Effects of Feeding Extruded Corn and Wheat Grain on Growth Performance and Digestibility of Amino Acids in Early-Weaned Pigs**

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ABSTRACT : This study was conducted to evaluate the extruding effects of corn and wheat on growth performance and fecal digestibility of amino acids in early-weaned pigs. Ground corn and wheat by a hammer mill (3 mm screen in diameter) were extruded at 130±2℃ with a moist-type extruder (Matador®). Treatments were: 1) 3 mm ground corn, 2) extruded corn, 3) 3 mm ground wheat, and 4) extruded wheat. A total of 160 pigs (14 d of age and 4.3±0.74 kg BW) were allotted with the dietary treatments for a 21-d feeding trial. All diets were mash and contained 30% corn or wheat products. For a digestibility trial, 16 pigs (14-d old and 4.2±0.32 kg BW) were employed in individual metabolic crates. There were no differences ($p>0.15$) in growth performance between corn-fed and wheat-fed groups. Feeding pigs diets containing extruded corn or wheat did not affect ADG ($p>0.15$) and ADFI ($p>0.15$), but it improved feed/gain ($p<0.01$). Also, feeding pigs diets containing extruded corn or wheat had lower true fecal digestibilities of arginine, histidine, isoleucine, lysine and valine ($p\leq 0.007$) in the pigs. In conclusion, our results suggest that extruding corn and wheat had no benefit on the growth of early-weaned pigs. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 2 : 224-230)*

Key Words : Corn, Wheat, Extrusion, Growth, Digestibility, Early-Weaned Pig

INTRODUCTION

Swine producers have continually decreased the age at weaning in order to increase the number of pigs per sow (Zijlstra et al., 1996) and to prevent disease transfer from lactating sows to piglets (Wiseman et al., 1994), resulting in improving growth rate (Dritz et al., 1996).

In this case, however, the abrupt change of diets from sow milk to solid diet causes one of the postweaning lags. So, efforts were made to alleviate the nutritional stress from a solid diet by development of highly digestible and palatable diets (Lee, 2000). Corn, wheat and sorghum are common ingredients as carbohydrate sources in swine diets. According to its energy value, wheat ranks second after corn among cereals, and it has been shown that it is possible to use wheat as the only grain for pigs (Todorov, 1988).

Extrusion has been of great interest to improve growth performance and nutrient digestibility for young pigs. It increases starch gelatinization (Bjorck, 1985) and destroys antinutritional factors (Hancock et al., 1991), thus improves nutrient digestibility (Noland et al., 1976; Skoch et al., 1983) and growth performance (Richert et al., 1992).

For grains, however, Herkelman et al. (1990) reported that extrusion of corn improved energy utilization but not utilization of lysine or nitrogen by pigs. Richert et al. (1992) showed that extruded corn and sorghum improved growth performance of pigsfor d 0 to 10 postweaning, but was of no benefit from d 10 to 38. Chae et al. (2000) also reported that extrusion of corn and sorghum tended to improve nutrient digestibility and feed efficiency, whereas no difference was found in average daily gain between the two grains in weaned pigs.

Limited data are available for feeding extruded corn and wheat in early-weaned pigs, which is incomplete development in digestive capability. In evaluating the effect of extrusion in feed grains, previous experiments were mostly conducted with weaned or growing pigs aged over 3 weeks old. Therefore, this study was conducted to evaluate the effects of feeding extruded corn and wheat on growth performance and fecal digestibilityof amino acids in pigs weaned at 14 d of age.

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MATERIALS AND METHODS

Growth and digestibility trials for experimental diets

Dietary treatments were: 1) ground corn (3 mm), 2) extruded corn, 3) ground wheat (3 mm), and 4) extruded wheat, arranged as a 2×2 factorial. To prepare the cereal grains for use in the diets, each grain was ground with a hammer mill (3 mm screen in diameter). Particle sizes of the grains were measured by the method of ASAE (1983).

Additionally, ground corn and wheat were extruded at 130±2℃ by a moist-type extruder (Matador®) with the production rate of about 7 M/T per hour. After extrusion, the cereal products were ground again through a hammer mill (3 mm screen in diameter).

Diets were mash, and formulated to contain 30% grain products and 1.65% lysine. Vitamins and minerals in the diets were formulated to exceed the estimated NRC (1998) requirements (table 1). Chromic oxide was added as an indigestible marker for determination of digestibility in the diets.

A total of 160 pigs (14 d of age and 4.3±0.74 kg BW) were allotted on the basis of sex and weight to four treatments (4 replicates/treatment) in a completely randomized block design for a 21-d feeding trial. Initial body weight was used as the blocking criterion. The pigs were housed in 2 m×2 m pens with woven wire flooring. Room temperature was maintained at 32, 30, and 28℃ for d 0 to 7, 7 to 14, and 14 to 21, respectively. The pigs were allowed *ad libitum* access to feed and water. To determine nutrient digestibility of experimental diets, a grab of sample of feces was taken from several pigs each pen and pooled by pen on the 14th day after feeding the experimental diets. Feces were dried in an air-forced drying oven at 60℃ for 72 h for chemical analysis.

Table 1. Formula and chemical composition of experiment diets for feeding trial

	Corn	Wheat
Ingredient (%)		
Corn	30.00	-
Wheat	-	30.00
Milk replacer	22.00	21.30
Soybean meal	15.50	14.58
Lactose	10.62	14.15
Soy oil	4.00	5.44
Fish meal	5.00	5.00
Spray-dried plasma protein	7.50	5.00
Dried porcine soluble	2.50	1.90
MCP	0.86	0.22
Limestone	0.77	1.00
Vit. premix[1]	0.20	0.20
Trace min. premix[2]	0.30	0.30
Salt	0.30	0.30
Avilamycin	0.05	0.05
L-Lysine HCl (78%)	0.07	0.22
DL-Methionine (50%)	0.13	0.14
Cr_2O_3	0.20	0.20
Total	100.00	100.00
Calculated composition (%)		
ME (kcal/kg)	3,435	3,400
CP	23.03	23.00
Lysine	1.65	1.65
Methionine	0.50	0.50
Calcium	0.90	0.90
Phosphorus	0.80	0.80

[1] Supplied per kilogram of diet : 9,600 IU vitamin A, 1,800 IU vitamin D_3, 24 IU vitamin E, 1.5 mg vitamin K (as menadione), 1.5 mg thiamine, 12 mg riboflavin, 24 mg pantothenic acid (as d-calcium pantothenate), 45 mg niacin, 0.1 mg biotin, 2.4 mg pyridoxine, 0.8 mg folic acid, 500 mg choline and 0.05 mg vitamin B_{12}.

[2] Supplied per kilogram of diet : 38 mg Mn, 125 mg Fe, 187 mg Zn, 0.5 mg Co, 224 mg Cu, 0.8 mg I, and 0.25 mg Se.

Digestibility trial for extruded corn and wheat

For a digestibility trial for the grain products (ground vs extruded), 16 pigs (14-d old and 4.2±0.32 kg BW) were employed in individual metabolic crates. Additional 4 pigs (14-d old and 4.1±0.21 kg BW) were allotted to determine endogenous amino acid excretions with a nitrogen-free diet. Diets (table 2)

Table 2. Ingredient composition of experimental diets for digestibility trial

	Corn	Wheat	N-free diet
Ingredient			
Corn	68.50	-	-
Wheat	-	67.86	-
Corn starch	-	-	30.00
Lactose	20.00	20.00	30.00
Sucrose	7.00	7.00	9.75
Glucose	-	-	20.00
Animal fat (80%)	-	-	4.00
Tricalcium phosphate	2.16	1.89	3.00
Limestone	1.09	2.00	1.85
Salt	0.30	0.30	0.30
Vitamin premix[1]	0.25	0.25	0.30
Trace mineral premix[2]	0.25	0.25	0.25
Choline chloride (25%)	0.10	0.10	0.10
Mecadox	0.10	0.10	0.20
Cr_2O_3	0.25	0.25	0.25
Total	100.00	100.00	100.00
Calculated composition (%)			
ME (kcal/kg)	3,245	2,917	3,533
CP	5.50	7.97	-
Lysine	0.18	0.22	-
Calcium	1.08	1.33	1.66
Phosphorus	0.57	0.58	0.54

[1] Supplied per kilogram of diet : 9,600 IU vitamin A, 1,800 IU vitamin D_3, 24 IU vitamin E, 1.5 mg vitamin K (as menadione), 1.5 mg thiamine, 12 mg riboflavin, 24 mg pantothenic acid (as d-calcium pantothenate), 45 mg niacin, 0.1 mg biotin, 2.4 mg pyridoxine, 0.8 mg folic acid, and 0.05 mg vitamin B_{12}.

[2] Supplied per kilogram of diet : 38 mg Mn, 125 mg Fe, 187 mg Zn, 0.5 mg Co, 224 mg Cu, 0.8 mg I, and 0.25 mg Se.

were formulated with purified ingredients (i.e., lactose, etc.) and vitamins and minerals were included in order to meet or exceed their requirements suggested by NRC (1998). Chromic oxide was added as an indigestible marker for determination of digestibility in the diets.

Each pig was fed a restricted amount of feed (5% of BW) three times daily. On the sixth day after feeding, fecal samples were collected for 3 days. The collected fecal samples were frozen immediately at -80℃, freeze dried (Samwon Inc., Korea), ground with 1 mm mesh Wiley mill, and stored in a refrigerator until analysis.

Chemical and statistical analyses

Proximate analyses of the diets and fecal samples were analyzed according to the methods of AOAC (1990) and gross energy was measured with an adiabatic bomb calorimeter (Model 1241, Parr Instrument Co., Molin, IL). Chromium was measured with an atomic absorption spectrophotometer (Contron 942, Italy). Following acid hydrolysis in 6 N HCl at 110℃ for 16 hours, amino acid concentrations were determined using a HPLC (Waters, 486). The degrees of gelatinization for extruded corn and wheat were measured as described by Wooton et al. (1971).

Data were analyzed using the General Linear Model (GLM) Procedure of SAS (1985). The statistical model was that appropriate for a randomized complete block design, with a 2×2 factorial arrangement of treatments.

RESULTS AND DISCUSSION

Particle sizes and chemical compositions of the grain products (ground and extruded) are listed in table 3. The particle sizes of ground corn and wheat were 440 and 490 μm, respectively. Corn was slightly finer than wheat when a 3 mm screen in diameter was used in the hammer mill. The degree of

Table 3. Particle sizes, degree of gelatinization and chemical composition of corn and wheat used in the experiment (DM-basis)

Item	Corn		Wheat	
	Ground	Extruded	Ground	Extruded
Particle size (μm)	440	410	490	430
Gelatinization (%)	-	62.50	-	65.70
Gross energy (kcal/kg)	3,921	3,950	3,804	3,870
Crude protein (%)	9.65	9.25	13.09	12.81
Ether extract (%)	4.48	3.11	3.16	2.37
Crude ash (%)	1.58	2.67	1.63	2.89
Calcium (%)	0.07	0.08	0.06	0.07
Phosphorus (%)	0.41	0.44	0.42	0.44
Amino acid(%)				
Indispensable				
Arginine	0.40	0.40	0.60	0.59
Histidine	0.21	0.15	0.25	0.16
Isoleucine	0.34	0.29	0.44	0.46
Leucine	0.90	0.92	0.93	0.92
Lysine	0.22	0.19	0.40	0.37
Phenylalanine	0.70	0.59	0.86	0.77
Threonine	0.20	0.27	0.30	0.31
Valine	0.40	0.39	0.80	0.55
Sub-total	3.37	3.19	4.58	4.12
Dispensable				
Alanine	0.56	0.37	0.38	0.49
Aspartic acid	0.65	0.54	0.63	0.74
Glutamic acid	1.81	1.63	3.45	3.28
Glycine	0.33	0.38	0.57	0.75
Proline	0.81	0.71	1.25	1.22
Serine	0.25	0.35	0.56	0.59
Tyrosine	0.44	0.57	0.48	0.59
Sub-total	4.85	4.54	7.35	7.65
Total	8.22	7.73	11.93	11.77

gelatinization was also similar between extruded corn and wheat (62.5 vs 65.7%).

On the other hand, energy content in corn and wheat were slightly increased by extrusion, but ether extracts were slightly reduced by extrusion. There were no differences in crude protein and amino acid contents in raw and extruded corn or wheat.

In the growth assay (table 4), ADG, ADFI, and feed/gain of pigs were not affected ($p>0.15$) by grain source or extrusion in phase 1 (d 0 to 7). In phase 2 (d 7 to 21), ADG and feed/gain of pigs were also not affected by dietary treatment, however, ADFI was reduced ($p=0.003$) when the grains were extruded, and an interaction was also occurred (grain × processing, $p<0.001$). During the overall period, ADG was not improved, although feed/gain was improved ($p=0.01$) by extrusion of the grains.

Diets containing corn products, raw or extruded, showed higher ($p=0.001$) energy digestibility than wheat products. Extruding corn or wheat also improved ($p=0.003$) energy digestibility in early-weaned pigs.

Apparent and true fecal digestibilities of amino acids in the extruded corn and wheat in early-weaned pigs are presented in tables 5 and 6, respectively. Apparent fecal digestibility (AFD) of the average amino acids in corn and wheat were not different ($p>0.15$) between corn and wheat, and those were not improved ($p>0.15$) by extrusion. However, the AFD of histidine and glycine were lower ($p<0.026$) in corn than in wheat. Also, extruding corn and wheat decreased ($p<0.001$) the AFD of lysine ($p<0.001$) and proline ($p<0.007$). No interactions were occurred for any of the AFD of amino acids (grain × processing, $p>0.15$).

A similar trend was found in true fecal digestibility (TFD) of the average amino acids in corn and wheat, as shown in table 6. But the TFD of isoleucine, threonine and valine was higher ($p<0.001$) in corn than in wheat, whereas those of histidine, aspartic acid, glycine and proline were higher ($p<0.001$) in wheat than in corn. Extruding corn and wheat reduced ($p \leq 0.007$) the TFD of arginine, histidine, isoleucine, lysine, valine, proline and tyrosine. Also, interactions were occurred for the TFD of isoleucine, threonine, valine and tyrosine (grain × processing, $p<0.002$).

Conclusively, between corn and wheat, there were no differences in growth performance in early-weaned pigs. This result is in agreement with the result of Kim (1988). He found no differences in the rate and efficiency of growth in weaned pigs. In general, wheat is considered to be unpalatable when it is finely-ground due to glutelin, which forms a pasty mass in the mouth (Todorov, 1988). In the present study, however, feed intake was not reduced in pigs fed wheat as compared to those fed corn.

Feed efficiency was improved when corn and wheat were extruded, even though ADG was not improved. Feed intake was reduced ($p<0.003$) when the grains were extruded during phase 2. Johnston et al. (1999) also found that feed intake was reduced when diets were expanded in nursery pigs. But the mechanism for reduced feed intake in extruded feeds is unclear yet (Ohh, 1999).

In terms of growth rate by feeding extruded grains, research data are inconsistent. In the present study, ADG of pigs fed extruded corn and wheat was not improved, which is in agreement with the previous reports with wheat (Kim, 1988), corn and sorghum (Chae et al., 1997, 2000). Richert et al. (1992), however, reported that ADG was improved by 12% with extrusion of sorghum.

In our previous study (Chae et al., 2000), the ADG of pigs weaned at 21 days old was not improved when extruded corn or wheat was fed. The digestive capability of pigs weaned at 14 days old might be less improved than those weaned at 21 days old. Our expectation was that early-weaned pigs fed extruded corn or wheat could grow faster than those fed simply ground grains, but there was no difference.

Increased feed efficiency by feeding extruded grains might be related to improved energy digestibility (table 3). It is reported that energy digestibility was improved by extrusion in corn (Kim, 1988; Herkelman et al., 1990), sorghum (Noland et al., 1976) and barley (Fadel et al., 1988). Skoch et al. (1983) also reported that DM and energy digestibilities and feed/gain of pigs were improved by extruding diets containing wheat middlings and corn. Extrusion cooking changes the physical characteristics of starch, and it also causes a shift of insoluble nonstarch polysaccharides (NPS) to soluble NSP, thus improving energy digestibility (Gomez and Aguilera, 1983; Fadel et al., 1988).

Like growth performance, the digestibility of amino acids were similar between corn and wheat. The average AFD of nine essential amino acids in corn and wheat was slightly low as compared to data reported by Cho et al. (1997), which appeared to be differences in the age of pigs (4 vs 16 kg of body weight).

As mentioned, digestibilities of some amino acids were reduced by extrusion in young pigs. Apparent and true fecal digestibility of lysine, the first limiting amino acid, were reduced ($p<0.001$) by extrusion both in corn and wheat. This is partially in agreement with the previous reports concerning to heat-treated feed ingredients (Liener, 1978; Wiseman et al., 1991). Lysine is very sensitive to heat treatment. Liener (1978) reported that overheat made lysine unavailable due to interaction with the reducing groups of sugar,

Table 4. Growth performance and nutrient digestibility of experimental diets as affected by extrusion of corn and wheat in early-weaned pigs

	Corn		Wheat		SE[1]	Contrast[2]		
	Ground	Extruded	Ground	Extruded		1	2	3
Growth performance								
D 0-7								
ADG	142	137	141	129	18.83	NS[3]	NS	NS
ADFI	193	199	188	172	20.91	NS	NS	NS
F/G	1.38	1.49	1.34	1.33	0.23	NS	NS	NS
D 7-21								
ADG	359	356	357	392	57.82	NS	NS	NS
ADFI	636	546	596	606	41.63	NS	0.003	0.001
F/G	1.79	1.57	1.71	1.60	0.29	NS	NS	NS
D 0-21								
ADG	286	283	285	304	35.62	NS	NS	NS
ADFI	488	430	460	447	47.57	NS	NS	NS
F/G	1.71	1.52	1.63	1.49	0.13	NS	0.010	NS
Nutrient digestibility (%)								
Gross energy	81.88[a]	82.34[a]	78.97[b]	79.65[b]	1.54	0.001	0.003	NS
Crude protein	75.47[ab]	78.24[a]	73.18[b]	75.55[ab]	2.20	NS	NS	NS

[a,b] Values with different superscripts in the same row differ ($p<0.05$).

[1] Pooled standard error.

[2] Contrast: 1) corn vs wheat, 2) ground vs extruded and 3) grain × processing.

[3] NS: not significant ($p \geq 0.15$).

Table 5. Effect of extruding corn and wheat on apparent fecal digestibility of amino acids in early-weaned pigs

	Corn		Wheat		SE[1]	Contrast[2]		
	Ground	Extruded	Ground	Extruded		1	2	3
Indispensable								
Arg	67.25	68.15	69.75	69.25	1.75	NS[3]	NS	NS
His	64.71[b]	67.05[ab]	70.11[ab]	68.15[a]	2.70	0.026	NS	NS
Ile	63.54	67.80	68.23	63.94	3.57	NS	NS	NS
Leu	70.01	69.39	68.51	67.88	1.93	NS	NS	NS
Lys	69.00[a]	63.19[b]	69.25[a]	61.83[b]	3.77	NS	0.001	NS
Phe	64.94[b]	70.09[a]	70.42[a]	67.74[ab]	2.83	NS	NS	NS
Thr	59.28[b]	66.04[a]	60.82[ab]	66.89[a]	3.50	NS	0.001	NS
Val	61.38	61.32	65.04	62.57	2.75	NS	NS	NS
Sub-mean	65.01[b]	66.63[ab]	67.77[a]	66.03[ab]	1.76	NS	NS	NS
Dispensable								
Ala	63.16[ab]	67.68[a]	63.49[b]	67.73[a]	2.90	NS	0.006	NS
Asp	66.05	65.99	68.17	68.57	2.21	NS	NS	NS
Glu	68.85[b]	71.22[a]	71.28[a]	69.80[b]	1.46	NS	NS	NS
Gly	66.45[b]	69.37[a]	69.52[a]	70.52[a]	1.98	0.029	0.040	NS
Pro	70.29[a]	65.45b	71.04[a]	68.07[ab]	2.79	NS	0.007	NS
Ser	69.21[ab]	70.89[a]	67.79[b]	68.56[ab]	1.66	0.043	NS	NS
Tyr	66.89[b]	70.85[a]	67.26[b]	68.32[ab]	2.05	NS	0.018	NS
Sub-mean	67.27	68.78	68.36	68.80	1.32	NS	NS	NS
Mean	66.14	67.57	68.07	67.41	1.40	NS	NS	NS

[ab] Values of the same row with different superscript is significantly differ ($p<0.05$).

[1] Pooled standard error.

[2] Contrast: 1) corn vs wheat, 2) ground vs extruded and 3) grain × processing.

[3] NS: not significant ($p \geq 0.15$).

Table 6. Effect of extruding corn and wheat on true fecal digestibility of amino acids in weaned pig

	Corn		Wheat		SE[1]	Contrast[2]		
	Ground	Extruded	Ground	Extruded		1	2	3
Indispensable								
Arg	82.13[a]	79.81[b]	82.09[a]	81.60[a]	1.15	NS[3]	0.007	NS
His	81.20[a]	77.83[b]	81.49[a]	80.33[a]	1.68	0.022	0.001	NS
Ile	81.87[ab]	81.62[b]	83.69[a]	76.66[c]	2.86	0.028	0.003	0.001
Leu	83.24[a]	82.71[a]	84.04[a]	82.78[a]	1.85	NS	NS	NS
Lys	83.28[a]	76.71[b]	82.45[a]	78.35[b]	2.98	NS	0.001	NS
Phe	83.54	82.55	82.25	82.11	1.31	NS	NS	NS
Thr	84.86[a]	84.71[a]	78.93[b]	84.41[a]	2.76	0.001	0.002	0.002
Val	85.37[a]	81.45[b]	80.36[c]	78.20[d]	2.73	0.001	0.001	0.002
Sub-mean	83.19	80.92	81.91	80.56	1.68	NS	NS	NS
Dispensable								
Ala	83.69	84.74	84.66	84.60	1.02	NS	NS	NS
Asp	72.97[b]	73.79[b]	77.73[a]	77.95[a]	2.49	0.001	NS	NS
Glu	77.51[b]	79.56[a]	78.73[ab]	77.15[b]	1.32	NS	NS	NS
Gly	78.85[b]	81.44[a]	82.24[a]	82.03[a]	1.63	0.007	NS	NS
Pro	78.10[b]	77.15[b]	81.16[a]	78.33[b]	1.80	0.008	0.014	NS
Ser	80.19	81.03	79.86	81.16	1.17	NS	NS	NS
Tyr	79.34[b]	79.68[b]	83.43[a]	76.32[c]	2.80	NS	0.001	0.001
Sub-mean	78.66	79.63	81.12	79.65	1.35	NS	NS	NS
Mean	83.19	80.92	81.91	80.56	1.32	NS	NS	NS

[ab] Values of the same row with different superscript is significantly differ ($p<0.05$).

[1] Pooled standard error.

[2] Contrast: 1) corn vs wheat, 2) ground vs extruded and 3) grain×processing.

[3] NS: not significant ($p \geq 0.15$).

and thus, no longer susceptible to tryptic and pancreatic cleavages.

On the other hand, true fecal digestibilities of some amino acids in extruded corn (glutamic acid and glycine) and wheat (threonine) were improved in the present study. This probably supports the previous reports: Extrusion processing improves protein digestibility in feeds through protein denaturation, thus protein molecules are more susceptible to proteolytic enzymes under the mild extruding temperature (Fadel et al., 1988; Hancock, 1992). Typical extruding temperature is 135-160℃ (Hancock, 1992). In the present study, the extruding temperature was 130℃, which was not high as compared to the conventional extruding temperature.

IMPLICATIONS

Growth performance was similar in pigs fed corn or wheat. Extrusion of corn and wheat did not affect the rate of growth, although the efficiency of growth was improved. Lysine digestibility in corn and wheat were reduced by extrusion. Conclusively, our results suggest that extruding corn or wheat had no benefit on the growth of early-weaned pigs.

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