Processing Effects of Feeds in Swine* - Review -

B. J. Chae[1] and In K. Han[2]
Dept. of Feed Science & Technology, College of Animal Agriculture, Kangwon National University, Chunchon, 200-701, Korea

ABSTRACT : Processing is generally employed to alter the physical and chemical properties of feeds used in pig diets, using hammer/roller mills, pellet mills and extruders/expanders. The reported optimum particle sizes of corn are approximately 500 μm, 500-700 μm, 400-600 μm, for nursery, growing-finishing, and breeder pigs respectively. Optimum particle size of grains are affected by diet complexity. There was a trend towards reducing particle size in order to increase ADG in pigs fed a simple diet, though such was not the case for pigs fed a complex diet. Uniformity of particle size also affects the nutritional values of swine feeds. Uniform particle sizes would consistently give greater nutrient digestibilities. In terms of pellet quality, it is reported that a higher incidence of fines in pelleted feeds has a direct correlation with poorer feed conversion ratio in pigs. Particle and pellet sizes are also very important for pelleting in terms of grinding, digestibility, stomach ulceration and pellet durability. A particle size of 600 μm, or slightly less, seemed optimal for corn in finishing pigs, and the 5/32 in. diameter pellets supported the best efficiencies of gain during nursery and finishing phases.

Extruder and/or expander processes would allow the feed industry an increased flexibility to utilize a wider spectrum of feed ingredients, and improve pellet quality of finished feeds. It would appear that extruded or expanded diets containing highly digestible ingredients have little effect on the growth performance of pigs, and the feeding values of the feeds over pelleted diets were not improved as pigs grew. The extruder or expander is much more effective than a pelletizer in salmonella control. Gastric ulcerations and/or keratinizations were consistently reported in pigs fed mash and processed diets containing finely ground grains, whereas carcass quality was not affected by diet processing methods such as pelleting, extruding or expanding. In corn- or sorghum-based diets, the electrical energy consumption is 4-5 times higher in the expanding than in the pelleting process. But the expander's processing cost was half of that shown by an extruder. Finally, the decision of which feed processing technology to adopt would depend on the processing cost, and any potential improvement in growth performance and digestibilities of nutrients should offset the increased operating and capital costs related to the extruder/expander technology over mash or pelleting processes in pigs.
(Key Words: Grinding, Pelleting, Extrusion, Expanding, Swine)

INTRODUCTION

With the rapid growth of feed production, there have been remarkable changes and advances in the feed industry. McEllhiney (1993) presented some that have taken place, or are taking place, in the world-wide feed industry as follows: bulk, rather than bagged handling of raw materials and finished products; improved pelleting and extrusion technology; tight registration, laws, regulations, and public concerns; new products, processes, raw materials, etc.

A number of technologies have been introduced in the feed industry during the last several decades to improve the versatility in the use of raw materials and quality of finished feeds. Currently, it is needless to say that much of the interest is given to the extruding/expanding technology in manufacturing swine feeds. An expander processing method was introduced as a way to improve pellet quality in pig feeds. But the effects of expanded diets on growth performance in pigs are inconsistent, and limited data are available. For particle size reduction and simple pelleting, there are still some topics to be

[1] Address reprint requests to Prof. B. J. Chae
[2] Dept. of Animal Science & Technology, College of Agriculture & Life Sciences, Seoul National University, Suweon, 441-744, Korea.
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discussed in order to utilize feed resources efficiently. Therefore, this paper was made to review recent advances in the fields of particle size reduction, pelleting, and extruding/expanding technologies in the processing of swine feeds.

Recent advances in feed processing technology for swine

Grinding

Efforts are still being made to find optimum particle size reduction of grains in swine feeds. Healy et al. (1994) conducted an experiment to investigate the effects of particle size reductions of corn and sorghum (from 900 to 300 μm) and concluded that optimum particle size of the grains would increase in relation to the rising age of nursery pigs. However, if only one particle size is used for the entire nursery phase, corn and sorghum milled to about 500 μm would optimize efficiency of gain in nursery pigs fed pelleted diets. In growing-finishing pigs, the reported optimum particle size of grains was 500-700 μm (Behnke, 1994).

For breeders, however, a slightly finer particle of grains is recommended. Wondra et al. (1995a, b) reported that the optimum particle sizes of corn in lactation diets were near 400 μm in primiparous and 400-600 μm in second-parity sows. But they suggested that further research is needed to define long term consequences of particle size reduction on stomach morphology with combinations of a finely ground diet during lactation and a coarsely ground diet during gestation, since reducing particle size from 1,200 to 400 μm increased the severity of ulcerations and keratinizations in stomach.

It should be noted that optimum particle size of grains is affected by diet complexity. Generally, reducing particle size of cereal grains resulted in greater performance. However, these benefits were observed in pigs fed relatively simple diets with high proportions of cereal grain. Kim (1995) compared the nutritional values of two particle sizes of corn (1,000 vs 500 μm) in weaning pigs fed both simple and complex diets. There was a trend towards reducing particle size to increase ADG to a greater extent for pigs fed a simple diet than a complex diet.

In addition to the diet complexity, uniformity of particle size also affects the nutritional values of swine feeds. Wondra et al. (1995c) conducted an experiment with finishing pigs to study the effect of particle size uniformity on growth performance and nutrient digestibility. They reported that more uniform particle sizes consistently gave greater nutrient digestibilities. To improve the uniformity of particle size of grains, roller mills are better than hammer mills (McEllhiney, 1983).

Pelleting

Pelleted diets for various farm animals have become popular in the last 2 or 3 decades and have many benefits, especially for pigs. Proposed benefits of pellet processing include decreased segregation, increased bulk density, reduced dustiness, improved handling and transportation characteristics, improved palatability, and thermal modification of starch and protein (Behnke, 1993).

Ohh (1991) summarized the effects of pelleted diets over mash on growth performance and feed efficiency in swine from 16 trials. The improvements in growth performance were 3-4%. Chae et al. (1997a) also conducted an experiment to determine the effect of pelleted diets on the growth performance of growing-finishing pigs as listed in table 5. The average daily gain of pigs (20-90 kg of body weight) fed pelleted diets was significantly higher than those of pigs fed mash or extruded feeds. Feed conversion was also better in pelleted diets than in mash feeds.

To maximize the effects of pelleting, the pellet quality is very important. One particular example of study with pellet quality found the more fines in pelleted feeds, the poorer performance and/or feed conversion ratio of pigs was obtained (Stark et al, 1993). In a finishing study with 80 gilts, increasing fines percentage (20 to 40%) also resulted in a linear trend toward poorer F/G.

There are many factors affecting pellet quality. Hilliker (1991) described these as; formulation, particle size, conditioning, die specification, and cooling and drying. Of the variables controlled by the operator, conditioning is likely the most important relative to pellet quality. Pellet quality parallels conditioning temperature; when conditioning is properly done, each particle containing starch is surface gelatinized creating the potential for the liquid bridge (Behnke, 1993). Particle size is also very important for pelleting in terms of grinding, digestibility, stomach ulceration and pellet durability. Several studies have been conducted with different particle sizes of corn. Martin (1984) reported that pellet quality was not affected when corn particle size ranged from 595 to 876 μm. Wondra et al. (1995c) also reported that a particle size of 600 μm, or slightly less, seemed optimal for corn in finishing pigs.

There are few reports in the literature on the effect of pellet size- and corn particle size and pellet sizes- on pig performance. Traylor et al. (1996) reported that pellet size (3/32, 5/32, 5/16, and 1/2 inch diameters) had little effect on growth performance during the early stages (d 0 to 5) of the nursery phase. However, the 5/32 in. diameter pellets supported the best efficiencies of gain during the overall nursery (d 0 to 29) and finishing phases. Chae et al. (1997e) also studied the interactions between corn particle sizes (3 versus 6 mm sieve) and pellet sizes (4.76 versus 6.80 mm in diameter) in growing-finishing pigs. There were no significant differences in ADG and F/G, but pigs fed smaller pellets displayed better F/G than those fed larger pellets, regardless of corn particle sizes (table 1).

Table 1. Effect of corn particle and pellet sizes on growth performance and carcass traits ingrowing-finishing pigs

Item	Corn particle size (mm)	3		6		SE	Contrast[1)]	
	Pellet diameter (mm)	4.76	6.80	4.76	6.80		1	2
Pellet quality[2)]								
Hardness (kg)		3.91[a]	3.08[bc]	3.82[a]	2.88[c]	0.97		
Durability (%)		95.39[a]	89.31[b]	93.74[a]	84.41[c]	4.80		
Nutrient digestibility (%)								
Energy		72.49[a]	70.73[ab]	67.75[b]	64.12[b]	12.58		
Crude protein		68.13[a]	65.37[ab]	63.25[b]	62.50[b]	11.64		
Growth performance (49-105 kg)								
ADG (g/d)		823	800	841	826	7.68	–	–
ADFI (g/d)		2,248	2,287	2,289	2,320	15.87	–	–
FCR		2.73	2.89	2.72	2.81	0.02	–	0.05

[1)] Contrasts were; 1) Corn particle sizes, 3 vs 6 mm. ; 2) Pellet diameters, 4.76 vs 6.80 mm and dashes indicate $p > 0.15$.
[2)] Mean values of 10 replicates/treatment, and contrast values were not checked.
[ab] Values on the same line without common superscripts differ ($p < 0.05$).

(Chae et al., 1997e).

Gastric ulcerations and/or keratinizations were consistently reported in pigs fed pelleted diets containing finely ground grains (Wondra et al., 1995a, b, c; Johnston and Hancock, 1997b). Carcass quality was not affected by diet pelleting (Wondra et al., 1995c; Traylor et al., 1996; Chae et al., 1997a).

Extruding/expanding

Extrusion is becoming an important tool for processing feeds to improve their nutritional values. Extruders can be broadly classified as wet or dry and single or twin-screw. Dry extrusion employs moisture levels of approximately 20%, while wet extrusion processes material at levels above this moisture (Hancock, 1992; Rokey, 1996). Dry extrusion does not employ preconditioners and is therefore limited in its ability to process a wide range of raw materials. The degree of cooking is different from extruders, as shown in table 2.

Table 2. Typical process parameters

Process	Temp (℃)	Moisture (%)	Max. fat (%)	Cook*
Pellet press	60 - 100	12 - 18	12	15 - 30
Expander/pellet press	90 - 130	12 - 18	12	20 - 55
Dry extrusion	110 - 140	12 - 18	12	60 - 90
Wet extrusion				
Single screw	80 - 140	15 - 35	22	80 - 100
Twin screw	60 - 160	10 - 45	27	80 - 100

* Cook is starch gelatinization by enzyme susceptibility.

(Hancock, 1992)

However, twin-extruders have become the process of choice when the following conditions exist; fat levels in recipes are above 17%, fresh meats or other wet ingredients added to recipes are above the 35% level, and final pellet size is smaller than 1.5mm in diameter (Rokey, 1996).

Extruders and expanders are quite similar, except for different operation conditions. As compared by Coelho

(1994) in table 3, expanders are usually quoted at much higher capacities than extruders. This is made possible by putting less energy into the product per unit of throughput.

An annular gap expander is an extruder installed between a typical conditioner and a pellet mill. In addition to the common effects of extruder or expander process alone, the effects of this process include: improved pellet quality and productivity, improved flexibility in the use of raw ingredients (i.e., liquids and fibrous feeds), and reduced die wear in pellet mills.

Table 3. Operating conditions for expanders and extruders

Item	Expander	Extruder
Moisture level (%)	15 - 25	20 - 35
Feed temperature (℃)	93 - 127	110 - 160
Retention time (sec)	10 - 30	50 - 120
Screw diameter (cm)	10 - 25	25 - 50
Motor horsepower	500 - 1,000	75 - 250
Enery consumption (kWh/t)	5 - 15	50 - 300
Production rate (t/h)	20 - 60	5 - 10

(Coelho, 1994)

For ingredient processing with extruders, numerous studies have been made to determine the effects of extrusion on growth performance and nutrient digestibility in pigs. A major part of any discussion of the effects of extrusion processing on protein sources will undoubtedly concern soybean proteins. Given that, the topics will focus upon the use of soybeans-extruded full fat soybeans or soybean meal. Experiments comparing extruded soybeans to soybean meal were well summarized by Kim (1995), and improved growth performances were shown when extruded soybeans were fed to swine. With this experimental data, however, it is hard to compare the economic benefits between the soy products because most reports lack explanation of extrusion conditions. Also most comparisons were made by substituting extruded soybeans for soybean meal without equalizing % fat or energy in the diets.

Recently, Chae et al. (1996) conducted an experiment with extruded corn and sorghum in nursery pigs. The feed conversion of pigs fed extruded corn or sorghum was better than those fed the unextruded ones. But extruded corn showed significantly better feed conversion than unextruded ground corn (900 μm), and ileal digestibilities of GE and CP were significantly higher in extruded corn or sorghum than in ground (900 μm) corn or sorghum.

To maximize the nutritional values of barley, Chu et al. (1997) compared digestibility and growth performance of growing pigs fed either ground or extruded barley. Extrusion of barley showed a trend to improve nutrient digestibility, and pigs fed extruded barley grew significantly faster than those fed ground barley. Also, extrusion of barley significantly improved feed/gain of pigs. Chung et al. (1996) also conducted an experiment with extruded barley (EB) in growing-finishing pigs. They ascertained that pigs fed the diet containing EB showed higher ADG and feed intake than those fed the diet containing ground barley (GB). There was a significantly higher carcass dressing % in pigs fed EB compared to those fed a corn-soy diet without barley. GB dietary group showed lower carcass dressing % than EB group, even though there was no significant difference. In addition, Piao et al. (1997) reported the best extrusion condition for barley, and feeding barley showed better performance when extruded at a higher temperature (150℃) compared to a lower temperature of 100℃ (table 4).

Much attention is given to the effect extrusion or expansion for complete swine diets has on the nutrient digestibility and growth performance over the pelleting process. For this standpoint, as of yet, limited data have

Table 4. Effect of extrusion condition of barley on growth performance of growing (24-60 kg)

Treatment*	Control (No extrusion)	No conditioning		Conditioning		SE
		100℃	150℃	100℃	150℃	
ADG (g/d)	814	840	878	858	879	9.57
ADFI (g/d)	1,884	1,906	1,988	1,956	1,972	23.39
F/G	2.27	2.27	2.26	2.28	2.24	0.01

Contrast	ADG	ADFI	F/G
Control vs Extrusion	0.1802	0.4086	0.4055
Temperature (100 vs 150℃)	0.0559	0.0700	0.9006
Conditioning (W vs W/O)	0.2606	0.3695	0.7551

* Temperature was measured at the last barrel.

abc Means with different superscript in the row differ ($p < 0.05$).

(Piao et al., 1997).

been published, while extrusion of pet foods is common. Much attention is given to the effect extrusion or expansion for complete swine diets has on the nutrient digestibility and growth performance over the pelleting process. For this standpoint, as of yet, limited data have been published, while extrusion of pet foods is common.

In pigs, the effects of extruding/expanding of complete diets over mash or pelleted feeds on nutrient digestibility and growth performance are shown in tables 5 and 6, respectively. According to the results of experiments listed in table 6, when diets were extruded or expanded, there was a trend that showed the energy digestibility, but not protein digestibility, was improved when compared to mash. But extruded or expanded feeds had little additional effects, if any, on the energy and protein digestibilities as compared to pelleted feeds. It would appear that the younger the pigs, the better the growth performance obtained when pigs are fed extruded or expanded products over mash or pelleted feeds. In other words, as pigs grew, pellet processing seemed to be enough in terms of growth performance. The expander processing, one of the new ones for pig diet processing, had little effect on the growth performance of growing-finishing pigs fed common diets. Johnston et al. (1996) reported that finishing pigs fed expanded diets (corn-soy based) over pelleted form had not improved ADG nor feed efficiency.

In addition to the age of pigs, it also would appear that the effects of extruder/expander processing on pig performance depend largely upon the ingredient characteristics. As shown in table 3, experiments using fibrous diets (Sauer et al., 1990; Boulduan et al., 1993) displayed better performance when compared to the experiments using highly digestible (Chae et al., 1997d), or corn-soy based diets (Johnston et al., 1996; Chae et al., 1997a). Chae et al. (1997d) conducted an experiment with a diet containing 11% milk replacer in weaned pigs, and obtained better growth rate in pigs fed a pelleted diet than in those fed an extruded diet. Another approach was made to determine the effects of expanding the various components of a complex nursery diet in weanling pigs (Johnston and Hancock, 1997a). Treatments were mash and standard pellet as controls, expanded corn, expanded corn-soybean meal, expanded corn-soybean meal-oil, and expanded complete diet. Efficiency of gain was increased by 13% with expanded portions of the diet compared to the mash control, but there was a marked decrease in performance when the complete diet was expanded. Expanded corn-soybean meal-oil supported the greatest ADG compared to other treatments (table 7).

On the other hand, moist heat processes are harmful to labile nutrients, such as vitamins, that can be easily oxidized, and extrusion is considered the most aggressive process against vitamins due to high temperatures, pressure and moisture (Coelho, 1996). Armstrong (1993) reported that weight gains of starter pigs were affected favorably by expanded diets. However feed efficiency was adversely affected, which may have been due to a reduction in vitamins or lysine availability during extrusion. Chae et al. (1997) also conducted an experiment with extruded feed in pigs, and obtained improved growth performance when vitamins were added to the diet after extruding compared to the diet which added vitamins before extruding (table 8). Unlike extruders, no significant influence of expander processing on protein content has been found by Peisker (1992). In table 9, the effects of expander treatment on the stability and availability of some amino acids is shown. Up to 120℃, there was no change in the total lysine and reactive lysine. At 130℃, there was a nonsignificant reduction of the total lysine content and available lysine. But synthetic amino acids such as lysine and methionine are expander stable, despite high processing temperature at 140℃ (table 10).

It was reported that extruding or expanding a complete diet caused a decline in feed intake which might account for the increase in digestibility (Chae et al., 1997c; Johnston and Hancock, 1997a). The heat and table 5, 6 pressure of extrusion processing is also known to affect flavor (Johnston and Hancock, 1997a). Maga (1989) reported that extrusion of nonvolatile flavor compounds associated with animal-origin feed ingredients were often bitter or astringent.

In view of the chemical and physical changes that feed ingredients may undergo during processing, there are several undesired chemical reactions (Van der Poel, 1997), which may affect feed palatability and animal performance.

Additional significant effects of extrusion are to reduce antinutritional factors and microbial contamination in feedstuffs. Recently the feed industry has become more aware of the need to eliminate the possibility of feed-origin microbial contamination. Extrusion is much more effective than pelleting in salmonella control. For fulfat soybeans, use of the extruder is indispensable to destroy trypsin inhibitors. Dry and wet extrusion destroys up to 95% of the trypsin inhibitor, but expanders destroy 70% of them by processing at 120℃ (Rockey, 1995).

To maximize the effects of extrusion, numerous factors which affect extrusion conditions should be considered. Of these factors, preconditioning is very important to obtain improved moisture and heat

Table 5. Pig performance as affected by pelleted, extruded and expanded feeds

Phase / Reference	Mash	Pelleted	Extrusion	Extruded pellet	Expanded pellet	Remark
Starting						
Sauer et al. (1990)						
ADG	–	356^{a}	386^{a}	375^{ab}	–	Feeding: 5-18 kg BW
F/G	–	1.75^{a}	1.65^{b}	1.75^{a}	–	Diet: cereal-based (wheat, barley, oat groats and 5% whey)
Bolduan and Peisker (1992)						
ADG	201	–	–	–	227	Feeding: 4-week old piglets, 2-week feeding
F/G	1.61	–	–	–	1.56	Diet: common pig starter
Bolduan et al. (1993)						
ADG	332	–	–	–	365	Feeding: 5-week old, 4-week feeding
F/G	1.79	–	–	–	1.89	Diet: wheat bran 30% included
Chae et al. (1997d)						
ADG	385	404	348	–	–	Feeding: 8-15kg BW
F/G	1.57	1.47	1.46	–	–	Diet: pig starter including 11% milk replacer
Johnston and Hancock (1997a)						
ADG	210	253	–	–	154	Feeding: 6.5 kg BW, 10 day feeding
F/G	1.12	0.79	–	–	1.20	Diet: complex
Browing - finishing						
Ohh et al. (1996)						
ADG	588^{b}	679^{b}	–	–	637^{ab}	Feeding: 18 kg BW. 6weeks period
F/G	2.15^{a}	1.79^{b}	–	–	1.99^{a}	Diet: Grain 52% (corn, sorghum, rye)
Chae et al. (1997a)						
ADG	741^{b}	846^{a}	–	771^{ab}	–	Feeding: 20-60 kg
F/G	2.14^{a}	1.96^{b}	–	2.04^{b}	–	Diet: corn-soy
Chae et al. (1007a)						
ADG	763	859	–	839	–	Feeding: 60-90 kg
F/G	3.04	2.74	–	2.76	–	Diet: corn-soy

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

Table 6. Nutrient digestibility as affected by feed processing methods in swine (%)

Phase / Reference	Mash	Pellet	Extrusion	Extruded pellet	Expanded pellet	Remark
Starting						
Sauer et al. (1990)						
Energy	–	80.7^{a}	83.2^{b}	83.3^{b}	–	BW: About 10 kgs
CP	–	75.9^{a}	80.4^{b}	80.2^{b}	–	Diet: Cereal-based
Boulduan et al. (1993)						
Energy	76.29	–	–	–	76.46	Age: 6 week old
CP	76.62	–	–	–	76.27	Diet: wheat bran 30% added
C. fiber	35.49^{a}	–	–	–	49.80^{b}	
Chae et al. (1997d)						
Energy	61.94^{c}	64.51^{b}	68.81^{a}	–	–	BW: About 10 kgs
CP	71.88^{b}	76.05^{a}	70.29^{b}	–	–	Diet: Pig starter including 11% milk repalcer
Growing-finishing						
Johnston and Hancock (1997c)						
Energy	90.5	92.2			93.3	BW: Finishing barrow
Nitrogen	86.9	89.0			90.1	Diet: Corn-soy
Chae et al. (1997a)						
Energy	70.09	68.23	–	68.90	–	BW: About 80 kgs
CP	67.50	69.58	–	74.10	–	Diet: Corn- soy based
V. der Poet et al. (1997)						
DM	–	89.3	–	–	84.9	BW: About 19 kgs
CP	–	83.0	–	–	81.0	Diet: Complex
Ohh et al. (1996)						
Energy	70.09^{b}	83.86^{a}	–	76.60^{ab}	–	BW: 18 kgs
CP	67.88	80.64	–	74.85	–	Diet: Grain-based (corn, milo, rye)

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

Table 7. The effect of expanding various components on growth performance of weanling pigs[a] and nutrient digestibility

Item	Meal	Pellet	Expanded				SE
			C	C-SBM	C-SBM-O	Diet	
Growth performance							
ADG (g)	377	382	346	359	420	193	17
ADFI (g)	401	350	333	338	382	257	18
G/F	0.94	1.09	1.04	1.06	1.10	0.75	30
Apparent digestibility (%)							
GE	80.7	81.3	86.0	87.3	86.1	85.7	0.54
DM	80.6	81.4	85.1	86.4	85.1	85.5	0.51
N	74.7	73.7	80.2	82.4	81.1	79.9	1.1
DE (kcal/kg)	3,212	3,236	3,422	3,474	3,426	3,414	22
DE (kcal/d)	1,288	1,133	1,140	1,174	1,309	877	51

Contrasts[b]	1	2	3	4	5
Growth performance					
ADG (g)	0.06	0.02	0.001	0.005	–[c]
ADFI (g)	0.002	–	0.001	0.05	–
G/F	0.05	0.006	0.001	–	–
Apparent digestibility (%)					
GE	0.001	0.001	–	–	0.14
DM	0.001	0.001	–	–	0.14
N	0.001	0.001	–	–	–
DE (kcal/kg)	0.001	0.001	–	–	0.14
DE (kcal/d)	0.020		0.001	0.05	–

[a] 168 pigs (average initial BW of 6.6 kg). (Johnston and Hancock, 1997a).

[b] Contrasts were: 1) meal vs others; 2) standard pellet vs expanded treatments; 3) expanded-corn, expanded-con soybean-meal, and expanded corn-soybean meal-oil vs the expanded-complete diet; 4) expanded-corn, expanded-con-soybean meal expanded corn-soybean meal-oil; and 5) expanded-corn vs expanded-con-soybean meal.

[c] Dashes indicate $p > 0.15$.

Table 8. Effects of thermal processing of a complete diet on the growth performance of growing pigs

Treatment	Mash	Pellet	Extruded/Pelleted[1]		SE
			A	B	
D 0-14 (13-20 kg)					
ADG (g)	497^{b}	526^{ab}	587^{ab}	666^{a}	26.73
ADFI (g)	812	834	837	869	21.43
F/G	1.65	2.59	1.44	1.37	0.07
D 15-44 (20-40 kg)					
ADG (g)	642	653	639	652	10.09
ADFI (g)	$1,417^{a}$	$1,281^{b}$	$1,306^{ab}$	$1,329^{ab}$	22.42
F/G	2.21	1.96	2.05	2.04	0.05
D 0-44 (13-40 kg)					
ADG (g)	596^{b}	613^{b}	623^{b}	656^{a}	7.58
ADFI (g)	$1,220^{a}$	$1,136^{b}$	$1,153^{ab}$	$1,180^{ab}$	14.08
F/G	2.05^{a}	1.85^{b}	1.85^{b}	1.80^{b}	0.04

[1] Extruded/Pelleted : Vitamin premix was incorporated before (A) and after (B) extrusion. (Chae et al., 1997c)

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

Table 9. Stability of amino acids (% of feed) after expander processing of a pig feed

Amino Acid	Untreated	Expanding temperature	
		120℃	130℃
Lysine (total)	0.84	0.83	0.78
Reactive lysine	0.80	0.79	0.74
Lysine availability[a] (%)	95	96	95
Threonine	0.61	0.59	0.57
Methionine	0.55	0.56	0.54

[a] Availability was defined as reactive lysine/total lysine.

(Peisker, 1992)

Table 10. Effect of expander treatment on the stability (% of feed) of synthetic amino acids

Amino acid	Untreated	Expander processed[b]
Lysine	0.48 + 0.35[a]	0.88
Methionine	0.23 + 0.22[a]	0.41

[a] Supplemented synthetic amino acids. (Peisker, 1992)

[b] Expanding temperature: 140℃; cone pressure: 50 bar; moisture content: 18%.

penetration for extrudates (Strahm, 1996). Chae et al. (1997) conducted an experiment to determine the effect of extrusion of soybean meal with or without preconditioning on the ileal digestibilities of nutrients in weaned pigs, and noticed beneficial effects. The digestibilities of GE and amino acids in extruded soybean meal were improved with preconditioning. Also, long term or expander conditioning increased pellet durability, but no benefit in growth performance of nursery pigs with long-term or expander conditioning of diets was observed (Johnston and Hancock, 1997b).

Like pelleting, extruding or expanding of complete pig diets affects stomach keratinization and ulcerations (Mills, 1994; Johnston and Hancock, 1997b, c). The more extreme the processing technique, the greater the incidence and severity of stomach lesions (Johnston and Hancock, 1997b, c). The degree of stomach lesions by expanded feeds would be reduced by selecting the coarser particle size of grains (Nielsen, 1995). However, dressing % and back fat thickness were not affected by expander processing of pig diets (Johnston and Hancock, 1997b, c).

The extruder/expander technology alone requires additional processing costs, as does the annular gap expander system. But there are some possibilities to reduce production costs through formulations (Anom., 1994). Therefore, it is said that the costs of the expander process depend on the target of the initiated operation and the raw materials or feed formulation in question (Van der Poel et al., 1997). Melcion and Van der Poel (1993) compared the relative costs between extrusion cooking and expansion cooking with soya. The processing cost by an expander was half of that showed by an extruder (table 11). Johnston and Hancock (1997c) also compared the electrical energy consumption between pelleting and expanding corn- or sorghum-based diets, resulting in 4-5 times higher in expanding than in pelleting process (table 12). The decision of which feed processing technology to adopt would depend on the processing cost, and any potential improvement in growth performance and/or digestibilities of nutrients should offset the increased operating and capital costs related to the extruder/expander technology over mash or pelleting process in pigs.

Table 11. Relative costs of different HTST-treatments

Process	Relative costs (%)
Twin screw extrusion cooking	100
Single screw extrusion cooking	50
Expander processing	34
Infrared radiation	25
Pressurized steaming	31

(Melcion & van der Poel, 1993).

Table 12. Effects of standard and expander conditioner of corn-based and sorghum-based diets on processing characteristics

Item	Corn-based diet			Sorghum-based diet		
	Meal	SP	EP	Meal	SP	EP
Pellet production rate (kg/h)	–	1,410	1,136	–	1,445	1,142
Elec. energy consumption						
Pellet mill (kWh/t)	–	8.6	8.7	–	9.1	10.4
Expander (kWh/t)	–	–	32.1	–	–	27.2
Gross (kWh/t)	–	8.6	40.8	–	9.1	37.6
Pellet durability (%)	–	83.0	96.6	–	83.7	93.4

※ SP: Standard pellet, EP: Expanded pellet. (Johnston and Hancock, 1997c)

REFERENCES

Anonymous, 1994. Expansion: A new technology in feed production. A technical report of Buhler. Uzwil, Switzerland.

Armstrong, H. 1993. Nutritional implications of expanded feeds. Feed Mix. 1:24.

Behnke, K. C. 1993. Factors affecting pellet quality. Feed Manufacturing Short Course Manual. Kansas State University. Manhattan, KS.

Behnke, K. C. 1994. Factors affecting pellet quality. Maryland Nutrition Conference. Dept. of Poultry Science and Animal Science, College of Agriculture, Uni. of Maryland, College Park.

Boulduan, G., M. Beck and M. Peisker. 1993. Effects of expander treatment on pig diets (in German). Kraftfutter. 6:266.

Chae, B. J., I. K. Han, J. H. Kim, I. H. Kim and J. D. Hancock. 1996. Effects of particle size and extrusion of corn and sorghum on ileal digestibility and growth performance in early weaned pigs. Unpublished.

Chae, B. J., I. K. Han, J. H .Kim, C. J. Yang, S. J. Ohh, Y. C. Rhee and Y. K. Chung. 1997a. Effects of feed processing and feeding methods on growth performance and carcass characteristics for growing-finishing pigs. Asian Aust. J. Anim. Sci. 10(2):164.

Chae, B. J., I. K. Han, J. H. Kim, Y. K. Chung, S. J. Ohh and K. H. Ryu. 1997b. Effect of different extrusion condition of corn and soybean meal on the ileal digestibility and growth performance of weaned pigs. Asian Aust. J. Anim. Sci. 10 (2):170.

Chae, B. J., H. I. Kang, I. K. Han, J. H. Kim, W. T. Cho, Y. K. Chung and M. S. Shim. 1997c. Effects of processing of a complete diet on growth performance and nutrient digestibility in growing pigs. Kor. J. of Anim. Nutr. Feed. 21:497.

Chae, B. J., H. I. Kang and Y. K. Chung. 1997d. Growth performance and nutrient digestibility in weaned pigs: The effect of pelleting and extrusion of a diet containing a milk product. Ann. Anim. Resources Sci. 8: In press.

Chae, B. J., H. I. Kang, I. K. Han, W. T. Cho, J. H. Kim, Y. K. Chung and M. S. Shim. 1997e. The effects of corn particle size and pellet size on growth and carcass traits in growing-finishing pigs. Submitted to Kor. J. Anim. Feed. Nutr.

Chu, K. S., J. H. Kim, B. J. Chae, Y. K. Chung and I. K. Han. 1997. Effects of processed barley on growth performance and ileal digestibility of growing pigs. Asian Aust. J. Anim. Sci. (Accepted for publication)

Chung, Y. K., B. J. Chae, J. H. Kim, K. S. Chu and I. K. Han. 1996. An evaluation of barley in finishing pig diets for high quality pork production. Biennial Report on Res. and Education Seoul National University. p. 279.

Coelho, M. 1994. Vitamin stability in expanders. Feed Management. 45(8):10.

Coelho, M. 1996. Stability of vitamin affected by feed processing. Feedstuffs (July 29). p. 9.

Hancock, J. D. 1992. Extrusion cooking of dietary ingredients for animal feeding. Contribution No. 92-316A. Kansas Agricultural Expansion Station. Published in Proceedings of the Distillers Feed Conference. Cincinnati. Ohio., Vol. 47. p. 33.

Healy, B. J., J. D. Hancock, G. A. Kennedy, P. J. Bramel-Cox, K. C. Behnke and R. H. Hines. 1994. Optimum particle size of corn and hard and soft sorghum for nursury pigs. J. Anim. Sci. 72:2227.

Hilliker, J. 1991. Proc. of the broiler pelleting seminar for Asia. Sponsored by California Pellet Mill Co. Sanfrancisco, CA.

Johnston, S. L., S. L. Trayler, R. H. Hines, J. D. Hancock, K. C. Behnke, S. P. Sorrell, I. H. Kim and G. A. Kennedy. 1996. Effects of expanders on growth performence in finishing pigs. Swine Day. Kansas State University.

Johnston, S. L. and J. D. Hancock. 1997a. Effects of expander conditioning of complex nursury diets on growth performance of weanling pigs. Unpublished.

Johnston, S. L. and J. D. Hancock. 1997b. Effects of expander conditioners on pellet quality and growth performance in nursury and finishing pigs. Unpublished.

Johnston, S. L. and J. D. Hancock. 1997c. Effects of expander conditioning of corn- and sorghum-based diets on pellet quality and performance in finishing pigs and lactating sows. Unpublished.

Kim, I. H. 1995. The effects of novel processing on nutritional value of soybeans and cereal grains for nursery, growing, and finishing pigs and lactation sows. Ph. D. Dissertation. Dept. of Animal Sciences and Industry. Kansas State University. Manhattan, KS.

McEllhiney, R. R. 1993. What's new in the feed milling industry in the 1990's. Feed Manufacturing Short Course Manual. Kansas State University. Manhattan, KS.

Maga, J. A. 1989. Flavor formation and retention during extrusion. In: Extrusion cooking(C. Mercier, P. Linko and J. M. Harper ed.). Am. Assoc. Cereal Chem. St. Paul, MN.

Martin, S. A. 1984. Comparison of hammer mill and roller mill grinding and the effect of particle size reduction on mixing and pelleting. Master Thesis. Kansas State Uni. Manhattan, KS.

Melcion, J. P. and A. F. B. Van der Poel. 1993. Process technology and antinutritional factors: principles, adequacy, and process optimization. In: Recent advances of research in antinutritional factors in legume seeds,, proc. of the 2nd international workshop on ANF's in legume seeds. Wageningen, The Netherlands. p. 419.

Mills, C. G. 1994. Extrusion of sorghum grain and soybeans for lactating sows. M.S. Thesis. Kansas State Univ. Manhattan, KS.

Nielsen, L. C. 1995. Danish experiences with structurized pig feeds. Proc. of Victam International. May 17-18. Utrecht, The Netherlands.

Ohh, S. J. 1991. Past and future of feed manufacturing and processing industry. Manual of short course on feed technology, Seoul. p. 138

Ohh, S. J., J. S. Lee, D. E. Jang, J. H. Jeon, S. J. Cho and J. Y. Lee. 1996. Effect of expander applied pellet processing on the prowth performances and nutrient digestibility in growing pigs. Annals of Anim. Res. Sci. 7:36.

Peisker, M. 1992. Physical and chemical changes during extrusion. Feed International. Feb.

Piao, X. S., B. J. Chae, J. H. Kim, J. Jin, W. T. Cho and I. K. Han. 1997. Effects of extrusion condition barley on growth performance, fecal digestibility and reductions in nutrient excretion in growing pigs. Unpublished.

Rokey, G. J. 1995. Extrusion technology and nutritional implications. Proc. Expo Aviga. Barcelona, Spain.

Rokey, G. J. 1996. Characteristics and application of extruders. In : Practical Feeds Extrusion Short Course Manual (E. W. Lusas and M. N. Riaz, ed.). Texas A&M University. College Station, TX.

Sauer, W. C., R. Mosenthin and A. B. Pierce. 1990. The utilization of pellet, extruded, and extruded and repelleted diets by early weaned pigs. Anim. Feed Sci. Technol., 31:269.

Stark, C. R., K. C. Behnke, J. D. Hancock and R. H. Hines. 1993. Pellet quality affects growth performance of nursery and finishing pigs. Swine Day Rep. Pro. 695. Kansas State Univ. Mahattan, KS.

Strahm, B. S. 1996. Preconditioning effects on extrusion of feedstuffs. In: Practical Feeds Extrusion Short Course Manual (E. W. Lusas and M. N. Riaz, ed.). Texas A&M University. College Station, TX.

Traylor, S. L., K. C. Behnke, J. D. Hancock, P. Sorrell, F. J. Fairchild and R. H. Hines. 1996. Influence of pellet size on growth performance in nursery pigs and growth perpormance, nutrient digestibility and Stomach morphology in finishing pigs. Swine Day. Kansas State Uni. Manhattan, KS.

Van der Poel, A. F. B. 1997. Expander processing: Chemical, physical and nutritional effects. Feed Processing Centere. Wageningen, The Netherlands.

Van der Poel, A. F. B., H. M. P. Franssen and M. W. Bosch. 1997. Effect of expander conditioning and/or pelleting of a diet containing tapioca, pea and soybean meal on the total tract digestibility for pigs. Ani. Feed Sci. Tech. In press.

Wondra, K. J., J. D. Hancock, G. A. Kennedy, R. H. Hines and K. C. Behnke. 1995a. Reducing particle size of corn in lactation diets from 1,200 to 400 micrometers improves sow and litter performance. J. Anim. Sci. 73:421.

Wondra, K. J., J. D. Hancock, G. A. Kennedy, K. C. Behnke and K. R. Wondra. 1995b. Effects of reducing particle size of corn in lactation diets on energy and nitrogen metabolism in second-parity sows. J. Anim. Sci. 73:427.

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines and C. R. Stark. 1995c. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757.