Effects of Feeding and Processing Methods of Diets on Performance, Morphological Changes in the Small Intestine and Nutrient Digestibility in Growing-Finishing Pigs**

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ABSTRACT : These experiments were conducted to investigate the effects of different feeding and processing methods of diets on performance, morphological changes in the small intestine and nutrient digestibility of growing-finishing pigs. One-hundred fifty growing pigs (Yorkshire×Landrace×Duroc; initial body weight of 23.33±0.75 kg) and one-hundred twenty finishing pigs (Yorkshire×Landrace×Duroc; initial body weight of 59.22±0.56 kg) were used in Exp. 1 and Exp. 2, respectively. Pigs were grouped on the basis of body weight and gender, and randomly allotted into 6 different treatments with 5 replications in each treatment in a 2×3 factorial arrangement. Treatments were 1) dry feeding with a mash diet (DM), 2) dry feeding with a pelleted diet (DP), 3) dry feeding with an expanded crumble diet (DEC), 4) dry/wet feeding with a mash diet (WM), 5) dry/wet feeding with a pelleted diet (WP), and 6) dry/wet feeding with an expanded crumble diet (WEC). In Exp. 1 (growing phase), there was no significant difference in average daily gain (ADG) and average daily feed intake (ADFI) among treatments during the entire experimental period, but feed conversion ratio (FCR) was significantly ($p<0.05$) improved in pigs fed pelleted diets regardless of feeding method. FCR was best in pigs fed a DP diet and worst in pigs fed a WM diet. Pigs fed a pelleted diet showed a 6.2% or 4.0% improvement in FCR compared with those fed a mash diet or an expanded crumble diet. Water disappearance was not significantly affected by dry/wet feeding or feed processing. Significant differences in villus height were not found among treatments, but villus height tended to be improved by dry/wet feeding. Dry/wet feeding or feed processing did not affect crypt depth. Digestibilities of calcium and phosphorus were significantly ($p<0.05$) improved in pigs fed an expanded crumble diet compared with pigs fed mash diets. Especially, pigs fed a WEC diet digested 8.1% more P than those fed a DM diet. Feed cost per kg weight gain (FCG) tended to be increased by dry/wet feeding rather than dry feeding. In Exp. 2 (finishing phase), ADG and ADFI were not significantly different among treatments, but a significant difference in FCR was found among feed processing forms. The best FCR was obtained in pigs fed a pelleted diet. Pigs fed a DP diet showed a 11.3% improvement compared with those fed a DEC diet. Water disappearance was significantly ($p=0.0408$) decreased by feeding the mash diet. However, water disappearance was not affected by dry/wet feeding during the finishing period. The villus height and crypt depth were not significantly different among treatments. However, crypt depth tended to be decreased by dry/wet feeding at the mid part of the small intestine. Fat digestibility was improved by dry feeding rather than dry/wet feeding, and was improved by 4.8% by feeding pellet diets compared with expanded crumble diets. Except for carcass grade, carcass characteristics were not significantly ($p<0.05$) different among treatments. Carcass grade was the best in pigs fed a WP diet. Feed cost per kg weight gain (FCG) was significantly decreased in pigs fed a pelleted diet compared with those fed an expanded crumble diet, and tended to be decreased by dry/wet feeding. In conclusion, these studies suggest that feeding the pelleted diet to growing-finishing pigs can be beneficial in terms of FCR and production cost. Dry/wet feeding can be helpful for the maintenance of villus height, but may not be reflected in improved growth performance or reduction of production costs. ***(Asian-Aust. J. Anim. Sci. 2001. Vol 14, No. 10 : 1450-1459)***

Key Words : Dry/Wet Feeding, Feed Processing, Growth Performance, Intestinal Morphology, Nutrient Digestibility, Growing-Finishing Pigs

INTRODUCTION

A wide range of feeding systems are currently employed in pig production and include dry/wet and wet feeding. Dry feeding is common in pig production, but recently, a lot of interest is being given to wet feeding to reduce waste water. Reduction in feed wastage was suggested as a possible reason for improved feed efficiency (Payne, 1991). In addition to the approximate 30% water saving (Maton and Daelemans, 1991) with a modern single space wet and dry feeder (SSWD) for pigs, growth rates was also increased with both meal (Taylor and Clark, 1990; Walker, 1990) and a pelleted diet (Payne, 1991). But Payne (1991) reported that the dry/wet feeding could produce a poorer carcass with lower dressing percentage due to thicker backfat. Maton and Daelemans (1991) demonstrated that there was no difference in backfat thickness between dry and wet feeding of mash and pelleted diets respectively, which was

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inconsistent with the report of Payne (1991).

It is widely accepted that the pelleting of diets will improve ADG and FCR in pigs. Ohh (1991) summarized the effects of pelleted diet over mash on growth and feed efficiency in swine from 16 trials and reported that the improvements in growth were 3-4%. Wondra et al. (1995) also observed that pelleting increased ADG, and both pelleting and particle size reduction improved FCR. Thomas et al. (1996) reported that the nutritional effects from treatment procedures might result from the operating conditions used during the subsequent conditioning, pelleting and cooling operations during manufacturing.

Currently, much 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. However, several researchers reported that the expander processing had little effect on the performance of growing-finishing pigs fed common diets (Johnston et al., 1996). However, Johnston and Hancock (1999a, b) demonstrated that dressing percentage and backfat thickness were not affected by expander processing of pig diets.

Generally, the effects of wet feeding and feed processing studied through a lot of studies. However in Korea dry/wet feeders rather than wet feeders are widely used in commercial farms. Therefore, two experiments were conducted to investigate dry/wet feeding effects of processed diets on performance, nutrient digestibility and morphological changes in the small intestine of growing and finishing pigs.

MATERIALS AND METHODS

One-hundred fifty growing pigs (Yorkshire×Landrace×Duroc; initial body weight of 23.33±0.75 kg) and one-hundred twenty finishing pigs (Yorkshire×Landrace×Duroc; initial body weight of 59.22±0.56 kg) were used in Exp. 1 and Exp. 2 to evaluate the effect of feeding and processing methods of diets on growing and finishing pigs. In Exp. 1 and Exp. 2, pigs were grouped on the basis of body weight and gender, and randomly allotted into 6 different treatments with 5 replications (5 pigs per 1.3×2.5 m^2 concrete floored pen for grower and 4 pigs per 1.6×3 m^2 concrete floored pen for finisher) in each treatment in a 2×3 factorial arrangement. Treatments were 1) dry feeding with a mash diet (DM), 2) dry feeding with a pelleted diet (DP), 3) dry feeding with an expanded crumble diet (DEC), 4) dry/wet feeding with a mash diet (WM), 5) dry/wet feeding with a pelleted diet(WP), 6) dry/wet feeding with an expanded crumble diet (WEC).

Experimental diets were formulated to meet or exceed the nutrient requirement for growing and finishing pigs recommended by the NRC (1998). Standard pellet and expanded crumble diets were processed by the following protocols. For standard pellet, corn grain was ground with a 3.5 mm diameter grinder (Hammer mill, BUHLER, Switzerland). Ground corn and other ingredients were processed in a conditioner for 8 seconds with 80°C, 2.5-3.0 kgf/cm^3 of steam pressure at 12.5Å. Then they were agglomerated into a large particle by the pellet mill. The pellet mill (California Pellet Mill Co., USA) had a 4.76 mm screen size and 63 mm of die thickness, with 200 horse power. The pelleted diets used in Exp. 1 and Exp. 2 had 98.2, 98.5 of pellet durability index, 664, 655 g/l of specific gravity and 33.9, 29.9 of α value that means degree of gelatinization.

For expanding (ALMEX, Netherlands), corn and wheat grains were ground with a 3.5 mm diameter grinder. Ground corn, wheat and other ingredients were processed in a conditioner for 9 seconds with 94°C, 4.0 kgf/cm^3 of steam pressure at 12.5Å. The barrel temperature of the expander was 140°C, with 350 horse power. After the expanding mill, the feeds were crumbled with an average particle size of 1-4 mm. The expanded crumble diet used in Exp. 1 and Exp. 2 had 532, 539 g/l of specific gravity and 38.9, 37.1 of α value. α value of mash diet used in Exp. 1 and Exp. 2 were 29.1, 24.5. α value was improved by pelleting and expanding by 22 and 51%, respectively.

Dry/wet feeders (AHWA Industry Co., Ltd., Korea) were allocated for growing and finishing pigs. For pigs in the dry/wet feeding group, a nipple waterer was installed in the feeder so that 2 pigs could consume feed and water simultaneously. Pigs were allowed *ad libitum* access to feed and water. For pigs in the dry feeding group, the nipple waterer in the feeder was turned off and a nipple waterer with water cup was supplementarily provided in the pen. The flow rate of water by nipple in the feeder and in the pen were 1.2 L/min and 1.25 L/min, respectively.

Body weight and feed intake were recorded at d 14, d 28 and d 49 in Exp. 1 and at d 21, d 42, d 56 and d 70 in Exp. 2. Body weight gain was calculated using the difference between the initial body weight and final body weight. Feed conversion was calculated by dividing the amount of feed consumed by the corresponding body weight gain. To measure water intake, a water gauge was installed in each pen. Water intake was measured twice a week.

At the termination of the experiment, 4 pigs from each treatment were randomly selected and slaughtered for examining the morphological changes in the small intestine. The samples of small intestine were obtained (≒ 4 cm in length) at distances of proportionately 0.25, 0.50 and 0.75 along the gut from the gastric pylorus to the ileo-caecal valve. These were fixed in neutral-buffered formalin and processed by the standard paraffin method. Sections (3-4 cm) were stained with haematoxylin and eosin, and examined under a light microscope. Measurements of villus hight and crypt depth were taken only from sections where the plane of the tissue section ran vertically from the tip of the villus to base of an adjacent crypt. From each section, a calibrated eyepiece graticule was used to measure 10 of the tallest well oriented villi from tip to crypt mouth, and 10 associated crypts from crypt mouth to base (Hampson et al., 1988).

For the determination of nutrient digestibility, the total fecal collection method was used. In Exp. 1 and Exp. 2, twelve pigs (6 boars and 6 gilts) averaging 40 kg and 81 kg of body weight were housed in an individual metabolic cage. After four days of adaptation period, total excreta were collected through three consecutive days. The amount of feed consumed and excreta were recorded daily. Collected excreta were pooled and dried in an air forced drying oven at 60°C for 72 hours and ground with 1 mm Wiley mill for chemical analyses. Analyses of proximate nutrients of the experimental diets and excreta were conducted according to the methods of AOAC (1990). Statistical analysis was carried out to compare means according to Duncan's multiple range test (Duncan, 1955), using General Linear Model (GLM) procedure of SAS (1985) package program.

RESULTS AND DISCUSSION

Performance

Table 2 shows the effects of feeding and processing methods of diets on the performance of growing and finishing pigs. Compared with a mash diet, none of the heat-processed diets (pellet and expanded crumble) significantly ($p>0.05$) improved ADG and ADFI. However, FCR was significantly ($p<0.05$) improved by feeding pelleted diets. Particularly in Exp. 1, pigs fed a DP diet showed 10% better FCR over those fed a WP diet. Several researchers (Hanke et al., 1972; Baird 1973; Wondra et al., 1995) have reported that the improved feed utilization in pigs as a result of feeding pelleted diets could be attributed to increased nutrient digestibility and also to decreased feed wastage. However, other studies failed to demonstrate a consistent improvement in performance when pigs were given pelleted diets (NCR-42 Committee on Swine Nutrition, 1969; Skoch et al., 1983). Meanwhile, in these studies, the positive effects of expanding on ADFI and ADG did not appear. This result was similar to data by Johnston et al. (1996) who reported that growing-finishing pigs fed an expanded diet over a pelleted form had no further improvement in ADG or FCR.

Dry/wet feeding did not significantly ($p>0.05$) improve ADG and ADFI compared with dry feeding. This result seems to be related to water disappearance since this was similar between the dry/wet feeding group and the dry feeding group. Smidt et al. (1965) observed no effects on body weight gains or feed efficiency for swine when similar levels of water were added to their diet. Meanwhile, FCR was improved ($p<0.05$) by dry feeding rather than dry/wet feeding in Exp. 1. This result indicates that the dry/wet feeder did not prevent feed wastage efficiently. Mike et al.

Table 1. Formula and chemical composition of the experimental diets

	Grower (23~60 kg)	Early finisher (60~88 kg)	Late finisher (88~110 kg)
Ingredients (%)			
Corn, yellow	42.65	49.30	54.58
Wheat	20.00	20.00	20.00
Lupin kernel	2.00	4.00	3.00
Corn germ meal	-	-	3.00
Rice bran polishing	2.00	1.00	-
Soybean meal (dehulled)	23.83	15.55	12.45
Sunflower meal	1.00	3.00	1.00
Animal fat	3.57	1.70	0.60
Molasses	2.00	3.00	3.00
Limestone	0.58	0.65	0.50
Tri-calcium phosphate	1.27	0.93	1.11
Salt	0.30	0.30	0.30
L-Lysine-HCl (78%)	0.17	0.19	0.18
DL-Methionine (Liq., 88%)	0.03	-	-
Vitamin-mineral mixture[1]	0.35	0.30	0.25
Antibiotics	0.20[2]	0.05[3]	-
Choline chloride (25%)	0.05	0.03	0.03
Total	100.00	100.00	100.00
Chemical composition[4]			
ME (kcal/kg)	3,370	3,270	3,250
Crude protein (%)	18.30	15.80	14.00
Lysine (%)	1.05	0.89	0.76
Methionine+ cystine (%)	0.60	0.53	0.49
Calcium (%)	0.75	0.65	0.64
Phosphate (%)	0.66	0.56	0.55

[1] Provided the following per kg of vitamin-mineral mixture : Vitamin A, 2,200,000 IU; Vitamin D_3, 500,000 IU; Vitamin E, 10,000 mg; Vitamin K_3, 800 mg; Vitamin B_1, 250 mg; Vitamin B_2, 1,760 mg; Niacin, 8,800 mg; Pantothenic acid, 6,500 mg; Pyridoxin, 440 mg, Choline 90,000 mg; Folic acid, 330 mg; Biotin 23 mg; Vitamin B_{12}, 9 mg; Cu, 67,800 mg; Zn, 42,600 mg; Se, 100 mg; Mn, 19,500 mg; Fe, 32,000 mg; 7,700 mg; I, 450 mg.

[2] Provided per kg of diet : Olaquindox 50 mg, Chlorotetracycline 110 mg.

[3] Provided per kg of diet : Virginiamycin 10 mg.

[4] Calculated values.

Table 2. Effects of feeding and processing methods of diets on growth performance of growing-finishing pigs

Treatments	Dry			Dry/Wet			SE[1]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Experiment 1							
Intial weight (kg)	23.33	23.34	23.37	23.34	23.32	23.30	0.55
Final weight (kg)	59.83	59.74	59.43	58.75	58.65	58.95	1.05
ADG (kg)	0.745	0.743	0.736	0.723	0.721	0.728	12.00
ADFI (kg)	1.754	1.644	1.718	1.757	1.656	1.715	35.05
FCR	2.35^{ab}	2.21^{c}	2.33^{ab}	2.43^{a}	2.30^{bc}	2.35^{ab}	0.02
Experiment 2							
Intial weight (kg)	59.54	59.52	59.17	58.87	59.10	59.10	1.09
Final weight (kg)	108.76	109.95	109.19	106.22	110.18	109.11	1.51
ADG (kg)	0.693	0.710	0.705	0.667	0.719	0.705	10.80
ADFI (kg)	2.193	2.080	2.293	2.048	2.117	2.112	44.46
FCR	3.16^{ab}	2.93^{c}	3.25^{a}	3.09^{abc}	2.95^{bc}	3.00^{bc}	0.05

	Feeding methods	Processing methods	Interaction (P value)
Experiment 1			
ADG (g)	0.3162	0.9945	0.9320
ADFI (g)	0.9272	0.2002	0.9918
FCR	0.0449	0.0038	0.6009
Experiment 2			
ADG (g)	0.7564	0.3145	0.7288
ADFI (g)	0.0779	0.2509	0.2101
FCR	0.0924	0.0200	0.1840

[1] Pooled standard error, [a,b,c] Means with different superscript in the same row differ at $p<0.05$.

(1997) reported that FCR was improved by 3% by dry feeding rather than dry/wet feeding. However, Rantanen et al. (1995) demonstrated that pigs fed diets from dry/wet feeders had 4% greater ADG than those fed diets from the dry feeders ($p<0.04$), but had no effect on ADFI and FCR ($p>0.24$). Recently, Chae et al. (1997) also reported finishing pigs (60-90 kg) fed a mash diet in wet form showed 12.4% and 9.7% improvement in ADG and FCR as compared with those fed a mash diet in dry form.

Effects of feeding and processing methods of diets on water disappearance in growing and finishing pigs are presented in table 3. In Exp. 1, during first 2 weeks, water disappearance of pigs fed pellet diets was decreased by 20% (p=0.0223) compared with pigs fed a mash diet. For the overall period of growing phase, water disappearance did not significantly differ among treatment. However, water disappearance decreased by dry/wet feeding of pellet diets by 3-13%. In Exp. 2, water disappearance significantly differed among processing methods (mash, pellet and expanded crumble). Pigs fed a WM diet showed 21% lower water disappearance than those fed a DM diet. This result is similar to data by Rantanen et al. (1995) who reported that water disappearance from a dry/wet feeder was reduced by 50%.

The result of growth performance indicates that feeding a pelleted diet rather than mash or expanded diets can improve FCR of finishing pigs by 2 to 11%, regardless of feeding method. The advantage of dry/wet feeding in growing and finishing pigs was not found in these studies. This seems to be related to the contamination of wet diets by pathogenic microorganism such as *E. coli*. When diets remain in a wet condition in the dry/wet feeder for a long time, they can easily be contaminated by microorganisms. The summer weather in Korea is very hot and humid (averaging 27°C and should be demonstrated, respectively). Therefore, application of a dry/wet feeding system might not improve performance, and may cause difficulties in managing the dry/wet feeding system. Conclusively this study suggests that the dry pelleted diet is more beneficial than a dry/wet feeding for growing-finishing pigs.

Morphological changes in the small intestine

Table 4 shows the effects of feeding and processing methods of diets on villus height and crypt depth at the three sites along the small intestine of growing and finishing pigs. Villus height and crypt depth did not significantly differ among treatments, but villus height tended to be consistently higher at the three sites examined in pigs fed dry/wet diets.

In Exp. 1, mean villus height along the length of the small intestine was 3-13% longer in pigs given dry/wet diets. Dry/wet feeding of processed diets tended to increase

Table 3. Effects of feeding and processing methods of diets on water disappearance of growing-finishing pigs

Treatments	Dry (L/d/pig)			Dry/wet (L/d/pig)			SE[1]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Experiment 1							
D 0-14	4.75[ab]	4.49[b]	4.59[b]	5.57[a]	4.03[b]	4.75[ab]	0.14
D 14-28	6.88	6.69	6.80	6.74	5.92	6.49	0.17
D 28-49	6.52	7.36	7.64	7.55	7.31	7.34	0.23
Overall	6.12	6.35	6.53	6.76	5.98	6.36	0.14
Experiment 2							
D 0-42	7.18[ab]	7.85[a]	7.85[a]	6.24[b]	8.05[a]	7.75[a]	0.22
D 42-70	6.36[a]	6.33[a]	6.46[a]	4.79[b]	5.71[ab]	5.84[ab]	0.19
Overall	6.85[a]	7.24[a]	7.29[a]	5.66[b]	7.12[a]	6.99[a]	0.19

	Feeding methods	Processing methods	Interaction (P value)
Experiment 1			
D 0-14	0.4886	0.0223	0.1252
D 14-28	0.2563	0.5009	0.7551
D 28-49	0.6523	0.7565	0.5183
Overall	0.9197	0.6587	0.3203
Experiment 2			
D 0-42	0.4653	0.0249	0.4407
D 42-70	0.0083	0.3292	0.3907
Overall	0.0978	0.0408	0.3434

[1] Pooled standard error, [a,b] Means with different superscript in the same row differ at $p<0.05$.

the villus height at the central (0.50) and distal part (0.75) of small intestine compared with dry feeding of processed diets. Crypt depth was not affected by dry/wet feeding, but tended to be deepened by feeding mash diets compared with expanded crumble diets.

In Exp. 2, villus height was increased by 2.7% by dry/wet feeding at the central part of small intestine. Crypt depth was not significantly different among treatments, but tended to be decreased by dry/wet feeding at the central part of small intestine. Crypt depth of pigs fed a WEC diet was 28% shorter than that of pigs fed a DEC diet. Crypt depth was shortest at the distal part of the small intestine comparing the three sites examined. This result is in agreement with those reported by Pluske et al. (1996) and Miller et al. (1986). Generally, an increase in crypt depth is compatible with an increase in crypt-cell production rate and an overall stimulation of cell turn-over in the small intestine (Al-Mukhtar et al., 1982). This change has been associated with a reduced digestive and absorptive capacity (Gay et al., 1976; Hampson, 1983).

Many researchers have indicated that the small intestine of the newly weaned piglet generally undergoes a reduction of villus hight and an increase of crypt depth (Hampson et al., 1986; Cera et al., 1988; Kelly et al., 1991a, b; Makkink et al., 1994a, b). Pluske et al. (1996) reported that crypt depth at the proximal jejunum was increased in all treatments by the time piglets were killed 5 days after weaning, and the increase was greatest for piglets given dry diets. In these studies, a significant reduction of crypt depth was not found by dry/wet feeding. These results indicate that dry/wet feeding in young pigs after weaning is very important in morphological changes, but may not significantly affect crypt depth both in growing and finishing pigs.

Effects of feeding and processing methods of diets on the length and weight of the gastrointestinal organs of finishing pigs are presented in table 5. The length of small intestine was not significantly different among treatments. The weight of the stomach was significantly increased by 9.6% by dry/wet feeding. However, weights of liver, pancreas and total small intestine were not affected by feeding methods or processing methods.

The present studies suggest that dry/wet feeding, regardless of processing method, could be helpful for the maintenance of villus height in the intestine of finishing pigs, and further studies are needed to evaluate exactly the effects of feeding methods on the growth performance from the birth to slaughter.

Nutrient digestibility

Effects of feeding and processing methods of diets on nutrient digestibility of growing and finishing pigs are presented in table 6.

In Exp. 1, digestibility of dry matter, crude protein and energy were not significantly different among treatments, but tended to be increased by feeding pelleted diets

Table 4. Effects of feeding and processing methods of diets on morphological changes in the small intestine of growing-finishing pigs

Treatments	Dry (L/d/pig)			Dry/wet (L/d/pig)			SE[1]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Experiment 1							
Villus height[2] (μm)							
0.25	569	607	618	683	608	676	21.57
0.50	626	582	637	675	633	689	18.72
0.75	634	594	559	654	688	658	19.34
Crypt depth (μm)							
0.25	363	369	399	411	339	408	15.86
0.50	358	327	335	371	329	342	13.50
0.75	367	342	327	369	351	344	13.87
Experment 2							
Villus height							
0.25	599	656	662	717	707	657	16.73
0.50	690	661	671	727	686	664	16.12
0.75	657	701	680	683	703	697	23.96
Crypt depth							
0.25	373	384	436	429	422	384	16.31
0.50	480	445	490	450	469	383	16.89
0.75	334	373	364	337	319	366	14.63

	Experiment 1			Experiment 2		
	Feeding methods	Processing methods	Interaction (P value)	Feeding methods	Processing methods	Interaction (P value)
Villus height						
0.25	0.2358	0.7919	0.6273	0.2358	0.7919	0.6273
0.50	0.2521	0.5456	0.9995	0.2521	0.5456	0.9995
0.75	0.1114	0.7478	0.6919	0.1114	0.7478	0.6919
Crypt depth						
0.25	0.7793	0.4443	0.6036	0.7793	0.4443	0.6036
0.50	0.8042	0.6041	0.9881	0.8042	0.6041	0.9881
0.75	0.7476	0.6480	0.9795	0.7476	0.6480	0.9765

[1] Pooled standard error.

[2] Distances of proportionately 0.25, 0.50 and 0.75 along the gut from the gastic pylorus to the ileo-caecal value.

compared with mash or expanded crumble diets. Digestibility of calcium and phosphorus were significantly ($p<0.05$) improved by pellet or expander processing. Fat digestibility of pigs fed a WP diet was significantly ($p<0.1$) higher than that of pigs fed a WM diet. The improved FCR of pigs fed a pelleted diet during the overall experimental period can be explained as the result of improved nutrient digestibility. These results are in agreement with some studies reported previously. Wondra et al. (1995) reported that the apparent digestibilities of DM, N, and GE in corn-based diets were increased by pelleting. Jensen and Becker (1965) also suggested that pelleting gelatinized starch, thus making it more susceptible to enzymatic digestion. The forces in the pelleting process that gelatinize starch also could disrupt the structure of corn particles making them more accessible for digestive enzyme, thus explaining the improved DM and N digestibilities. In this study, the α value of processed diets was 16-33% higher than that of mash diet by which seems to improved the nutrient digestibility of processed diets. Meanwhile, there was no significant difference in nutrient digestibility between dry/wet feeding and dry feeding. Similar to this result, Kornegay et al. (1969) reported that the dry matter, crude protein, ether extract, crude fiber and nitrogen-free extract (NFE) were not affected by dry/wet feeding.

In Exp. 2, only fat digestibility showed significant ($p<0.01$) differences among treatments. Fat digestibility was improved by dry feeding rather than dry/wet feeding, and was improved by feeding pelleted diets compared with expanded crumble diets by 4.8%. Digestibilities of calcium and phosphorus had a tendency to be improved by dry/wet feeding. Even though there was no significant difference in

Table 5. Effects of feeding and processing methods of diets on the length and weight in gastrointestinal tract of finishing pigs

Treatments	Dry			Dry/wet			SE[1]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Body weight (kg)	115.0	113.2	115.3	113.5	113.9	114.2	0.55
Small intestine[2] length (mm)	15.0	16.6	14.7	15.9	16.1	15.3	0.26
Organ weight[3]							
Small intestine (g)	12.3	13.0	12.4	13.4	13.7	12.9	0.26
Stomach (g)	4.9^{ab}	4.7^{b}	5.0^{ab}	5.1^{ab}	5.6^{a}	5.3^{ab}	0.12
Liver (g)	12.2	11.8	12.1	12.3	11.9	12.7	0.14
Total (g)	29.3	29.5	29.5	30.9	31.2	31.0	0.34

	Feeding methods	Processing methods	Interaction (P value)
Body weight	0.5761	0.6841	0.6965
Small intestine length	0.5086	0.1006	0.5120
Organ weight			
Small intestine	0.1564	0.5988	0.8894
Stomach	0.0484	0.8782	0.4966
Liver	0.3190	0.3030	0.7579
Total	0.3338	0.9994	0.1138

[1] Pooled standard error, [2] Small intestine length (mm)/kg bodyweight, [3] Gastrointestine weight (g)/kg bodyweight.
[a,b] Means with different superscript in the same row differ at $p<0.05$.

nutrient digestibility among feed processing groups (mash, pelleted and expanded crumble diets), nutrient digestibility of pigs fed a pelleted diet showed a tendency to be higher than that of pigs fed mash or expanded crumble diets.

These studies suggest that the use of processed diets can improve digestibilities of crude protein, calcium and phosphorous, while dry/wet feeding may not be helpful to increase the digestibility of some nutrients during the growing-finishing period.

Carcass characteristics

As shown in table 7, significant differences were not found in carcass length, backfat thickness and carcass percentage among treatments. However, backfat thickness had a tendency to be decreased in pigs fed pelleted diets. Pigs fed a WP diet had decreased backfat thickness by 13% as compared with those fed a DEC diet. Backfat thickness of pigs fed a DEC diet was the thickest, and it seems to be related with highest feed intake for the overall experimental period. Peet (1989) and Payne (1991) reported that higher feed intake from single space wet and dry feeder could lead to an increase in carcass backfat in the same genotypes of pigs to the extent that the benefits from improved efficiency were negated by loss in carcass characteristics. However, in this study, carcass length and carcass percentage were similar among treatments regardless of feeding method or feed processing. Interaction between feeding methods and processing method was shown in carcass grade. According to the result above, a mash diet was suitable for dry feeding, but processed diets were suitable for dry/wet feeding. Carcass grade was significantly improved in pigs fed a WP diet as compared with those fed DP or DEC diets.

Carcass characteristics including carcass percentage, backfat thickness and carcass length were not affected by dry/wet feedings, which agrees with the findings of Kornegay et al. (1969), Maton and Daelemans (1991) and Chae et al. (1997). However, in this study, carcass grade in pigs fed processed diets was significantly improved by dry/wet feeding. This advantage did not appear in pigs fed a mash diet. Conclusively, this study suggests that dry/wet feeding of pellet diets would be helpful for improving the carcass characteristics of finishing pigs.

Feed cost

The effects of feeding and processing methods of diets on feed cost of growing and finishing pigs is presented in table 8. In Exp. 1, total feed cost per pig (TFC) was slightly decreased in the pelleted diet groups than mash or expanded crumble diet groups, but there was no significant difference among treatments. Dry/wet feeding did not affect TFC. Feed cost per kg body weight gain (FCG) decreased by the use of pelleted diets. Especially, compared with mash diet groups, pelleted diet groups decreased FCG by 3%.

In Exp. 2, TFC was highest in the DEC diet group and lowest in the WM diet group. This result seems to be related to increased ADFI for the overall experiment period. Even though TFC had a tendency to be decreased by dry/wet feeding, there was no significant difference

Table 6. Effects of feeding and processing methods of diets on nutrient digestibility of growing-finishing pigs[1]

Treatments	Dry			Dry/wet			SE[2]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Experiment 1							
Dry matter (%)	91.2	92.0	89.7	90.7	92.0	91.3	0.30
Crude protein (%)	90.2	91.0	88.7	89.5	90.8	89.3	0.35
Crude fat (%)	86.0[ab]	87.3[ab]	87.5[ab]	85.4[b]	89.3[a]	89.0[a]	0.48
Calcium (%)	87.1[ab]	87.0[ab]	88.9[a]	85.8[b]	87.8[ab]	89.2[a]	0.43
Phosphorus (%)	75.2[b]	78.1[ab]	76.8[ab]	74.5[b]	78.8[ab]	81.3[a]	0.77
Energy (%)	90.8	91.8	89.5	90.4	91.8	91.0	0.32
Experiment 2							
Dry matter (%)	92.8	93.0	92.5	92.9	93.2	92.5	0.34
Crude protein (%)	90.2	91.6	89.7	90.2	92.0	89.0	0.52
Crude fat (%)	90.9[a]	91.1[a]	90.9[a]	87.8[a]	88.9[a]	81.0[b]	0.94
Calcium (%)	86.6	85.7	84.6	87.2	88.5	87.2	0.64
Phosphorus (%)	67.9	74.4	66.0	71.5	76.1	68.8	1.56
Energy (%)	92.2	92.4	91.8	92.1	92.7	92.0	0.35

	Feeding methods	Processing methods	Interaction (P value)
Experiment 1			
Dry matter	0.5404	0.0808	0.2518
Crude protein	0.8879	0.1079	0.7517
Crude fat	0.2603	0.0405	0.4096
Calcium	0.9562	0.0370	0.5134
Phosphorus	0.2785	0.0361	0.2596
Energy	0.5855	0.1149	0.3147
Experiment 2			
Dry matter	0.9785	0.6370	0.9278
Crude protein	0.9149	0.1110	0.8783
Crude fat	0.0003	0.0177	0.0225
Calcium	0.1024	0.6859	0.7098
Phosphorus	0.3309	0.0814	0.9586
Energy	0.8606	0.7055	0.9729

[1] Average body weight of pigs used in Exp. 1 and Exp. 2 were 50.4 kg and 81.4 kg, [2] Pooled standard error.
[a,b] Means with different superscript in the same row differ at $p<0.05$.

Table 7. Effects of feeding and processing methods of diets on carcass characteristics of finishing pigs[1]

Treatments	Dry			Dry/wet			SE[2]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Slaughter weight (kg)	109.9	110.4	110.9	110.8	110.8	110.4	0.60
Carcass length (cm)	101.6	101.8	100.6	100.8	101.1	101.0	0.45
Backfat thickness (mm)	31.2	29.1	32.9	32.2	29.1	31.2	0.70
Dressing percentage (%)	76.9	76.9	77.1	76.1	77.6	76.9	0.26
Carcass grade[3]	1.67[ab]	2.22[a]	2.22[a]	2.22[a]	1.22[b]	1.78[ab]	0.14

	Feeding methods	Processing methods	Interaction (P value)
Slaughter weight	0.8183	0.9695	0.8957
Carcass length	0.7282	0.8302	0.8372
Backfat thickness	0.8818	0.2203	0.7616
Dressing percentage	0.8847	0.5325	0.5033
Carcass grade	0.2431	0.6343	0.0467

[1] Total 54 pigs (6 pigs each treatment) were randomly selected and killed at the end of experiment, [2] Pooled standard error.
[3] Based on a scale with 1 = grade A, 2 = grade B, 3 = grade C, 4 = grade D.
[a,b] Means with different superscript in the same row differ at $p<0.05$.

Table 8. Effects of feeding and processing methods of diets on feed cost of growing-finishing pigs

Treatments	Dry			Dry/wet			SE[1]
	Mash	Pelleted	Expanded crumble	Mash	Pelleted	Expanded crumble	
Experiment 1							
FC (₩/kg feed)	268.8	274.5	272.8	268.8	274.5	272.8	-
TWG (kg/pig)	36.48	36.48	36.06	35.41	35.35	35.66	0.59
TFI (kg/pig)	85.92	80.56	84.16	86.10	81.15	84.03	1.72
TFC (₩/pig)	23,096	22,113	22,958	23,114	22,274	22,923	461.32
FCG (₩/pig)	631.2[ab]	606.5[b]	635.7[ab]	653.3[a]	630.5[ab]	640.9[a]	5.16
Experiment 2							
FC (₩/kg feed)	229.0	234.5	233.0	229.0	234.5	233.0	-
TWG (kg/pig)	48.52	49.73	49.32	46.68	50.34	49.32	0.76
TFI (kg/pig)	153.5	145.6	160.5	147.4	148.2	147.8	3.11
TFC (₩/pig)	35,157	34,155	37,399	32,833	34,759	34,440	724.42
FCG (₩/pig)	724.0[ab]	687.0[ab]	757.1[a]	706.3[b]	691.2[b]	699.1[b]	10.63

	Feeding methods	Processing methods	Interaction (P value)
Experiment 1			
TWG	0.3192	0.9958	0.9337
TFI	0.9274	0.2004	0.9918
TFC	0.9265	0.4490	0.9917
TCG	0.0440	0.0527	0.5860
Experiment 2			
TWG	0.7564	0.3145	0.7288
TFI	0.0779	0.2509	0.2101
TFC	0.0780	0.1742	0.2065
FCG	0.0844	0.0696	0.1705

[1] Pooled standard error.

* Abbreviation : FC, feed cost; TWG, total weight gain per pig; TFI, total feed intake per pig; TFC, total feed cost per pig; FCG, feed cost/kg body weight gain.

[a,b] Means with different superscript in the same row differ at $p<0.05$.

between dry/wet feeding and dry feeding. FCG was decreased when pigs were fed pelleted diets rather than mash or expanded crumble diets. As FCR was greater, FCG was lower. FCG was significantly ($p<0.1$) decreased by dry/wet feeding. Especially, pigs fed a WP diet showed the best result in FCG.

This study suggests that the feed cost in growing and finishing phase can be decreased by dry/wet feeding of a pelleted diet. However, expanding process may not be suitable for growing and finishing pigs because of the increase of feed cost without improvement in performances compared with the pelleting process.

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