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Influence of Feed Particle Size on the Efficiency of Broiler Chickens Fed Wheat-Based Diets

Roger G. Lentle, Velmurugu Ravindran, Ganesharanee Ravindran and Donald V. Thomas

Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand

In this study, we examined production efficiency in broiler chickens fed diets based on three wheat cultivars (Equinox, Regency and Claire) that resulted in different particle spectra ($P < 0.05$) on hammer milling to 4 mm, yet did not differ significantly in nutrient composition or non-starch polysaccharide content. The parameters evaluated in this 21-day feeding trial included weight gain, feed intake, feed conversion ratio, apparent metabolisable energy, transit time and relative losses of particle sizes of various classes during transit through the digestive tract. Weight gain, feed intake and apparent metabolisable energy were not ($P > 0.05$) influenced by the treatments. The mean transit time also did not differ significantly ($P > 0.05$) between diets, but the diet with the higher ($P < 0.05$) relative proportion of coarser particles and giving greatest ($P < 0.05$) reduction in the number of larger particles following digestion, resulted in the best ($P < 0.05$) feed conversion ratio in broiler chickens. The present data suggest that coarse feed particle size is advantageous in terms of feed efficiency in broilers fed wheat-based diets.

Key words : particle size distribution, wheat, feed conversion ratio, broiler chickens

Introduction

The importance of physical aspects of the diet in augmenting digestion and productivity is increasingly recognized in the broiler industry. Feed ingredients based on seeds, such as cereal grains and grain legumes, are subjected to some type of particle size reduction prior to incorporation into poultry diets. It is generally thought that smaller particles with an increased surface area will allow increased access to digestive enzymes and enhance digestion of nutrients (Waldroup, 1997). Limited research, however, have been carried out regarding the optimum particle size for different grains. In addition, it has not been easy to come to any definite conclusions regarding grain particle size reduction for poultry. Firstly, the influence of diet particle size appear to be confounded with the complexity of the diet, type of mill used (hammer mill versus roller mill) and further processing such as pelleting or crumbling (Goodband *et al.,* 2002). Secondly, it would appear that the grain type also influences the responses to feed particle size differences.

In the case of wheat, there is significant variation in the growth performance, apparent metabolisable energy (AME) and nutrient digestibility when diets based on different wheat cultivars are fed to broilers (Mollah *et al.,* 1983, Rogel *et al.,* 1987 ; Choct *et al.,* 1999 ; Wiseman, 2000 ; Ravindran *et al.,* 2001 ; Scott, 2004). This phenomenon has been attributed to the presence of significant concentrations of non-starch polysaccharides (NSP), which are thought to limit the efficiency of enzyme/substrate interaction (Annison, 1993 : Annison and Choct, 1991). Such limitation could either occur directly at the surface of the substrate by. insoluble and adherent NSP directly interfering with the interaction of enzyme and substrate or indirectly by soluble NSP increas-

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Correspondence to : Velmurugu Ravindran, Institute of Food, Nutrition and Human Health, Massey University, Private Bag 11 222, Palmerston North, New Zealand
Tel : +64 6 350 5528 Fax : +64 6 350 5684 E-mail : V.Ravindran@massey.ac.nz

ing the viscosity of the fluid phase of digesta and reducing its permeation though the solid phase of digesta. It is possible to test the relative contribution of direct and indirect effects of NSPs on digestive efficiency by assessing the changes in particle size spectrum following digestion. Digesta contains a heterogeneous array of particle sizes with smaller particles, coming to occupy the spaces between larger particles so as to reduce mean void space radius and thus permeability (Wise, 1952 ; Deresiewicz, 1958). Under such conditions a local increase in the numbers of larger particles may lead to a local increase in permeability. Similarly an aggregation of small particles may lead to a local decrease in permeability. The former effect may lead to more rapid permeation of digestive fluids through sites where there is a greater proportion of larger particles, and result in better digestive efficiency and improve bird performance. This was the hypothesis tested in the present study wherein the effect of differing particle size distributions of diets based on three wheat cultivars of similar nutrient composition was examined in terms of weight gain, feed conversion ratio (FCR), AME, transit time and relative losses of particles of various sizes following digestion.

Table 1. **Composition and calculated analysis (g/100 g as fed) of the basal diet**

Ingredient	
Wheat	65.923
Soybean meal	20.300
Meat and bone meal	8.000
Tallow	2.100
Soya oil	1.500
Biolysine, 65% lysine	0.370
DL Methionine	0.240
L-Threonine	0.072
Dicalcium phosphate	0.880
Salt	0.120
Sodium bicarbonate	0.120
Vitamin-trace mineral premix[1]	0.300
Xylanase[2]	0.075
Calculated analysis	
AME (MJ/kg)	12.38
Crude protein, %	22.6
Lysine, %	1.15
Methionine+cysteine, %	0.94
Calcium, %	1.09
Available phosphorus, %	0.45

[1] Supplied per kilogram of diet : antioxidant, 100 mg ; biotin, 0.2 mg ; calcium pantothenate, 12.8 mg ; cholecalciferol, 60 μg ; cyanocobalamin, 0.017 mg ; folic acid, 5.2 mg ; menadione, 4 mg ; niacin, 35 mg ; pyridoxine, 10 mg ; *trans*-retinol, 3.33 mg ; riboflavin, 12 mg ; thiamine, 3.0 mg ; dl-α-tocopheryl acetate, 60 mg ; choline chloride, 638 mg ; Co, 0.3 mg ; Cu, 3 mg ; Fe, 25 mg ; I, 1 mg ; Mn, 125 mg ; Mo, 0.5 mg ; Se, 200 μg ; Zn, 60 mg.

[2] Kemzyme, Kemin (Asia) Pte Ltd, Singapore.

Materials and Methods

Experimental procedures were approved by the Massey University Animal Ethics Committee and complied with the New Zealand Code of Practice for the Care and Use of Animals for Scientific Purposes.

Wheats and Diets

Grains from three wheat cultivars, namely Equinox, Regency and Claire (designated as Wheat A, B and C, respectively), from 2004 harvest season were obtained from commercial sources and ground in a hammer mill to pass through a 4-mm mesh. The basal diet was based on wheat and soybean meal (Table 1) and formulated to meet or exceed the NRC (1994) recommendations for major nutrients for broiler starters. Following mixing, all diets were cold-pelleted (70℃).

General Procedures

Day-old male broiler (Ross) chicks were obtained from a commercial hatchery and randomly assigned to 12 pens (8 birds/ pen) in 3-tier electrically heated battery brooders that were housed in an environmentally controlled room. Each of the three dietary treatments was randomly assigned to four pens of eight chicks each. The birds were transferred to colony cages in an environmentally controlled room on day 14. Room temperature was maintained at 32 ±1℃ during the first week and gradually decreased to 24℃ by the end of the third week. Twenty-four hour fluorescent lighting was provided throughout the trial. The diets were offered *ad libitum* and water was available at all times.

Body weights and feed intake were recorded on a pen basis at weekly intervals. Mortality was recorded daily. Any bird that died was weighed and the weight was included in weekly weight gain data and used to calculate the FCR. The trial lasted three weeks.

Determination of Transit Time

On Day 15, feed was withdrawn for two hours and diets containing 0.1% chromic oxide were offered for 15 min and the transit time was measured as described by Golian and Polin (1984). The transit time was determined as the time from the introduction of the diets to the first appearance of green-coloured excreta.

Collection and Processing of Samples

During the third week (days 17–21), feed intake and excreta output were measured quantitatively per pen over four consecutive days for the determination of AME. Excreta were pooled within a pen, mixed well using a blender and two representative wet sub samples taken per pen. One other sub-sample was stored at −20℃ pending particle size analysis. The other sub-sample was freeze-dried and subsequently ground to pass through a 0.5 mm sieve then stored in an airtight plastic container at −4℃ pending chemical analyses.

Determination of Particle Size Distribution in the Diet and Excreta

Particle size spectra in the diet and the excreta were determined by wet sieving according to the procedures of Waghorn (1986). The diets and frozen excreta were weighed and each was divided into two sub-samples. The sub-samples were assigned randomly to one of two subsequent procedures. The first was oven dried at 80℃ in a forced draft oven for 3 days to determine dry matter content and the second was wet sieved in a set of Endocot (London, U.K.) sieves of size 2, 1, 0.5, 0.25, 0.106 and 0.072 mm. The excreta samples were thawed and suspended in 50 m*l* of distilled water prior to sieving. The feed samples were similarly suspended in 50 m*l* of distilled water and left to stand for 15 min prior to sieving to ensure adequate hydration. Each sample was then washed though the sieves and the contents of each of the sieves subsequently washed onto a dried, pre-weighed filter paper. Samples of elute were retained for determination of soluble matter. Filter papers and samples of elute were then dried for 24 h in a forced draft oven at 80℃ before re-weighing. This entire procedure was repeated for each replicated excreta and feed sample.

The masses of particles from each sieve were expressed as percent of total dry matter recovered including solubles. The mean of the two replicates from sample was used in all subsequent calculations.

Chemical Analysis

The dry matter, nitrogen, crude fat, crude fibre, neutral detergent fibre and acid detergent fibre content of the three wheat cultivars were determined using standard procedures (AOAC, 1990). Starch content was determined using an assay kit (Megazyme, Boronia, VIC, Australia) based on the use of thermostable α-amylase and amyloglucosidase (McCleary *et al.* 1997). The total and soluble NSP were determined using an assay kit (Englyst Fiberzyme Kit GLC ; Englyst Carbohydrate Services Limited, Cambridge, U.K.), which is based on the procedures described by Englyst *et al.* (1994). Gross energy (GE) of the diets and excreta was determined using an adiabatic bomb calorimeter (Gallenkamp Autobomb, UK) standardised with benzoic acid.

Calculations

The FCR was calculated as unit of feed consumed per unit of weight gain. The AME values were calculated using the following formula. Appropriate corrections were made for differences in dry matter content.

$$\mathrm{AME(MJ/kg)} = \frac{(\text{Feed intake} \times \mathrm{GE_{diet}}) - (\text{Excreta output} \times \mathrm{GE_{excreta}})}{\text{Feed intake}}$$

Data Analysis

The performance and passage rate data were analysed as a completely randomised design using the General Linear Model procedure of the SAS® (SAS Institute, 1997). When a significant ($P < 0.05$) F-test was detected, the means were compared by Tukey's test. Particle size distributions were compared by multivariate (or discriminant) analysis in SYSTAT (Wilkinson, 1990). The technique is not fully efficient statistically because the discriminant function is optimal for normally distributed data, but nevertheless significant results indicate adequate discrimination and in this case the proportions are averaged so the central limit theorem applies. In multivariate analyses Wilks 'λ' provides a test of whether groups based on a character for discrimination are significantly different. '% correct' indicates the percentage correctly classified after suitable weighting for prior probabilities. 'Component loading' indicates the contribution of that standardised variable to the discriminant function, with higher values indicating greater importance.

Results

Nutrient Composition of Wheats

The nutrient composition of the three wheat

Table 2. **Composition of the three wheat cultivars[1] used in the study (g/100 g dry matter basis)**

	Wheat A	Wheat B	Wheat C
Dry matter	88.6	88.6	89.1
Crude protein (nitrogent × 5.89)[2]	11.8	12.4	11.9
Crude fat	2.1	1.9	2.0
Crude fibre	3.1	2.8	2.6
Neutral detergent fibre	12.6	13.0	13.4
Acid detergent fibre	4.0	3.6	4.1
Ash	1.7	1.2	1.1
Starch	58.9	60.2	61.8
Total NSP[3]	13.1	12.4	12.1
Soluble NSP[3]	2.7	2.1	2.4

[1] Wheat cultivars, A, Equinox ; B, Regency and C, Claire harvested in 2004.
[2] Tkachuk (1969).
[3] Non-starch polysaccharides.

Table 3. **Weight gain, feed intake, feed conversion ratio (FCR), apparent metabolisable energy (AME) and rate of passage of broiler chickens as influenced by diets based on different wheats[1,2]**

Diet type	Weight gain, g/bird	Feed intake, g/bird	FCR, g feed/g gain	AME, MJ/kg DM	Transit time, min[3]
Wheat A	878	1280	1.459[c]	12.45	141
Wheat B	903	1238	1.371[a]	12.66	149
Wheat C	880	1241	1.416[b]	12.69	153
Pooled SEM[4]	11.6	18.2	0.013	0.138	7.14
Statistics					
P value, P=	0.29	0.23	0.008	0.46	0.14

[a, b] Means in a column with different superscripts differ ($P<0.05$).
[1] Wheat cultivars, A, Equinox ; B, Regency and C, Claire.
[2] Values are means of four replicate pens (8 birds/pen).
[3] First appearance of green colour in the excreta after ingestion of respective wheat diets containing chromic oxide ; determined on Day 16 post-hatching.
[4] Pooled standard error of mean.

cultivars was similar (Table 2). Only minor differences were observed in the concentrations of total and soluble NSP.

Effects of Wheat Type on Performance, AME and Transit Time

The three wheat types had no significant ($P>0.05$) influence on the weight gains and feed intake of broilers, but the FCR was significantly ($P<0.01$) affected (Table 3). Feed conversion ratio of birds fed diets containing wheat B was lower ($P<0.05$) than those fed the other two wheats. Feed conversion ratio of birds fed diets containing wheat C was lower ($P<0.05$) than those fed Wheat A. The AME and the mean transit time of the diets were not influenced ($P>0.05$) by the type of wheat (Table 3).

Particle Size Analyses

Comparisons among diets

The results showed successful distinction ($P<0.001$) between the three feeds on a basis of the relative proportions in each particle size class (Table 4). Based on discriminant function 1, there was successful discrimination between diet C and the other two diets on the basis of the content of particles of all classes other than >2 mm. The discrimination was particularly evident in 1–2 mm and very fine (0.072–0.010 mm) classes (Figure 1). Thus diet C had lower scores than either diet A or B on the basis of higher content of 1–2 mm, 0.5–1 mm and 0.072–0.0106 mm particles.

Similarly there was successful discrimination between diets A and B (discriminant function 2) on a

Table 4. **Particle size characteristics of diets containing three wheat cultivars[1] hammer milled to pass through a 4 mm mesh**
[1] Wheat cultivars, A, Equinox ; B, Regency and C, Claire.

a) Proportion of particle size classes (mean±standard error) in the diets (on a dry weight basis)

Particle size class	Diet A	Diet B	Diet C
>2 mm	0.024±0.001	0.044±0.002	0.026±0.001
1–2 mm	0.292±0.012	0.375±0.030	0.300±0.005
0.5–1 mm	0.156±0.001	0.178±0.007	0.211±0.007
0.25–0.5 mm	0.092±0.004	0.084±0.002	0.092±0.004
0.106–0.25 mm	0.062±0.002	0.046±0.002	0.062±0.002
0.072–0.0106 mm	0.027±0.008	0.019±0.001	0.034±0.005
Solubles	0.348±0.006	0.245±0.012	0.275±0.004

b) Canonical discriminant functions[1] (standardised within variances)

Particle size class	Loadings	
	Function 1	Function 2
>2 mm	+2.354	+1.292
1–2 mm	−8.643	−0.390
0.5–1 mm	−5.000	+1.188
0.25–0.5 mm	−4.489	+0.025
0.106–0.25 mm	−1.957	−1.457
0.072–0.0106 mm	−6.620	+0.027
Solubles	0.000	0.000

Wilks' λ $F=136.0$; df_{12} ; $P<0.001$; Jack-knifed classification 90% correct.

[1] Canonical discriminant functions are a series of values derived by multivariate analysis which each is multiplied by the proportion of material in the corresponding particle size class. Thus in discriminant function 1, +2.354 is multiplied by the proportion in particle size class '>2 mm' in the sample, similarly −8.643 is multiplied by the proportion in particle size class '1–2 mm' in the sample and so on. The algebraically summed totals of all the values obtained from each discriminant function for each sample enable maximal discrimination between the groups the samples were drawn from ; in this case the wheat cultivar. Thus for example discriminant function 1 contrasts the proportion of material >2 mm with that between 1–2 mm so that a sample with a higher proportion of particles >2 mm and lower proportions of all other classes will tend to score with a higher positive value than a sample with the reverse distribution.

basis of the content of >2 mm plus 0.5–1 mm particles contrasted with that of 0.072–0.0106 mm particles (Figure 1). Diet B had greater content of >2 mm and 0.5–1 mm particles and lower content of 0.072–0.0106 mm sized particles than Diet A. Overall, diet B differed from the other two diets by having greater relative proportions of coarse particles and lower content of fine particles.

Comparison of particle size changes between feed and faeces (feed particle fraction - faecal particle fraction)

The results showed marked distinction between the effects of the three diets on the basis of relative reductions in the proportion of the various particle fractions (Table 5 and Figure 2). Thus discriminant function 1 contrasted the change in content of 1–2 mm feed particles with that of medium (0.5–1 mm) and fine particles (<0.25 mm) and solubles. Diet B had the lowest factor 1 score as it caused the greatest decrease in the proportion of 1–2 mm particles, the lowest increase in that of medium particles (0.5–1.0 mm) and highest increase in solubles.

Discussion

In the present study, the influence of three wheat cultivars known to differ in grain hardness, but determined to be not different in nutrient and NSP contents, on the performance of broiler chickens was investigated. Hardness in wheat grains is defined as the proportion of fine particles after milling, with grains with higher hardness yielding relatively

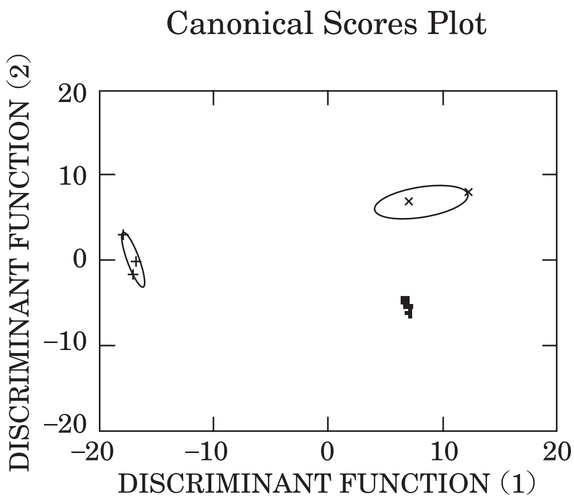

Fig. 1. **Graph of discriminant functions from comparison of mean proportion of various particle size classes of diets based on three wheat cultivars hammer milled to 4 mm screen size.** The scores derived from the two discriminant functions are plotted for each sample of wheat. The symbols indicate the type of wheat and the circles enclose all of the values from a given wheat cultivar. The lack of overlap between the circles indicates successful discrimination between wheat cultivars on a basis of particle size spectrum.
'O', Diet A (Equinox) ; 'X', Diet B (Regency) ; '+', Diet C (Claire)

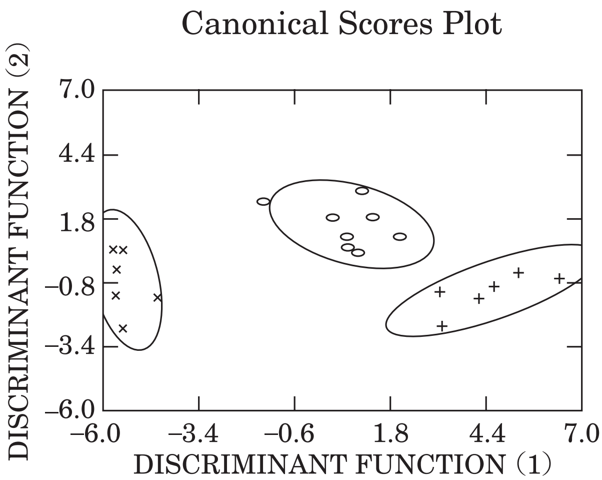

Fig. 2. **Graph of discriminant functions from comparison of changes in the proportion of various particle size classes in diets based on three wheat cultivars following digestion (Diet-excreta).** The scores derived from the two discriminant functions are plotted for each sample. The symbols indicate the type of wheat cultivar on which the birds were fed and the circles enclose all of the values from the differences between the particle size spectra of feeds and the excreta from birds fed a given wheat cultivar. The lack of overlap between the circles indicates successful discrimination on a basis of the change in particle size during digestion for particular wheat cultivars.
'O', Diet A (Equinox) ; 'X', Diet B (Regency) ; '+', Diet C (Claire)

lower proportion of fine particles (AACC, 1995). Owing to the differences in hardness, these three wheats resulted in different particle size spectra on hammer milling to pass through a 4 mm mesh. This spectra enabled the testing of the hypothesis that a greater proportion of coarser particles in feed will result in better efficiency in broilers. The results of the current study confirm our original hypothesis and show that whilst AME and transit time did not differ significantly between the three wheat types, the diet B with significantly higher content of coarse particulate matter resulted in significantly better feed efficiency. Published data on different particle sizes in wheat-based diets on broiler performance are scanty, but the present results are in general agreement with those of Nir *et al.* (1994) and Yasar (2003) in showing that the presence of greater proportions of coarser particles in wheat-based broiler feeds improved feed efficiency.

In the current study, we also compared the impact of the digestive processes on the various classes of particle size in the three diets by subtracting the masses of particles of various size classes in the faeces from those present in the diet. Whilst it is possible that a proportion of the finer particles in the faeces were indigestible residues from the digestion of larger particles, it is noteworthy that the change in relative proportions of the finest particles did not differ greatly between the diets and was not a major basis of discrimination in the analysis. The results of this comparison showed that the birds consuming the diet with the largest proportion of coarse particles had the best feed efficiency and also showed the greatest relative reduction in the number of large particles and the greatest increase in the proportion of solubles. On the basis of the reasoning outlined earlier this suggests that, in spite of the lower proportion of soluble NSP than insoluble NSP in all wheats, feed efficiency appears to be limited by indirect effects of NSP *via* permeation and pore size rather than by direct effects at the substrate surface.

There are a number of potential explanations for

Table 5. **Changes in mean proportion % of various particle size classes (dry weight) following digestion of diets based on three wheat cultivars[1] hammer milled to pass through 4mm mesh**
[1] Wheat cultivars, A, Equinox ; B, Regency ; C, Claire

a) Changes in the proportion of particle size classes (mean±standard error) between the diet and excreta samples (on a dry weight basis)

Particle size class	Diet A	Diet B	Diet C
>2 mm	+0.011±0.004[2]	+0.027±0.003	+0.013±0.003
1–2 mm	+0.203±0.010	+0.259±0.029	+0.182±0.009
0.5–1 mm	−0.058±0.008	−0.029±0.015	−0.029±0.007
0.25–0.5 mm	−0.047±0.005	−0.044±0.004	−0.025±0.005
0.106–0.25 mm	−0.017±0.003	−0.019±0.003	−0.001±0.006
0.072–0.0106 mm	+0.001±0.008	−0.005±0.002	+0.017±0.004
Solubles	−0.102±0.010	−0.198±0.026	−0.157±0.010

[2] Plus (+) sign indicates a decrease and minus (−) sign an increase in that particle size class.

b) Canonical discriminant functions[1] (standardised within variances)

Particle size class	Loading Function 1
>2 mm	+0.026
1–2 mm	−5.321
0.5–1 mm	+4.143
0.25–0.5 mm	+2.617
0.106–0.25 mm	+3.007
0.072–0.0106 mm	+2.636
Solubles	+6.475

Wilks' λ $F=9.99$; $df_7,14$; $P<0.0001$; Jack-knifed classification matrix 80% correct.
[1] For more detail on discriminant functions, see Table 4.

these findings. Firstly, that the greater proportion of coarse particulate matter led to longer residence time within the gizzard and small gut leading to more complete digestion and thus better feed efficiency. However this seems less likely given that there was no significant difference in the mean transit time among diets. Secondly, that the greater proportion of coarse particulate matter stimulated greater activity of the gizzard leading to more efficient grinding with production of greater quantities of finer particles that were more readily digested. This also seems unlikely given that there were no significant changes in the relative proportions of finer particles following digestion The third alternative is the converse of the second, that with greater requirement for action of the gizzard to reduce particle size, efficiency is reduced, a greater proportion of coarser material enters the small intestine and that this coarser particulate material in some way stimulates digestive efficiency and is itself digested more readily. The latter speculation is consistent with the recent research on the biophysics of digesta by Lentle *et al.* (2005 a, b) that nutrients within the solid phase are solubilised by alternate permeation and extrusion of digestive juices and soluble nutrients and that such permeation is aided by the presence of coarse particles particularly in a situation where the presence of NSPs may increase the viscosity of the liquid phase. Further work is warranted to determine which of these three hypotheses is plausible by determining the transit time and particle size changes in different segments of the gastrointestinal tract, and in the gizzard in particular.

In summary, in the present study, the wheat-based diet with the higher relative proportion of coarser particles and giving greatest reduction in the number of larger particles following digestion, had the best feed efficiency in broiler chickens. Viewed in the light of the relative scaling of factors that are known to affect permeability, this finding indicates that any adverse effects of NSP in wheat on digestion are likely to occur indirectly as a result of their influence on the permeation of digestive fluids through the solid phase of digesta, and could be ameliorated by higher proportions of coarser particles. Overall, the present data suggest that coarse feed particle size will be beneficial to improve feed efficiency in broilers fed wheat-based diets.

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