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The Effect of Feeding Extruded Corn on the Growth Performance of Nursery Pigs Reared under Tropical Conditions

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ABSTRACT

The research was conducted to study the metabolizable energy value of extruded corn and the effect of feeding extruded corn on the growth performance of nursery pigs. Twelve three-way crosses of pigs averaging 18.3 kg BW were used to compare the metabolizable energy value between ground corn and extruded corn. The results indicated that the metabolizable energy value for ground corn and extruded corn was 3497 and 3653 kcal/kg, respectively. The effect of feeding extruded corn on the growth performance was investigated using 192 three-way crosses of pigs averaging 7.8 kg BW. Pigs were randomly separated into three dietary treatments based on three carbohydrate sources (broken rice, ground corn and extruded corn). The pigs were fed with experimental mash diets from 4 to 9 weeks of age. It was found that pigs fed with extruded corn had a poorer average daily weight gain (ADG) and feed conversion ratio (FCR) than pigs fed with ground corn and broken rice ($P < 0.05$). No significant differences in daily feed intake and mortality were observed among the treatments. Pigs fed with either broken rice or extruded corn were found to have a higher feed cost ($P < 0.05$) and feed cost per kg body weight gain ($P < 0.01$) than pigs fed with ground corn.

Key words: extruded corn, nursery pigs, metabolizable energy, growth performance, tropical conditions

INTRODUCTION

Corn is one of the most important sources of dietary energy with about two-thirds of the world corn production utilized as animal feed (Willm, 1994). Recently, corn has been more and more utilized in ethanol production and this has resulted in competition for corn supplies between animal feed utilization and bio-fuel production. The shortage in supply of world corn for the feed industry has triggered animal nutritionists to develop ways of increasing corn utilization (Watson, 2007). Several methods have been employed to improve the nutritive value of corn, such as toasting, micronization, microwaving, steam flaking and extrusion (Pfost, 1976). Extrusion is a process in which the material was forced to flow through a die, under one or more varieties of mixing, heating and shearing (Riaz, 2000). Thus, the extrusion process increased the gelatinization and surface area of the starch granules, which consequently improved starch utilization (Björk *et al*., 1985; Raiz, 2000), energy utilization, palatability (Noland *et al*., 1976; Björk *et al*., 1985; Hancock and Behnke, 2001) and nitrogen digestibility, especially in poor quality

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grain sorghum (Herkelman *et al*., 1990). Various results on animal performance regarding the use of extruded grain have been reported (Hongtrakul *et al*., 1998; Chae *et al*., 2000). The type of extruder (single or twin screw) and the conditions of the extrusion process such as temperature, pressure and water flow rate were among the important factors responsible for some controversial results. For instance, dry extrusion of corn flour improved the energy digestibility, whereas wet extrusion appeared to significantly reduce the availability of energy (Allen Davis and Arnold, 1995). Therefore, the objective of this study was to elucidate the effect of the dry extrusion process of corn on the energy utilization and growth performance of nursery pigs.

MATERIALS AND METHODS

Yellow flint corn from Chiang Rai Province, Thailand was extruded through a single screw extruder (Model PHG 135, Wuhan Machinery, China) using the dry extrusion process, with a barrel length of 0.81 m, 24 die openings, and a die diameter of 0.6 cm. Extrusion conditions were: 14 l/h water flow rate, 107°C barrel jacket temperatures at the second head, 53.6°C hot product (exit) temperature, 8.6% hot product (exit) moisture, 68.4 kWh/t electrical energy consumption of extruding energy and 385 kg/h production rate of extrusion. The extrudate was air-dried overnight and measured for bulk density. The bulk density of whole corn and extruded corn before grinding was 823.8 and 135.4 g/l, respectively. The extrudate was then ground through a 15-horse-power hammer mill equipped with a 1.7 mm screen. Samples were taken and then analyzed for proximate analysis (AOAC, 1990). Electrical energy consumption and the production rate of fine grinding were 4.4 kWh/t and 1,311 kg/h, respectively. Total electrical energy consumption for both extruding and fine grinding was 72.8 kWh/t.

Metabolizable energy

Twelve three-way crosses (Duroc × Large White × Landrace) of castrated male pigs averaging 18.3 kg BW were used to compare the metabolizable energy value of ground corn and extruded corn. The pigs were kept in 0.45 × 1.0 m individual cages in an open–air facility. Corn starch and soybean meal were used as a basal diet to calculate the metabolizable energy, which was determined using the substitution method according to Herkelman *et al*. (1990). Corn starch in the basal diet was replaced by corn or extruded corn to make up experimental diets (Table 1). Chromic oxide was added to the diets at a level of 0.4% for the five day collection period as an indigestible marker. Samples of each diet were taken and analyzed for bulk density. The experimental diets were fed from day 8 until day 12 after a preparatory period of seven days and were fed at 80% of full feed intake. The feeding times were at 7.00 am and 4.00 pm. Water was provided *ad libitum*.

Urine and feces samples were collected for five days beginning on the eighth day of the experiment. Collection of urine and feces samples was started after the marker first appeared and was terminated when the empty marker appeared. Urine was collected twice daily in plastic containers containing 25 ml of 6 *N* HCl. Total urine volumes were recorded daily and 25% of the total urine was sampled and frozen for later analysis for gross energy. Feces samples were collected twice daily in plastic containers, air-dried at 50° C, ground through a 1.00-mm screen and frozen for later analysis. Feces samples and experimental diets were analyzed for the chromic oxide content (Czarnocki *et al*., 1961), moisture content (AOAC, 1990) and gross energy (PARR 1261 bomb calorimeter) which were used to determine the metabolizable energy content of corn and extruded corn by using the equation of Adeola (2001).

The chemical composition value and metabolizable energy were subjected to t-test

Table 1 Composition of experimental diets.

Ingredient (%) as-fed basis	Reference Diet	Corn diet	Extruded corn diet
Corn starch	75.0	15.0	15.0
Normal corn	-	60.0	-
Extruded corn	-	-	60.0
Soybean meal (48% CP)	19.0	19.0	19.0
Sweet whey (13% CP)	5.0	5.0	5.0
Vitamin premix[1/]	0.5	0.5	0.5
Salt	0.5	0.5	0.5
Chromic oxide	0.4	0.4	0.4
Total	100.0	100.0	100.0

[1/] Vitamin and mineral premix provided per kg of diets : 5,000,000 IU vitamin A ; 1,000,000 IU vitamin D ; 10.0 mg vitamin E ; 750 µg vitamin K3 ; 500 µg vitamin B1 ; 3.0 mg vitamin B2 ; 10.0 mg vitamin B3 ; 2.0 mg vitamin B6 ; 12.5 µg vitamin B12 ; 5.0 mg pantothenic acid ; 250 µg folic acid ; 50 µg biotin ; 5.0 mg Cu ; 37.5 mg Fe ; 500 µg I ; 20 mg Mn ; 100 µg Se ; 50.0 mg Zn.

analysis (Steel and Torrie, 1980).

Growth performance

A total of 192, 4-week-old, three-way crosses (Duroc × Large White × Landrace) pigs (average initial BW of 7.8 kg) were randomly assigned to three dietary treatments, with eight replications per treatment. The trial was divided into two phases of four to seven weeks and eight to nine weeks, respectively. Pigs were housed in environmentally controlled nurseries with 1.8 × 2.0 m pens and were allowed free access to water and feed. The ambient temperature and relative humidity throughout the experiment were between 22 to 33°C and 62 to 86%, respectively. Three dietary treatments based on three different carbohydrate sources (broken rice, ground corn, and extruded corn) were formulated in order to make all diets isocaloric and isonitrogenous as shown in Table 2. All diets were fed in mash form in both phases.

Average daily gain, daily feed intake, feed conversion ratio, mortality and feed cost were subjected to analysis of variance procedures using a completely randomized design using a general linear model procedure. The statistical significance of differences among treatments was assessed using the least-significant difference test (Steel and Torrie, 1980).

RESULTS

Metabolizable energy

The chemical composition of the corn and extruded corn are shown in Table 3. The extrusion process significantly decreased ($P < 0.05$) crude fat, crude fiber and moisture content. However, the concentration of nitrogen-free extract in the extruded corn was found to be higher than in corn ($P < 0.01$). The metabolizable energy content for pigs of both corn and extruded corn were analyzed to be 3497 and 3653 kcal/kg, respectively (Table 3).

Growth performance

Pig performance from four to seven weeks of age is shown in Table 4. No significant differences in average daily gain, daily feed intake and mortality were observed among dietary treatments. However, pigs fed the extruded corn had a higher ($P < 0.05$) feed conversion ratio than those fed broken rice or ground corn.

During the eighth and ninth week age-period, pigs fed extruded corn had poorer

Table 2 Ingredient composition and nutrient content of experimental diets.

Ingredients,% (as-fed basis)	4-7 weeks of age Broken rice diet	Ground corn diet	Extruded corn diet	8-9 weeks of age Broken ricediet	Ground corn diet	Extruded corn diet
Broken rice	46.1	-	-	53.3	-	-
Corn	-	46.9	-	-	54.7	-
Extruded corn	-	-	47.7	-	-	56.0
Wheat bran	6.7	6.7	6.7	8.0	8.0	8.0
Soybean meal (44% CP)	8.0	8.0	8.0	23.8	22.9	22.0
Full fat soybean	24.4	23.6	22.7	6.7	6.7	6.7
Fish meal (60% CP)	3.0	3.0	3.0	3.0	3.0	3.0
Sweet whey (13% CP)	8.0	8.0	8.0	-	-	-
Vegetable oil	-	-	-	1.1	0.9	0.5
Limestone	1.2	1.4	1.4	1.5	1.4	1.4
Monodicalcium phosphate	1.5	1.2	1.2	1.5	1.2	1.2
Salt	0.21	0.25	0.31	0.22	0.27	0.27
Vitamin-mineral premix 1/	0.20	0.20	0.20	0.20	0.20	0.20
l-Lysine	0.10	0.15	0.17	0.10	0.15	0.18
dl-methionine	0.07	0.06	0.07	0.03	0.03	0.03
Flavoring agent	0.03	0.03	0.03	-	-	-
Sweetener	-	-	-	0.03	0.03	0.03
Antibiotic 2/	0.53	0.53	0.53	0.53	0.53	0.53
Total	100	100	100	100	100	100
Cost (baht/kg) 3/	12.26	11.17	11.86	9.63	8.41	9.19
Bulk density, g/l	633.35	591.81	433.82	614.28	562.54	498.80
Calculated chemical composition						
Metabolizable energy, kcal/kg	3350	3350	3350	3300	3300	3300
Protein, %	20.00	20.00	20.00	20.00	20.00	20.00
Calcium, %	1.00	1.00	1.00	1.00	1.00	1.00
Total phosphorus, %	0.70	0.70	0.70	0.70	0.70	0.70
Available phosphorus, %	0.50	0.50	0.50	0.50	0.50	0.50
Lysine, %é	1.25	1.25	1.25	1.20	1.20	1.20
Methionine, %	0.43	0.38	0.38	0.41	0.35	0.35
Methionine+Cystine, %	0.70	0.70	0.70	0.66	0.66	0.66
Threonine, %	0.82	0.78	0.77	0.80	0.75	0.74
Tryptophan, %	0.26	0.24	0.23	0.27	0.24	0.24

1/ Vitamin and mineral premix provided per kg of diets: 5,000,000 IU vitamin A; 1,000,000 IU vitamin D; 10.0 mg vitamin E; 750 µg vitamin K3; 500 µg vitamin B1; 3.0 mg vitamin B2; 10.0 mg vitamin B3; 2.0 mg vitamin B6; 12.5 µg vitamin B12; 5.0 mg pantothenic acid; 250 µg folic acid; 50 µg biotin; 5.0 mg Cu; 37.5 mg Fe; 500 µg I; 20 mg Mn; 100 µg Se; 50.0 mg Zn.

2/ Antibiotic premix provided per kg of diets: 100 ppm Colistin; 500 ppm antifungals; 300 ppm antioxidants.

3/ Cost at 19 February 2005

($P < 0.05$) average daily gain than those fed broken rice and ground corn. However, there were no significant differences among dietary treatments based on daily feed intake, feed conversion ratio and mortality (Table 5).

Overall (from age four weeks to age nine weeks), pigs fed with broken rice or ground corn had a greater ($P < 0.05$) average daily gain and feed conversion ratio than those fed with extruded corn. No significant differences in daily feed intake

Table 3 Chemical composition and metabolizable energy of corn and extruded corn (% dry matter)[1/].

Items	Corn	Extruded corn	P-value
Moisture, %	9.71 ± 0.04 [x]	5.90 ± 0.08 [y]	0.0003
Crude ash, %	1.40 ± 0.03	1.34 ± 0.09	0.4401
Crude protein, %	8.14 ± 0.28	8.36 ± 0.01	0.4535
Crude fat, %	4.65 ± 0.11 [a]	3.21 ± 0.25 [b]	0.0180
Crude fiber, %	3.35 ± 0.22 [a]	2.54 ± 0.05 [b]	0.0364
Nitrogen free extract,% [2/]	72.75 ± 0.66 [y]	78.65 ± 0.33 [x]	0.0078
Calcium,%	0.07 ± 0.01	0.06 ± 0.01	0.5000
Phosphorus,%	0.24 ± 0.02	0.25 ± 0.02	0.5918
Metabolizable energy, kcal/kg [3/]	3,497.17 ± 122.53	3,652.90 ± 98.95	0.0953

[1/] Based on duplication analysis.
[2/] Nitrogen free extract was calculated base on the proximate analysis.
[3/] Four replication per treatment.
[x,y] Mean values ± SD in the same row with different superscripts were highly significantly different. ($P < 0.01$)
[a,b] Mean values ± SD in the same row with different superscripts were significant different. ($P < 0.05$)

Table 4 The effect of feeding extruded corn on pig performance from four to seven weeks of age.

Item	Diets			P-value
	Broken rice	Ground corn	Extruded corn	
No. of pigs	64	64	64	-
Initial body weight (kg/pig)	7.63 ± 1.28	7.80 ± 1.01	7.71 ± 1.48	0.9654
Body weight at 7 wk (kg/pig)	15.22 ± 1.49	14.97 ± 1.10	14.62 ± 1.35	0.6672
Average daily gain (g/day)	361.42 ± 35.33	341.17 ± 23.23	329.05 ± 38.64	0.1661
Daily feed intake (g/pig/day)	561.91 ± 52.94	547.65 ± 31.99	572.77 ± 48.47	0.5493
Feed conversion ratio	1.56 ± 0.08[b]	1.61 ± 0.09 [b]	1.76 ± 0.21 [a]	0.0260
Mortality, %	3.13 ± 5.79	1.56 ± 4.42	4.69 ± 6.47	0.5487

[a,b] Mean values ± SD in the same row with different superscripts were significantly different. ($P < 0.05$)

Table 5 The effect of feeding extruded corn on pig performance during the eighth and ninth week age-period.

Item	Diets			P-value
	Broken rice	Ground corn	Extruded corn	
Body weight at 9 wk(kg)	24.24 ± 1.67	23.84 ± 1.54	22.75 ± 1.39	0.1608
Average daily gain(g/day)	644.31 ± 41.46[a]	633.83 ± 38.24[a]	580.96 ± 48.92[b]	0.0172
Daily feed intake (g/pig)	1146.63 ± 81.77	1180.65 ± 101.54	1120.70 ± 90.60	0.4372
Feed conversion ratio	1.78 ± 0.12	1.86 ± 0.07	1.94 ± 0.21	0.1233
Mortality,%	3.13 ± 5.79	0	0	0.1216

[a,b] Mean values ± SD in the same row with different superscripts were significantly different. ($P < 0.05$)

and mortality were observed among the treatments. Pigs fed with broken rice or extruded corn were found to have a greater feed cost ($P < 0.05$) and feed cost per kg body weight gain ($P < 0.01$) than pigs fed with ground corn (Table 6).

DISCUSSION

Nutritional changes in corn during extrusion processing are reported in Table 3. Crude fat, crude fiber and the moisture content of extruded corn were lower than in native corn, which was in agreement with earlier reports (Herkelman *et al*., 1990; Amornthewaphat *et al*., 2005). Chemical or physicochemical changes such as binding, cleavage, loss of native conformation, recombination of fragments and thermal degradation can occur during extrusion cooking and the composition of corn can be changed by physical losses, including leakage of oil and evaporation of water and volatile compounds at the die (Riaz, 2000). Furthermore extrusion of corn has been reported to change the starch solubility, with the amount of soluble starch being increased as corn moisture decreased (Gomez and Aguilera, 1983). In this experiment, corn moisture was extremely low, which enhanced the amount of more-soluble fiber and lessened the amount of insoluble fiber in the extruded corn.

The metabolizable energy content of ground corn compared to extruded corn was not significantly different, but extruded corn tended to have a higher ($P = 0.10$) metabolizable energy than ground corn. The extrusion of corn has been reported to increase the gelatinization and surface area of starch granules, which consequently improves starch utilization (Björk *et al*., 1985; Raiz, 2000), energy utilization and palatability (Noland *et al*., 1976; Björk *et al*., 1985; Hancock and Behnke, 2001).

Pigs fed with extruded corn showed a lower growth performance than pigs fed with broken rice or ground corn. This result was in agreement with Hongtrakul *et al*. (1998), who reported that pigs fed with extruded diets had a lower gain:feed ratio than pigs fed with non-extruded diets ($P < 0.05$). However, other studies have reported positive responses in growth performance to the processing of the corn by the extrusion process (Noland *et al*., 1976; Chae *et al*., 2000). One possible explanation for the variation in the response to extrusion processing could be the type of extruder (moist vs dry, single vs twin screw) and the extruder conditions (for example moisture, temperature and pressure) (Allen Davis and Arnold, 1995). Another possible explanation for the negative response in growth performance was the lower bulk density in the

Table 6 The effect of feeding extruded corn on pig performance from age four weeks to age nine weeks.

Item	Diets			P-value
	Broken rice	Ground corn	Extruded corn	
Average daily gain(g/day)	474.58 ± 24.65^{a}	458.23 ± 25.04^{a}	429.82 ± 30.60^{b}	0.0107
Daily feed intake (g/pig)	801.83 ± 58.63	801.92 ± 52.05	792.74 ± 58.63	0.9330
Feed conversion ratio	1.69 ± 0.09^{b}	1.75 ± 0.06^{ab}	1.85 ± 0.16^{a}	0.0239
Mortality,%	6.25 ± 6.68	1.56 ± 4.42	4.69 ± 6.47	0.2963
Feed cost (baht/pig)	299.26 ± 22.54^{a}	267.47 ± 16.88^{b}	286.84 ± 21.50^{a}	0.0174
Feed cost per 1 kg body weight gain (baht)	18.01 ± 0.84^{x}	16.68 ± 0.51^{y}	19.12 ± 1.62^{x}	0.0080

^{x,y} Mean values ± SD in the same row with different superscripts were highly significantly different. ($P < 0.01$)

^{a,b} Mean values ± SD in the same row with different superscripts were significantly different. ($P < 0.05$)

extruded corn. The current study found that the bulk density of the extruded corn diets was also lower than in the broken rice diets or ground corn diets, as shown in Table 2. The extrusion process caused a loss of moisture content in the extruded material due to a sudden change of pressure and temperature at the exit head. This induced water to evaporate out of the cell structure (Amornthewaphat *et al*., 2005). Generally, bulky feed affected the feed intake, average daily gain and feed conversion rate due to its influence on the physicochemical characteristics of digesta, such as a modification of viscosity and the rate of digesta passage through the lower part of the gut (Kyriazakis and Emmans, 1995; Anguita *et al*., 2007). Therefore, although the extrusion process increased metabolizable energy, there was no observed improved growth performance in pigs when using a mash diet. Furthermore the extrusion process also increased the feed cost of the diet by 19.37 baht/pig when compared with a ground corn diet. Mash extruded corn feed decreased the growth rate of pigs reared under tropical conditions. However, using steam-conditioned pelleting may be necessary to overcome the lower bulk density of extruded corn, and optimize the growth performance of pigs fed with extruded corn.

CONCLUSION

Under the conditions described in this study, using the dry extrusion process for corn increased the metabolizable energy of nursery pigs. However, the extruded corn did not improve the growth performance in the nursery pigs when compared to ground corn or broken rice.

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