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Effects of particle size and extrusion of maize and sorghum on ileal digestibility and growth performance in pigs weaned at 14 and 21 days of age *

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ABSTRACT

Two experiments were conducted to compare apparent ileal digestibilities and growth performance in pigs fed ground and extruded maize and sorghum. In Experiment 1, for digestibility, 24 early-weaned pigs (14 d old and 3.2 kg BW; EW) were given a terminal ileum exteriorization, and another 24 conventionally-weaned (CW) piglets (21 d old and 6.3 kg BW) were fitted with simple T-cannulae. An additional 8 piglets were employed for correction of endogenous amino acid excretions. Dietary treatments consisted of six differently processed maize and sorghum diets: 1. maize 900 µm, 2. maize 400 µm, 3. extruded maize, 4. sorghum 900 µm, 5. sorghum 400 µm, and 6. extruded sorghum. In Experiment 2, 150 piglets (21 d of age and 6.4 kg BW) were allotted to the same dietary treatments and used in a 33-d feeding trial.

Reduced particle sizes of the grains from 900 to 400 µm tended to improve the apparent ileal digestibilities (AID) of Thr, Val, Leu, and Lys in maize and Thr, Val, and Leu in sorghum for EW, but not for CW piglets. The AID of essential amino acids were higher ($P<0.05$) in CW than in EW piglets. In true ileal digestibilities (TID) of essential amino acids in tested grains, there was a similar trend with the AID of essential amino acids, with the exception of improvement by 10.7% in EW, and

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by 8.1% in CW piglets. In this study, however, the ileal digestibility of amino acids was highly (P<0.05) different between weaning ages. The differences were 19.6% in averaged AID, and 17.0% in TID of essential amino acids, respectively, between weaning ages. Extrusion of maize and sorghum did not improve the ileal digestibilities of amino acids, but the digestibility of Met in sorghum was improved (P<0.05) in EW pigs as compared with ground maize and sorghum. Between maize and sorghum, the ileal digestibility of amino acids was similar. During the overall period (d 0 to 33), diets with extruded maize and sorghum reduced ADFI (P<0.05) and improved gain/feed (P<0.05) by 3% compared with diets with the ground grains.

In conclusion, the ileal digestibility of amino acids in the grains was considerably affected by weaning ages of piglets, while ileal digestibility of amino acids and growth of pigs was not affected by reductions in particle sizes of maize and sorghum from 900 to 400 mm in complex weaner diets.

KEY WORDS: maize, sorghum, particle size, extrusion, ileal digestibility, performance, piglets

INTRODUCTION

Typical processing of cereal grains involves grinding to crack the kernel and to reduce particle size. Improved feed efficiency and digestibility of nutrients and energy were reported with fine grinding of major grains such as maize (Reimann et al., 1968; Hedde et al., 1985; Wondra et al., 1995), and sorghum (Owsley et al., 1981). But the optimum particle size is probably dependent on the age of pigs. Healy et al. (1994) reported that optimum particle size for maize and sorghum increased with increasing age of nursery pigs, and the overall performance was optimized at 500 µm.

Likewise, extrusion of cereal grain increases the gelatinization and surface area of starch granules (Bjorck, 1985), which improves nutrient digestibility (Noland et al., 1976; Skoch et al., 1983), and growth performance (Richert et al., 1992). However, Herkelman et al. (1990) reported that extrusion of maize improved energy utilisation but not utilisation of lysine or N by pigs. The report of Richert et al. (1992) showed that extruded maize and sorghum improved performance for d 0 to 10 postweaning, but was of no benefit from d 10 to 38.

The effects of particle size and extrusion of maize and sorghum on ileal digestibility of nutrients and growth performance in young pigs need further investigation. Furthermore, there might be differences in digestibilities of nutrients between early- and conventionally-weaned pigs. Chae et al. (1999) reported that the apparent ileal digestibilities of most essential amino acids in soyabean meal and isolated soya protein significantly differ (P<0.05) between early- (14 d) and conventionally-weaned (21 d) pigs. Therefore, this study was conducted 1. to compare the effects of particle size or extrusion of maize and sorghum on ileal digestibility of amino acids between early- (14-day-old) and conventionally-weaned (21-day-old) pigs, and 2. to investigate the comparative feeding values of the processed grains in young pigs weaned at 21 days of age.

MATERIAL AND METHODS

Digestibility experiment (Experiment 1)

Dietary treatments were 1. maize 900 µm, 2. maize 400 µm, 3. extruded maize, 4. sorghum 900 µm, 5. sorghum 400 µm, and 6. extruded sorghum, and arranged as a 2 x 3 factorial design. To prepare the cereal grains for use in the diets, each grain was ground to the targeted particle size with a roller mill (Roskamp Manufact. Inc., USA). For the 400 µm particle size, the grains were ground twice to obtain the targeted particle size. Particle size of the ground grains was determined with 100 g aliquots of the samples using ASAE procedures (1983). For the extrusion (Insta-Pro®, USA) treatments, the grains were adjusted to 20% moisture and processed with a last barrel temperature and production rate of 530.7 kg/h at 134°C for maize and 571.5 kg/h at 122°C for sorghum. After extrusion, the extrudates were coarsely ground through a roller mill and the degree of gelatinization was measured by the method of Wootton et al. (1971).

All diets were formulated to exceed NRC (1998) standards for all vitamins and minerals (Table 1). Chromic oxide was added as an indigestible marker. For the digestibility trial, three-way cross-bred (Landrace x Yorkshire x Duroc) piglets were employed. In early-weaned (EW) pigs, 24 piglets (14 d old and 3.2 kg BW) were removed from the sows and given terminal ileum exteriorization (TIE) according to the method of Chae et al. (1999): after anaesthesia, the right flank was shaved with surgical clippers and scrubbed with iodine for disinfection. A surgical drape was placed in position over the site and laparotomy was performed with a 4-5 cm incision in the right abdominal wall. The caecum and attached ileal loop were exteriorized, and the terminal ileum was transected at a position approximately 5 cm from the ileocaecal juncture. The caecum end of the ileum was cut, then closed using a purse-string suture with size 4-0 sutures (green monofilament polyglyconate, D&G Monofil, USA). A stab incision was made through the right flank, ventral to the initial incision, to allow pulling the ileum through the body wall. The length of the stab incision was sutured directly to the outer body wall. The abdominal incision was then closed. The peritoneum and muscle layers were closed using size 4-0 sutures, the skin was closed with size 2-0 sutures. Proclain penicillin (2 ml) was administered before closing the incision site.

In conventionally weaned (CW) pigs, 24 (21 d old and 6.3 kg BW) were removed from the sows and simple T-cannulas were inserted into the lumen of the terminal ileum according to the method suggested by Walker et al. (1986). To correct endogenous excretion of amino acids with a nitrogen-free diet (Table 1), TIE surgery was given to four of 14 d old (3.28 kg) castrated EW piglets, and simple T-cannulas were inserted into four 21 d old (5.63 kg) castrated CW piglets.

TABLE 1

Formula and chemical composition of diets for a digestibility trial

	Maize	Sorghum	N-free
Ingredient, %			
grain source	64.00	63.74	-
maize starch	-	-	30.00
glucose	-	-	20.00
sucrose	-	-	9.75
lactose	18.00	18.00	30.00
dicalcium phosphate	3.95	3.98	3.00
soya oil	4.00	4.00	4.00
limestone	-	0.23	1.85
salt	0.30	0.30	0.30
vitamine-mineral mixture[1]	2.50	2.50	0.55
antibiotic[2]	1.00	1.00	0.20
chromic oxide	0.25	0.25	0.25
Chemical composition[3], %			
crude protein	10.36	10.59	2.30
lysine	0.47	0.46	-
methionine	0.24	0.23	-

[1] supplied per kg of mixture: 2,000,000 IU of vit. A, 400,000 IU of vit. D_3, 250 IU of vit. E, 200 mg of vit. K (as menadione), 20 mg of vit. B_1 700 mg of vit. B_2, 10,000 mg of ribofilavin, 3,000 mg of pantothenic acid (as d-calcium pantothenate), 8,000 mg of niacin, 30,000 mg of choline, and 13 mg of vit. B_{12} 12,000 mg of Mn, 4,000 mg of Fe, 15,000 mg of Zn, 100 mg of Co, 500 mg of Cu, 40 mg of folic acid, 5,000 mg of BHT, sucrose to make 1 kg vit.-min. mixture

[2] supplied per kg of diet: 110 mg of chlortetracycline, 110 mg of sulfathiazole, and 55 mg of penicillin

[3] calculated values

Immediately following surgery, the pigs were transferred to individual metabolism cages. Room temperature was maintained at 32°C during the entire experimental period. The pigs were allotted to a completely randomized design (four replications), and given 5 d of convalescence. Each pig was fed a restricted amount of feed (5% of BW/d) four times daily. Diets were mixed with water (1:1) and fed as a wet mash to improve feed intake. On the sixth day post-surgery, digesta samples were collected.

The collected samples were frozen immediately at -20°C, freeze-dried (Ilsin Engineering Co., Korea), ground through a 1 mm screen (Wiley mill), and stored in a refrigerator (4°C) until analysis.

Growth assay (Experiment 2)

One hundred fifty piglets (Pig Improvement Co., Line 326 boars x C 15 sows, Franklin, KY, USA; 21 d of age and 6.4 kg average BW) were allotted on the basis of sex, weight, and ancestry to six treatments in a completely randomized block design. Initial body weight was used as the blocking criterion. Treatments were the same as in Experiment 1. The grain preparations were the same as in Experiment 1, but the finished diets were pelletized (CPM Co. USA). Composition of experimental diets is presented in Table 2.

The pigs (three gilts and three barrows) were housed in 1.2 m x 1.5 m pens with woven wire floor. Room temperature was maintained at 32, 30, 28, and 27°C from

TABLE 2

Formula and chemical composition of the experimental diets for growth assay

	Maize			Sorghum		
	d 0~7	d 8~21	d 22~33	d 0~7	d 8~21	d 22~33
Ingredients, %						
grain source	31.82	43.93	59.15	31.60	43.63	58.75
soyabean meal (48%)	21.43	27.66	33.48	21.66	27.96	33.90
dried whey	20.00	20.00	-	20.00	20.00	-
lactose	10.00	-	-	10.00	-	-
wheat gluten	4.00	-	-	4.00	-	-
spray dried plasma protein	-	4.00	-	-	4.00	-
soya oil	2.00	2.00	3.00	2.00	2.00	3.00
spray dried blood meal	2.00	2.00	2.00	2.00	-	-
dicalcium phosphate	1.90	1.62	1.51	1.89	1.61	1.50
antibiotic[1]	1.00	1.00	1.00	1.00	1.00	1.00
limestone	0.67	0.73	0.90	0.66	0.73	0.90
zinc oxide	0.37	0.23	-	0.37	0.24	-
copper sulphate	-	-	0.09	-	-	0.09
vitamine premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
lysine×HCl	0.25	0.15	0.15	0.25	0.15	0.15
mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
salt	0.10	0.20	0.30	0.10	0.20	0.30
DL-methionine	0.07	0.08	0.02	0.07	0.08	0.02
Chemical composition[4], %						
crude protein	23.51	21.68	21.24	23.66	21.89	21.52
lysine	1.60	1.45	1.30	1.60	1.45	1.30
Ca	0.90	0.90	0.80	0.90	0.90	0.80
P	0.80	0.80	0.70	0.80	0.80	0.70

[1] supplied per kg of diet: 110 mg of chlortetracycline, 110 mg of sulfathiazole, and 55 mg of penicillin

[2] supplied per kg of diet: 5,513 IU of vit. A, 551 IU of vit. D_3, 22 IU of vit. E, 2.2 mg of vit. K (as menadione), 5.5 mg of ribofilavin, 13.8 mg of pantothenic acid (as d-calcium pantothenate), 30.3 mg of niacin, 551 mg of choline, and 0.03 mg of vit. B_{12}

[3] supplied per kg of diet: 100 mg of Mn, 100 mg of Fe, 100 mg of Zn, 40 mg of Ca 264 mg of Cu, 3.0 mg of I, 1.0 mg of Co, and 0.03 mg of Se

[4] calculated value

d 0 to 7, 7 to 14, 14 to 21, and 21 to 33 after weaning, respectively. The pigs were allowed *ad libitum* access to water and feed during the 33-d growth assay. Pigs and feeders were weighed at d 7, 21, and 33 to determine average daily gain (ADG), average daily feed intake (ADFI), and gain/feed.

Chemical and statistical analyses

Chemical composition of the diets and ileal digesta were analyzed according to AOAC methods (1990) and chromium was measured with an atomic absorption spectrophotometer (Shimadzu AA625, Japan). Following acid hydrolysis in 6 N HCl at 110°C for 16 h (Mason, 1984), amino acid concentrations were determined, using an amino acid analyzer (LKB 4150 alpha, Pharmacia Instrument Co, England).

The computations were performed by de use of GLM procedure of SAS (1985). The linear model was that appropriate for a randomized complete block design, with a 2 x 3 factorial arrangement of treatments. Treatment comparisons were made using orthogonal contrasts 1. maize vs sorghum, 2. coarse vs. fine particle sizes, and 3. ground vs extruded grains.

RESULTS AND DISCUSSION

Grain processing and ileal digestibility

The particle sizes of ground maize and sorghum for 900 μm ranged from 936 and 932 μm, and those for 400 μm ranged from 458 and 419 μm, respectively. The target sizes of maize and sorghum were obtained. The degrees of gelatinization were similar and equaled 76.2% for extruded maize and 78.3% for extruded sorghum.

The effects of particle sizes and extrusion of maize and sorghum on apparent and true ileal digestibilities of essential amino acids in EW and CW pigs are presented in Tables 3 and 4, respectively.

For many essential amino acids, the apparent ileal digestibilities (AID) of maize and sorghum were affected by the processing methods in EW or CW pigs. The average AID of essential amino acids were similar (1~2% improvement in AID, and 3~4% improvement in TID) in sorghum and in maize for EW, but not for CW pigs. The AID of essential amino acids were consistently higher ($P<0.05$) in CW than in EW pigs. In terms of average AID of essential amino acids, there were no significant differences among grain sources. But there were interactions between weaning ages and processing methods. In true ileal digestibilities (TID) of essential amino acids in the tested grains, there was a similar trend with the

TABLE 3

Apparent amino acids digestibility of grain sources in early and conventional weaned pigs

Age	Source	Thr	Val	Met	Ile	Leu	Phe	His	Lys	Arg	Avg
early weaning	C-900	48.99[e]	48.62[e]	59.46[c]	49.90[d]	49.07[c]	54.46[e]	65.13[efg]	60.82[cb]	57.62[f]	55.07[d]
	C-400	51.64[e]	50.90[e]	49.52[d]	54.22[cd]	52.11[c]	54.61[e]	65.73[defg]	67.12[bc]	61.40[ef]	56.36[d]
	C-Ex	50.08[e]	53.56[e]	58.98[c]	59.46[bc]	48.47[c]	52.84[e]	61.93[g]	62.50[bc]	66.16[de]	57.11[cd]
	M-900	55.12[cde]	54.83[e]	61.29[c]	63.36[b]	54.45[bc]	64.45[d]	69.84[abcd]	59.96[c]	68.72[cde]	61.34[bc]
	M-400	59.27[c]	62.41[d]	60.30[c]	58.30[bc]	60.46[b]	62.18[d]	68.28[bcde]	64.18[bc]	72.02[bcd]	63.04[b]
	M-Ex	57.32[cd]	54.64[e]	69.01[b]	63.90[b]	60.38[b]	62.27[d]	62.32[fg]	67.73[b]	63.68[ef]	62.36[b]
conven. weaning	C-900	70.97[b]	72.13[c]	77.46[a]	78.38[a]	79.44[a]	77.85[b]	74.39[a]	83.43[a]	82.00[a]	77.34[a]
	C-400	80.24[a]	86.30[a]	78.93[a]	79.81[a]	83.12[a]	66.10[d]	70.70[abc]	84.73[a]	80.87[a]	78.98[a]
	C-Ex	76.13[ab]	81.48[ab]	79.54[a]	82.27[a]	83.55[a]	74.93[c]	73.99[ab]	84.50[a]	80.42[a]	79.65[a]
	M-900	73.40[ab]	78.74[bc]	78.77[a]	79.07[a]	79.19[a]	77.74[bc]	71.26[abc]	86.70[a]	81.22[a]	78.45[a]
	M-400	78.82[ab]	80.96[ab]	81.88[a]	80.69[a]	81.11[a]	83.30[ab]	68.96[cdef]	85.22[a]	79.32[a]	80.03[a]
	M-Ex	78.01[ab]	84.56[ab]	84.47[a]	80.61[a]	82.34[a]	83.44[a]	69.11[abcde]	83.43[a]	74.71[a]	79.74[a]
SE[1]		12.42	14.32	11.61	11.78	14.86	10.85	4.85	11.43	9.22	10.45
Between weaning ages											
early weaning		53.74[b]	54.16[b]	59.75[b]	58.46[b]	54.07[b]	58.47[b]	65.67[b]	63.72[b]	64.90[b]	59.24[b]
conven. weaning		76.05[a]	80.24[a]	80.10[a]	80.31[a]	81.44[a]	76.29[a]	71.20[a]	84.54[a]	79.54[a]	78.80[a]
Among grain sources											
C-900		59.98	60.37	68.46[ab]	64.95	64.25	66.16[ab]	69.76[ab]	72.12	69.80	66.21
C-400		65.94	68.60	64.22[b]	68.26	67.36	60.36[b]	68.47[ab]	75.92	71.14	67.73
C-Ex		63.12	67.67	69.49[ab]	70.47	66.06	62.57[ab]	67.56[ab]	72.85	72.25	68.01
M-900		64.36	66.85	70.10[ab]	71.25	66.83	70.78[ab]	71.33[a]	73.32	74.93	69.95
M-400		68.30	71.60	70.55[ab]	69.13	70.68	71.50[a]	67.79[ab]	74.98	75.96	71.16
M-Ex		67.66	68.10	76.74[a]	72.25	71.35	72.85[a]	65.72[b]	75.58	69.19	71.05
Probability											
weaning ages		*[2]	*	*	*	*	*	*	*	*	*
grain sources		NS[3]	NS	NS	NS	NS	NS	NS	NS	NS	NS
WA x PS		*	*	*	*	*	*	*	*	*	*

[abcdefg] $P<0.05$

[1] pooled standard error; [2] * $P<0.001$; [3] NS ($P>0.12$)

TABLE 4

True amino acids digestibility of grain sources in early and conventional weaned pigs

		Thr	Val	Met	Ile	Leu	Phe	His	Lys	Arg	Avg
Age	Source										
early	C-900	62.16^{d}	54.67^{d}	72.03^{c}	60.36^{c}	56.69^{c}	64.73^{c}	75.00^{fg}	70.10^{d}	65.27^{g}	64.56^{d}
weaning	C-400	63.80^{cd}	62.73^{c}	71.71^{c}	66.16^{bc}	60.87^{c}	64.81^{c}	75.89^{fg}	77.51^{bc}	68.52^{fg}	68.00^{cd}
	C-Ex	62.04^{d}	63.01^{c}	75.23^{bc}	63.38^{bc}	58.00^{c}	63.14^{c}	73.60^{g}	71.53^{cd}	73.30^{ef}	67.03^{cd}
	M-900	68.25^{bcd}	62.98^{c}	72.82^{c}	66.65^{bc}	62.22^{c}	74.93^{b}	79.30^{def}	72.46^{cd}	74.47^{de}	70.45^{bc}
	M-400	73.12^{b}	73.23^{b}	74.55^{c}	64.82^{b}	71.22^{b}	74.79^{b}	80.03^{cdef}	80.08^{b}	79.25^{cd}	74.57^{b}
	M-Ex	71.66^{bc}	66.72^{bc}	82.30^{a}	69.20^{b}	72.22^{b}	74.78^{b}	76.99^{efg}	77.59^{bc}	81.17^{c}	74.74^{b}
conven.	C-900	83.14^{a}	86.72^{a}	81.71^{ab}	86.34^{a}	85.24^{a}	86.34^{a}	89.20^{a}	88.17^{a}	89.19^{a}	86.23^{a}
weaning	C-400	88.19^{a}	92.17^{a}	85.19^{a}	89.31^{a}	88.02^{a}	86.02^{a}	85.15^{abc}	90.06^{a}	87.45^{ab}	87.95^{a}
	C-Ex	86.01^{a}	94.34^{a}	86.76^{a}	90.97^{a}	88.51^{a}	87.13^{a}	86.02^{ab}	88.75^{a}	86.87^{ab}	88.37^{a}
	M-900	85.41^{a}	90.89^{a}	83.84^{a}	87.09^{a}	83.70^{a}	85.40^{a}	82.45^{bcde}	92.48^{a}	90.18^{a}	86.83^{a}
	M-400	86.77^{a}	88.77^{a}	82.23^{ab}	85.07^{a}	84.84^{a}	87.38^{a}	83.57^{bcd}	89.18^{a}	88.61^{ab}	85.36^{a}
	M-Ex	85.99^{a}	90.18^{a}	86.21^{a}	86.08^{a}	83.91^{a}	87.26^{a}	82.31^{bcde}	88.76^{a}	83.39^{bc}	85.12^{a}
SE[1]		11.07	14.70	6.73	12.31	12.88	10.10	5.45	8.59	8.78	9.42
Between weaning ages											
early weaning		66.84^{b}	63.89^{b}	74.77^{b}	65.09^{b}	63.54^{b}	69.53^{b}	76.80^{b}	74.88^{b}	73.66^{b}	69.89^{b}
conven. weaning		85.92^{a}	90.52^{a}	84.33^{a}	87.46^{a}	85.37^{a}	86.59^{a}	84.38^{a}	89.57^{a}	87.61^{a}	86.87^{a}
Among grain sources											
C-900		72.65	70.69	76.87^{b}	73.35	70.97	75.53	82.10	79.14	77.23	75.39
C-400		75.99	77.45	78.45^{ab}	77.68	74.44	75.41	82.52	83.78	77.98	77.98
C-Ex		74.02	78.68	80.99^{ab}	77.18	73.25	75.13	79.08	80.14	80.09	77.70
M-900		76.83	76.97	78.33^{ab}	76.87	72.96	80.17	80.87	82.47	82.32	78.64
M-400		79.95	81.00	78.39^{ab}	74.95	77.03	81.09	81.07	84.63	83.93	80.27
M-Ex		78.83	78.45	84.26^{a}	77.64	78.06	81.02	79.17	83.17	82.28	80.32
Probability											
weaning ages		**[2]	**	**	**	**	**	**	**	**	**
grain sources		NS[3]	NS	NS	NS	NS	NS	NS	NS	NS	NS
WA×PS		**	**	**	**	**	**	**	**	**	**

abcdefg $P<0.05$

[1] pooled standard error; [2] * $P<0.01$; ** $P<0.001$; [3] NS ($P>0.12$)

AID of essential amino acids, with the exception of improvement by 10.7% in EW, and by 8.1% in CW pigs.

In general terms, the ileal digestibilities of the essential amino acids were not significantly affected by finer grinding of maize and sorghum from 900 to 400 μm in either EW or CW pigs. But reduced particle sizes of the grains tended to improve the digestibilities of Thr, Val, Leu, and Lys in maize and Thr, Val, and Leu in sorghum. Previous studies showed improved nutrient digestibility when particle sizes of grain were reduced (Owsley et al., 1981; Leibholz, 1982; Ohh et al., 1983; Gieseman et al., 1990; Healy et al., 1994), even though the selected particle sizes and ages of pigs tested were different. Increased surface area of the diet and increased fluidity of digesta contents increases contact with digestive enzymes, and may be involved in the improved digestibility of nutrients (Ohh et al., 1983). Healy et al. (1994) also reported that apparent digestibility of nutrients improved linearly as mean particle size was reduced from 900 to 300 μm.

In this study, however, the ileal digestibility of amino acids in maize and sorghum was highly ($P<0.05$) different between weaning ages. The differences were 19.6% in averaged AID, and 17.0% in TID of essential amino acids, respectively, between weaning ages. The increase in amino acid digestibility with increasing age is consistent with a previous study (Chae et al., 1999). The poor digestibility of nutrients in early-weaned pigs may be due to the incomplete development of the digestive tract as mentioned by Chae et al. (1999).

In addition to the age factor affecting ileal digestibility of nutrients in feeds, different digesta collection methods were employed between EW and CW pigs in the present study. For EW pigs, TIE surgery was given because it was difficult to install T-cannulae in the terminal ileum of very young pigs. Schumann et al. (1986) and Hennig et al. (1988) reported that ileo-rectal anastomosis, which is similar to TIE, gives the same results for amino acid digestibility as do cannulation techniques.

Extrusion cooking alters chemical composition and digestibility of nutrients at the ileum (Fadel et al., 1988). In the present study, extrusion of maize and sorghum did not improve the ileal digestibilities of amino acids, with the exception that the digestibility of Met in sorghum was improved ($P<0.05$) in EW pigs as compared with ground maize or sorghum. This result is in partial agreement with previous studies for maize (Herkelman et al., 1990) and sorghum (Noland et al., 1976). Herkelman et al. (1990) reported that extrusion improved energy utilisation but did not affect utilisation of lysine or N in maize by growing pigs. Noland (1976) also reported that extrusion improved energy digestibility of high tannin sorghum grain when fed to nursery pigs. It seemed that the extrusion temperature for maize and sorghum was moderate in this study. Hancock (1992) suggested that the ideal extrusion temperature is not as high as the range of temperature (120-170°C), and Chae et al. (1998) reported that the apparent ileal digestibility of amino acids in maize was not reduced when the grain was extruded at 130-150°C.

In the present study, the ileal digestibilities of amino acids were similar in maize and sorghum, and were comparable to the valued reported by Taverner et al. (1981) and Cho et al. (1997). Sorghum used in this study was low in tannin content. As the tannin content increased, rate and efficiency of gain decreased. The feeding value of sorghum (i.e., efficiency of gain) relative to maize ranged from 91 to 99%, with an average of 95% (Hancock and Bramel-Cox, 1992).

In addition, the levels of dietary crude protein or dietary amino acids in the diets tested are important (Sauer et al., 1989; Donkoh and Moughan, 1994; Fan et al., 1994). Chae (1996) conducted a digestibility trial with only maize and sorghum in early-weaned pigs and obtained very low apparent ileal digestibility coefficients. Apparent ileal digestibility can be greatly influenced by endogenous protein recoveries. Donkoh and Moughan (1994) conducted an experiment with meat-and-bone meal to investigate the effects of dietary protein content (25, 60, 95, 130, 165 and 200 g CP/kg diet) on the apparent ileal digestibility of N and amino acids in growing rats. As dietary protein content increased from 25 to 200 g/kg, so did apparent ileal digestibility for all amino acids examined. To minimize the effect of endogenous protein losses, Batterham (1994) recommended that the minimum dietary crude protein (CP) levels of tested diets be at least 105 g CP/kg, while Sauer et al. (1989) suggested a range of 150 to 160 g CP/kg. Other experiments were also conducted with diets, fortified with casein, to determine the apparent ileal digestibility of amino acids in cereal grains (Easter, 1972; Cousins, 1979; Purser et al., 1979; Owsley et al. 1981; Cho et al., 1997).

Growth performance

In the growth assay (Experiment 2; Table 5), ADG, ADFI, and gain/feed were not affected ($P>0.12$) by grain source, particle size, or extrusion in Phase 1 (d 0 to 7). In Phase 2 (d 7 to 21), ADG and gain/feed were not affected by dietary treatment. However, ADFI was reduced by 3% ($P=0.028$) when the grains were extruded. ADG, ADFI and gain/feed were not affected ($P>0.12$) by particle size or extrusion during Phase 3 (d 21 to 33). During the overall period (d 0 to 33), diets with extruded maize and sorghum reduced ADFI ($P=0.039$) and improved gain/feed ($P=0.035$) by 3% compared to diets with the ground grains.

Generally, ADG and gain/feed were not affected by fine grinding of maize and sorghum (900 vs 400 μm) for nursery pigs. This result did not agree with the report of Healy et al. (1994) in nursery pigs. They suggested that the response to reducing particle size (from 900 to 300 μm) was greatest during the first 2 weeks postweaning and that optimum particle size for maize and sorghum increased with the age of nursery pigs. Fine grinding also was reported to improve gain/

TABLE 5

Effects of particle size[1] and extrusion of maize and sorghum on performance in nursery pigs

	Maize			Sorghum			SE	Contrasts[2]		
	900 μm	400 μm	extrusion	900 μm	400 μm	extrusion		1	2	3
d 0 to 7										
ADG, g	353	327	346	347	358	329	5.79	-[3]	-	-
ADFI, g	363	336	351	366	366	336	5.75	-	-	-
G/F, g/kg	972	973	986	948	978	979	8.45	-	-	-
d 8 to 21										
ADG, g	488	458	499	509	484	464	8.07	-	-	-
ADFI, g	662[ab]	625[ab]	650[ab]	679[a]	630[ab]	605[ab]	9.07	-	-	0.028
G/F, g/kg	737	738	768	750	768	767	6.13	-	-	-
d 0 to 21										
ADG, g	439	411	444	450	438	416	605	-	-	-
ADFI, g	562[ab]	528[ab]	551[ab]	575[a]	542[ab]	515[b]	7.04	-	-	0.023
G/F, g/kg	781	778	806	783	808	808	4.92	-	-	-
d 22 to 33										
ADG, g	705	682	706	705	715	694	6.12	-	-	-
ADFI, g	1.113	1.045	1.060	1.089	1.101	1.035	12.76	-	-	-
G/F, g/kg	633	653	666	647	650	672	5.84	-	-	-
d 0 to 33										
ADG, g	533	506	536	540	536	514	4.87	-	-	-
ADFI, g	762	716	736	762	745	705	8.19	-	-	0.039
G/F, g/kg	699[b]	707[ab]	728[a]	709[ab]	719[ab]	29[a]	3.80	-	-	0.035

[ab] $P<0.05$

[1] actual geometic mean particle sizes were 936 μm and 458 μm for maize and 932 μm and 419 μm for sorghum

[2] contrast: 1. maize vs sorghum; 2. vs fine; 3. ground vs extrusion

[3] dashes nidicate $P>0.12$

feed in starter pigs fed maize (Wu, 1985) and sorghum (Ohh et al., 1983). However, the optimum particle size of grains is affected by diet complexity (Kim et al., 1995). They compared the feeding values of two different particle sizes of maize (1,000 vs 500 µm) in weaned pigs fed simple and complex diets. Reduction of particle size tended to increase ADG to a greater extent for pigs fed a simple than a complex diet. In the present study, the diet types were complex, so the growth performance in pigs fed 400 µm grains was possibly not great as compared to 900 µm grains.

Gain/feed improved when pigs were fed extruded compared to unextruded maize or sorghum, although ADG was not improved. This may be related to improved energy digestibility for the extruded grains as described previously. Skoch et al. (1983) reported that DM and energy digestibilities and feed/gain of pigs were improved by extruding diets containing 15% wheat middlings and 44% yellow maize vs feeding the diet as a mash. Richert et al. (1992) reported that ADG improved by 12% and feed/gain improved by 10% with extrusion of sorghum. The results obtained in the present study are partially in agreement with those of Richert et al. (1992). One of the differences for conducting the experiments between the present study and that of Richert et al. (1992) was diet forms (pellet vs meal), which can affect the performance of pigs. However, Noland (1976) reported that extruding sorghum grain resulted in no improvement in rate of gain or feed efficiency in young pigs.

CONCLUSIONS

Reducing particle size of maize and sorghum from 900 to 400 µm gave partial improvement in ileal amino acid digestibility in EW pigs, while the growth of pigs was not affected by reductions in particle sizes of maize and sorghum in complex weaner diets. Extrusion of the grains tended to improve the gain/feed in CW pigs, although the improvement in ileal digestibilities of amino acids was not as consistent. The ileal digestibility of amino acids in the grains was considerably higher in CW than in EW pigs, thus much attention should be given to the diets for early-weaned pigs.

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STRESZCZENIE

Wpływ wielkości cząstek i ekstruzji ziarna kukurydzy i sorgo na strawność jelitową i rozwój prosiąt odsadzonych w 14 lub 21 dniu życia

Przeprowadzono 2 doświadczenia, w których zastosowano śrutowane i ekstrudowane ziarno kukurydzy i sorgo. W doświadczeniu 1 oznaczono strawność na 24 wcześnie odsadzonych prosiętach (w wieku 14 dni, o m. c. 3,2 kg; grupa EW) i 24 prosiętach odsadzonych w 21 dniu życia (grupa CW) i m.c. 6,3 kg, z prostymi T-przetokami do końca jelita biodrowego. Dodatkowo na 8 prosiętach oznaczono poprawkę na ilość wydzielanych endogennych aminokwasów. Diety zawierały różnie przygotowane ziarno kukurydzy lub sorgo: 1. kukurydza 900 µm, 2. kukurydza 400 µm, 3. ekstrudowana kukurydza, 4. sorgo 900 µm, 5. sorgo 400 µm i 6. ekstrudowane sorgo. W doświadczeniu 2, 150 prosiąt odsadzonych w 21 dniu życia przy m.c. 6,4 kg, żywiono przez 33 dni takimi samymi dawkami jak w doświadczeniu 1. Przy zmniejszeniu wielkości cząstek ziarna z 900 do 400 µm wystąpiła tendencja poprawienia strawności jelitowej (AID) treoniny, waliny, leucyny i lizyny kukurydzy oraz treoniny, waliny i leucyny sorgo w grupie EW. AID niezbędnych aminokwasów była większa ($P<0,05$) u prosiąt z grup CW niż EW. Rzeczywista strawność jelitowa (TID) niezbędnych aminokwasów była podobna jak w przypadku AID z tym, że u prosiąt z grupy EW poprawiła się o 10,7%, z grupy CM o 8,1%. Różnice w strawności niezbędnych aminokwasów w zależności od wieku prosiąt były istotne ($P<0,05$) i wynosiły średnio 19,6% dla AID oraz 17,0% dla TID. Ekstruzja ziarna kukurydzy i sorgo nie poprawiła strawności jelitowej aminokwasów, tylko strawność metioniny u prosiąt EW otrzymujących sorgo była lepsza ($P<0,05$) niż u prosiąt otrzymujących śrutowaną kukurydzę lub sorgo.

W ciągu całego doświadczenia (0-33 dni) prosięta otrzymujące ekstrudowaną kukurydzę lub sorgo pobierały średnio dziennie mniej paszy ($P<0,05$) i lepiej ją wykorzystywały ($P<0,05$) niż prosięta otrzymujące śrutowane ziarno.

W podsumowaniu stwierdzono, że jelitowa strawność aminokwasów ziarna zależy w dużym stopniu od wieku prosiąt, natomiast zmniejszenie wielkości cząstek z 900 d0 400 µm nie wpływa ani na strawność aminokwasów ani na rozwój prosiąt.