Study on the Development of the Optimum Feeding Regimen for Pigs Weaned at 21 Days of Age

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ABSTRACT : This experiment was conducted to investigate the effect of various feeding regimens on growth performance, nutrient digestibilities, nitrogen retention, blood urea nitrogen (BUN) concentration and feed cost in young pigs weaned at 21 days of age. One hundred twenty crossbred pigs (Landrace×Large White×Duroc, average 6.8 kg BW), weaned at 21 days of age, were allotted to 5 treatments in a 5 replicates by a randomized completely block (RCB) design. Treatments were as follow: 1) 1P (1-4 weeks: CP 23% and lysine 1.60%), 2) 2P-I (1 week: CP 23% and lysine 1.60%, 2-4 weeks: CP 21% and lysine 1.45%), 3) 2P-II (1-2 weeks: CP 23% and lysine 1.60%, 3-4 weeks: CP 21% and lysine 1.45%), 4) 2P-III (1-3 weeks: CP 23% and lysine 1.60%, 4 week: CP 21% and lysine 1.45%), 5) 3P (1 week: CP 23% and lysine 1.60%, 2-3 weeks: CP 21% and lysine 1.45%, 4 week: CP 19% and lysine 1.30%). Three different diets were formulated and supplied according to phase feeding programs. Diet 1 contains 23% crude protein and 1.60% lysine, diet 2 contains 21% crude protein and 1.45% lysine and diet 3 contains 19% crude protein and 1.30 lysine, respectively. Although there was no significant difference in growth performances, there was a beneficial effect of 3 phase feeding. The ADG was higher in 3P treatment than other treatments and it was observed clearly in late period (3-4 weeks) than in early period. Also, with increase in age, growth rate of pigs in 3P treatment was higher than that in 1P treatment approximately 37% ($p=0.1379$). There were no significant differences among all treatments in nutrient digestibility. The concentration of BUN was higher in pigs were fed diet containing 21% crude protein and 1.45% lysine (eg, 2P-1 and 3P) than those supplied diet containing high nutrient value at 2 week. The lowest feed cost/kg weight gain of pigs showed in 3P among treatments ($p<0.05$) whereas, high feed cost/kg weight gain of pigs was calculated in 1P and 2P-II treatments compared with 2P-I and 2 P-II ($p<0.05$), because of high milk products were used in those diet. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 10 : 1518-1523)***

Key Words : Phase Feeding, Weaned Pigs, Growth Performance, Nutrient Digestibility, Blood Urea Nitrogen

INTRODUCTION

There are many factors to affect on growth, health status and mortality of nursery pigs. First of all, newly weaned pigs are exposed to nutritional (loss of sow's milk), psychological (mixing and moving) and environmental (change in ambient temperature) stressors that are occurred abruptly and simultaneously (Pluske et al., 1995). Secondly, there are marked changes in the structure and function of the small intestine of pigs that happens within 24 h after weaning. Villous height and specific activities of the digestive enzymes such as lactase and sucrase are decreased whereas crypt depth is increased, which affect on absorptive capacity of weaning pigs (Gay et al., 1976; Hampson, 1983; Miller et al., 1986; Cera et al., 1988a; Kelly et al., 1991a,b,c). Thirdly, diarrhea occurs frequently in weaning pigs due to proliferation of enterotoxigenic bacteria in the small intestine and/or fermentation of less digestible nutrients of the weaner diet in the large intestine (McCracken and Kelly, 1993). The combined effects of these changes result in poor growth or weight loss, low feed intake, morbidity and death of weaned pigs (Pluske et al., 1995). Thus, in modern swine nutrition, it is very important issue to prevent growth lag or mortality after weaning to maintain growth potential of pigs.

In the last decade, phase feeding for nursery period was developed to achieve normal growth performance for pigs in USA (Goodband, 1993). Because of phase feeding, weaned pigs can be adjusted very successfully from a high milk product, high protein and complex diet to low milk product, low protein and simple diet (Pluske et al., 1995). Although a few researches on phase feeding for young pigs were conducted, there were some beneficial effects on pigs producer such as to avoid postweaning growth depression of weaned pigs and reduce feed cost to supply milk products.

The effect of phase feeding depends on a farm situation such as environmental temperature, body weight, age at weaning and genetic potential of nursery pigs. Thus, it is very important to collect the information about farm situation to set up proper feeding regimen for maximal growth performance (Han et al., 2001; Lee et al., 2001).

In Korea, there was few research on phase feeding for nursery pigs. Although there was some phase feeding program in USA, it might be risky to apply directly the similar phase feeding program into Korea, because farm situations, genetic potential, weaning time and body weight

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Trt \ Week	1 week	2 week	3 week	4 week
1P	23% CP, 1.60% Lys.			
2P-I	23% CP, 1.60% Lys.	21% CP, 1.45% Lys.		
2P-II	23% CP, 1.60% Lys.		21% CP, 1.45% Lys.	
2P-III	23% CP, 1.60% Lys.			21% CP, 1.45% Lys.
3P	23% CP, 1.60% Lys.	21% CP, 1.45% Lys.		19% CP, 1.30% Lys.

Figure 1. Experimental design

Table 1. Formula and chemical composition of the experimental diets

Ingredients	Diet 1	Diet 2	Diet 3
Corn	12.72	22.17	43.88
Milk replacer[a]	25.55	20	10
SBM	19.05	19	19
Lactose	21.13	21.13	10
Soyoil	3	1.8	3.78
Fish meal	4.81	3.7	2.65
SDPP	4.81	3.7	2.7
DPS	5.91	5	4
MCP	0.99	1.33	1.61
Limestone	0.63	0.73	0.94
Vitamin mix.[b]	0.2	0.2	0.2
Mineral mix.[c]	0.3	0.3	0.3
Salt	0.3	0.3	0.3
Avilamycine	0.05	0.05	0.05
L-lysine-HCl	-	0.06	0.14
DL-methionine	0.35	0.33	0.25
Cr_2O_3	0.2	0.2	0.2
Total	100	100	100
Chemical composition[d]			
ME (kcal/kg)	3,504	3,450	3,474
CP (%)	23.00	21.05	19.04
Lysine (%)	1.60	1.45	1.30
Met+cys (%)	0.96	0.87	0.78
Ca (%)	0.90	0.90	0.90
P (%)	0.80	0.80	0.80

[a] 89.5% dried whey, 1.5% soy flour, 0.5% silicate.

[b] Provided the following per kilogram of diet: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 μg; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg.

[c] Provided the following per kilogram of diet : Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; $CuSO_4$, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[d] Calculated value.

at weaning in Korea were totally different from those in USA. Therefore, this experiment was conducted to determine the optimal feeding regimen for pigs weaned at 21 days of age in Korea.

MATERIALS AND METHODS

Experimental animals

One hundred pigs [(Landrace×Large White)×Duroc] averaging 6.81 kg BW, weaned at 21 days of age were allotted in 5 treatments by body weight and sex. Treatments were: 1) 1P (1-4 weeks: CP 23% and lysine 1.60%). 2) 2P-I (1 week: CP 23% and lysine 1.60%. 2-4 weeks: CP 21% and lysine 1.45%). 3) 2P-II (1-2 weeks: CP 23% and lysine 1.60%, 3-4 weeks: CP 21% and lysine 1.45%). 4) 2P-III (1-3 weeks: CP 23% and lysine 1.60%. 4 week: CP 21% and lysine 1.45%). 5) 3P (1 week: CP 23% and lysine 1.60%, 2-3 weeks: CP 21% and lysine 1.45%. 4 week: CP 19% and lysine 1.30%). Each treatment has 5 replicates with 4 pigs per pen (Figure 1).

Experimental diet

Three different experimental diets were formulated and supplied according to phase feeding programs. Diet 1 contains 23% crude protein and 1.60% lysine, diet 2 contains 21% crude protein and 1.45% lysine and diet 3 contains 19% crude protein and 1.30 lysine, respectively. All other nutrients met or exceeded requirements of NRC (1998). The formula and chemical composition of experimental diet was presented in Table 1.

Housing and blood sampling

All pigs were housed in a plastic woven floored pen, equipped with a feeder and a nipple waterer, and allowed *ad libitum* access to feed and water throughout the whole experimental period. The temperature was maintained at 30°C in the first week and decreased 1°C every week, and 26°C in the last week. Body weight and feed intake were recorded weekly to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed/gain ratio (FCR).

Blood was collected from anterior vena cava of the same pigs weekly during the whole experimental period for blood urea nitrogen (BUN) analysis. After blood sample was collected into vacuum tube contained $EDTA_3$, all samples were quickly centrifuged for 15 min at 3,000 rpm and 5°C. The plasma was carefully removed to plastic vials and stored at -20°C until BUN analyses. Total BUN concentration was analyzed using blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co.).

Digestive trial

Twenty pigs (4 pigs per treatment) in different body weight group averaging 6.0, 9.8, 14.9 and 16.8 kg body

Table 2. Effect of different feeding regimen on growth performance in weaning pigs[a]

Item	1P	2P-I	2P-II	2P-III	3P	SEM[b]
Body weight (kg)						
Initial	6.81	6.82	6.81	6.80	6.81	0.18
Final	19.34	19.51	19.07	19.57	21.06	0.40
ADG (g)						
1-2 weeks	454	462	416	412	472	11.53
3-4 weeks	463	477	467	499	544	11.60
Overall	458	470	442	456	508	9.88
ADFI (g)						
1-2 weeks	617	613	526	576	634	20.72
3-4 weeks	818	875	794	881	970	26.92
Overall	729	754	667	728	802	21.73
FCR						
1-2 weeks	1.36	1.33	1.26	1.40	1.34	0.03
3-4 weeks	1.78	1.82	1.70	1.78	1.78	0.04
Overall	1.59	1.60	1.51	1.60	1.57	0.02

[a] Initial weight was 6.8 kg and final weight was 19.9 kg. [b] Standard error of the mean.

weight. were housed in an individual metabolic crate. Experimental diets were provided twice a day. Each experimental period was 8 d. After 4 days of adaptation period. pigs were subjected to a 4-d collection period. The total amount of feed consumed and excreta produced were recorded daily during the metabolic trial. Collected excreta from each pig were pooled, sealed in plastic bags, and dried in an forced air drying oven at 60°C for 72 h and ground to 1 mm in a Wiley Mill for chemical analysis.

Chemical analysis

Analysis of the experimental diets and excreta was conducted according to the methods of the AOAC (1995). The amino acid contents of the experimental feed and excreta were determined by amino acid analyzer (Biochrom 20. Pharmacia Biotech. England), after acid hydrolysis with 6 N HCl at 110°C for 24 h (Mason. 1984). Chromium concentration was measured using an atomic absorption spectrophotometer (Shimadzu. AA6145F. Japan).

Statistical analysis

Data in this experiment was anaylzed as a randomized complete block (RCB) design using the ANOVA procedure of SAS (1989). and treatment means were compared using Duncan's multiple range test (Duncan. 1955).

RESULTS AND DISCUSSION

Growth performance

Table 2 showed the effect of different feeding regimen on growth performance in weaning pigs. Although there was no significant difference in all criteria. a beneficial effect was observed in 3 phase feeding. The ADG was improved in 3P treatment than other treatments and it was observed clearly in late period (3-4 weeks) than in early period. With increase in age, growth rate of pigs in 3P treatment was also improved approximately 37% compared to 1P treatment (p=0.1379).

According to the equation of lysine requirement in NRC (1998). lysine requirement were decreased markedly from 1.45% to 1.05% by body weight in nursery pigs (BW 5-20 kg). In the present study. the dietary lysine levels of each experimental diet in phase I, II and III were 1.60. 1.45 and 1.30%, respectively. The range of change in dietary lysine levels of 3P treatment was slightly smaller than that in NRC (1998). although lysine level supplied to pigs were higher by 14-24% than lysine requirement of NRC (1998). This result demonstrated that 3 phase feeding may supply various levels of crude protein and lysine which is suitable to change in requirement for nursery pigs weighed 5-20 kg.

Adapting NRC (1998) equation on lysine requirement and digestible energy intake to the present study. lysine:energy ratio for young pigs was expected to be decreased from 3.87 to 3.20 g/Mcal DE due to changing in body weight. In the present study, changing in lysine:energy ratio similar to that adapted NRC (1998) equation was found in 3P treatment. In that treatment, the range of lysine:energy ratio was 4.34-3.59 g lysine/Mcal DE when feed intake was considered. These changes were resulted from decrease in lysine content in diet and increase in feed intake simultaneously. Nam and Aherne (1994) reported that optimum lysine:energy ratio for maximum weight gain of weanling pigs was 3.95 g of lysine/Mcal DE when feed intake was considered.

After weaning, there were dramatic changes in intestinal morphology and digestive enzyme activity in nursery pig for about 4 weeks. According to Cranwell's review (1995). all enzyme activities and the amount of enzyme production were decreased for first 1-2 weeks after weaning and initiated to increase from 2-3 weeks after weaning. Hall and Byrne (1989) reported that villous height of intestine of pigs

Table 3. Effect of different feeding regimens on nutrient digestibility in weaning pigs (%)

Item	1P	2P-I	2P-II	2P-III	3P	SEM[a]
Dry matter	90.76	89.01	89.85	90.72	88.37	0.39
Crude protein	88.11	85.84	86.83	87.98	85.51	0.47
Crude fat	85.60	77.56	79.52	83.10	78.96	1.56
Crude ash	67.04	62.52	65.63	66.73	61.06	1.11
Ca	69.64	67.11	70.07	71.22	67.03	0.89
P	68.18	61.63	65.50	67.34	62.76	1.54
Energy	90.41	88.32	89.30	90.30	87.68	0.44

[a] Standard error of the mean.

Table 4. Effect of different feeding regimens on amino acids digestibility in young pigs (%)

Item	1P	2P-I	2P-II	2P-III	3P	SEM[a]
Threonine	86.89	84.63	85.73	86.61	83.36	0.46
Valine	83.06	80.43	81.39	82.94	78.58	0.72
Methionine	91.37	90.96	90.88	91.72	88.94	0.72
Isoleucine	84.51	84.55	84.70	85.21	82.88	0.62
Leucine	87.66	86.68	87.30	88.04	85.77	0.46
Phenylalanine	88.61	87.64	88.54	89.60	86.11	0.56
Lysine	88.02	84.66	86.01	87.89	84.35	0.67
Histidine	91.90	88.25	89.55	91.64	87.59	0.69
Arginine	92.74	90.71	91.57	92.35	89.94	0.42
EAA[b]	88.31	86.50	87.30	88.44	85.28	0.53
Asparagine	85.45	83.44	85.00	86.27	81.49	0.73
Serine	88.79	87.64	88.31	88.49	86.43	0.46
Glutamine	89.88	88.48	88.95	89.91	87.62	0.44
Proline	90.72	88.79	89.59	90.63	87.22	0.85
Glycine	84.28	80.91	82.25	83.92	80.12	0.74
Alanine	84.32	82.38	82.41	82.79	79.10	1.40
Tyrosine	89.94	90.10	90.62	91.46	87.67	0.59
NEAA[c]	87.63	85.96	86.73	87.64	84.23	0.65
Total AA[d]	87.97	86.23	87.02	88.04	84.76	0.57

[a] Standard error of the mean. [b] Essential amino acids.
[c] Non essential amino acids. [d] Total amino acids.

weaned at 21 days of age was decreased until 28 days and subsequently increased until 42 days of age. Hampson (1986) demonstrated that villous height in weaning pigs was decreased until 26 days of age and started to increase from 29 days of age. Cera et al. (1988a) observed that villous height was decreased until 7 days after weaning and subsequently increased and almost recovered preweaning height at 21 days after weaning. As result from previous studies on morphology of intestine, shortened villi and reduced enzyme activity after weaning started to recover from 2-4 week after weaning. Consequently, increase the increment of corn and soybean meal in weaning pig's diets from 3 weeks after weaning would be logical. In the present study, pigs in 3P treatment were supplied diets containing more corn and soybean meal than other diets supplied to other treatments in the same period. However, growth performance of 3P treatment was not impaired compared to other treatments.

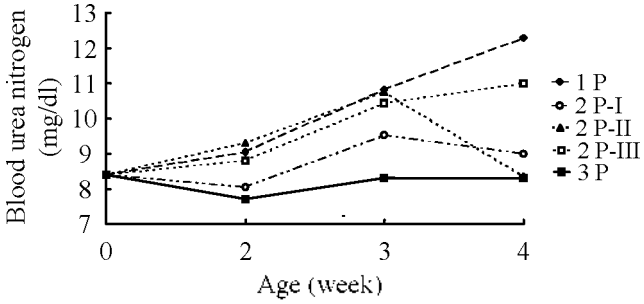

Figure 2. Effects of different feeding regimens on blood urea nitrogen (BUN) concentration in weaning pigs.

Nutrient digestibility

Effects of different feeding regimens on nutrient digestibility and amino acid digestibility were presented in Tables 3 and 4, respectively.

There was no significant difference among all treatments in nutrient digestibility. These results agreed with that of Cera et al. (1988b) and might imply that the changes in feed ingredients used in the present experiment did not affect intestinal morphology but well matched to development of digestive enzyme or villi in intestine.

Crude protein, crude fat and amino acid digestibilities in 1P treatments tended to be higher than 3P treatment ($p<0.10$). Also the digestibilities of nutrient in 2P treatments were increased as feeding regimen changed from 2P-I, 2P-II and 2P-III. This result demonstrated that nutrient digestibility in weaning pig was improved in proportional to the increase in milk products in diets. This trend in the nutrients digestibilities was generally accepted, however, the growth performance showed the adverse trends to nutrients digestibilities. These contrast results could be explained by blood urea nitrogen concentration.

Blood urea nitrogen

Figure 2 showed the effects of different feeding regimens on blood urea nitrogen (BUN) concentration in young pigs. Although there were no significant differences among all treatments, BUN concentrations of pigs fed diet containing 21% crude protein and 1.45% lysine (e.g., 2P-I and 3P) were lower than those fed diet containing high nutrient value at 2 week after weaning. These patterns were lasted during rest of experimental period except for 2P-II. Blood urea nitrogen concentration in 2P-II was decreased dramatically at 4 week. Blood urea nitrogen concentration in 1P treatment increased linearly with increase in age, on the contrast. BUN concentration in 3P treatment was not changed greatly and maintained similar levels.

In general, it is well known that BUN concentration is pretty good indicator for determination of protein and amino acid utilization by pigs (Eggum, 1970). High level of BUN represented that excessive amino acids were metabolized and circulated in the blood during the excretion.

Table 5. Effect of different feeding regimen on feed cost per gain in young pigs[d]

Item	1P	2P-I	2P-II	2P-III	3P	SEM[e]
Total weight gain (kg)	12.84	13.15	12.38	12.76	14.24	0.28
Total feed cost/pig (US$)	19.05	17.47	15.99	18.18	16.92	0.51
Feed cost/kg weight gain (US$)	1.48[a]	1.32[b]	1.29[bc]	1.43[a]	1.18[c]	0.03

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

[d] Feed cost for each diets were 0.93 dollar/kg for diet 1, 0.80 dollar/kg for diet 2 and 0.58 dollar/kg for diet 3, respectively.

[e] Standard error of the mean.

Yen et al. (1986) suggested that BUN concentration of pigs was higher when dietary lysine and protein levels were increased above the pig's requirements. Chiba et al. (1991) demonstrated that BUN concentrations of pigs fed diets containing different levels of protein were increased linearly with an increase in lysine content of the diets. In the present study, BUN concentrations of pigs fed diet containing high protein and lysine during 28-42 days of age after weaning were higher than those fed diet containing low protein and lysine. This result suggested that 23% dietary protein and 1.60% dietary lysine might be excessively high for nursery pigs after about 50 days of age.

As shown in Figure 2, BUN concentration in 3P treatment was the lowest among treatments. This result can explain the reason of adverse trends between nutrient digestibility and growth performance. Although digestibility in 3P was lower, availability of nutrient in body was higher than other treatments. Subsequently, growth performance of weaning pigs in 3P was higher than pigs in other treatments.

Feed cost

Table 5 showed the effect of different feeding regimen on feed cost per gain in young pigs. Total feed cost per pig tended to be higher in 1P and 2P-III than other treatment ($p=0.1951$) and 3P showed the lowest feed cost/kg weight gain among treatments ($p<0.05$).

The milk products are generally more expensive feed ingredients than grains. Assuming that feed intakes are same, the feed containing more milk products is more expensive than that containing less milk products or grain based diet. In the present experiment, overall experimental period milk replacer and lactose were used more in the diet provided to pigs in 1P and 2P-III compared with those in other treatments. Therefore total feed cost per pig and feed cost/kg weight gain were higher in 1P and 2P-III than other treatment, although feed intakes of these treatments are similar to 2P-I and lower than 3P.

Generally, it is known that feed cost is comprised of 50-60% of the total cost of production in swine industry. Although feed intake in 3P was the highest among treatments, 3P showed the lowest feed cost/kg weight gain. When pigs were fed 3P diet, feed cost could be saved approximately 9.3% and 25.4% compared to 2P-II and control, respectively. This resulted from low feed cost as well as high weight gain. Milk replacer and lactose were treatment substituted by corn in diet 3 provided to pigs in 3P during the last week. Consequently adequate phase feeding resulted in economical benefits as well as improved growth performance.

IMPLICATION

Both of two and three phase feeding system did not show any adverse effect on growth performance in weaning pigs compared to one phase feeding. In addition, 3 phase feeding showed a tendency to improve growth performance of weaning pigs. Although nutrient digestibility in 3 phase feeding system was slightly lower than the other treatments amino acid utilization in 3 phase feeding system which was explained with BUN concentration, was higher and maintained constantly during overall experimental period. Moreover, 3 phase feeding is economically beneficial to pig producer due to the reduction of the feed cost. Based on the previous results, the optimal feeding system for weanling pigs of 5 weeks periods of time was 3 phase feeding system.

REFERENCES

AOAC. 1995. Official methods of analysis (15th ed). Association of official analytical chemists. Washington, DC., USA.

Cera, K. R., D. C. Mahan, R. F. Cross, G. A. Reinhart and R. E. Whitmoyer. 1988a. Effect of age, weaning and postweaning diet on small intestinal growth and jejunal morphology in young swine. J. Anim. Sci. 66:574-584.

Cera, K. R., D. C. Mahan and G. A. Reinhart. 1988b. Effects of dietary dried whey and corn oil on weanling pig performance, fat digestibility and nitrogen utilization. J. Anim. Sci. 66:1438-1445.

Chiba, L. I., A. J. Lewis and E. R. Peo, Jr. 1991. Amino acid and energy interrelationships in pigs weighing 20 to 50 kilograms: I. rate and effiency of weight gain. J. Anim. Sci. 69:694-707.

Cranwell, P. D. 1995. Development of the neonatal gut and enzyme systems. In: The Neonatal Pig, Development and Survival (Ed. M. A. Varley). CAB international, Wallingford, Oxon, UK. pp. 99-154.

Duncan, D. B. 1995. Multiple range and multiple F tests. Biometrics. 11:1.

Eggum, B. O. 1970. Blood urea measurement as a technique for assessing protein quality. Br. J. Nutr. 24:983.

Gay, C. C., I. K. Barker and P. Moore. 1976. Changes in piglet intestinal villous structure and intestinal enzyme activity associated with weaning. In: Proceedings of the IVth International Pig Veterinary Society Congress. Vol. 5 (Ed. W. E.

Brandt, R. D. Glock, D. L. Harris, N. E. Hutton and A. D. Lennon). American Association of Swine Practitioners, College of Veterinary Medicine, Iowa State University, Ames, p. 11.

Goodband, R. D., M. D. Tokach and J. L. Nelssen. 1993. Feeding the weaned pig. In: Advances in Pork Production (Ed. G. R. Foxcroft). University of Alberta, Edmonton, Canada. pp. 1-15.

Hall, G. A. and T. F. Byrne. 1989. Effects of age and diet on small intestinal structure and function in gnotoiotic piglets. Research in Veterinary Sci. 47:387-392.

Han, In K., J. H. Lee, X. S. Piano and Defa Li. 2001. Feeding and management system to reduce environmental pollution in swine production, A review. Asian-Aust. J. Anim. Sci. 14:432-444.

Hampson, D. J. 1983. Post-weaning changes in the piglet small intestine in relation to growth-checks and diarrhoea. Ph. D. thesis, University of Bristol, Bristol, USA.

Kelly, D., T. P. King, D. S. Brown and M. McFadyen. 1991a. Polyamide profiles of porcine milk and intestinal tissue of pigs during suckling. Reproduction, Nutrition and Development. 31:73-80.

Kelly, D., J. A. Smyth and K. J. McCracken. 1991b. Digestive development in the early-weaned pig. I. Effect of continuous nutrient supply on the development of the digestive tract and on changes in digestive enzyme activity during the first week post-weaning. Br. J. Nutr. 65:169-180.

Kelly, D., J. A. Smyth and K. J. McCracken. 1991c. Digestive development in the early-weaned pigs. II Effect of level of food intake on digestive enzyme activity during the immediate post-weaning period. Br. J. Nutr. 65:183-191.

Lee, J. H., J. H. Kim, J. D. Kim, S. W. Kim and In K. Han. 2001. Effect of low crude protein diets supplemented with synthetic amino acids on performance, nutrient utilization and carcass characteristics in finishing pigs reared using a phase feeding regimen. Asian-Aust. J. Anim. Sci. 14:655-667.

Mason, V. C. 1984. Metabolism of nitrogen compound in the large gut (Emphasis on recent findings in the sheep and pig). Proc. Nutr. Soc. 43:45.

McCracken, K. J. and D. Kelly. 1993. Development of digestive function and nutrition/diease interactions in the weaned pig. In: Recent Advances in Animal Nutrition in Australia 1993 (D. J. Farrell). Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, Australia. pp. 182-192.

Miller, B. G., P. S. James, M. W. Smith and F. J. Bourne. 1986. Effect of weaning on the capacity of pig intestinal villi to digest and absorb nutrients. J. Agri. Sci. (Camb.) 107:579-589.

Nam, D. S. and F. X. Aherne. 1994. The effects of lysine:energy ratio on the performance of weanling pigs. J. Anim. Sci. 72:1247-1256.

NRC. 1998. Nutrient Requirements of Swine, 10th Ed. National Academy Press, Washington DC., USA.

Pluske, J. R., I. H. Williams and F. X. Aherne. 1995. Nutrition of the neonatal pig. In: The Neonatal Pig, Development and Survival (Ed. M. A. Varley). CAB international, Wallingford, Oxon, UK. pp. 187-238.

Yen, H. T., D. J. A. Cole and D. Lewis. 1986. Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg liveweight to dietary ideal protein. Anim. Prod. 43:141-154.