Effects of Feed Processing Methods on Growth Performance and Ileal Digestibility of Amino Acids in Young Pigs**

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ABSTRACT : Three experiments were conducted to determine the feed processing method best suited for early and conventionally-weaned pigs, and to investigate the effects of different extrusion temperatures on ileal digestibility of amino acids in diets containing different protein sources. In exp.1, a total of 108 pigs (Landrace×Yorkshire×Duroc; 24 d of age and 7.60 kg average body weight) were alloted on the basis of sex, weight and ancestry to three treatments in a randomized complete block design. Feed processing methods used were mash (M), simple pellet (SP), and expanded pellet (EP). In exp. 2, a total of 96 pigs (Landrace×Yorkshire×Duroc; 14 d of age) were allotted on the basis of sex, weight, and ancestry to three treatments in a randomized complete block design. Diets were mash (M), expanded pellet (EP), and expanded pellet crumble (EPC). In exp. 3, a study was designed to investigate the effect of different extrusion temperatures (100, 120, and 140°C) over the control (untreated) on the ileal digestibility of amino acids in diets containing protein sources such as spray-dried plasma protein (SDPP), whey protein concentrate (WPC), and fish meal (FM). Results in exp.1 showed that ADG, ADFI and the F/G ratio of pigs fed the SP diet were improved ($p<0.05$) compared with those fed the M or the EP diets, but the digestibility of nutrients was not different ($p>0.05$) among the treatments. In exp. 2, pigs fed expanded pellet treatments (EP or EPC) had a significantly improved ($p<0.05$) F/G ratio compared to the pigs fed the M diet which was primarily attributed to the significant reduction ($p<0.05$) in ADFI, but the overall growth rate of pigs fed expanded pellet diets was not improved. In exp. 3, there was a significant interaction effect ($p<0.05$) between the extrusion temperature and protein source on the ileal digestibility of amino acids. With an extrusion temperature of 100°C, the ileal digestibility of Lys, Val, Gly and Ser was significantly lower in the diet containing WPC compared to the diet containing SDPP. Increasing the temperature to 120°C led to significant differences ($p<0.05$) in the digestibility of Thr and Tyr between diets containing WPC and SDPP. Regardless of extrusion temperatures, the weaned pigs' diet containing either SDPP or FM had significantly higher Lys, Phe, Thr, Val, and Gly digestibility relative to the WPC diet. Results of the present study suggest that simple pelleting of diets containing protein sources such as whey protein concentrate, spray-dried plasma protein and fish meal would be better than the extruded or expanded pellet diets. Extruder or expander processing of weaned pigs' feed could reduce palatability and ileal digestibility of several amino acids and therefore may be responsible for a negative growth response in weaned pigs. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 12 : 1765-1772)***

Key Words : Pellet, Expanding, Extruding, Temperature, Ileal Digestibility, Pig

INTRODUCTION

Pelleting of diets has been extensively used in commercial feed production. It is well known that pelleting improves ADG and feed efficiency in swine (Hansen et al., 1992; Wondra et al., 1992; Traylor et al., 1996; Chae et al., 1997c). In an attempt, however, to further improve the nutritional value of swine feeds, extruder and/or expander processing has been introduced for the past several decades. Extruder/expander conditions such as degree of cooking, preconditioning, and temperature can alter the nutritional value of feeds (Chae et al., 1997d; Piao et al., 1999; Johnston et al., 1999). The feed conversion of nursery pigs fed extruded corn and sorghum was better than those fed the unextruded feed (Chae et al., 2000). Growing pigs fed extruded barley showed significantly improved growth performance and higher crude protein digestibility over pigs fed finely ground barley (Chu et al., 1998). In addition, most of the anti-nutritional factors such as those found in soybeans are heat labile. Thus, extrusion processing yielded a full-fat soy product of greater nutritional value than a roasting process (Kim et al., 1999).

Chae and Han (1998) emphasized that the effect of processing methods on the growth performance of pigs depends largely on the ingredients characteristics. They stated that extruded or expanded pellet diets containing highly digestible ingredients have little effect on the growth performance of pigs. Furthermore, the nutritional value of the feeds over pelleted diets was not improved as pigs grew. Chae et al. (1997a) suggested pelleting as a desirable processing method for weaned pigs' diet containing a milk product. This resulted in a better growth rate in pigs fed a pelleted diet than those fed an extruded diet. The energy and crude protein digestibility was significantly improved

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when a mash diet was pelleted but a reduction in crude protein digestibility resulted with an extruded pellet. This reduction in crude protein digestibility was probably caused by the high temperature during extrusion processing. It was reported by Johnston et al. (1999) that increasing the cone pressure of the expander from 0 to 14 kg/cm^2 with a steam conditioning temperature of 54°C resulted in a linear decrease in the rate of weight gain of weaned pigs, suggesting that heat damaged the diet. However, it was shown that heat damage could be minimized by using more steam when the conditioning temperature was increased to 63°C. But none of the pigs fed expanded pellet diets compared favorably to the pigs fed the conditioned (54°C) pellets processed with no cone pressure. Likewise, Steidinger et al. (2000) demonstrated that conditioning the diets containing 5% spray-dried animal plasma at temperatures above 77°C decreased ADG and ADFI of weaned pigs.

Since only few studies have been documented concerning feed processing of complex nursery or weaned pigs' diets, the objectives of the research reported herein were to determine the form of processed feed appropriate for early and conventionally-weaned pigs, and to investigate the effects of extrusion temperatures on the ileal digestibility of amino acids in diets containing different protein sources.

MATERIALS AND METHODS

Experimental animals, designs and diets

Exp. 1 : One hundred eight conventionally-weaned pigs (Landrace×Yorkshire×Duroc; 24 d of age and 7.60 kg average body weight) were allotted on the basis of sex, body weight, and ancestry to three treatments in a randomized complete block design. Each treatment was replicated three times with twelve pigs per replicate (pen). The treatments were 1) mash (M), 2) simple pellet (SP), and 3) expanded pellet (EP).

The M diet was formulated to contain 21.8% crude protein (CP) and a metabolizable energy (ME) of 3,500 kcal/kg; supplemented with vitamins, minerals and amino acids to meet or exceed the nutrient requirements listed in NRC (1998) (Table 1). For the SP diet, the mash diet was steam conditioned to 35°C and pelleted using a 220 hp pellet mill (Model; 12 type, Matador, Denmark) with a 2.8 mm die in diameter. The EP was produced by subjecting the M diet to a 300 hp expander (Model M12, Matador, Denmark) with 180 amperes, a gap opening of 39% and temperature of 95°C. The expanded diet was further processed through a pellet mill similar to the one used for the SP diet.

The pigs were housed in partially slotted and concrete floored pens with a self feeder and nipple waterer to allow

Table 1. Formula and chemical composition of experimental diets for weanling pigs

Ingredient (%)	Experiment	
	1	2
Corn, ground	39.96	20.34
Soybean meal (46%)	14.00	21.16
Whey protein concentrate (34%)	10.00	-
Milk replacer	-	31.00
Lactose	5.00	10.00
Biscuit meal	6.00	-
Spray-dried plasma protein (79%)	5.00	6.50
Wheat germ	5.00	-
Fish meal (68%)	4.50	3.10
Soy oil	3.50	5.26
Sucrose	3.00	-
Tricalcium phosphate	1.70	-
Limestone	0.50	0.74
L-lysine (78%)	0.12	0.06
DL-methionine (50%)	0.13	0.12
Salt	0.10	0.20
Avilamycine (100 g/kg)	-	0.25
Mono-calcium phosphate	-	0.92
Choline chloride (25%)	0.10	-
Vitamin premix[a]	0.30	0.15
Mineral premix[b]	0.20	0.20
Zinc oxide	0.34	-
Apramycin (100 g/kg)	0.15	-
Chlorotetracycline (100 g/kg)	0.10	-
Cabadox (50 g/kg)	0.10	-
Organic acid[c]	0.20	-
Total	100.00	100.00
Calculated chemical composition (as-fed)		
Metabolizable energy, kcal/kg	3,500	3,479
Crude protein, %	21.8	23.0
Lysine, %	1.55	1.65
Calcium, %	0.95	0.91
Phosphorus, %	0.85	0.80

[a] Supplied per kg diet : 12,000 IU vitamin A, 3,000 IU vitamin D_3, 30 IU vitamin E, 3.45 mg vitamin K_3, 1.8 mg vitamin B_1, 14.4 mg vitamin B_2, 3 mg vitamin B_6, 0.045 mg vitamin B_{12}, 30 mg pantothenic acid, 90 mg niacin, 0.105 mg biotin, 0.75 mg folic acid.

[b] Supplied per kg diet : 143 mg Cu, 125 mg Fe, 102 mg Zn, 38.74 mg Mn, 0.75 mg Co, 0.75 mg I, 0.23 mg Se.

[c] This product consists of phosphoric acid, propionic acid, calcium formate and buffer.

ad libitum access to the feed and water. The pigs were weighed and feed intake was recorded on d 0, d 7, and d 14. A digestibility trial was performed using chromic oxide (0.25%) as an indicator. The pigs were fed diets mixed with chromic oxide on d 7 and fecal samples were collected on d 12 to d 14. The fecal samples were dried in an air forced drying oven at 60°C for 72 h and ground with a 1 mm mesh Wiley mill for chemical analysis.

Exp. 2 : A total of ninety-six early-weaned pigs (Landrace×Yorkshire×Duroc; 14 d of age, 5.21±0.71 kg body weight) were distributed to 3 treatments in a randomized complete block design. The early-weaned pigs were blocked by sex, body weight and ancestry and randomly assigned to treatments such as: 1) meal (M), 2) expanded pellet (EP), and 3) expanded pellet crumble (EPC). Each treatment was replicated 4 times with 8 pigs per replicate (pen).

The M diet was formulated to contain 23.0% CP and a ME of 3,479 kcal/kg and to meet or exceed NRC (1998) requirement estimates for all other nutrients (Table 1). The M diet was steam conditioned and expanded at 71°C using a 300 hp expander (Model M12, Matador, Denmark) with 56 amperes and a gap opening of 25%. The expanded diet was further processed through a pellet mill with 250 hp at 60°C forming a 2.8 mm die in diameter (EP). The expanded pellet was passed through a crumbler for the EPC diet.

Facilities, management, and response criteria including the digestibility trial were the same as in experiment 1.

Exp. 3 : Twelve cannulated weaned pigs (Landrace×Yorkshire×Duroc) weighing an average of 7.44±1.6 kg (21 d old) were used to investigate the effects of different extrusion temperatures (100°C, 120°C, and 140°C) over the control (untreated), on the ileal digestibility of amino acids in diets containing a protein source such as spray-dried plasma protein (SDPP; APC, USA), whey protein concentrate (WPC; Suprema Spec. Ltd., USA), or fish meal (FM; Esbjerg Fiske, Denmark) (Table 2). The cannulated weaned pigs were individually distributed into 12 individual metabolism cages. The digestibility trial was repeated 3 times each for SDPP, WPC and FM using the same cannulated weaned pigs with a 3 to 4 d interval between each digestibility trial.

Dietary treatments were prepared by mixing each protein source with corn and subjecting it to different extrusion temperatures. After which the extruded feeds were mixed with the other feed ingredients to produce diets containing 20.4, 16.7, and 20.0% CP and a ME of 3,598, 3,490 and 3,504 kcal/kg with SDPP, WPC or FM, respectively (Table 3). Corn was included in the test diets to facilitate extrusion processing.

Each pig was fitted with a simple T-cannula located at the distal ileum approximately 7 cm from the ileocecal junction as suggested by Walker et al. (1986). After surgery, the pigs were immediately transferred to individual cages (90 cm×60 cm×50 cm). The cages were equipped with a woven plastic floor and a nipple waterer. The pigs were fed on an ad libitum basis until they fully recuperated from the surgery. The pigs were then fed their respective diets with 0.25% chromic oxide for 4 days. Then ileal samples were collected continuously at 2 h intervals for 5 consecutive days. The collected samples were immediately stored at -50°C, freeze dried and ground with a 1 mm mesh Wiley mill for the amino acid analysis.

Table 2. Chemical composition of protein sources[1] for ileal digestibility trial (as-fed)

Chemical composition	SDPP	WPC	FM
Dry matter, %	93.0	94.0	94.0
Metabolizable energy, kcal/kg	3,800	3,315	3,510
Crude protein, %	79.0	34.0	68.0
Calcium, %	0.15	0.55	4.50
Phosphorus, %	1.25	0.56	2.70
Lysine, %	6.60	2.37	5.18
Methionine, %	0.63	0.47	1.34

[1] SDPP: Spray-dried plasma protein, WPC: Whey protein concentrate, FM: Fish meal.

Table 3. Formula and chemical composition of diets for ileal digestibility trial (Exp. 3)

Ingredient (%)	Weaning Diet		
	SDPP	WPC	FM
Spray-dried plasma protein	21.58	-	-
Whey protein concentrate	-	36.88	-
Fish meal	-	-	23.32
Corn, ground	39.96	49.96	49.97
Corn starch	30.51	4.27	19.53
Soy oil	3.72	5.00	5.00
Dicalcium phosphate	2.00	2.00	0.84
Limestone	0.89	0.81	-
Salt	0.50	0.25	0.50
Vitamin premix[a]	0.25	0.25	0.25
Mineral premix[b]	0.24	0.24	0.24
Apramycin (100 g/kg)	0.15	0.15	0.15
Cabadox (50 g/kg)	0.10	0.10	0.10
Choline chloride (25 %)	0.10	0.10	0.10
Total	100.00	100.00	100.00
Calculated chemical composition (as-fed)			
Metabolizable energy, kcal/kg	3,598	3,490	3,504
Crude protein, %	20.4	16.7	20.0
Lysine, %	1.52	0.99	1.33
Calcium, %	0.80	1.00	1.40
Phosphorus, %	0.50	0.64	0.96

[a] Supplied per kg diet: 12,000 IU vitamin A, 3,000 IU vitamin D_3, 30 IU vitamin E, 3.45 mg vitamin K_3, 1.8 mg vitamin B_1, 14.4 mg vitamin B_2, 3 mg vitamin B_6, 0.045 mg vitamin B_{12}, 30 mg pantothenic acid, 90 mg niacin, 0.105 mg biotin, 0.75 mg folic acid.

[b] Supplied per kg diet: 143 mg Cu, 125 mg Fe, 102 mg Zn, 38.74 mg Mn, 0.75 mg Co, 0.75 mg I, 0.23 mg Se.

Chemical and statistical analyses

Chemical analyses of the experimental diets and intestinal digesta including chromium were carried out following the AOAC (1990) methods. Gross energy and chromium were measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Molin, IL) and an atomic absorption spectrophotometer (Shimadzu, Japan), respectively. Amino acid contents were determined following an acid hydrolysis in 6N HCl at 110°C for 16 h (Mason, 1984) with HPLC (Model 486, Waters, USA).

Data collected was subjected to a statistical analysis using the General Linear Model Procedure of SAS (1985).

Comparisons of means were done according to Duncan's multiple range test (Duncan, 1955).

RESULTS

Exp. 1

The effects of processing feed on growth performance and nutrient digestibility in conventionally weaned pigs are summarized in Table 4. There was no significant difference in ADFI observed among treatments during the first 7 d feeding period. Compared with pigs receiving EP diets, pigs fed SP diets had higher ($p<0.05$) ADG and an improvement in the F/G ratio. During the 8-14 d and overall period, the growth rate, feed intake, and efficiency of feed utilization were significantly improved in pigs fed SP diets. Pigs fed mash and EP diets performed equally. There was no significant effect ($p>0.05$) of processing methods on the fecal digestibility of nutrients. But pelleting tended to increase fecal digestibility of dry matter and energy in feeds.

Exp. 2

Neither the EP nor EPC diets improved the growth performance of early weaned pigs (Table 5). The ADFI was significantly reduced ($p<0.05$) in pigs fed expander processed diets. Although there was better ($p<0.05$) feed utilization in pigs fed the expanded diets, the overall growth rate was not improved compared to those fed mash diets.

Table 4. Effects of processing feed on growth performance and apparent fecal digestibility of nutrients in conventionally weaned pigs (Expt. 1)

Item	Treatment			SE[3]
	Mash	SP[1]	EP[2]	
Growth performance				
d 0-7				
ADG, g	276[ab]	332[a]	264[b]	33.90
ADFI, g	401	422	389	18.62
F/G	1.45[a]	1.27[b]	1.48[a]	0.11
d 8-14				
ADG, g	401[b]	465[a]	408[b]	32.53
ADFI, g	607[b]	629[a]	612[b]	12.14
F/G	1.51[a]	1.35[b]	1.50[a]	0.09
d 0-14				
ADG, g	329[b]	389[a]	325[b]	32.06
ADFI, g	504[b]	526[a]	500[b]	13.43
F/G	1.48[a]	1.31[b]	1.49[a]	0.10
Fecal digestibility, %				
Dry matter	85.0	85.4	84.1	0.88
Energy	87.1	87.4	85.1	1.22
Crude protein	89.1	88.0	86.6	2.06
Ether extract	88.2	85.3	88.7	5.64
Crude ash	71.1	72.3	63.7	6.77

[ab] Values with different superscripts within the same row are significantly different ($p<0.05$).
[1] SP: Simple pellet.
[2] EP: Expanded pellet.
[3] Pooled standard error.

Table 5. Effects of processing feed on growth performance and apparent fecal digestibility of nutrients in early-weaned pigs (Exp. 2)

Item	Treatment			SE[3]
	Mash	EP[1]	EPC[2]	
Growth performance				
d 0-7				
ADG, g	185[a]	150[ab]	117[b]	40.93
ADFI, g	219[a]	141[b]	122[b]	50.37
F/G	1.19[a]	0.94[b]	1.04[b]	0.15
d 8-14				
ADG, g	249	220	256	48.10
ADFI, g	326[a]	266[b]	251[b]	52.62
F/G	1.31[a]	1.21[a]	0.98[b]	0.22
d 0-14				
ADG, g	217	185	187	35.45
ADFI, g	273[a]	204[b]	187[b]	47.62
F/G	1.26[a]	1.10[b]	1.00[b]	0.15
Digestibility, %				
Dry matter	80.6	81.2	81.0	1.70
Energy	79.9	81.6	82.8	2.45
Crude protein	78.1	75.9	78.8	2.78
Ether extract	56.5[b]	67.8[a]	68.4[a]	7.83
Crude ash	35.6	32.8	30.8	5.79

[ab] Values with different superscripts within the same row are significantly different ($p<0.05$).
[1] EP: Expanded pellet.
[2] EPC: Expanded pellet crumble.
[3] Pooled standard error.

There were no significant differences on fecal digestibility of dry matter, energy and crude protein observed among treatments except for the ether extract.

Exp. 3

The ileal digestibility of amino acids in diets containing different protein sources at different extrusion temperatures are presented in Table 6. The results showed no significant effect of extrusion temperatures on the ileal digestibility of amino acids. But there was an interaction effect between extrusion temperature and the protein source on the digestibility of His, Lys, Phe, Thr, Val, as well as non-essential amino acids. Control diets containing whey protein concentrate had significantly lower ($p<0.05$) His, Phe, and Gly ileal digestibility compared to diets containing either SDPP or FM whereas, Asp and Ser digestibility was significantly lower in the FM diet relative to the SDPP diet. With an extrusion temperature of 100°C, digestibility of Lys, Val, Gly and Ser was significantly lower in the WPC diets than in the SDPP diet, but digestibility of Val, Gly and Ser was not different in the FM diet. Other amino acids affected by an extrusion temperature of 120°C in the WPC diet included Ile, Thr, and Tyr. At an extremely high temperature (140°C) ileal digestibility of Ala and Tyr in the FM diet, and Gly and Pro in the WPC diet were significantly lower ($p<0.05$) compared to similar amino

Table 6. Ileal digestibility of amino acids in diets containing different protein source (PS) at different extrusion temperatures (T)

T	PS	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
Control	SDPP	84.9	88.7^{ab}	91.9	93.0	95.2^{a}	86.8	94.2^{a}	90.4^{a}	89.0^{ab}	89.3^{abc}	92.7^{ab}	86.5^{a}	92.9^{abc}	84.1^{ab}	78.6^{abcd}	91.6^{a}	87.1^{a}
	WPC	92.6	52.1^{d}	90.0	90.5	80.6^{ab}	77.0	57.7^{c}	75.1^{a}	85.9^{abc}	92.9^{a}	92.2^{ab}	76.8^{ab}	94.7^{ab}	63.0^{e}	71.1^{bcd}	61.6^{cd}	70.6^{bc}
	FM	82.2	90.7^{a}	83.6	84.6	89.9^{a}	84.2	89.8^{a}	92.6^{a}	91.8^{a}	81.2^{bcd}	76.8^{d}	95.3^{a}	87.0^{bc}	90.6^{a}	84.2^{abc}	52.5^{d}	80.2^{ab}
100°C	SDPP	83.3	83.9^{ab}	83.4	92.0	92.8^{a}	83.5	90.7^{a}	90.4^{a}	88.8^{ab}	90.3^{ab}	94.5^{ab}	97.3^{a}	94.3^{abc}	83.5^{ab}	77.6^{abcd}	91.5^{a}	88.3^{a}
	WPC	92.9	86.8^{ab}	84.9	92.3	70.3^{b}	89.8	85.1^{ab}	87.2^{a}	70.3^{d}	88.9^{abc}	91.2^{abc}	90.1^{a}	92.3^{abc}	72.7^{cd}	80.1^{abcd}	68.5^{bc}	87.9^{a}
	FM	87.9	77.7^{ab}	93.8	93.0	86.0^{ab}	74.8	82.7^{ab}	87.3^{a}	84.2^{abc}	92.3^{ab}	88.0^{abc}	95.8^{a}	93.3^{abc}	79.1^{bc}	88.9^{a}	69.7^{bc}	87.0^{a}
120°C	SDPP	87.5	87.5^{ab}	95.0	96.6	97.3^{a}	83.1	95.9^{a}	93.8^{a}	91.3^{a}	89.8^{ab}	96.0^{a}	87.2^{a}	96.1^{a}	84.9^{ab}	76.9^{abcd}	93.9^{a}	89.3^{a}
	WPC	90.8	88.8^{ab}	77.5	83.9	71.3^{b}	82.7	73.5^{b}	56.0^{b}	78.2^{cd}	89.3^{abc}	90.4^{abc}	78.2^{ab}	88.0^{abc}	69.2^{de}	72.0^{abcd}	74.1^{b}	71.8^{bc}
	FM	84.0	82.6^{ab}	87.2	86.5	89.2^{a}	86.7	85.7^{ab}	92.7^{a}	87.5^{ab}	78.6^{cd}	80.5^{cd}	57.7^{b}	86.2^{c}	81.1^{bc}	87.7^{ab}	84.7^{a}	81.3^{ab}
140°C	SDPP	82.5	90.7^{a}	77.8	89.8	95.0^{a}	81.9	90.0^{a}	85.8^{a}	86.3^{abc}	91.4^{ab}	91.2^{abc}	92.5^{a}	89.9^{abc}	82.6^{ab}	69.3^{cd}	89.1^{a}	87.0^{a}
	WPC	88.0	68.2^{c}	87.5	93.7	70.1^{b}	78.9	86.4^{ab}	84.8^{a}	80.7^{bc}	91.3^{ab}	93.7^{ab}	74.5^{ab}	95.6^{a}	50.4^{f}	64.9^{d}	69.1^{bc}	82.1^{ab}
	FM	75.7	83.4^{ab}	92.5	92.3	93.1^{a}	82.3	85.3^{ab}	91.7^{a}	86.1^{abc}	78.1^{d}	83.8^{bcd}	90.0^{a}	92.5^{abc}	81.2^{bc}	86.3^{abc}	71.6^{bc}	65.1^{d}
SE[1]		8.90	11.50	8.84	7.16	12.18	7.59	11.80	13.51	6.86	7.02	7.49	13.19	4.76	11.27	10.61	13.69	10.07
Among temperatures (T)																		
Control		86.6	77.2	88.5	89.3	88.6	82.6	80.6	86.0	88.9	87.8	87.2	86.2	91.5	79.3	78.0	68.5	79.3
100°C		88.0	82.8	87.4	92.4	83.0	82.7	86.2	88.3	81.1	90.5	91.2	94.4	93.3	78.4	82.2	76.6	87.7
120°C		87.4	86.3	86.6	89.0	85.9	84.2	85.0	80.8	85.7	85.9	89.0	74.4	90.1	78.4	78.9	84.2	80.8
140°C		82.0	80.7	85.9	91.9	86.1	81.0	87.2	87.4	84.4	86.9	89.6	85.7	92.6	71.4	73.5	76.6	78.0
Among protein sources (PS)																		
SDPP		84.5^{b}	87.7	87.0	92.9	95.1^{a}	83.8	92.7^{a}	90.1^{a}	88.8^{a}	90.2^{a}	93.6^{a}	90.9	93.3	83.8	75.6^{b}	91.5^{a}	87.9
WPC		91.1^{a}	74.0	85.0	90.1	73.1^{b}	82.1	75.7^{b}	75.8^{b}	78.8^{b}	90.6^{a}	91.9^{a}	79.9	92.6	63.8^{b}	72.0^{b}	68.3^{b}	78.1
FM		82.4^{b}	83.6	89.3	89.1	89.6^{a}	82.0	85.9^{ab}	91.1^{a}	87.4^{a}	82.6^{b}	82.3^{b}	84.7	89.8	83.0	86.8^{a}	69.6^{b}	78.4
SE[1]		4.96	11.29	5.85	3.86	10.27	4.22	10.31	10.64	6.09	5.29	5.91	11.52	3.35	11.25	7.73	13.40	8.11
Probability																		
T		NS[2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PS		0.0160	NS	NS	NS	0.0001	NS	0.0429	0.0562	0.0204	0.0330	0.0013	NS	NS	0.0026	0.0033	0.0053	NS
T×PS		NS	0.0001	NS	NS	0.0056	NS	0.0002	0.0104	0.0004	0.0289	0.0095	0.0552	NS	0.0001	0.0528	0.0001	0.0055

[a,b,c,d,e,f] Means with different superscripts in the same column are statistically different ($p<0.05$).

[1] Standard error.

[2] Not significant ($p>0.05$).

acids in the SDPP diet.

Regardless of extrusion temperatures, results showed that Arg, Pro, and Ser were highly digestible ($p<0.05$) in the WPC, FM and SDPP diets, respectively. The WPC diet had the lowest digestibility ($p<0.05$) for Lys, Phe, Thr, Val, and Gly relative to the other diets. Ala and Asp digestibility was significantly lower ($p<0.05$) in the FM diet compared to either the WPC or SDPP diets.

DISCUSSION

Exp. 1

In this study, simple pelleting seemed to be a desirable method of processing conventionally weaned pigs' diet. The response of pigs to a SP diet resulted in 18.24% and 11.49% improvements in ADG and the F/G ratio, respectively. This result is higher compared to the 13.4% and 9.8% improvements in ADG and F/G ratio reported by Chae et al. (1997b). Traylor et al. (1996) observed much higher responses of 25% and 36% improvements in ADG and F/G ratio, respectively, when weaned pigs were fed a pelleted diet compared to a meal diet from d 0 to 5 after weaning. Also, it is normally observed that more feed wastage occurs in pigs fed mash diets which may subsequently decrease the F/G ratio. Hansen et al. (1992) reported that the improvement in F/G ratio in pigs fed pelleted diets was a result of decreased ADFI. Contrary to this, the improvement in feed utilization of pigs fed SP diet in this study could be attributed to increased ADFI with a corresponding increase in ADG. It is important to point out that an increase in feed intake will not only stimulate growth rate, but also improve feed efficiency because the extra nutrients can be used in growing animals almost exclusively for growth rather than for maintenance (Pekas, 1985).

Increased nutrient digestibility is often associated with pelleted diets (Stark, 1994), and it is widely accepted that pelleting improves the energy digestibility in cereal-based diets. Chae et al. (1997b) evaluated the effects of processing methods on nutrient digestibility in growing-finishing pigs and reported a slight increase in crude protein and fat digestibility but not in energy digestibility. In contrary, the present study showed no significant increase in nutrient digestibility as a result of pellet processing. This is in agreement with the previous report made by Skoch et al. (1983). It can however be noted in the present report that there was a total increase in the nutrients absorbed and utilized as a result of increased ADFI which eventually led to improvements in ADG and the F/G ratio.

Also, the present study indicates that subjecting the mash diet to expander processing prior to pellet processing failed to further improve the performance of weaned pigs. The pigs fed the EP diet exhibited similar growth performance as those fed the mash diet. Johnston et al. (1999) stated that the general advantage in F/G ratio with pelleting was pronounced only with standard conditioning. Skoch et al. (1983) reported that during pellet processing feeds could reached temperatures of 85°C but about 100°C in expander processing. Since the diets used in this study contained specialty ingredients (Table 1), a temperature of 85°C could burn or scorch some of the specialty ingredients (Skoch et al., 1983) and it is possible that the temperatures reached during expander and pellet processing could have initiated additional effects on Maillard reactions thereby decreasing not only the nutritional value of the diet but the feed intake as well. Burnt or scorched feeds are bitter and unpalatable and consequently negatively affect the feed intake. The excessively high temperatures brought about by both expander and pellet processing may be responsible for the decreased performance of the pigs. According to Steidinger et al. (2000) conditioning diets containing 5% spray-dried animal protein (SDAP) at temperatures above 77°C decreased weaned pigs' growth performance. From d 0 to 7 after weaning, ADG and ADFI decreased as conditioning temperature increased, with the largest decrease observed above 70°C.

Exp. 2

Expander processing is used in swine diets. This is to maximize the nutritional value of feeds such as corn (Chae et al., 2000), sorghum (Traylor et al., 1997; Chae et al., 2000), and barley (Piao et al., 1999). In this study, subjecting early-weaned pigs' diet to expander processing prior to pelleting did not result in any significant improvement ($p>0.05$) in ADG or ADFI. Pigs fed the mash diet consumed significantly more feed ($p<0.05$) and gained more weight than those fed either the EP or EPC diets. The improvement in the F/G ratio ($p<0.05$) with the EP or EPC diets over that of the mash diet appeared to be attributed primarily to low feed intake. Take note that the complex diet for early weaned pigs used in this study contained protein sources such as spray-dried plasma protein, fish meal and milk replacer. It is most likely that heat and pressure of expander processing could have affected the palatability of the diet. Maga (1989) reported that extrusion of non-volatile compounds associated with animal-origin ingredients were often bitter or astringent, thus lowering the feed intake of pigs with either the EP or EPC diets. This reasonably adds to the suggestion of Stark (1994), that the increased animal efficiency resulted from a reduction in feed wastage of the pelleted form of the feed.

Chae and Han (1998) stated that when diets were extruded or expanded, there was a trend showing that the energy digestibility but not protein digestibility was improved when compared to the mash diet. Chu et al. (1998) demonstrated that extrusion improved ileal digestibility of amino acids in 11 kg pigs fed barley-based diets. In the present study, the slight increase in the digestibility of dry matter and energy, and significant increase in the digestibility of ether extract did not contribute much to the improvement of feed utilization because there were no significant differences among treatments observed on the overall growth rate of early weaned pigs. These results confirmed the findings of Traylor (1997) who reported that nursery pigs fed expanded complex diets tended to have a lower rate of weight gain. It was also shown by Johnston et al. (1999) that pigs fed the expanded conditioned treatments had a 39% decrease in rate of weight gain, a 25% decrease in feed consumption, and a 21% decrease in efficiency of feed utilization when the feed was pelleted. They conclusively stated that expanding complete complex nursery diets was of no benefit; it was actually a detriment as evidenced by the sharp declines in the rate of weight gain and the very low feed intakes of piglets fed the complete expanded diet. Similarly, feeding the EPC diet to weaned pigs failed to improve their growth performance. Stark et al. (1993) showed that when there were more fines in pelleted feeds, a poorer performance and/or feed conversion ratio was obtained. Moran (1989) reported an increase of only 1% efficiency in turkeys fed reground pelleted diets over the mash diet while feeding the whole pellet increased the efficiency by 16%.

Exp. 3

Extrusion conditions can alter the nutritional value of feeds. During the process, addition of heat and water by conditioning will alter components such as starch and protein in the feed (Thomas and van der Poel, 1996). As a result nutrient digestibility will increase. Barley, for instance, extruded at 150°C gave better digestibility of DM, CP and GE than barley extruded at low temperature (Piao et al., 1999). In line with these findings, Chu et al. (1998) reported an improvement in ileal amino acid digestibility in weaned pigs fed extruded barley-based diets.

In this study, there was an interaction effect between extrusion temperature and protein source. An extrusion temperature of 140°C greatly reduced the ileal digestibility of some amino acids in weaned pigs' diets which could be caused by the ingredients characteristics. It appeared that a weaned pigs' diet containing WPC was most affected by the extrusion temperatures compared to the FM and SDPP diets. Among the limiting amino acids, digestibility of Lys and Thr was greatly reduced in diets containing WPC when extruded at 100°C and at 120°C respectively, as compared to either the SDPP or FM diets. These observations were not in agreement with Peisker (1992) who reported no change in the total lysine and reactive lysine when the feed was subjected to 120°C during an expander treatment. Peisker (1992) attributed the non-significant reduction in the total lysine content and available lysine to the expander stability (140°C) of the synthetic amino acids, L-lysine and Dl-methionine. In this report, neither synthetic lysine nor methionine was included in the diet. The ileal digestibility of Met, Arg, Ile, and Leu in the different weaned pigs' diets were not greatly affected by extrusion temperatures even at 140°C because Met, Arg, Ile and Leu seemed to be heat stable. An experiment conducted by Batterham (1992) demonstrated that overheating has detrimental effects on amino acid digestibility, especially of lysine. An extensive reduction of methionine digestibility was also observed in overheated fish meal (Wiseman et al., 1991). In this study, the digestibility of Ala and Tyr was significantly low when the FM diet was extruded at 140°C compared with the SDPP and WPC diets. Other non-essential amino acids affected by extrusion temperatures were Ser, Tyr, Gly and Pro in the WPC diet. According to Skoch et al. (1983) a temperature of 85°C could burn or scorch some of the protein sources and increase the potential for initiating the Maillard reaction, thereby decreasing their nutritional value. Excessively high temperatures during pellet processing or other thermal processing (i.e., extruder or expander) may be responsible for the decreased performance of pigs fed diets containing animal protein sources (Traylor et al., 1997; Hongtrakul et al., 1998; Johnston et al., 1999).

Regardless of the protein source in the diet, results showed no significant effect ($p>0.05$) of extrusion temperatures on the ileal digestibility of amino acids. Inconsistent trends were observed showing an alternating increase or decrease pattern. Chae et al. (1997d) reported no improvement in ileal digestibility of amino acids in soybean meal extruded at 125 to 150°C. The extrusion temperatures used in this study were from 100 to 140°C. Chae et al. (1997d) attributed the non-significant effect of extrusion temperature to the low moisture content of the diet (less than 18%) which was quite similar to the moisture content of the diets used in this study. Hancock (1992) suggested that a compromise with pre-extrusion moisture concentrations of 18 to 25% and extrusion temperatures of 120 to 170°C seemed to result in high gelatinization and minimal protein damage in cereal grains.

Also, it is a common notion that nutrients from milk products and milk by-products are highly digestible so they are highly recommended to be included in weaned pigs' diets. When extruded at 120 and 140, however, the degree of reduction in ileal digestibility of Lys and Gly in the WPC diet was substantially high ($p<0.05$) compared to the SDPP and FM diets. Among the protein sources evaluated, however, the diet of weaned pigs containing WPC had the lowest ileal digestibility for Lys, Thr, Phe, Val and Gly regardless of extrusion temperatures. This suggests that the protein fraction is not a limiting factor in the utilization of milk by-products. Mahan (1992) conclusively stated that the lactose component of whey was primarily responsible for the beneficial effects of whey. On the other hand, both the SDPP and FM diets which are generally high in protein contain highly digestible amino acids. The significant differences on the ileal digestibility of Ala, Asp, Pro, and Ser between the SDPP and FM diets could be due to the quality of fish meal used in this study. The quality of fish meal may vary greatly depending on the quality of raw materials and the processing method used in manufacturing the fish meal.

IMPLICATIONS

Pellet processing of diets containing high quality animal protein sources such as whey protein concentrate, fish meal and spray-dried plasma protein would be better than extruder or expander processing for weaned pigs' diets. Extruder or expander processing of diets could reduce palatability and ileal digestibility of several amino acids which may have a negative effect on the growth performance of weaned pigs.

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