Performance and digestive function of broiler chickens given grit in the diet

Short title: Grit and broiler performance

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Abstract 1. A series of experiments were carried out to study the effect of grit on broiler performance, gizzard development and fate of grit in the digestive tract.

2. In Experiment 1, performance, gizzard weight and content of grit in the gizzard of broiler chickens given access to granite-type grit was investigated, while in Experiment 2, the effect of grit stones on performance and gizzard development was assessed in diets with or~~and~~ without whole wheat.

3. In Experiment 3, the effect of grit in the form of zeolite, granite or marble on gizzard development and digestive tract grinding and passage wa~~a~~s studied in diets with or~~and~~ without whole wheat.

4. Grit stones had no effect on performance of broiler chickens, which may be explained by the fact that grit stones did not stimulate gizzard development to the same extent as with other structural materials.

5. The lack of stimulation is at least partly due to the fact that a majority of the grit stones eaten pass through the small intestine without being retained in the gizzard.

6. Grit in the form of marble reduced feed intake and weight gain.

Key words: gizzard function, particle size, digestive tract passage, whole wheat, granite grit

Introduction

The beneficial nutritional effects of stimulating gizzard development through dietary structural components such as hulls, wood shavings or large cereal particles are~~is~~ now well established. The improvement in nutrient digestibility has been linked to finer grinding of particles ((Hetland *et al.*, 2002, 2003; Amerah *et al.*, 2009), improved digestion in the gizzard due to a longer retention time and a lower pH (Svihus, 2011), and a higher secretion of digestive enzymes from the pancreas (Husveth *et al.*, 2015). Other hypotheses~~factors~~, such as improved synchronization of material flow from the anterior digestive tract to the small intestine, remains interesting but speculative~~ hypotheses~~. The gizzard reacts very rapidly to structural material. Thus, Biggs and Parsons (2009) observed a large increase in gizzard size already by~~at~~ 7 d of age when whole wheat was added to the diet of day-old broiler chickens.

In the wild, many bird species~~s will~~ consume small stones to aid grinding in the gizzard. In a survey where~~of~~ 1440 gizzards from 90 American bird species were examined, grit stones were found in the gizzard of 69% of the species, with highest prevalence for galliformes (Gionfriddo and Best, 1996). For example, all the 37 gizzards from ring-necked pheasants contained grit stones, with the median number~~ amount~~ of stones being as high as 88 and average diameter being 2.3 mm. Similarly, Norris *et al.* (1975) found the gizzard of wild ptarmigans to contain an average of more than 100 gizzard stones during the fall. As discussed extensively by Gionfriddo and Best (1999), grit stones appear to be very important for a complete digestion in many wild birds.

Early data showed a clear beneficial effect of insoluble grit stones on performance of both broiler chickens and layer hens, particularly when whole grains were used in the diet (Balloun and Phillips, 1956; Scott and Heuser, 1957; Oluyemi *et al.*, 1978). More recent experiments, however, have generally failed to detect any beneficial effects of access to grit stones on performance of either layers or broiler chickens, even when whole cereals were included in the diet (Svihus *et al.*, 1997; Waldenstedt *et al.*, 1998; Jones and Taylor, 1999; Bennett and Classen, 2003; Hetland *et al.*, 2003; Silva Jr. *et al.*, 2003; Garipoglu *et al.*, 2006; Schneider *et al.*, 2016). The exception is Evans *et al.*, (2005), who observed improvements in nutrient availability when layers were fed zeolite grit stones, and Adeniji (2010), who observed improvements in feed efficiency and nutrient retention. Hetland *et al.* (2003) observed a significantly reduced duodenal particle size when grit stones were used, corroborating the results of Evans *et al.* (2005). These conflicting data on effect of grit stones may have a number of causes, for example the physical characteristics of the grit stones.

Due to the fact that the size of the grit stones has often not been reported, there is lack of data on the effect of size. When reported, ~~a~~ sizes between 1 and 3 mm dominated (Waldenstedt *et al.*, 1998; Adeniji, 2010; Bale-Therik *et al.*, 2012; Garipoglu *et al.*, 2006; Svihus *et al.*, 1997) except in the work by Schneider *et al.* (2016), where grits were 0.4 to 1 mm. The source of grit stones may also influence the results. In older reports, no clear effect of source of grit stones, such as granite, feldspar and limestone, was~~ere~~ observed (Balloun and Phillips, 1956; Scott and Heuser, 1957), but it would be logical to assume that both hardness of the grit and mineral composition could have an effect. Thus, Jones and Taylor (1999) reported poorer results with limestone than with granite grit. This could both be due to a softer structure~~,~~ and ~~due to~~ disturbance in mineral balance caused by the high calcium content.

Since grit stones are considered important for particle degradation in the gizzard of wild birds (Gionfriddo and Best, 1999), another cause for variable effects could be diet structure. However, none of the studies where diet structure was included as a factor was~~ere~~ able to demonstrate an interaction between extent of grinding of the cereal component of the diet, and effect of grit stones (Svihus *et al.*, 1997; Waldenstedt *et al.*, 1998; Jones and Taylor, 1999; Bennett and Classen, 2003; Hetland *et al.*, 2003; Silva Jr. *et al.*, 2003; Garipoglu *et al.*, 2006; Adeniji, 2010; Schneider *et al.*, 2016).

The contention of the fundamental role of grit stones (Giofreddo and Best, 1999), the recent awareness of the importance of structural components, and the conflicting results in regards to the effect of grit stones, were~~as~~ the motivation for carrying out a series of experiments with grit stones. In addition to testing the hypothesis that grit stones from various sources would improve performance and nutrient digestibility in a similar way as other structural components, the fate of grit stones in the digestive tract was studied.

Materials and methods

Experiment 1

Eighty day-old unsexed broiler chickens (Ross 308) were allocated randomly to each of 8 floor pens covered with wood shavings. Each pen contained either an automatic bell drinker or nipple drinkers with drip cups and a plastic bucket plate feeder. Birds were given *ad libitum* access to water and a commercial (Felleskjøpet, Kambo, Norway) ~~pelleted~~ starter (1 to 10 d of age) and~~,~~ grower ~~(10 to 21 d of age) and finisher~~ diet ~~(21 to 30 d of age)~~ based on wheat and soy bean meal, with nutrient composition as shown in Table 1 ~~(composition not shown)~~.

Birds in 4 of the pens were given granite grit (730 g/kg silica oxide and 130 g/kg aluminium oxide, Franzefoss, Vinterbro, Norway) from 4 d of age. The grit was sieved to a size between 1.6 to 3.6 mm, with the majority of particles in the upper size range (Figure 1). A total of 15 g grit per bird was provided on plates placed on the floor, with 1.9 g at d 4 and the remainder equally divided between 7, 9 and 11 d of age. At 18 d of age, the plates were removed. Feed intake and weight gain was recorded at 10, 21 and 28 days of age~~regularly~~.

At 10, 21 and 28 d of age, 6 birds were randomly selected from each of the 4 pens given grit stones. The birds were killed by cervical dislocation, and contents from the gizzard was collected quantitatively. Contents from each pen were pooled before further analysis. At 30 d of age, birds were sent to a commercial slaughter facility. Birds from the two different treatments were slaughtered separately, allowing for collection of 208 randomly selected gizzards from each treatment. These gizzards were cleaned and weighed individually.

The birds in this experiment as well as in Experiment 3 were cared for according to the laws and regulations governing experiments with live animals in Norway (the Animal Protection Act of December 20, 1974, and the Animal Protection Ordinance concerning experiments with animals of January 15, 1996).

Experiment 2

A growth performance experiment was carried out with broiler chickens held in floor pens (1.58 x 1.16 m). The pens were placed in four centred rows along the entire length of a ~~were carried out in a~~ commercial chicken house holding 9000 birds of the same age as those in the experiment (Specialist Laboratory of Piast Group in Olszowa, Poland). A total of 624 day-old female Ross 308 chickens were randomly distributed among 4 dietary treatments using 13 replicate pens per treatment and 12 birds per pen. Wheat straw was used as bedding material. The dietary treatments consisted of a diet with or without whole wheat and with or without grit stones added in a 2 x 2 arrangement. The diet was ~~a wheat/maize-based diet~~ produced by Piast Pasze factory (Lewkowiec, Poland) where all the wheat either was ground in a hammer mill ~~prior~~through a 10 mm sieve prior to pelleting, or where 60 to 80 g/kg wheat added postpelleting replaced ground wheat added pre-pelleting (Table 21). Diets were pelleted at 80ºC and were fed *ad libitum* throughout the experiment.

Birds either had no access to grit stones, or were given 3 g grit stones of a smaller size per bird on the 4th d of life and 7 g grit stones of a larger size on the 7th d of life. The grit stones were of a granite grit type (Kruszywa-Margo, Wroclaw, Poland). The smaller stones were between 1 and 4 mm in size (750 g/kg were smaller than 2.5 mm), while the larger ones were between 2 and 7 mm (830 g/kg were in the range 4 to 7 mm).

The birds had 23 h light and 1 h darkness during the first week and then 19 h light and 5 h darkness from d 7 to 21. From 22 to 42 d of age, there was 23 h light and 1 h darkness. Birds and feed were weighed on day 11, 21, 35 and 41regularly, and mortality and weights of dead birds were recorded twice daily. At termination of the experiment, 10 randomly selected birds per pen were killed by stunning followed by cervical dislocation, gizzard was excised and cleaned for surrounding fat, and weighed prior to pH measurement of contents.

This study was carried out in strict accordance with the recommendations of the National Ethic Commission (Warsaw, Poland). All procedures and experiments complied with the guidelines and were approved by the Local Ethic Commission of the Poznań University of Life Sciences (Poznań, Poland) with respect to animal experimentation and care of animals under study, and all efforts were made to minimize suffering.

Experiment 3

Five d old male broiler chickens (Ross 308) which had been raised in pens with wood shavings and with *ad libitum* access to a commercial starter diet, were placed 4 per cage in 48 cages (depth 35 cm x width 50 cm x height 20 cm) with wire-mesh floor. Birds were randomly selected, but very small birds as detected by individual weighing, were excluded. They were given *ad libitum* access to water and a commercial (Norgesfôr, Råde, Norway) ~~pelleted~~ starter (1 to 11 d of age) and grower ~~(11 to 18 d of age)~~ diet based on wheat and soybean meal, with nutrient composition as shown in Table 1 ~~(composition not shown)~~. Room temperature the first week was approximately 28℃, and extra heating was provided by heat lamps so that temperature in the cage was above 30℃. Room temperature was reduced to 22℃ over the three following weeks, while lighting was continuous throughout the experiment.

Twelve cages were allocated to each of four treatments consisting of different grit addition regimes. In the control treatment no grit was added, while one out of three different types of grit was provided in the other cages. The zeolite grit had a size range from 1 to 2.5 mm (Zeozem, Bystré, Slovakia, 690 g/kg silica oxide, 130 g/kg aluminium oxide) ~~(13 percent)~~, the granite grit had a size range from 2 to 3.5 mm (Sibelco, Modum, Norway, 800 g/kg silica oxide, 100 g/kg aluminium oxide), and the marble grit had a size range from 0.5 to 2.0 mm (Visnes Kalk AS, Lyngstad, Norway, 900 g/kg calcium carbonate). Grit were given on top of the feed, with 2 g given per bird at 5 d of age and 3.75 g given per bird on 7 and 9 d of age. At 5, 11, 13 and 18 d of age, birds and feed were weighed. Feed residues were sifted to recover remaining grit stones when relevant. From 18 to 21 d of age, a starter diet diluted with 150 g/kg whole wheat was given. In addition, 1 g of grit per bird per day were added on top of the feed.

One randomly selected bird from each cage was weighed and killed by cervical dislocation at 13, 18 and 21 d of age. The gizzard was removed, weighed full after removing excessive fat, and the contents were collected quantitatively and weighed, before freezing at -20 ℃. Excreta was quantitatively collected and immediately frozen once per day from trays under each cage in the periods 5 to 11, 11 to 13, 13 to 18 and 18 to 21 d of age. At 21 d of age, 6 birds per treatment in separate cages were starved for 12 h and were then given *ad libitum* access to whole wheat. After 2 h, feed was taken away and clean trays were placed under the cages. Five h after commencement of feeding, the birds were killed by cervical dislocation and contents from the whole digestive tract excluding the caeca, as well as excreta content in the trays, were collected.

Analyses

To measure pH of the gizzard content, the probe of a pH-meter (VWR pH100 in Norway, VWR pHenomenal pH 11001 in Poland) was inserted into the contents immediately after thawing. Dry matter of feed, excreta and gizzard content were determined by drying at 105 ± 2°C overnight. Whole wheat kernels were picked out manually from digestive tract content and excreta of birds given whole wheat at 21 d of age, by soaking the sample in excess water overnight, followed by gentle rinsing and thereafter drying of the whole wheat. Apparent metabolisable energy (AME) based on feed intake and excreta production between 13 to 18 and 18 to 21 d of age was determined using a Parr 6400 bomb calorimeter (Parr, Molina, US).

To separate the grit from the gizzard content and excreta, the material was emptied into a ceramic bowl and held under a slow-running faucet with a constant flow under agitation, so that low density particles floated and flowed out of the bowl. The remaining heavy-density grit particles were dried at 105 ± 2°C overnight before weighing. For calculation of grit content in excreta, the content for cages where grit was given was corrected for weight of residues after carrying out the procedure on excreta from cages where grit was not provided. To determine particle size distribution, excreta was soaked in water for 10 minutes while stirring, and where then wet-sieved in a Retsch sieve shaker (AS 200 Control) for 2 min while shaking at an amplitude of 1.50/s and with running water flowing through from the top, followed by 1 min without water added. The contents were then weighed, and representative samples were collected for dry matter determination. Thereafter, the material on each sieve was washed as described above to measure grit content. The particle size of excreta was corrected for weight of grit stones.

Data in Experiment 1 and 3 ~~and~~ were subjected to a one-way ANOVA and data in Experiment 2 were subjected to a two-way ANOVA (grit stone × diet), followed by pair-wise comparisons using the Ryan-Einot-Gabriel-Welsh procedure (Experiment 1 and 3) or Duncan's multiple range test where relevant, with $P < 0.05$ as the significance level (SAS Institute, 2006).

Results

Experiment 1

Performance was not affected by grit (Table 3~~2~~). Mortality was low for both treatments, and was not affected by grit (3.1 vs 2.5%). Weight of the gizzard increased ($P<0.05$) by provision of grit (Table 3~~2~~). Gizzards contained considerable amounts of grit stones both at 10 (2.6 g), 21 (4.8 g) and 28 (3.3 g) d of age. At 10 and 21 d of age, the grit stones constituted 37% of the DM in the gizzard, while this proportion was reduced to 21% at 28 d of age (data not shown). The amount of grit in the gizzards varied considerably, but never exceeded 4, 8 and 9 g at 10, 21 and 28 d, respectively. As shown in the figure, grit stones in the gizzard were generally smaller than those fed. Counting of grit stones revealed that the average number~~amounts~~ of grit stones were 161, 231 and 140 per gizzard at 10, 21 and 28 d of age (data not shown). Ample amounts of grit were~~as~~ also observed in the gizzards assessed at 30 d of age.

Experiment 2

As shown in Table 43, performance was not affected by grit stones, and neither were there any interaction effects due to the provision of whole wheat detected. However, provision of whole wheat resulted in an improvement in feed efficiency. Mortality was below 2%, and with no apparent effect of treatments. Gizzard weight increased when whole wheat was used (P<0.05), but was not affected by grit (Table 43). Gizzard pH was not affected by treatment.

Experiment 3

As shown in Table 54, grit in the form of zeolite or granite did not affect performance of the birds, while grit in the form of marble resulted in a reduced feed intake and weight gain (P<0.05). Grit had no effect on AME, neither in the period 18 to 21 d of age, when the diet contained 15 % whole wheat. Grit did not affect gizzard characteristics, apart from a higher relative weight of gizzard content at 13 d of age for the granite grit compared to the zeolite and marble grit treatment.

As shown in Table 65, birds ate less of the marble than of the other types of grit (P<0.05). The amount of grit in the gizzard was higher for granite than for zeolite and marble, and was also higher for zeolite than for marble at 13 d of age (P<0.05). A large portion of the grit consumed passed through the digestive tract and was recovered in the excreta, with the highest proportion recovered in the excreta between 5 and 11 d of age (Table 54). Less marble was recovered in the excreta than the other grit types, and this combined with small quantities recovered in the gizzard, resulted in a higher proportion of grit unrecovered between 5 and 18 d of age than for the other types of grit (P<0.05). Due to a higher amount of grit in the gizzard, granite grit had a lower proportion of grit unrecovered than the zeolite grit

(P<0.05). Sieving of the recovered grit in the excreta revealed a particle size distribution similar to the particle size of the grit fed (data not shown). Only small differences were found in excreta particle size distribution as affected by grit (Table 65). Granite grit resulted in a higher proportion of large particles and a lower proportion of small particles in excreta collected between 11 and 13 d of age than when no grit or marble was used (P<0.05). Also for excreta collected between 18 and 21 d of age, the proportion of large particles were higher with granite than with the other treatments (P<0.05).

As shown in Table 76, birds adapted to zeolite or granite grit tended to consume more whole wheat, resulting in a larger amount of whole wheat in the crop at time of killing (P<0.05). Apart from that, grit did not have any significant effects on the ability of the birds to handle large amounts of whole wheat.

Discussion

Despite the prominent role of grit stones in wild birds (Gionfriddo and Best, 1999), and the fact that broiler chickens consume significant amounts of grit stones when offered, the performance results as well as AME data indicate that grit stones do not improve performance. The hypothesis was that grit stones would be beneficial through facilitating gizzard development and the grinding of feed particles. Thus, the fact that the grit stones in many cases failed to stimulate gizzard development or gizzard pH and did not have any detectable effect on excreta particle size, seems to indicate that this hypothesis must be rejected. Hetland *et al.* (2003) did observe less large particles in the duodenum of broilers given granite grit. As particles entering the duodenum is a more nutritionally relevant measure of grinding, particle size as measured in excreta may have been inadequate. It is also possible that the method for correction for grit stones in excreta may have confounded the results. However, if the grit stones had facilitated grinding, an effect on AME would have been expected, not the least when whole wheat was added to the diet.

Beneficial effects of structural components observed previously have~~s~~ been linked to a considerable stimulation of gizzard size and a significant reduction in gizzard pH. For example, Svihus (2011), reviewing the literature, showed that size of the gizzard as an average increased nearly 50% by addition of oat hulls, and that structural components resulted in a significant reduction of gizzard pH. In the current experiments, either no increase or a moderate increase of 9% (Experiment 1) was observed, and no effect on gizzard pH was observed. A considerable enlargement of the gizzard of between 20 and 30% has been observed before (Hetland *et al.*, 2003; Garipoglu *et al.*, 2006). Thus, it is possible that environmental factors or the characteristics of the grit may have had an influence in unknown ways. One such interacting effect could be the coarseness of the diet. However, grit stones did not interact with structure as observed in Experiment 2, and neither was any significant effects observed for grinding of whole wheat in Experiment 3. This is in accordance with earlier experiments, which have failed to detect any interactions between diet structure and grit use (Hetland *et al.*, 2003; Adeniji, 2010).

The marble grit used in Experiment 3 impaired feed intake and thus weight gain. A negative effect of grits such as marble containing large amounts of calcium has been observed before (Scott and Heuser, 1957). A logical explanation for such a negative effect is disturbance of calcium balance. A negative effect through an increase in gizzard pH could also be expected, but no such effect was observed in the current experiment.

A careful quantitative assessment of fate of grit particles does not seem to have been carried out before in domesticated chickens, and the results reported here demonstrated that a large portion of the grit passed through the digestive tract without being ground~~inded~~ down in the gizzard. Vance (1971) demonstrated this mechanism in pheasants, and were able to recover 25 % of the grit stones in the excreta. In the current experiment, around two-thirds of the zeolite and granite grit stones consumed were recovered in the excreta. Although care was exerted to minimize error due to spilling of grit stones from the feeder (e.g. by excluding exposed and clean grit stones not embedded in excreta), such flaws cannot be excluded for the excreta collected between 5 and 11 d of age. In excreta collected after that, however, this potential source of error was eliminated, since the birds did not have access to grit and neither was able to peck on excreta. Thus, it can be concluded that a large portion of the grit stones eaten will pass through the digestive tract. For granite grit, only 10% of the grit seem to have been ground~~inded~~ down during the experimental period. As there was no conspicuous difference in size distribution between particles in the excreta and those fed, it seems that many grit particles will pass through the digestive tract without a considerable retention time in the gizzard. If so, this, combined with the fact that consumption of grit stones is moderate, may explain the lack of significant effect of grit stones on gizzard development and hence bird performance.

In conclusion, grit stones do not stimulate gizzard development in a similar way as other structural materials, and this may explain the lack of nutritional responses. The lack of stimulation is at least partly due to the fact that a majority of the rather moderate amount of grit stones eaten passes through the small intestine without being retained in the gizzard. Marble particles are not suitable as grit.

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Table 1. Calculated composition of the diet used at different ages in Experiment 1 and 3 (g/kg)[1]

	Starter Exp. 1	Grower Exp.1	Starter Exp. 3	Grower Exp. 3
Metabolisable energy (MJ/kg)1	12.3	11.9	12.2	12.4
Crude protein	235	192	228	215
Crude fat	68	67	72	75
Lys	13.2	11.3	13.8	12.6
Met	7.5	6.2	6.7	6.1
Ca	9.0	7.2	9.2	8.6
Total P	6.2	5.7	5.3	5.1

[1]A crumbled diet was used until 10 days of age, and thereafter a 3.5 mm pellet was used.

Table 2~~1~~. Composition of the diet used at different ages in Experiment 2 (g/kg)[1]

	1 to 10 d	11 to 21 d	22 to 35 d	36 to 41 d
Wheat[2~~1~~]	354.3	308.6	289.8	321.0
Maize	250.0	270.0	310.0	320.0
Soybean meal, 467 g CP/kg	232.5	113.1	114.3	73.8
Full fat extruded soya, 320 g CP/kg	63.1	70.0	60.0	60.0
Rapeseeds, 203 g CP/kg	20.0	25.0	25.0	30.0
Hemoglobin meal	17.6	9.1	4.8	10.5
Rapeseed expeller	15.0	100.0	100.0	100.0
Soybean oil	13.5	24.0	29.6	14.6
Lard	-	7.0	11.0	17.0
Soybean expeller	-	50.0	10.0	10.0
Rapeseed meal	-	-	25.0	29.7

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Minor ingredients[32]	34.0	23.2	20.5	13.4
Calculated composition:				
Metabolisable energy (MJ/kg)1	12.6	13.3	13.5	13.5
Crude protein	215.5	199.9	194.4	186.8
Crude fat	52.4	81.4	88.0	81.5
Lys	13.3	12.1	11.6	10.9
Met	6.3	5.5	5.2	4.9
Thr	9.1	8.2	8.6	7.7
Ca	7.0	5.5	5.0	3.0
Total P	6.9	5.5	4.6	4.4

[1]A crumbled diet was used until 10 days of age, and thereafter a 3.2 mm pellet was used

[21]Wheat ground through a hammer mill (2 mm sieve was used, except for in diet with whole wheat, where 60 and 80 g/kg whole wheat added after pelleting replaced ground wheat at 11 to 21 and 22 to 41 d, respectively.

[32]Vitamins, micro minerals, amino acids, salt, sodium bicarbonate, limestone, mono- and di-calcium phosphate and enzymes added according to commercial standards.

Table 32. Performance and gizzard weight in broiler chickens as affected by provision of grit. Experiment 1[1]

	No grit	Grit	√MSE	P-value
1 – 28 d of age				

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Feed intake, g per bird	2382	2365	34.0	NS
Weight gain, g per bird	1699	1702	33.1	NS
FCR (fFeed/gain)	1.40	1.39	0.017	NS
Gizzard weight, g[21]	21.9	23.8	3.29	<0.001

[1]Four replicates per treatment.

[21]Measured when slaughtering at 30 d of age.

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Table 43. Performance of 1 to 41 d old broiler chickens as affected by whole wheat (WW) and grit (GR) added to a control diet (C). Experiment 2[1]

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Treatments	P-values

	C	C+WW	C+GR	C+WW+GR	√MSE ~~SEM~~	Wheat	Grit
Feed intake, g	4440	4383	4405	4331	138.1~~19.2~~	0.089	NS
Weight gain, g	2774	2771	2747	2735	97.0~~13.1~~	NS	NS
FCR (f~~F~~eed/gain)	1.60	1.58	1.60	1.58	0.030~~04~~	0.008	NS
Gizzard weight[2~~1~~]	5.5~~4~~	6.3~~4~~	5.9~~88~~	6.3~~1~~	0.87~~75~~	0.030	NS
Gizzard pH[3~~2~~]	2.8	2.3	2.6	2.6	0.53~~28~~	NS	NS

[1]Thirteen replicates per treatment.

[2~~1~~]Gizzard with contents, g/kg body~~ird~~ weight.

[3~~2~~]Measured in gizzard contents.

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Table 54. Performance, apparent metabolisable energy (AME) and gizzard characteristics in broiler chickens given different sources of grit. Experiment 3[1]

	No grit	Zeolite	Granite	Marble	√MSE	P-value
5 – 18 d of age, per bird						
Feed intake, g	931[a]	955[a]	932[a]	876[b]	37.0	<0.001
Weight gain, g	748[a]	769[a]	754[a]	702[b]	35.6	<0.001
FCR F(feed/gain)	1.25	1.24	1.24	1.25	0.028	NS
AME						
13 – 18 d, MJ/kg DM	13.5	13.6	13.7	13.6	0.40	NS
18 – 21 d, MJ/kg DM	14.0	14.1	14.2	13.5	1.04	NS
Gizzard characteristics						
pH, 13 d	3.1	3.5	3.4	3.5	0.59	NS
pH, 18 d	3.3	3.6	3.6	3.1	0.80	NS
pH, 21 d	3.0	2.8	2.9	2.8	0.48	NS
Gizzard 13 d[21]	21.4	22.1	22.6	20.5	2.26	NS
Content 13 d[21]	13.4[ab]	12.4[b]	16.3[a]	11.4[b]	3.94	0.023
Gizzard 18 d[21]	15.6	15.8	15.5	16.1	2.56	NS
Content 18 d[21]	8.9	7.9	9.1	9.7	5.59	NS
Gizzard 21 d[21]	15.9	15.2	15.6	15.4	1.72	NS
Content 21 d[21]	8.2	8.6	9.4	7.3	2.12	NS

[1]Twelve replicates er treatment.

[21]Weight, g/kg bodyird weight.

[ab]Means within a row not sharing the same superscript are significantly different (P<0.05).

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Table 65. Fate of grit in the digestive tract and excreta particle size in broiler chickens given different sources of grit. Experiment 3[1]

	No grit	Zeolite	Granite	Marble	√MSE	P-value
Grit flow and grinding						
Intake/bird 5 - 11 d, g	-	9.3^{a}	9.3^{a}	5.8^{b}	1.12	<0.001
Grit in gizzard 13 d, g	-	0.9^{b}	3.1^{a}	0.0^{c}	0.575	<0.001
Grit in gizzard 18 d, g	-	0.1^{b}	1.6^{a}	0.0^{b}	0.937	<0.001
Excreta 5 - 11 d, g/g[21]	-	0.39^{a}	0.45^{a}	0.26^{b}	0.085	<0.001
Excreta 11 - 13 d, g/g[21]	-	0.18^{a}	0.12^{b}	0.20^{a}	0.062	0.006
Excreta 13 - 18 d, g/g[21]	-	0.07^{b}	0.10^{a}	0.00^{c}	0.042	<0.001
Unrecovered 5 - 18 d, g/g[32]	-	0.33^{b}	0.10^{c}	0.54^{a}	0.092	<0.001
Excreta particle size						
11 – 13 d of age						
> 1.4 mm, g/g	0.10	0.11	0.08	0.07	0.046	NS
1.4-0.8 mm, g/g	0.12^{b}	0.12^{b}	0.18^{a}	0.11^{b}	0.020	<0.001
0.8-0.5 mm, g/g	0.09^{a}	0.07^{b}	0.10^{a}	0.10^{a}	0.015	<0.001
0.5-0.2 mm, g/g	0.07^{b}	0.12^{a}	0.08^{b}	0.06^{b}	0.027	<0.001
< 0.2 mm, g/g	0.62^{ab}	0.58^{bc}	0.56^{c}	0.67^{a}	0.060	<0.001
13 – 18 d of age						
> 1.4 mm, g/g	0.11	0.12	0.08	0.10	0.041	0.0736
1.4-0.8 mm, g/g	0.13	0.14	0.15	0.13	0.032	NS
0.8-0.5 mm, g/g	0.10	0.11	0.11	0.11	0.025	NS
0.5-0.2 mm, g/g	0.08	0.09	0.10	0.09	0.032	NS
< 0.2 mm, g/g	0.58	0.54	0.56	0.58	0.104	NS
18 – 21 d of age						
> 1.4 mm, g/g	0.19	0.21	0.17	0.15	0.065	NS
1.4-0.8 mm, g/g	0.09^{b}	0.08^{b}	0.13^{a}	0.08^{b}	0.034	0.003
0.8-0.5 mm, g/g	0.10	0.10	0.10	0.09	0.034	NS
0.5-0.2 mm, g/g	0.14^{b}	0.22^{a}	0.15^{b}	0.14^{b}	0.042	<0.001
< 0.2 mm, g/g	0.48	0.40	0.45	0.53	0.145	NS

[1]Twelve replicates per treatment.

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[21]Amount grit in the excreta as proportion of grit eaten.

[32]Proportion of grit eaten for a cage not accounted for in either excreta or gizzard content. Content in the two remaining live birds at 18 d were estimated based on average content in killed birds within treatment.

[abc]Means within a row not sharing the same superscript are significantly different (P<0.05).

Table 76. Consumption and fate of whole wheat given to 21 d old broiler chickens adapted to different forms of grit. Experiment 3[1]

	No grit	Zeolite	Granite	Marble	√MSE	P-value
Intake	16.1	27.4	21.5	16.6	7.52	0.057
Amount in crop[21], g	2.3[b]	7.6[a]	4.4[ab]	1.4[b]	3.04	0.010
Amount in gizzard[21], g	2.6	2.9	1.3	2.2	1.02	0.069
Amount in intestines[21], g	0.1	0.1	0.1	0.0	0.15	NS
Amount in excreta[21], g	0.2	0.1	0.3	0.3	0.46	NS
Amount unrecovered[21], g	10.8	16.8	15.4	12.6	5.00	NS
Amount passed gizzard, g[21]	0.4	0.1	0.3	0.4	0.55	NS
Proportion grinded, g/g[32]	0.78	0.84	0.90	0.83	0.10	NS

[1]Six replicates per treatment.

[21]As intact kernels in birds starved for 12 hours, fed whole wheat for 2 hours and then killed 3 hours later.

[32]Amount of unrecovered intact kernels in proportion to amount passed the crop.

[ab]Means within a row not sharing the same superscript are significantly different (P<0.05).

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