Effect of Cereal Type on the Performance, Gastrointestinal Tract Development and Intestinal Morphology of the Newly Hatched Broiler Chick

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The objective of this study was to determine the effect of cereal type on the performance and gastrointestinal responses of broiler chicks. Diets based on wheat, sorghum and maize, and formulated to contain similar levels of major nutrients, were fed to broiler chicks from days 1–14 post hatch. The wheat-based diet also contained a commercial xylanase at 0.075% level. Birds fed the maize-based diet grew faster ($P < 0.05$) than those fed the sorghum-based diet. Weight gains of birds fed the wheat-based diet did not differ ($P > 0.05$) from those fed either the maize- or sorghum-based diets. Birds fed the maize-based diet had the lowest and those fed the sorghum-based diet had the highest feed per gain, but the differences were not significant ($P > 0.05$). The treatments had no effect ($P > 0.05$) on gastrointestinal tract or intestinal morphometry measurements. Performance differences observed between birds fed maize- and sorghum-based diets were not related to gastrointestinal tract or intestinal morphology.

Key words: broiler chick, Cereal type, gastrointestinal tract development, performance

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Introduction

Composition of pre-starter diet can influence the subsequent growth and development of broiler chickens. Because of their immature digestive system, newly hatched chicks are less efficient in utilising nutrients and it is possible that they may benefit from diets based on easily digested cereals. Cereals are known to contain varying levels of non-starch polysaccharides (NSP) giving rise to differing viscosity levels in both the feeds manufactured from these cereals and in the digesta of chickens fed these feeds. Increased digesta viscosity is known to reduce digestion and absorption of a range of nutrients (Annison, 1993). Wheat-based diets are more viscous than maize-based diets as they contain higher levels of NSP and as a result are less efficiently utilised than maize-based diets by poultry, especially the young chicks. Sorghum, another common cereal, is a good energy source with the apparent metabolisable energy (AME) level greater than wheat (Hughes and Choct, 1999), but may contain significant amount of tannins that have been shown to reduce amino acid digestibility (Ravindran *et al.*, 2005), feed intake, growth and feed efficiency in poultry (Nyachoti *et al.*, 1997).

The gastrointestinal tract is a major consumer of nutrients in animals, with rapid cell turnover utilising significant quantities of both nutrients and energy. An increase in the proportional size of the gastrointestinal tract will therefore increase the nutrient demand by the gut and reduce the feed efficiency of the bird. It has been shown that cereals with high NSP level may increase the size of the gastrointestinal tract. A significant positive correlation between arabinoxylan level in wheats and the relative weights of the duodenum, jejunum and ileum has been reported by Steinfeldt (2001). It is known that diet composition may produce microscopic alterations in the intestinal mucosa (Yamauchi, 2002) and it is possible that dietary NSP levels may also influence the morphology of the gastrointestinal tract. Iji (1999) found that guar gum and xanthin gum significantly increased crypt depth of both the jejunum and ileum, suggesting that NSP may promote gastrointestinal tract cell turnover. Greater crypt depth indicates increased villus cell proliferation, and therefore an increase in nutrients being utilised by the gastrointestinal tract. Thus it is tempting to hypothesize that the differences in performance generally observed between different cereal-based diets (Ao and Choct, 2004) may be related, partly, to differences in relative gastrointestinal tract size and intestinal morphology. However, published data on the effects of manipulation of cereal types on gastrointestinal tract development are limited.

The aim of this research was to examine the performance and gastrointestinal responses of the newly hatched

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broiler chick fed diets based on wheat, sorghum or maize from 1 to 14 days of age.

Materials and Methods

All experimental procedures were approved by the Massey University Animal Ethics Committee and complied with the Massey University Code of Ethical Conduct for the Use of Live Animals for Teaching and Research.

Diets

Three dietary treatments based on wheat, sorghum and maize were used in the trial. The diets were formulated to have similar levels of metabolisable energy, essential amino acids, calcium and available phosphorus. The diets were formulated to meet or exceed the NRC (1994) requirements for all nutrients. The wheat-based diet was supplemented with a commercial xylanase as this is standard commercial practice and necessary if the research results are to have practical relevance. All diets were steam pelleted at 60°C. The ingredient composition of the diets is shown in Table 1.

General Procedures

Day-old male broilers (Ross 308) were weighed and allocated to 18 cages of eight chicks each. Each dietary treatment was then assigned to six replicate cages. The chicks were housed in 3-tier electrically heated brooder

pens with 400 cm²/bird space allocation. Brooding temperature was maintained at 32°C on day 1 decreasing to 27°C on day 14. Ventilation was controlled by a central ceiling extraction fan and wall inlet ducts. Feed and water were available at all times. Bodyweight and feed intake were measured at weekly intervals. Moisture loss from the feed was measured over the first seven days and feed intake adjusted. Mortality was recorded on a daily basis. The trial lasted for 14 days.

Collection and Processing of Samples

On day 14, two birds per replicate pen were weighed and killed by intravenous injection of sodium pentobarbitone and the gastrointestinal tract removed. The lengths of the intestinal segments (duodenum, jejunum, ileum) and caeca were obtained. The weights of the liver and pancreas, and empty weights of proventriculus, gizzard, duodenum, jejunum, ileum and caecum were recorded.

Two more birds per replicate were euthanased and tissue samples were obtained for gut morphological measurements. The gut samples were taken from the following four sites: proximal duodenum (the top of the descending portion of the duodenal loop), duodenal loop (the base of the duodenal loop), distal duodenum/proximal jejunum (at the top of the ascending portion of the duodenal loop) and distal jejunum/proximal ileum (around Meckel's diverticulum). The samples were immediately fixed in Bouin's fluid for a 24 hour period and then stored in a 70% alcohol solution until further processing.

Morphological Measurement

Gut samples were fixed in Bouin's solution and then stored in a 70% alcohol solution before being paraffin-embedded. Each fixed sample was then embedded into wax, and sectioned at a thickness of 7 µm, stained with alcian blue/haematoxylin-eosin and examined by light microscopy. Five intestinal segments were fixed in each slide and the slides were viewed on a Zeiss Axiophot microscope. Visual measurements of villus height, crypt depth and epithelium thickness were made on 10 villi at 100x and 200x magnifications using imaging software (Image Pro Plus, Version 4.1.0.9, Media Cybernetics, Silver Spring, MD).

Data Analysis

The data were analysed by analysis of variance using the General Linear Model procedure of the SAS[®] (SAS Institute, 1997) with pen means as the experimental unit for performance data. Morphological measurements were based on individual bird measurements. Differences were considered to be significant at $P < 0.05$ and significant differences between means were separated by the Least Significant Difference test.

Results

Performance data

The performance data are shown in Table 2. Birds fed the maize-based diet grew faster ($P < 0.05$) than those fed the sorghum-based diet. Growth rate for the wheat-based diet did not differ ($P > 0.05$) from either maize- or sorghum-

Table 1. Composition and calculated analysis (g/100g as fed) of diets based on wheat, sorghum and maize

Ingredient	Wheat diet	Sorghum diet	Maize diet
Wheat	65.76	—	—
Sorghum	—	61.08	—
Maize	—	—	58.62
Soybean meal	27.34	32.19	35.18
Soybean oil	2.73	2.09	1.78
Dicalcium phosphate	2.03	1.91	2.17
Limestone	0.34	0.94	0.78
Salt	0.14	0.16	0.23
Lysine.HCl	0.34	0.29	0.18
DL-methionine	0.24	0.33	0.25
L-threonine	0.12	0.08	0.03
Sodium bicarbonate	0.36	0.33	0.18
Vitamin- trace mineral premix ¹	0.30	0.30	0.30
Xylanase ²	+	—	—
<i>Calculated analysis</i>			
AME, MJ/kg	12.5	12.5	12.5
Crude protein	22.0	22.0	22.0
Lysine	1.35	1.35	1.35
Methionine + cystine	0.95	0.95	0.95
Calcium	0.95	0.95	0.95
Available phosphorus	0.48	0.48	0.48

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 Industries, Singapore, added 0.075 g/100 g diet.

Table 2. Weight gain, feed intake and feed per gain of male broiler chicks fed diets based on wheat, sorghum or maize¹

		Wheat	Sorghum	Maize	Pooled SEM
1-7 days	Weight gain, g/bird	142 ^{ab}	131 ^b	148 ^a	3.8
	Feed intake, g/bird	154	151	160	5.1
	Feed per gain g/g	1.108	1.155	1.093	0.030
1-14 days	Weight gain, g/bird	438 ^{ab}	422 ^b	463 ^a	10.8
	Feed intake, g/bird	568	553	588	13.6
	Feed per gain, g/g	1.304	1.324	1.277	0.025

^{a,b} Means in the same row with different superscripts are significantly different ($P < 0.05$).

¹ Mean of six replicates (8 birds/replicate).

Table 3. Relative weights (g/100 g body weight) and relative length (cm/100 g body weight) of gastrointestinal tract segments in male broiler chicks fed diets based on wheat, sorghum or maize^{1,2}

	Wheat	Sorghum	Maize	SEM
<i>Relative weight</i>				
Liver	3.39	3.25	3.23	0.14
Pancreas	0.38	0.34	0.34	0.02
Proventriculus	0.63	0.67	0.62	0.04
Gizzard ³	1.64	1.87	1.69	0.07
Duodenum	1.02	1.02	0.99	0.05
Jejunum	2.06	1.94	2.09	0.07
Ileum ⁴	1.65	1.72	1.50	0.07
Small intestine ⁵	4.73	4.68	4.57	0.16
Caeca	0.38	0.42	0.37	0.02
<i>Relative length</i>				
Duodenum	4.55	4.43	4.31	0.14
Jejunum	12.18	12.15	12.17	0.40
Ileum	11.12	11.69	11.10	0.35
Small intestine ⁵	27.85	28.27	27.58	0.79
Caeca ⁴	2.20	2.25	1.95	0.08

¹ Differences were not statistically significant ($P > 0.05$).

² Mean of 12 observations (six replicates $\times$ 2 birds/replicate); determined on day 14 posthatch.

³ $P = 0.09$.

⁴ $P = 0.07$.

⁵ Duodenum + jejunum + ileum.

based diets. There was no difference ($P > 0.05$) in feed intake between the three dietary treatments, although there was a numerical trend for feed intake to increase from sorghum to wheat to maize diet, which paralleled weight gain of the birds. There was a numerical improvement in feed per gain from sorghum to wheat to maize, but the differences were not significant ($P > 0.05$). The patterns in performance over the two week trial period were similar to those for the first week.

Gastrointestinal tract measurements

The effects of cereal type on the relative weights and lengths of gastrointestinal tract segments are shown in Table 3. There were no treatment differences ($P > 0.05$) for any of the parameters, but there was a tendency for birds fed sorghum based diets to have a larger gizzard ($P = 0.09$) and ileum ($P = 0.07$). The lengths of the duodenum, jejunum, ileum and caeca and small intestine showed

Table 4. Intestinal morphological measurements of male broiler chicks fed diets based on wheat, sorghum and maize^{1,2}

	Wheat	Sorghum	Maize	Pooled SEM
<i>Proximal duodenum (μm)</i>				
Villous tip-crypt base	1530	1478	1526	225
Villous height	1303	1241	1296	200
Crypt depth	211	197	201	53
Epithelial thickness	41	38	37	7.6
<i>Duodenal loop (μm)</i>				
Villous tip-crypt base	1791	1793	1795	262
Villous height	1562	1556	1572	231
Crypt depth	215	209	211	50
Epithelial thickness	44	43	42	8.1
<i>Duodenum/jejunum (μm)</i>				
Villous tip-crypt base	1075	1069	1114	175
Villous height	879	876	902	154
Crypt depth	189	196	198	42
Epithelial thickness	38	40	44	9.3
<i>Jejunum/ileum (μm)</i>				
Villous tip-crypt base	810	723	812	130
Villous height	542	586	660	108
Crypt depth	149	138	150	34
Epithelial thickness	33	31	34	4.7

¹ Differences were not statistically significant ($P > 0.05$).

² Mean of 12 observations (six replicates $\times$ 2 birds/replicate); determined on day 14 posthatch.

no treatment differences ($P > 0.05$) although birds fed the maize based diet tended ($P = 0.07$) to have shorter caeca.

Morphological measurements

The influence of dietary treatments on the morphological measurements at the four sampling sites is summarised in Table 4. No significant treatment differences ($P > 0.05$) were observed at any of the four sites measured. All morphological measurements showed a high degree of variation, suggesting that a larger sample size would be necessary for any significant differences to be detected. The only significant effect was the effect of sampling sites on villous height ($P < 0.01$). The villous height increased from proximal duodenum to duodenal loop and then decreased to distal duodenum and distal jejunum.

Discussion

Non-starch polysaccharide levels in wheat are higher

and more variable than those of maize (Choct, 1997), giving rise to a high variability in chicken performance. This is attributed, in part, to increases in digesta viscosity in wheat based diets which may lower nutrient digestion by impeding the diffusion of digestive enzymes and their substrates and products (Annison, 1993) or through viscosity-microflora interactions (Hubener *et al.*, 2002). Non-starch polysaccharides have also been shown to increase the size of organs of the gastrointestinal tract (Jorgensen *et al.*, 1996) and to affect intestinal morphology (Iji, 1999), both of which may reduce the efficiency of feed utilisation.

Results from the current trial showed the chicks fed the maize-based diet grew faster and had a numerically lower feed per gain than those fed the sorghum-based diet. The performance of birds fed the wheat-based diet, however, was not significantly different from either the maize- or sorghum-based diets. Based on these reported differences in NSP levels in the three cereals (Choct, 1997), it was anticipated that chicks fed the maize- and sorghum-based diets would grow faster and more efficiently than those fed the wheat based diet. Thus the present findings were unexpected, but may be explained by the fact that the addition of a commercial xylanase in the present study which may have which may have ameliorated the digesta viscosity of this diet and reduced the anti-nutritive effect of wheat non-starch polysaccharides on bird performance (Annison and Choct, 1991; Bedford and Schulze, 1998). The wheat-based diet was supplemented with xylanase because this is standard commercial practice and it was decided to be necessary if the research results are to have practical relevance. Comparing bird performance of birds fed wheat, sorghum and maize based diets, Ao and Choct (2004) found that birds fed diets based on sorghum and maize grew faster and had better feed efficiency than those fed a wheat-based diet and that maize fed chickens grew more efficiently than those fed the sorghum diet. However, in their study, exogenous xylanase was not added to the wheat-based diet.

Published data comparing the feeding value of sorghum with other common cereals are equivocal. Tulasi *et al.* (2004) found that substituting sorghum for maize gave a similar growth rate, but a higher feed per gain in the chicks fed the sorghum based diets. However, Connor *et al.* (1976) compared the AME of sorghum and maize hybrids and found significant hybrid differences for sorghum. Black *et al.* (2005) reported that available energy is utilised less efficiently in sorghum than in wheat possibly because sorghum protein has a lower digestibility than wheat protein. Another possible reason for the lower performance of the sorghum diet may be the presence of tannins, which have anti-nutritional effects including reduced protein digestibility and poor feed efficiency (Nyachoti *et al.*, 1997; Ravindran *et al.*, 2005).

Dietary levels of NSP have been shown to influence the size of the gastrointestinal tract with a higher NSP level increasing both the length of the tract, and the relative weights of the duodenum, jejunum, ileum and caeca (Jor-

gensen *et al.*, 1996; Steenfeldt, 2001). In the present study, cereal type had no effects on the relative weights or lengths of the gastrointestinal tract. As noted earlier, the addition of xylanase may explain the lack of effects in birds fed the wheat-based diet.

Non-starch polysaccharides have also been observed to affect gut morphology (Iji, 1999). In the present study, wide variability in intestinal morphology measurements was observed between individual birds and this variability was responsible largely for the lack of significant differences between cereal types. Although not an intended aim of the study, comparison of data along the intestine shows interesting patterns. The villous height was highest and the crypt depth was lowest at the duodenal loop than those at the duodenal/jejunal and jejunal/ileal junctions. These findings appear to be related to intestinal function, as duodenum is the vigorous absorptive segment in avian intestine (Yamauchi, 2002). Our data are also in agreement with those of Yamauchi *et al.* (1995) who reported that White Leghorn starter chicks had the highest villi in the duodenum followed by lower in jejunum and the lowest in ileum.

The present results suggest that the performance differences observed between birds fed diets based on wheat, sorghum and maize were not related to differences in gastrointestinal tract weights or intestinal morphology, as these parameters were unaffected by dietary cereal type. It would appear that other factors are responsible for observed differences in growth. Probable factors include better nutrient digestion of maize (Ravindran *et al.*, 2005) and the possible presence of tannins in sorghum, which may affect feed intake and digestive efficiency (Nyachoti *et al.*, 1997).

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