Effects of Ring Die Hole Parameters on Pellet Feed Processing Quality and Broiler Growth Performance[^1]

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Abstract

This experiment aimed to investigate the effects of ring die hole parameters on pellet feed processing quality and broiler growth performance. By fixing the die hole diameter (3 mm) and varying the die hole length-to-diameter ratio (6:1, 8:1, 10:1), and by fixing the die hole length-to-diameter ratio (10:1) and varying the die hole diameter (3.0, 3.5, 4.0 mm), five types of broiler pellet feeds with different diameters and hardness levels were produced. A total of 864 21-day-old Arbor Acres (AA) broilers with similar body weight were selected and randomly divided into 6 groups, with 8 replicates per group and 18 broilers per replicate. Groups I–V were fed pellet feeds with die hole diameter and length-to-diameter ratio of 3.0 mm and 6:1, 3.0 mm and 8:1, 3.0 mm and 10:1, 3.5 mm and 10:1, and 4.0 mm and 10:1, respectively; Group VI was fed in a two-stage manner, receiving pellet feed with die hole diameter and length-to-diameter ratio of 3.0 mm and 10:1 from days 22–35, and pellet feed with die hole diameter and length-to-diameter ratio of 4.0 mm and 10:1 from days 36–42. The experimental period lasted 21 days. The results showed: 1) When the die hole diameter was the same, pellet hardness increased extremely significantly with increasing die hole length-to-diameter ratio ($P<0.01$); when the die hole length-to-diameter ratio was the same, pellet hardness increased extremely significantly with increasing die hole diameter ($P<0.01$). There were no significant differences in Pellet Durability Index (PDI) among all groups ($P>0.05$), and all values were above 95%. 2) When the die hole diameter was the same, as pellet hardness increased, final body weight and average daily gain of broilers decreased gradually, while feed conversion ratio increased gradually. The final body weight and average daily gain of Group I were significantly or extremely significantly higher than those of Group III ($P<0.05$ or $P<0.01$), and the feed conversion ratio of Group I was significantly lower than that of Groups II and III ($P<0.05$). 3) When the die hole length-to-diameter ratio was the same, there were no significant differences in final body weight, average daily gain, or average daily feed intake among

groups (P>0.05); as pellet diameter increased, feed conversion ratio decreased gradually, and the feed conversion ratio of Group III was significantly higher than that of Group V (P<0.05). In conclusion, increasing both die hole length-to-diameter ratio and diameter significantly increased pellet hardness. Within a certain range, increasing pellet hardness decreased final body weight and average daily gain of broilers and increased feed conversion ratio, while increasing pellet diameter decreased feed conversion ratio.

Full Text

Effects of Ring Die Hole Parameters on Pellet Feed Processing Quality and Broiler Growth Performance[^1]

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Abstract: This experiment was conducted to study the effects of ring die hole parameters on the processing quality of pellet feed and on broiler growth performance. By fixing the die hole diameter (3 mm) and changing the die hole length-to-diameter ratio (6:1, 8:1, 10:1), and by fixing the die hole length-to-diameter ratio (10:1) and changing the die hole diameter (3.0, 3.5, 4.0 mm), five types of broiler pellet feed with different diameters and hardness were produced. A total of 864 Arbor Acres (AA) broilers of similar body weight at 21 days of age were selected and randomly divided into 6 groups, with 8 replicates per group and 18 birds per replicate. Groups I–V were fed pellet feeds with die hole diameter and length-to-diameter ratio of 3.0 mm and 6:1, 3.0 mm and 8:1, 3.0 mm and 10:1, 3.5 mm and 10:1, and 4.0 mm and 10:1, respectively; group VI was fed in two stages: from 22 to 35 days of age, it was fed pellet feed with a die hole diameter and length-to-diameter ratio of 3.0 mm and 10:1, and from 36 to 42 days of age, it was fed pellet feed with a die hole diameter and length-to-diameter ratio of 4.0 mm and 10:1. The experimental period was 21 d. The results showed that: 1) when die hole diameter was the same, pellet hardness increased extremely significantly with increasing die hole length-to-diameter ratio ($P < 0.01$); when the die hole length-to-diameter ratio was the same, pellet hardness increased extremely significantly with increasing die hole diameter ($P < 0.01$). There were no significant differences among groups in pellet durability index (PDI) ($P > 0.05$), and all values were above 95%. 2) When die hole diameter was the same, with increasing pellet hardness, final body weight and average daily gain of broilers gradually decreased, while the feed-to-gain ratio gradually increased. The final body weight and average daily gain of

group I were significantly or extremely significantly higher than those of group III ($P < 0.05$ or $P < 0.01$), and the feed-to-gain ratio of group I was significantly lower than those of groups II and III ($P < 0.05$). 3) When the die hole length-to-diameter ratio was the same, there were no significant differences among groups in final body weight, average daily gain, or average daily feed intake ($P > 0.05$); with increasing pellet diameter, the feed-to-gain ratio gradually decreased, and the feed-to-gain ratio of group III was significantly higher than that of group V ($P < 0.05$). In summary, increases in the die hole length-to-diameter ratio and diameter both significantly improved pellet hardness. Within a certain range, increasing pellet hardness reduced broiler final body weight and average daily gain and increased the feed-to-gain ratio, whereas increasing pellet diameter reduced the feed-to-gain ratio.

Key words: ring die parameters; broiler; pellet feed; processing quality; growth performance

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In recent years, numerous experimental studies at home and abroad have shown that, during broiler production, pellet feed can achieve better average daily gain (ADG) and a lower feed-to-gain ratio (F/G) than mash feed[ˆ1-3]. Broiler pellet feed is mainly processed by steam conditioning and ring-die pelleting. Adjustment of ring die parameters changes the diameter and hardness of pellet feed, thereby affecting broiler growth performance. Therefore, selecting pellet feed with an appropriate diameter and hardness is of great importance for broiler production.

Tan Hequn et al.[ˆ4], in studying the effects of pelleting process parameters on broiler growth performance, concluded that pellet feed produced with a small die hole diameter showed better feeding effects than pellet feed produced with a large die hole diameter. However, some studies have also suggested that, compared with broilers fed small-diameter pellet feed, broilers fed large-diameter pellet feed showed no differences in feed intake, feed intake amount, or weight gain, and that practical application was relatively ideal[ˆ5]. Zhang Zhenzheng et al.[ˆ6] conducted a comparative experiment in which pellet feed size was changed after broilers reached 28 days of age, and also concluded that small pellet feed had no significant effect on feed intake. In terms of pellet hardness, Sun Yongtai[ˆ7] considered that, when pellet feed was produced using ring dies with the same hole diameter but different length-to-diameter ratios, the hardness increased significantly as the die hole length-to-diameter ratio increased. Che Lu et al.[ˆ8] studied

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It has also been found that increasing the die hole length-diameter ratio can reduce transverse cracks produced on the cross-section of pelleted feed and improve the palatability and appearance of pelleted feed. However, Chen Zhongbing et al.[9] reported that excessive pellet hardness reduces feed palatability and digestibility; therefore, pelleted feed processing requires an appropriate hardness.

In recent years, there have been many studies on the effects of raw-material grinding particle size, moisture content, and conditioning temperature during the conditioning stage on pelleted feed quality and broiler growth performance, but relatively few reports have addressed the effects of pellet diameter, especially pellet hardness. Therefore, the objective of this experiment was to study the effects of ring-die hole parameters on the processing quality of pelleted feed and on the growth performance of broilers aged 21-42 days, so as to provide a reference for the production and processing of pelleted feed for broilers.

1 Materials and Methods

1.1 Experimental design and feed processing parameters

In this experiment, five types of broiler pelleted feeds with different hardnesses and diameters were produced by fixing the die hole diameter (3 mm) and changing the die hole length-diameter ratio (6:1, 8:1, and 10:1), and by fixing the die hole length-diameter ratio (10:1) and changing the die hole diameter (3.0, 3.5, and 4.0 mm). A total of 864 21-day-old Arbor Acres (AA) broilers with similar body weights were selected and randomly divided into 6 groups, with 8 replicates per group and 18 birds per replicate. The specific feed processing parameters for each group are shown in Table 1. Groups I-V were fed pelleted feeds with die hole diameters and length-diameter ratios of 3.0 mm and 6:1, 3.0 mm and 8:1, 3.0 mm and 10:1, 3.5 mm and 10:1, and 4.0 mm and 10:1, respectively. Group VI was fed in two phases: at 22-35 days of age, the pelleted feed had a die hole diameter and length-diameter ratio of 3.0 mm and 10:1; at 36-42 days of age, the pelleted feed had a die hole diameter and length-diameter ratio of 4.0 mm and 10:1. The experiment used the same basal diet, and the experimental period was 21 d.

Table 1 Processing parameters of feed

Processing condition	I	II	III	IV	V	VI
The aperture of mill shattering raw materials/mm	2.0	2.0	2.0	2.0	2.0	2.0
Die hole diameter/mm	3.0	3.0	3.0	3.5	4.0	3.0, 4.0
Die hole length-radial ratio	6:1	8:1	10:1	10:1	10:1	10:1
Conditioning temperature/℃	75	75	75	75	75	75

1.2 Basal diet

The feed was processed and produced at Xinsanfeng Feed Mill, Miyun County, Beijing. The composition and nutrient levels of the basal diet are shown in Table 2.

Table 2 Composition and nutrient levels of the basal diet (air-dry basis) %

Items	Content
Ingredients	
Corn	60.34
Soybean meal	28.42
Rapeseed meal	5.00
Soybean oil	2.24
$CaHPO_4$	1.34
Limestone	1.33
NaCl	0.35

Items	Content
DL-Met	0.24
L-Thr	0.03

Premix 1.00

Choline chloride (50%) 0.20

Total 100.00

Nutrient levels

ME/(MJ/kg) 12.71

CP 18.98

Ca 0.90

TP 0.65

AP 0.40

Lys 1.00

Met 0.386

Met+Cys 0.689

The premix provided the following per kg of the diet: VA 8 000 IU, VD_3 750 IU, VE 15 IU, VK_3 0.5 mg, VB_1 2.0 mg, VB_2 5.0 mg, pantothenic acid 10.0 mg, nicotinic acid 30.0 mg, VB_6 3.5 mg, biotin 0.05 mg, folic acid 0.55 mg, VB_{12} 0.01 mg, choline 1 000 mg, Fe 80 mg, Cu 8.0 mg, Zn 80 mg, Mn 100 mg, I 0.7 mg, Se 0.3 mg, flavomycin 4 mg, and salinomycin 50 mg.

1.3 Feeding management

The experiment was conducted at the Nankou Pilot Base of the Chinese Academy of Agricultural Sciences. Except for the feed, all other rearing conditions were the same. Before the experiment, the chicken house was thoroughly disinfected. The experimental method was cage rearing, and feeding management was carried out with reference to the *AA Broiler Feeding Management Manual*. The experimental broilers had free access to feed and water and were managed by designated personnel; feed was added frequently in small amounts, and attention was paid to the growth status of the broilers.

1.4 Measurement indices and methods

1.4.1 Pellet hardness Pellet hardness was measured with reference to the method for determining the hardness of pelleted feed in *Feed Inspection Laboratory Technician*[^{10}].

1.4.2 Pellet durability index (PDI) A 500 g sample that had been sieved to remove fines was placed in the pellet durability testing device and tumbled for 10 min. The sample was then removed and sieved, and the weight of the remaining pelleted feed was weighed. PDI was calculated according to the following formula:

PDI(%) = (weight of pelleted feed after tumbling/weight of pelleted feed before tumbling)×100.

1.4.3 Growth performance indices Feed was withdrawn on the evening of 42 days of age, with free access to water. On the morning of 43 days of age, the broilers were weighed individually, and the final body weight (FBW) of the experimental chickens in each group was calculated using the replicate as the unit.

The amount of feed added each day was accurately recorded. When dead chickens occurred, the remaining feed was weighed. Feed was withdrawn on the evening of 42 days of age, and the remaining feed for each replicate was accurately weighed to calculate total feed consumption.

Average daily feed intake (ADFI) = total feed consumption/(number of experimental chickens × number of experimental days);

Average daily gain = total weight gain/(number of experimental chickens × number of experimental days);

Feed-to-gain ratio = total feed consumption/total weight gain.

1.5 Data processing

Experimental data are expressed as mean ± standard deviation. All data were subjected to one-way analysis of variance (one-way ANOVA) using SAS 9.2 software, and Duncan's multiple comparison test was used to test the significance of differences among groups. The levels of significance and extreme significance were set at $P < 0.05$ and $P < 0.01$, respectively.

2 Results and analysis

2.1 Effects of different ring-die parameters on the processing quality of pelleted feed

As can be seen from Table 3, pellet hardness increased extremely significantly with increasing die-hole diameter and length-to-diameter ratio ($P < 0.01$), and V

group was the highest, reaching 69.39 N. When the die-hole diameter was unchanged, the larger the length–diameter ratio of the die hole, the higher the PDI; when the length–diameter ratio of the die hole was unchanged, the larger the die-hole diameter, the lower the PDI. However, there were no significant

differences in PDI among the groups ($P > 0.05$), and all values were above 95%.

Table 3 Effects of circular mold parameter on processing quality of pellet feed

Groups	Diameter of die hole/mm	Length-radial ratio of die hole	Pellet hardness/N	PDI/%
I	3.0	6:1	43.60$±3.98 < sup > A < /sup > |95.94±0.05||II|3.0|8 : 1|49.23±4.58 < sup > B < /sup > |96.28±0.17||III|3.0|10 : 1|54.19±5.74 < sup > C < /sup > |96.37±0.10||IV|3.5|10 : 1|61.75±5.76 < sup > D < /sup > |96.13±0.12||V|4.0|10 : 1|69.39±6.90 < sup > E < /sup > |95.94±$0.07	

In the same column, values with different small-letter superscripts mean significant difference ($P < 0.05$), and with different capital-letter superscripts mean highly significant difference ($P < 0.01$), while with the same or no letter superscripts mean no significant difference ($P > 0.05$). The same applies below.

2.2 Effects of different circular die parameters on broiler growth performance

2.2.1 Effects of feed pellet hardness on broiler growth performance

As can be seen from Table 4, with increasing feed pellet hardness, the final body weight and average daily gain of broilers gradually decreased, while the feed-to-gain ratio gradually increased. The final body weight of group I was the highest, at 2.57 kg, significantly higher than that of group III ($P < 0.05$); the average daily gain of group I was significantly higher than that of group II ($P < 0.05$) and extremely significantly higher than that of group III ($P < 0.01$). There

were no significant differences in average daily feed intake among the groups ($P > 0.05$). The feed-to-gain ratio of group I was significantly lower than those of groups II and III ($P < 0.05$). The above experimental results indicate that, when pellet diameter is the same, excessively high feed pellet hardness is not conducive to broiler growth.

Table 4 Effects of pellet hardness of feed on growth performance of broilers

Groups	Length-radial ratio of die hole	IBW/kg	FBW/kg	ADG/g	ADFI/g	F/G
I	6:1	0.88$±0.05	2.57±0.07 ^a			
		80.26±2.13 ^{Aa}				
		165.27±4.13	2.06±0.06 ^a			
		II	8 : 1	0.90±0.03	2.47±0.12 ^{ab}	
		74.53±6.17 ^{ABb}				
		163.16±10.24	2.19±0.09 ^{bc}			
		III	10 : 1	0.90±0.03	2.43±0.08 ^b	
		73.29±3.30 ^{Bb}				
		164.53±3.81	2.25±$0.08c			

2.2.2 Effects of feed pellet diameter on broiler growth performance

As can be seen from Table 5, except for group VI, which was fed in phases, with increasing feed pellet diameter, there were no significant differences among groups in final body weight, average daily gain, or average daily feed intake

($P > 0.05$), but final body weight and average daily gain showed a gradually increasing trend, while the feed-to-gain ratio showed a gradually decreasing trend. After phased feeding, the final body weight, average daily gain, average daily feed intake, and feed-to-gain ratio of broilers in group VI did not differ significantly from those of the other groups ($P > 0.05$). The feed-to-gain ratio of group III was higher than those of the other groups and was significantly higher than that of group V ($P < 0.05$). The above experimental results indicate that, compared with 3 mm-diameter pellet feed, 4 mm-diameter pellet feed has a better feeding effect.

Table 5 Effects of pellet diameters of feed on growth performance of broilers

Groups	Pellet diame-ter/mm	IBW/kg	FBW/kg	ADG/g	ADFI/g	F/G
III	3.0	0.90$±0.03	2.43±0.08	73.29±3.30	164.53±3.81	2.25±$0.08a
IV	3.5	0.91$±0.02	2.51±0.09	76.13±4.65	165.64±7.14	2.18±$0.12ab
V	4.0	0.90$±0.02	2.52±0.08	77.23±3.99	164.77±7.08	2.13±$0.05b
VI	3.0, 4.0	0.90$±0.06	2.49±0.15	75.64±4.64	166.54±8.57	2.20±$0.08ab

3 Discussion

3.1 Effects of ring-die die-hole parameters on the processing quality of pelleted feed

Hardness is an important indicator of the appearance quality of pelleted feed; it is directly related to the pulverization rate and feed utilization rate. How to regulate the hardness of feed pellets is a problem that some manufacturers and scientific researchers are actively exploring[7].

In this experiment, marked changes in feed-pellet hardness were produced by changing the die-hole length-to-diameter ratio and diameter. When the die-hole diameter was unchanged, the smaller the die-hole length-to-diameter ratio, the lower the pressure during pelleting; the material was more easily extruded in the die hole, production rate was higher, but hardness was lower and the pulverization rate was higher[11]. Conversely, the larger the die-hole length-to-diameter ratio, the less easily the material was extruded from the hole; production rate was lower, the pellets were harder, and the pulverization rate was lower. When the die-hole length-to-diameter ratio was unchanged, feed-pellet hardness increased with increasing die-hole diameter. This is consistent with the views obtained by Yu Cuiping et al.[12] in their study on quality control of pelleted feed. The possible reason is that, under a given die-hole length-to-diameter ratio, the interparticle forces, degree of adhesion, and bulk density among raw-material particles in large-diameter pelleted feed are the same as those in small-diameter pelleted feed; however, at the same length, the amount

of raw material contained is greater, thereby increasing the overall adhesion and hardness of a single pellet. A large number of studies have shown that PDI is positively correlated with pellet hardness. In this experiment, because pellet hardness was relatively high, PDI was relatively high and averaged above 95%; therefore, there were no significant differences among groups, but the trend of change was consistent with previous studies.

3.2 Effects of feed-pellet hardness on broiler growth performance

For livestock and poultry feeds, feed pellets should have sufficient hardness to ensure a low pulverization rate, thereby reducing losses during transport and storage[13]. Adjusting the die-hole length-to-diameter ratio can produce pelleted feeds with different hardness. Feed-pellet hardness has a certain degree of influence on the digestibility of nutrients and the growth performance of broilers. Some studies suggest that, within a certain range, increasing feed-pellet hardness promotes broiler growth performance; this may be because increasing feed-pellet hardness reduces the pulverization rate, thereby improving feed utilization. However, excessively high feed-pellet hardness instead reduces feed palatability and digestibility[9]. This indicates that feed-pellet hardness must be controlled within a reasonable range to achieve the best feeding effect. In terms of the broiler' s own structure and digestive characteristics, there are no teeth in the oral cavity, the salivary glands are underdeveloped, and the crop functions to store food temporarily and secrete fluid to soften the feed. Broilers have a small glandular stomach, and food remains in it for a relatively short time[14]; therefore, the time available for feed to be decomposed and digested before entering the small intestine is very limited. Pellets with high hardness may be less easily softened and decomposed by the digestive tract, thereby limiting the efficiency of nutrient absorption in the intestine and causing a decline in broiler growth performance. In this experiment, compared with the other feeds, the feed with the best feeding effect showed no significant difference in PDI but had lower hardness. This is similar to previous research results. It indicates that, provided that PDI is sufficient, appropriately reducing pellet hardness can improve broiler growth performance. According to GB/T 16765-1997 *General Technical Requirements for Pelleted Feed*, the pulverization rate of broiler feed should be $ $10%, that is, PDI should be $ $90%. At present, there are few studies and reports on the effects of changes in feed-pellet hardness on broiler growth performance; therefore, the patterns of influence and the specific causes remain to be further explored.

3.3 Effects of feed-pellet diameter on broiler growth performance

Through studies on the development of the digestive tract and the characteristics of nutrient digestion and absorption in young chickens, Xi Xingui et al.[15] concluded that the improvement in digestive capacity of young chickens is very rapid, and that the digestibility of starch at 21 days of age is higher than 85%. This indicates that the digestive system of broilers aged 22–42 days is basically

fully developed and can digest and absorb nutrients in feed relatively sufficiently. Therefore, compared with indicators such as starch gelatinization degree, the size of feed pellets at this time may have a more significant effect on their growth performance.

An appropriate feed-pellet size is beneficial to the development of the chicken gastrointestinal tract, improves feed utilization, and thereby enhances growth performance[16]. In an experiment on the effects of pelleted feeds of different lengths and diameters on broiler growth performance, Abdollahi et al.[17] found that the feed-to-gain ratio of broilers aged 22–42 days in the group fed pelleted feed with a feeding diameter of 4.76 mm was significantly lower than that of the group fed pelleted feed with a diameter of 3.00 mm; subsequent repeated experiments[18] also obtained similar results. However, in the experiment of Tan Qun et al.[4], pelleting with a 3 mm die-hole diameter increased broiler average daily gain by 5.0% compared with pelleting with a 4.8 mm die-hole diameter, and reduced the feed-to-gain ratio by 4.5%. In the present experiment, when the die-hole length-to-diameter ratio was unchanged, the feed-to-gain ratio of the 4 mm die-hole-diameter group was significantly lower than that of the 3 mm die-hole-diameter group; this is consistent with the results of Abdollahi et al.[17]. After group VI was fed in stages, broiler growth performance was between that of the 3 and 4 mm die-hole-diameter groups, and the differences compared with the two groups were both

not significant. The above experimental results indicate that, under certain conditions, appropriately increasing pellet diameter can improve broiler growth performance, but feeding by different phases had no significant effect. This result differs from the findings of Wang Weiguo[13] and Tan Hequn et al.[4]; this may have been caused by interactions between hardness or other processing conditions (such as conditioning temperature, particle size of the ground raw materials, moisture content, etc.) and feed pellet diameter. A large number of trials have shown that changing processing conditions likewise has significant effects on broiler growth performance.

4 Conclusion

During the ring-die pelleting process, when the die-hole diameter remained unchanged, pellet hardness increased extremely significantly as the length-to-diameter ratio of the die hole increased; when the length-to-diameter ratio of the die hole remained unchanged, pellet hardness increased extremely significantly as the die-hole diameter increased.

An increase in pellet hardness within a certain range led to decreases in final body weight and average daily gain of broilers, and an increase in feed-to-gain ratio. Therefore, provided that PDI $\geq$ 90% is ensured, feeds with relatively lower pellet hardness should be selected for feeding.

Appropriately increasing feed pellet diameter had an improving effect on broiler growth performance, but the effect of phase feeding was not obvious. Moreover,

because using a ring die with a larger hole diameter can relatively reduce equipment energy consumption and improve production efficiency, this experiment suggests that a ring-die diameter of 4 mm is appropriate for the production of pelleted feed for broilers.

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Effects of Ring Die Parameter on Pellet Quality and Growth Performance of Broilers

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Abstract: This experiment was conducted to study the effect of ring die parameter on pellet quality and growth performance of broilers. By fixing the diameter of die hole (3 mm) and changing the length-radial ratio of die hole (6:1, 8:1 and 10:1), fixing length-radial ratio of die hole (10:1) and changing diameter of die hole (3.0, 3.5 and 4.0 mm) to produce 5 kinds of pellets feed with different diameter and hardness. A total of 864 broilers with similar body weight were randomly allocated into 6 groups with 8 replicates per group and 18 broilers per replicate. Broilers in the groups I to V were fed the pellet feed which the diameter and length-radial ratio of die hole were 3.0 mm and 6:1, 3.0 mm and 8:1, 3.0 mm and 10:1, 3.5 mm and 10:1, 4.0 mm and 10:1, respectively; broilers in the group VI were fed the pellet feed which the diameter and length-radial ratio of die hole were 3.0 mm and 10:1 at 22 to 35 days of age, and 4.0 mm and 10:1 at 36 to 42 days of age. The experiment lasted for 21 days. The results showed as follows: 1) in the same diameter of die hole, the pellet hardness was significantly increased with the length-radial ratio of die hole increased ($P<0.01$). In the same length-diameter ratio of die hole, the pellet hardness was

significantly increased with the diameter of die hole increased (P<0.01). There was no significant difference on pellet durability index (PDI) among all groups (P>0.05), and all PDI was hi

greater than 95%. 2) At the same die-hole diameter, as pellet hardness increased, final body weight and average daily gain decreased, whereas the feed-to-gain ratio increased. The final body weight and average daily gain of group I were significantly higher than those of group III ($P < 0.05$ or $P < 0.01$), and the feed-to-gain ratio of group I was significantly lower than that of groups II and III ($P < 0.05$). 3) At the same length-to-diameter ratio of the die hole, there were no significant differences among all groups in final body weight, average daily gain, or average daily feed intake ($P > 0.05$). The feed-to-gain ratio decreased as the die-hole diameter increased, and the feed-to-gain ratio of group III was significantly higher than that of group V ($P < 0.05$). In conclusion, the length-to-diameter ratio and diameter of the die hole can significantly increase pellet hardness. Within a certain range, increasing pellet hardness can reduce final body weight and average daily gain and increase the feed-to-gain ratio, whereas increasing pellet diameter can decrease the feed-to-gain ratio.

Key words: ring die parameter; broilers; pellet feed; processing quality; growth performance

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Note: Figure translations are in progress. See original paper for figures.