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Effects of Feed Particle Size and Feed Form on Growth Performance, Nutrient Metabolizability and Intestinal Morphology in Broiler Chickens

J. J. Zang, X. S. Piao, D. S. Huang, J. J. Wang, X. Ma and Y. X. Ma*
National Key Lab of Animal Nutrition, China Agricultural University
No. 2 Yuanmingyuan West Road, Beijing, 100193, China

ABSTRACT : This study was conducted to investigate the effect of feed particle size and feed form on growth performance, nutrient metabolizability and intestinal morphology in broiler chickens. This experiment was a 2×2 factorial arrangement including two feed particle sizes (fine and coarse) and two feed forms (mash and pellet). A total of two hundred and eighty eight day-old male Arbor Acre broilers were used in this six week experiment. Birds were randomly allotted to four dietary treatments with six replicates per treatment and twelve birds per replicate. The results showed that pelleting diets resulted in greater ADG ($p<0.01$), greater ADFI ($p<0.01$) and lower feed to gain ratio (F/G) ($p<0.05$) during starter, grower and overall period. Also, pelleting improved both apparent metabolizable energy (AME) ($p<0.01$) and the apparent metabolizability of crude protein ($p<0.05$) and organic matter ($p<0.05$) regardless of the phase. Reduction of feed particle size enhanced AME ($p<0.05$) during d 19 to 21. Increased villus height ($p<0.05$) and crypt depth ratio ($p<0.05$) within duodenum, jejunum, and ileum were observed in birds fed the pellet diet compared with those given the mash diet. In conclusion, results indicated that feed pellets might enhance performance by improving nutrient metabolizability and digestive tract development. (**Key Words :** Feed Particle Size, Feed Form, Nutrient Metabolizability, Intestinal Morphology)

INTRODUCTION

Many feed ingredients, especially cereal grains, are ground before they are incorporated into poultry diets. A smaller particle size is associated with a larger surface area of the grain, possibly resulting in higher digestibility in poultry due to a greater interaction with digestive enzymes in the gastrointestinal tract (Goodband et al., 2002). However, studies which relate particle size to digestibility of nutrients are limited, and with somewhat conflicting results. Therefore, this topic is necessary to be further investigated in broilers. Amerah et al. (2007a) concluded that coarse grinding of a wheat-based diet may facilitate digestion of energy substrates, therefore enhancing values of apparent metabolizable energy (AME). However, such a beneficial effect of coarse grinding may not be evident for a corn-based diet. However, earlier research showed that no effect of wheat particle size on the AME (Svihus et al., 2004). Compared with coarse diet, Parsons et al. (2006) reported that fine grinding of maize decreased the efficiency of nitrogen and lysine retention in broilers. The conflicting results showed that fine grinding wheat improved starch digestibility and AME (Peron et al., 2005). Lott et al. (1992) found that coarser grain size reduced performance. However, earlier work showed that bird fed the coarse diets performed better than birds given the fine particle diets (Reece et al., 1985). Feed physical form is one of most important factors, which confound the effect of particle sizes on digestibility of nutrients and growth performance. Pelleting is the most preferred form of diet for broiler chickens, during the starter and grower periods, showing an increased feed intake and weight gain and improved feed to gain ratio (Calet, 1965). Also, pelleting feed for broilers can improve AME and apparent metabolizability of organic matter (Kilburn and Edwards, 2001; Zelenka, 2003; Svihus et al., 2004).

The beneficial effects of pelleted feed on digestibility of nutrients may arise from their influence on intestinal morphology, but the published data on this aspect are so scanty. The only available research (Amerah et al., 2007b) related to this line of research was focused on starter broilers (0-21 d), not growers (22-42 d). Villi and crypts are the functional units of the small intestine, assuming the role of digestion and absorption. The morphological alterations of the intestine will affect function, secretion of digestive

* Corresponding Author: Yongxi Ma. Tel: +86-10-62733588, Fax: +86-10-62733688, E-mail: mayongxi2005@163.com
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Table 1. Diet composition and nutrient levels (as-fed basis)[1]

Items	d 0 to 21	d 22 to 42
Ingredients (%)		
Corn	51.15	56.08
Soybean meal	31.00	29.10
Fishmeal	6.00	3.00
Wheat middling and reddog	5.00	5.00
Soybean oil	3.00	3.00
Dicalcium phosphate	1.00	1.12
Limestone	1.35	1.25
Sodium chloride	0.30	0.30
DL-methionine (99%)	0.20	0.15
Premix[2]	1.00	1.00
Nutrient level[3]		
ME (kcal/kg)	3,022	3,053
Crude protein (%)	22.46	20.00
Lysine (%)	1.19	1.03
Methionine+cysteine (%)	0.91	0.73
Calcium (%)	1.00	0.90
Total phosphorus (%)	0.75	0.65

[1] For pelleted fine and coarse diets, the standardized pellet durability index (PDI) was 87.85%, 86.27%, respectively.

[2] Supplied per kilogram of complete diet: vitamin A, 9,100 IU; vitamin D_3, 1,850 IU; vitamin E, 18 IU; riboflavin, 7.0 mg; pantothenic acid, 15.0 mg; niacin, 36 mg; cobalamin, 10 μg; choline chloride, 300 mg; biotin, 0.1 mg; folic acid, 0.6 mg; thiamine, 1.0 mg; pyridoxine, 3.0 mg; Fe, 75.0 mg; Zn, 60.0 mg; Mn, 80.0 mg; I, 0.4 mg; Cu, 4.0 mg; Se, 0.3 mg.

[3] All values except ME were analyzed.

enzymes and absorption of nutrients. The objectives of this study were to compare the effect of feed particle size and feed form on growth performance, nutrient metabolizability, and intestinal morphology in broilers during starter, grower and overall period.

MATERIALS AND METHODS

Experimental design and diets

A 2×2 factorial design including two feed particle sizes (coarse and fine) and two feed forms (mash and pellet) was conducted for this trial. Corn and soybean meal-based diets (Table 1) were formulated to meet or exceed nutrient requirements estimated by the NRC (1994) that differed only in physical characteristics. Particle sized screen was achieved by using a hammer mill (SFSP56X40, Muyang Corp., Yangzhou, China) with different opening sizes of screens. The coarse and fine mash diet was prepared by mixing corn and soybean meal that was ground through a 5-mm or 3-mm screen, then blended with all other ingredients to yield a final dietary particle size of 953 and 597 μm, respectively. The particle size was determined by the standard method (American Dairy Science Association, 1970). Half of the mash diets of pelleted treatments, were steam-conditioned for approximately 10-s, with a constant temperature of 85°C. Pellets were subsequently formed using a pllet mill (MUZL-350, Muyang Corp., Yangzhou, China) equipped with a 38-mm thick die with 2-mm diameter holes, then cooled with ambient air in a cooler (SKLN14X14A, Muyang Corp., Yangzhou, China). Standardized pellet durability index (PDI) was determined using procedures detailed in the ASAE standard S269.4 (ASAE, 1997).

Experimental animals

The animal protocol for this experiment was approved by China Agricultural University Animal Care and Use Committee. The experiment was divided into two phases, which included starter (d 0-21) and grower (d 22-42) phases. A total of 288 Arbor Acre male broilers (1 d of age, initial BW = 27.03±0.10 g) were randomly allocated to four dietary treatments. The birds were housed in 90×60 cm pens containing 12 birds, and each treatment contained 6 replicate pens of birds. All birds were raised in an environmentally controlled room with continuous light (10 to 20 lux). Temperature was maintained at 33°C from 0 to 5 d and then gradually reduced, according to normal management practices, until a temperature of 22°C was achieved. Feed and water were supplied *ad libitum*.

Experimental procedures

On d 22 and 42, chicks were weighed by pen, and feed consumption was recorded. Average daily gain (ADG), average daily feed intake (ADFI), and feed to gain ratio (F/G), including mortality weight were calculated for each phase. Excreta were total collected on d 19 to 21 and d 40 to 42, sampled, dried at 60°C and ground through 20 mesh screens to determine apparent metabolizable energy (AME) and apparent metabolizability of dry matter (DM), crude protein (CP) and organic matter (OM). One bird per pen was randomly selected from each pen and killed by cervical dislocation on d 42. Tissue samples for morphological measurements were taken from the duodenum (5 cm from the pylorus), jejunum (5 cm posteriorto the yolk stalk), and ileum (2 cm anterior to the ileocecal valve), rinsed in physiological saline, every sample about 2 cm in length fixed in phosphate-buffered formalin (10%, pH = 7.6). Histological slides were prepared from 3 cross-section (5 μm thick) of each intestinal sample, processed in low-melt paraffin and stained with hematoxylin-eosin to evaluate morphological parameters.

Nutrient contents in both diets and excreta were analyzed according to AOAC (1995) procedures. Villus height (VH) and crypt depth (CD) were measured using the Image-Pro Plus as described by Touchette et al. (2002) and then the VH:CD ratio (VCR) was calculated.

Statistical analysis

All data was subjected to the two-way ANOVA procedures for completely randomized designs using the

Table 2. Effects of feed particle size and feed form on growth performance of male broilers[1]

Items	Mash		Pellet		PSEM[2]	p-value		
	Coarse	Fine	Coarse	Fine		PS[3]	FF[4]	PS×FF
Initial BW (g)	27.0	27.0	27.1	27.0	0.1			
d 0-21								
21 d BW (g)	767[a]	739[a]	915[b]	914[b]	19	0.3995	<0.0001	0.4403
ADG (g)	35.2[a]	33.9[a]	42.3[b]	42.2[b]	0.9	0.3983	<0.0001	0.4372
ADFI (g)	48.2[a]	45.6[a]	54.0[b]	53.9[b]	0.9	0.1375	<0.0001	0.1670
F/G	1.37[a]	1.35[a]	1.28[b]	1.28[b]	0.015	0.5700	0.0053	0.6219
d 22-42								
42 d BW (g)	2,252[a]	2,146[a]	2,517[b]	2,493[b]	37	0.1124	<0.0001	0.3063
ADG (g)	70.8[a]	67.0[a]	76.3[b]	75.2[b]	1.1	0.1767	0.0008	0.4456
ADFI (g)	152.4[a]	142.2[a]	160.1[b]	157.2[b]	2.2	0.0753	0.0042	0.3099
F/G	2.15[a]	2.13[a]	2.10[b]	2.09[b]	0.009	0.2171	0.0107	0.4801
d 0-42								
ADG (g)	53.0[a]	50.5[a]	59.3[b]	58.7[b]	1.0	0.1125	<0.0001	0.3059
ADFI (g)	100.3[ac]	93.9[ad]	107.1[b]	105.5[b]	1.6	0.0354	<0.0001	0.1776
F/G	1.89[a]	1.87[a]	1.81[b]	1.80[b]	0.010	0.0859	<0.0001	0.2843

[a, b] Means among groups of feed form within particle size different superscript are significantly different at p<0.05.
[c, d] Means among groups of particle size within feed form different superscript are significantly different at p<0.05.
[1] Data are means of six replicates. [2] PSEM = Pooled standard error of the mean. [3] PS = Particle size. [4] FF = feed form.

GLM models of SAS. The statistical model included the effects of feed particle size (fine vs. coarse), feed form (pellet vs. mash), and their interaction. Statistical significance of differences was assessed among dietary treatments by using the least significant difference (LSD) test. Results were expressed as least-square means and standard error of the means (SEM). An alpha level of $p < 0.05$ was used as the criterion for statistical significance.

RESULTS

Growth performance

The effects of feed particle size and feed form on broiler performance are shown in Table 2. No feed particle size×feed form interaction for BW, ADG, ADFI, and F/G was observed throughout the 42-d trial. Significantly increased BW ($p<0.01$), ADG ($p<0.01$), ADFI ($p<0.01$) and lowered F/G ($p<0.05$) were observed in birds given the pellet diet compared with mash-fed birds during starter, grower and overall period. Although the growth performance was not influenced by the feed particle size during starter and grower periods, fine particle size decreased ADFI ($p<0.05$) in birds overall period.

Nutrient metabolizability

The nutrient metabolizability data are presented in Table 3. There were no feed particle size×feed form interactions for AME and metabolizability of CP, DM, and OM throughout the 42-d trial. During d 19 to 21 and d 40 to 42, pelleting feed increased AME ($p<0.01$), the apparent CP and OM metabolizability ($p<0.05$). At the same time, AME was significantly enhanced ($p<0.05$) when birds were given the fine diet during d 19 to 21; feed intake should decrease with the increase of AME, however, there was no

Table 3. Effects of feed particle size and feed form on apparent metabolizable energy (AME) and apparent metabolizability of crude protein (CP), dry matter (DM) and organic matter (OM)[1]

Items	Mash		Pellet		PSEM[2]	p-value		
	Coarse	Fine	Coarse	Fine		PS[3]	FF[4]	PS×FF
d 19-21								
AME (kcal/kg)	2,901[ac]	2,990[ad]	3,072[b]	3,120[b]	22	0.0351	<0.0001	0.5013
CP (%)	54.50[a]	55.80[a]	58.11[b]	60.06[b]	0.86	0.3168	0.0217	0.8402
DM (%)	70.13	70.53	70.50	71.13	0.39	0.5389	0.5626	0.8874
OM (%)	72.56[a]	72.72[a]	74.69[b]	76.52[b]	0.50	0.2161	0.0011	0.3000
d 40-42								
AME (kcal/kg)	2,905[a]	2,977[a]	3,080[b]	3,126[b]	27	0.1836	0.0012	0.7707
CP (%)	50.73[a]	51.07[a]	54.60[b]	57.52[b]	1.09	0.4200	0.0168	0.5205
DM (%)	70.26	68.93	68.44	67.49	0.61	0.3654	0.2024	0.8785
OM (%)	72.17[a]	72.91[a]	74.06[b]	75.28[b]	0.48	0.2867	0.0274	0.7919

[a, b] Means among groups of feed form within particle size different superscript are significantly different at p<0.05.
[c, d] Means among groups of particle size within feed form different superscript are significantly different at p<0.05.
[1] Data are means of six replicates. [2] PSEM = Pooled standard error of the mean. [3] PS = Particle size. [4] FF = Feed form.

Table 4. Effects of feed particle size and feed form on intestinal morphological parameters of villus height (VH), crypt depth (CD), and VH:CD ratio (VCR) for 42 d of age male broilers[1]

Items	Mash		Pellet		PSEM[2]	p-value		
	Coarse	Fine	Coarse	Fine		PS[3]	FF[4]	PS×FF
Duodenum								
VH (μm)	1,318[a]	1,353[a]	1,451[b]	1,455[b]	24.31	0.6629	0.0159	0.7278
CD (μm)	125	129	133	128	1.91	0.9369	0.3910	0.3206
VCR	10.54[a]	10.53[a]	10.93[b]	11.32[b]	0.13	0.4392	0.0196	0.4055
Jejunum								
VH (μm)	939[a]	981[a]	1037[b]	1051[b]	16.98	0.3654	0.0115	0.6602
CD (μm)	110	114	116	112	2.26	0.9720	0.6283	0.4395
VCR	8.58[a]	8.64[a]	8.95[b]	9.39[b]	0.12	0.2451	0.0154	0.3758
Ileum								
VH (μm)	651[a]	685[a]	759[b]	741[b]	18.31	0.8143	0.0258	0.4503
CD (μm)	83	85	88	86	1.11	0.9481	0.2831	0.4085
VCR	7.81[a]	8.01[a]	8.66[b]	8.63[b]	0.17	0.8087	0.0345	0.7200

[a, b] Means among groups of feed form within particle size different superscript are significantly different at $p<0.05$.

[1] Data are means of six replicates. [2] PSEM = Pooled standard error of the mean. [3] PS = Particle size. [4] FF = Feed form.

significant difference (Table 2) in terms of ADFI between coarse and fine diets, this maybe relate to the difference of experimental period (d 19-21 vs. d 0-21). The feed particle size and feed form had no effect on the DM metabolizability regardless of the growth phase.

Intestinal morphology

As indicated by Table 4, there was no feed particle size×feed form interactions for VH, CD, and VCR within duodenum, jejunum or ileum for 42 d of age broilers. Pellet-fed birds showed higher VH ($p<0.05$) and larger VCR ($p<0.05$) regardless of intestinal segments, but no difference in CD for three segments. There was no significant difference between broilers fed the fine diet or the coarse diet in regard to VH, CD, and VCR within the duodenum, jejunum or ileum.

DISCUSSION

The results of this experiment indicated that feed form had a greater effect on the growth performance, nutrients digestibility and intestinal morphology than feed particle sizes. Feed particle sizes had no significant effects on growth performance, except that fine (3 mm) mash diet had resulted in lower ADFI than coarse (5 mm) mash during overall period, but pelleting masked the effects of different particle sizes in present sutdy. The results were similar to those reported by Amerah et al. (2007b). Partial differences of the results between two studies may be due to different opening sizes of screens used. Particle sizes also had no effects on growth performance in pelleted diets, which indicated that particle size was more critical in mash diets than in pelleted diets on performances.

It is commonly accepted that pelleting poultry rations increases weight gain and improves feed efficiency. Consistent with the previous finding that pelleting complete diets improved weight gain, feed conversion (Douglas et al., 1990), and feed intake (Nir et al., 1995) in broilers, the observations of current experiment demonstrated that pelleting of feed improved BW, ADG, ADFI, and F/G in broilers during starter, grower and overall period. The advantage may result from an increase in appetite and diet density, a decrease in feed waste, and alterations in ingredients (Jensen, 2000). It's noted that pelleted feed increased the feed intake by about 7-10%, and the absolute increase of ADFI in broilers fed pellets was about 7 g, 12 g, during starter and grower, respectively, compared with mash diet in this study. The preference for pelleted diets over mash tends to increase with bird age, suggesting that older birds desire a feed in particulate form in order to conform to changes in dimension of the oral cavity (Moran, 1989).

It is conceivable that the improvement in performance is the result of increased diet digestibility. Nutrient metabolizability in broiler chickens is influenced by a number of factors, such as ingredient, genotype, environment and husbandry. The feed-related factors that are of practical relevance include feed processing, feed formulation and so on. Jensen (2000) suggested that pelleting not increase metabolizable energy (ME) of diet but greatly increase available or productive energy in broilers. Some results have also shown that pelleting feed for broilers can improve AME during d 13 to 15 (Kilburn and Edwards, 2001), d 21 to 24 (Svihus et al., 2004), d 75 to 78 and d 82 to 85 (Zelenka, 2003), respectively. In our study, we found that pelleting feed improved AME from 2,946 to 3,096 kcal/kg during d 19 to 21 and from 2,942 to 3,103 kcal/kg during d 40 to 42, respectively. Furthermore, reduction of feed particle size can improve AME ($p<0.05$) during d 19 to 21, which is also in accordance with the previous results (Kilburn and Edwards, 2001). Besides improved AME, pelleting of feed also enhanced the apparent metabolizability of CP and OM of the diet. Zelenka (2003) observed increased apparent OM metabolizability with pelleted feed, but the apparent metabolizability of CP was unaffected. Jensen and Becker (1965) suggested that the pelleting process to some extent gelatinized starch. Also, pelleting of diets can reduce their particle size substantially (Engberg et al., 2002). The combination of particle size reduction and starch gelatinization may expose feed particles more efficiently to enzymatic digestion, which may explain the improved AME and the apparent CP and OM metabolizability observed in our study.

The intestinal morphology is an indicator of gut health. Fine particle size affected the integrity of the stomach, as well as the structure of the small intestine in pigs (Morel et al., 2007). However, relatively few studies have been conducted on the effect of feed form on the intestinal morphology in broilers overall period. Only available data showed that pelleted feed increased the villus height and crypt depth, compared with mash diets, and the 2-way interactions were not significant for these morphological parameters in broiler starter (Amerah et al., 2007b). In our study, significant increase in VH and VCR were also observed in the small intestinal mucosa of chickens fed the pellet diet compared with those given the mash diet, and no interaction effects; but CD wasn't influenced by feed form during starter, grower and over period. The improved VH and VCR for various segments of birds fed the pellet diet were in agreement with enhanced growth performance and increased metabolizability of nutrients. Extending of villus may enlarge total luminal villus absorptive area and subsequently result in adequate digestive enzyme action and higher transport of nutrients at the villus surface (Cera et al., 1988). In addition, the higher VCR in the broilers fed the pellet diets is favorable aspect as it is an indication for an decreased turnover rate of the intestinal mucosa. A slower turnover rate of the intestinal epithelium results in a lower maintenance requirement, which can finally lead to a higher growth rate or growth efficiency of the animal. Thus, the changes in intestinal morphology may influence nutrient metabolizability and performance.

IMPLIATIONS

Pelleting the diet results in improved growth performance and nutrient metabolizability, which relate with better development of digestive tract in broilers. However, no obvious effects on performance were observed in feed particle sizes, except that coarse significantly increased ADFI during overall period than fine in mash, not in pellet; there is no interaction between feed particle size and feed form either. That feeding pelleted diet by coarsely grinding could be alternative nutritional strategy of optimizing intestinal tract health and feed utilization, improving production efficiency with energy saving in broiler industry.

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