and absorptive functions of broiler chickens and may help to explain the improvement in ADG and ADFI observed during the experimental period.

5. Conclusions

Feeding crumbled and pelleted diets had positive effects on growth performance, ileal nutrient digestibility and the morphometric indices of the jejunum. The effect of feed processing on improvement of energy utilization efficiency is largely important, especially during periods of heat stress when feed consumption is reduced. Therefore, the use of pellets is recommended in wheat-based diets for broilers subjected to heat stress. Our findings could be helpful in establishing guidelines for broiler reared under high ambient temperatures.

Disclosure statement

No potential conflict of interest was reported by the authors.

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