Effects of Enzyme Complex on Growth Performance and Nutrient Digestibility in Pigs Weaned at 14 Days of Age**

Z. N. Xuan, J. D. Kim[1], J. H. Lee, Y. K. Han*, K. M. Park[2] and In K. Han[3]
Department of Animal Science & Technology, College of Agriculture and Life Sciences
Seoul National University, Suweon 441-744, Korea

ABSTRACT : This study was conducted to investigate the effect of supplemented enzyme complex on growth performance and nutrient digestibility in pigs weaned at 14 days of age. Eighty pigs (4.02±0.11 kg of average body weight) were allotted in a completely randomized block design. Treatments were as follows: 1) control (negative), 2) control (positive, Kemzyme®), 3) 0.1%, 4) 0.2% and 5) 0.3% of newly developed enzyme complex. Each treatment has 4 replicates with 4 pigs per replicate. During phase I period (d 0 to 14), ADG and ADFI were numerically higher in pigs fed diets supplemented enzyme complex regardless of their inclusion levels compared to pigs fed control (negative) diet. Feed/gain (F/G) was also better in pigs fed enzyme complex diet than that of pigs fed control (negative) diet. In addition, with increasing the inclusion level of enzyme complex, ADG and ADFI were improved. However, there was no significant difference between treatment in all growth parameters. During phase II period (d 15 to 28), ADG, ADFI and F/G showed the same tendency as in phase I period. For overall period (d 0 to 28) ADG was highest in pigs fed diet included 0.2% enzyme complex in all treatments but not significantly different. During phase I period, the digestibilities of all nutrients did not showed any significant difference between treatments. However, pigs fed diet contained enzyme complex and positive control diet (Kemzyme) showed numerically higher nutrient digestibilities in all nutrients than pigs fed negative control diet. During phase II period, data were consistent with those observed in phase I period. Especially, the digestibility of phosphorus was significantly higher in pigs fed diets contained enzyme complex including phytase than pigs fed control (negative and positive) diets ($p<0.05$). For overall experimental period, fecal or ileal amino acid digestibility were not affected by dietary treatment. Enzyme complex newly developed and used in this study can be possibly recommended as a growth promoter when supplemented in diet for early weaned piglets. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 2 : 231-236)*

Key Words : Weaned Pigs, Enzyme, Growth, Digestibility

INTRODUCTION

Recently, there have been numerous studies and reviews on the use of enzymes for improvement of growth rate and feed utilization in non-ruminants (Chesson, 1987; Bohme, 1990; Campbell and Bedford, 1992; Inborr et al., 1993; Bedford, 1995). The primary objective of the use of enzymes as pig feed additives is the potential degradation of 'fiber' prior to the ileum increasing the availability of nutrients within the small intestine. This approach may improve the utilization of currently used feedstuffs and the complex non-starch polysaccharides (NSPs). Therefore, enzyme additives must contain a mixture of enzymes with different specifications. In addition, a review by Dierick (1989) concluded that effects of added enzymes were more apparent in young than in old animals.

There is a considerable potential for improving growth rate and feed utilization in pigs by exogenous enzymes which may be summarized as follows : 1) the significant difference between the gross energy and the metabolisable or net energy content of several feedstuffs is partly due to the high level of NSP. It is probable that this difference can be reduced by adding NSP-degrading enzymes; 2) the presence of specific target feed components: a) non-starch gel-forming polysaccharides including β-glucans, pentosans, b) specific anti-nutritional factors (ANFs) in raw materials; 3) augmentation of the digestive capacity of the host in specific categories of animals. For example, endogenous hydrolytic enzymes may be supplied to young pigs before and immediately after weaning, on the assumption that enzyme supply limits hydrolysis and that added enzymes survive both the acid conditions and proteolysis in the digestive tract (Dierick and Decuypere, 1994).

* Corresponding Author: Y. K. Han. Feed Research Institute, National Livestock Cooperative Federation, Korea. Tel: +82-31-399-0781, Fax: +82-31-399-2653, E-mail: moakin@chollian.net.
[1] 212 Animal Science Laboratory, 1207 West Gregory Drive, Urbana, IL 61801, USA.
[2] Department of Food and Life Science, College of Life Science and Natural Resources, Sungkyunkwan University, Korea.
[3] Address reprint requests to In K. Han. Tel: +82-2-502-0757, Fax: +82-2-502-0758, E-mail: inkhan@kornet.net.
** This study was partially funded by the MAF-SGRP (Ministry of Agriculture and Forestry-Special Grants Research Program) in Korea.
Received July 25, 2000; Accepted October 25, 2000

In the near future, as consumer demands for substitutes to antibiotics as growth promoters will increase, the replacement by more environmentally-friendly substances such as natural enzymes, will probably accepted. Addition to or pre-treatment of the feed with enzymes will not only lead to an improved nutritional value of the feed but may have a major beneficial impact on the environment in terms of composition and quantity of excreta. On the level of phosphoprus and nitrogen applied to soils, will encourage the use of enzymes in pig nutrition. Therefore, the present study was conducted to evaluate the effects of enzyme complex newly developed and to determine the optimal inclusion level for weaned pig diet.

Table 1. Formula and chemical composition of the experimental diets

Ingredients & chemical composition	Phase I (d 0~14)		Phase II (d 15~28)	
	Control (positive, negative)	Enzyme treatment	Control (positive, negative)	Enzyme treatment
Ingredients (%):				
Corn	20.06	20.30	25.43	25.70
Soybean meal	20.20	20.20	23.00	23.00
Wheat	6.00	6.00	10.00	10.00
Fish meal	1.50	1.50	1.50	1.50
Milk replacer	25.00	25.00	20.00	20.00
Lactose	10.00	10.00	7.00	7.00
SDPP[3]	9.00	9.00	5.00	5.00
Soy oil	5.00	5.00	4.30	4.30
MCP[4]	0.85	0.05	1.06	0.25
Limestone	1.02	1.38	1.05	1.40
L-Lys · HCl	0.19	0.19	0.27	0.27
Methionine	0.17	0.17	0.12	0.12
Threonine	0.07	0.07	0.17	0.16
Vitamin-mixture[2]	0.20	0.20	0.20	0.20
Mineral-mixture[1]	0.20	0.20	0.20	0.20
Antibiotics	0.20	0.20	0.20	0.20
Salt	0.14	0.14	0.20	0.20
Cr_2O_3	0.20	0.20	0.20	0.20
Total	100.00	100.00	100.00	100.00
Chemical composition:				
ME (Mcal/kg)	3.40	3.40	3.35	3.35
Crude protein (%)	22.68	22.68	21.18	21.18
Lysine (%)	1.70	1.70	1.55	1.55
Methionine (%)	0.45	0.45	0.41	0.41
Threonine (%)	1.11	1.11	1.01	1.01
Calcium (%)	0.90	0.90	0.90	0.90
Total phosphorus (%)	0.80	0.60	0.80	0.60

[1] Supplied per kg mixture : Mn, 12,000 mg; Zn, 15,000 mg; Co, 100 mg; Cu, 500 mg; Fe 4,000 mg; BHT, 5,000 mg.
[2] Supplied per kg mixture : vitamin A, 4,000,000 IU; vitamin D_3, 800,000 IU; vitamin E, 16,000 IU; vitamin K_3, 1,200 mg; vitamin B_2, 1,600 mg; calcium pantothenate, 4,000 mg; niacin, 8,000 mg; vitamin B_{12}, 6 mg; biotin, 32 mg; ethoxyquin, 6,000 mg.
[3] SDPP : Spray Dried Plasma Protein.
[4] MCP : Mono-Calcium Phosphate.

MATERIALS AND METHODS

This experiment was conducted with eighty crossbred pigs (Landrace × Large White × Duroc) at the Swine Research Farm, Seoul National University. Pigs, with 4.02±0.11 kg of averaged body weight and weaned at 14 days of age, were allotted in a completely randomized block design. Treatments were as follows: 1) control (negative), 2) control (positive, Kemzyme®), 3) 0.1%, 4) 0.2% and 5) 0.3% of newly developed enzyme complex. Each treatment included 4 replicates with 4 pigs per replicate.

Formulas and chemical composition of experimental diets are presented in table 1 and the formula of two enzyme products used in this study are specified in table 2. Basal diet for phase I (d 0 to 14) was formulated to contained 3.4 Mcal ME/kg diet, 22.68% crude protein and 1.7% lysine, and basal diet for phase II (d 15 to 28) contained 3.35 Mcal ME/kg diet, 21.18% crude protein and 1.55% lysine. Other nutrients were met or exceeded the requirement of NRC (1998). Feed and water were provided *ad libitum*, and the environmental temperature was maintained at the range of 30℃ (at the beginning of experiment) to 26℃ (at the termination of experiment). Body weight and feed intake were recorded weekly to calculate the ADG (average daily gain), ADFI (average daily feed intake) and F/G (feed/gain).

Experimental diets contained 0.2% Cr_2O_3 to determine the digestibilities of experimental diets, and

Table 2. Specification of Kemzyme® and enzyme complex (kg of mixture)

Kemzyme® (positive control)		Enzyme complex	
α-amylase	2,000,000 IU	α-amylase	1,350,000 IU
β-amylase	2,000,000 IU	Xalanase	10,000 IU
Xalanase	1,300,000 IU	β-glucanase	100 IU
β-glucanase	33,000 IU	Protease	360,000 IU
Protease	2,000,000 IU	Lipase	500 IU
Cellulase	3,750,000 IU	Phytase	80,000 FTU[1]
Pectinase	27,500 IU		

[1] FTU: The quantity of enzyme which liberate 1 micromole of inorganic phosphorus per minute from 0.0015 mol/l sodium phytase at pH 5.5 and 37℃.

feces were collected three times a day for three days after a four-days adjustment period. All pigs, used for a metabolic trial, were accustomed to the experimental diet during one week, before they were moved into metabolic crates. Fecal samples were dried in an air-forced drying oven at 60℃ for 72 hours and ground with a 1 mm mesh Wiley Mill.

Twenty pigs cannulated at the terminal ileum by surgical operation were penned in individual metabolic cages to determine apparent ileal digestibility of nutrients. The cannula and surgical procedures used in this study were conducted according to the methods suggested by Walker et al. (1986).

Feed and fecal samples were analyzed to determine proximate nutrient digestibilities according to AOAC (1995) methods. Chromium content in diets and feces were measured using an Atomic Absorption Spectrophotometer (Shimadzu, AA6145F, Japan). Phosphorus content was measured by using the UV-visible spectrophotometer (Hitachi, U-100, Japan) and bomb calorimeter (Parr Instrument Co., Model 1241, USA) was used to measure the content of gross energy in diet and feces. Amino acid composition was measured by using an automatic amino acid analyzer (Pharmacia Biotech, Biochrom 20, England) after 24 hours of acid hydrolysis in 6 N HCl.

Data were analyzed as a randomized complete block design by using the GLM procedure of SAS (1989), and treatment means were compared by using Duncan's multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Growth performance

The effect of newly developed enzyme complex on growth performance in weaned pigs is presented in table 3. During phase I period (d 0 to 14), treatment with enzyme complex resulted in a 24.7% increase ranging 12 to 30% in the ADG compared with control(negative), and ADFI were numerically higher in pigs fed diets supplemented enzyme complex regardless of their inclusion levels compared to pigs fed control (negative) diet. F/G was also improved with 5.3% in pigs fed enzyme complex diet than pigs fed control (negative) diet. In addition, ADG and ADFI were improved with increasing the inclusion level of enzyme complex. However, there was no significant difference among treatments in all growth parameters. During phase II period (d 15 to 28), treatment with enzyme complex resulted in a 1.7% increase in the ADG compared with control (negative), and ADFI and F/G showed same tendency with those of phase I period. For overall period (d 0 to 28) ADG was highest in pigs fed diet included 0.2% enzyme complex in all treatments but not significantly different. Especially, pigs fed positive control diet and those fed diet supplemented 0.2% enzyme complex showed similar growth rate for overall experimental period.

There has been numerous studies on the effect of enzyme addition and many recent developments on the use of enzyme mixtures as additives to animal feeds. However, researches on the effects of multi or complex enzymes are comparatively less than that of single enzymes. Burnet (1966) reported that the addition of α-amylase to a barley diet for young pigs improved growth rate and FCR by about 4%. But, in growing and finishing pigs amylase supplementation to cereals did not affect performance of pigs. Pentosanase supplementation to rye-based pig diets improved weight gain by 7% and FCR by 8% (Thacker et al., 1991). Skoufos and Ftenakis (1992), with a pentosanase supplemented wheat diet for starter pigs, reported an improvement in weight gain and FCR of 8.8% and 7.4% respectively compared with the control diet. Bedford et al. (1992) observed a significant improvement in rate of growth when the diet was supplemented with β-glucanase. But, in a study, Bedford et al. (1992) reported that only in weanling pigs, there significant improvements in weight gain and nutrient digestibiltiy by β-glucanase supplementation. In this study, the supplementation of enzyme complex increased ADG by 3.3% (0.1% supplementation), 9.9% (0.2% supplementation) and 8.9% (0.3% supplementation) for overall period (d 0 to 28), respectively. The result of study conducted by Bedford et al. (1991) are in agreement with those of the present study. Also, Dierick (1991) concluded that

Table 3. Effect of enzyme complex on growth performance of weaned pigs

Treatment	Control		Enzyme complex (%)			SE[2]
	(+)[1]	(-)	0.1	0.2	0.3	
Phase I (d 0~14):						
ADG (g)	215	168	188	217	218	9.2
ADFI (g)	303	240	271	308	312	9.8
F/G	1.4	1.5	1.5	1.4	1.4	0.0
Phase II (d 15~28):						
ADG (g)	453	440	441	451	444	10.6
ADFI (g)	638	653	647	651	632	16.6
F/G	1.4	1.5	1.5	1.4	1.4	0.0
Overall (d 0~28):						
ADG (g)	334	304	314	334	331	7.9
ADFI (g)	468	447	459	479	472	11.4
F/G	1.4	1.5	1.5	1.4	1.4	0.0

[1] Kemzyme®, 0.1%. [2] Pooled standard error.

the effects of added enzymes were greater in poultry than in pigs and more apparent in young than in old animals. It means that the animal and age affected the effect of supplemented enzymes. Therefore, animal and age should be considered carefully, when supplementing single enzyme or enzyme complex to animal diet.

Nutrient digestibility

Table 4 shows the effect of enzyme complex on nutrient digestibility in weaned pigs. During phase I period, the fecal digestibilities of all nutrients did not showed any significant difference among treatments. However, pigs fed diet contained enzyme complex and positive control diet showed numerically higher digestibilities in all nutrients than pigs fed negative control diet. The nutrient digestibilities of experimental diet during phase II period showed similar tendency with those observed in phase I period. Especially, the digestibility of phosphorus was significantly higher in pigs fed diets which contained enzyme complex compared to pigs fed control (negative and positive) diets ($p<0.05$). Significantly higher phosphorus digestibility in pigs fed enzyme complex was attributed to the inclusion of phytase (80,000 FTU) in enzyme complex as shown in table 2. Microbial phytase has been the most successful example of exogenous enzymes used in pigs diets (Johnson et al., 1993). And numerous studies (Alain, 1986; Jongbloed et al., 1990; Simons and Versteegh, 1990; Kwon et al., 1995; Cromwell et al., 1993; Mroz, 1994) have confirmed the biological efficacy of microbial phytase in improving the pig's utilization of phosphorus from phytate. In most recent study of Kwon et al. (1985), supplementation of 500~1,000 FTU phytase improves growth performance, phosphorus utilization and reduce phosphorus excretion in pigs. Therefore, nowadays, phytase is commonly used in pig diet.

Until recently, several studies have investigated the effects of enzyme supplementations on nutrient digestibility in pigs. Dierick and Decuypere (1996) reported improvements in both *in vitro* and *in vivo* digestibilities. With wheat-by-product diets, ileal digestibilities of protein, fat, NSPs, dietary fibre, amino acids and phosphorus increased. In this study, the digestibilities of diet increased when enzyme complex supplemented. And, additionally, with increasing the inclusion level, the digestibilities of dry matter, crude protein, crude fat, crude ash, calcium and phosphorus were also improved. Noh et al. (1995a, b) reported that the addition of commercially used enzyme product (Kemzyme®) showed improved ADG (8.0%) and F/G (13%) compared with control treatment. In this study, when comparing between positive (Kemzyme®) and negative (without enzyme) control, pigs fed positive control diet showed improved growth rate and feed utilization than pigs fed negative control diet.

The effect of enzyme complex on fecal essential amino acid digestibility in early weaned pigs was summarized in table 5. During phase I and II periods, supplementation of enzyme complex to diets did not affect fecal essential amino acid digestibility regardless of supplementation levels. Table 6 shows effect of enzyme complex on apparent ileal digestibility of essential amino acids in early weaned pigs. Only during phase I period, digestibility of some essential amino acids (Methionine, Leucine and Phenylalanine) was increased by dietary treatments. But, overall, apparent ileal digestibility of essential amino acids were not affected by the level of dietary enzyme complex.

The use of drugs like antibiotics and growth promoters in pig industry is thought to have an adverse impact on human health and the environment. Substitutions for these chemically synthesized drugs must be harmless, environmental friendly and 'natural'. Enzymes may be able to meet these requirements. Enzyme complex newly developed and used in this study seemed to be potential growth promoter when included in diet for early weaned piglets. However, more research are needed to evaluate the efficacy of this enzyme complex compared to other multi enzyme

Table 4. Effect of enzyme complex on nutrient digestibilities of weaned pigs (%)

Treatment	Control		Enzyme complex (%)			SE[2]
	(+)[1]	(-)	0.1	0.2	0.3	
Phase I (d 0~14):						
Gross energy	80.0	78.9	79.9	79.9	79.9	0.16
Dry matter	79.3	78.2	78.1	79.4	79.7	0.17
Crude ash	30.5	27.0	25.1	31.9	34.8	1.47
Crude protein	78.4	76.2	78.5	77.4	79.0	0.52
Crude fat	69.1	64.6	65.5	65.6	66.5	0.81
Calcium	65.2	64.6	64.0	64.3	65.5	1.30
Phosphorus	44.0	43.1	44.2	44.2	47.9	0.98
Phase II (d 15~28):						
Gross energy	79.2	79.0	79.0	79.1	79.6	0.22
Dry matter	77.8	77.9	77.9	78.0	80.0	0.32
Crude ash	32.5	28.4	37.7	37.4	37.8	1.83
Crude protein	77.7	75.3	76.2	76.3	77.4	0.37
Crude fat	73.1[a]	66.0[b]	67.6[ab]	68.2[ab]	68.9[ab]	0.93
Calcium	64.9	61.8	61.3	66.2	68.0	1.48
Phosphorus	51.1[bc]	45.5[c]	58.4[ab]	62.8[a]	62.4[a]	1.87

[1] Kenzyme®, 0.1%. [2] Pooled standard error.

[a,b] Means with different superscripts on the same now are significantly different ($p<0.05$)

Table 5. Effect of enzyme complex on apparent fecal digestibilities of essential amino acids in weaned pigs (%)

Treatment	Control		Enzymes complex (%)			SE[2]
	(+)[1]	(-)	0.1	0.2	0.3	
Phase I:						
THR	77.0	76.4	76.8	77.4	77.7	0.89
VAL	79.4	78.4	79.3	81.0	81.1	1.23
MET	78.0	77.8	77.8	78.1	78.1	0.64
ILE	78.1	78.0	78.1	78.2	78.2	0.69
LEU	80.3	79.8	78.2	78.3	78.8	1.17
PHE	81.2	80.0	80.3	80.4	80.1	1.23
HIS	86.3	87.3	86.4	86.7	85.5	0.84
LYS	88.9	87.1	88.3	89.4	90.0	1.28
ARG	92.1	90.0	90.2	91.0	91.4	0.77
Submean	82.4	81.7	81.7	82.3	82.3	0.68
Phase II:						
THR	80.1	79.9	80.0	80.4	80.1	0.72
VAL	81.0	79.2	79.3	80.2	80.4	1.14
MET	80.3	78.9	79.9	80.6	80.7	0.68
ILE	80.3	78.7	79.0	79.4	80.6	0.79
LEU	81.6	80.3	80.4	81.2	81.0	1.04
PHE	81.5	80.2	80.7	80.9	81.4	1.24
HIS	86.3	85.3	84.5	85.0	85.3	0.82
LYS	90.0	88.4	88.7	89.8	89.7	1.09
ARG	92.0	90.1	90.4	91.4	91.5	0.73
Submean	83.7	82.3	82.5	83.2	83.4	0.64

[1] Kenzyme®, 0.1%. [2] Pooled standard error.

Table 6. Effect of enzyme complex on apparent ileal digestibilities of essential amino acids in weaned pigs (%)

Treatment	Control		Enzymes complex (%)			SE[2]
	(+)[1]	(-)	0.1	0.2	0.3	
Phase I:						
THR	82.0	80.0	81.0	81.4	82.4	0.52
VAL	82.7	80.3	81.1	81.9	81.4	1.41
MET	83.3[a]	80.5[b]	82.9[ab]	83.0[ab]	83.5[a]	0.53
ILE	82.2	81.1	81.3	81.9	82.1	0.96
LEU	86.8[a]	81.0[b]	83.5[ab]	84.6[ab]	84.6[ab]	0.97
PHE	83.7[a]	79.1[b]	82.5[ab]	82.9[ab]	82.9[ab]	0.98
HIS	81.3	82.5	80.5	80.4	80.4	0.76
LYS	91.1	89.4	90.1	90.0	91.1	1.65
ARG	92.1	90.6	91.7	92.1	91.2	0.69
Submean	85.0	82.7	83.8	84.3	84.4	0.89
Phase II:						
THR	81.1	78.4	80.3	80.2	81.8	0.72
VAL	81.6	79.4	79.2	80.6	80.9	1.14
MET	80.4	79.8	80.0	81.4	81.1	0.68
ILE	80.3	78.7	79.0	79.4	80.1	0.79
LEU	83.0	81.5	82.4	83.3	83.0	1.04
PHE	84.4	80.2	83.0	82.9	83.0	1.24
HIS	81.1	80.2	81.4	81.1	81.3	0.77
LYS	90.3	89.0	90.7	90.1	91.7	1.32
ARG	93.3	91.1	92.0	93.4	93.2	0.69
Submean	83.9	82.0	83.1	83.6	84.0	0.56

[1] Kenzyme®, 0.1%. [2] Pooled standard error.

products already broadly used in a commercial situation and to determine the optimal inclusion level in weaned pigs.

REFERENCES

Alain, L. R. 1986. Safety and efficacy of sustained-release recombinant derived bovine somatotropin administered to lactating dairy cows. Graduate Thesis, Minnesota Univ.

AOAC. 1995. Official Methods of Analysis (16th Ed.). Association of Official Analytical Chemist. Washington, DC., USA.

Bedford, M. R. 1995. Mechanism of action and potential environmental benefits from the use of feed enzymes. Anim. Feed Sci. Technol. 53:145-155.

Bedford, M. R., J. F. Patience, H. L. Classen and J. Inborr. 1992. The effect of dietary supplementation of rye-and barley-based diets on digestion and subsequent performance in weaning pigs. Can. J. Anim. Sci. 72:97-105.

Bohme, H. 1990. Experiments on the effect of enzyme supplements as growth promoter for piglets. Landbauforschung Volkenrode. 40(3):213-217.

Campbell, G. A. and M. R. Bedford. 1992. Enzyme application for monogastric feeds : a review. Can. J. Anim. Sci. 72:449-466.

Chesson, A. 1987. Supplementary enzymes to improve the utilization of pig and poultry diets. In: Recent Advances in Animal Nutrition (Ed. W. Haresign and D. J. A. Cole). Butterworths, London, UK. pp. 71-89.

Cromwell, G. L., T. S. Stahly, R. D. Coffey, H. J. Monegue and J. H. Randolpoh. 1993. Efficacy of phytase in improving the bioavailability of phosphorus in soybean meal and corn-soybean meal diets for pigs. J. Anim. Sci. 71:1831-1840

Dierick, N. A. and J. A. Decuypere. 1994. Enzymes and growth in pigs. In: Principles of Pig Science (Ed. D. J. A. Cole, J. Wiseman and M. A. Varley). Nottingham University Press, UK. pp. 169-195.

Dierick. N. and J. Decuypere. 1996. Mode of action of exogenous enzymes in growing pig nutrition. Pig News and Information. 17(2):41-48.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics. 11:1.

Inborr, J., M. Schmitz and F. Aherne. 1993. Effect of adding fiber and starch degrading enzymes to a barley/wheat based diet on performance and nutrient digestibility in different segments of the shall intestine of early weaned pigs. Anim. Feed Sci. Technol. 44:113-127.

Johnson, R., P. Williams and R. Campbell. 1993. Use of enzymes in pig production. In: Enzymes in Animal Nutrition (Ed. C. Wenk and M. Boessinger). Kartause Ittingen, Thurgau, Switzerland. pp. 49-60.

Jongbloed, A. W., P. A. Kemme and B. Dellaret. 1990. Microbial phytase in de voeding van varkens. In: Verslag van de themadag veevoeding and milie, Lelystat, 19 April. pp. 51-57.

Kwon, K., In K. Han, K. S. Sohn, C. H. Kwon and J. H. Kwack. 1995. Effects of microbial phytase on performance, nutrient digestibility and phosphorus excretion in weaning-growing pigs fed corn-weat-soy diets. Kor. J. Anim. Sci. 37:353-362.

Lei, X. G., P. K. Ku, E. R. Miller, D. E. Ullrey and M. T. Yokoyama. 1993. Supplemental microbial phytase improves bioavailability of dietary zinc to weaning pigs. J. Nutr. 123:1117-1123.

Mroz, Z. 1994. Apparent digestibility and retention of nutrients bound to phytate complexes as influenced by microbial phytase and feeding regimen in pigs. J. Anim. Sci. 72:126-132.

Noh, S. H., C. H. Lee, Y. J. Choi and I. K. Han. 1994a. Effect of antibiotics, enzyme, yeast, probiotics and β-agonist on the growth performance and nutrient availability in broilers. Kor. J. Anim. Sci. 36:630-637.

Noh, S. H., I. K. Han, T. H. Won and Y. J. Choi. 1994b. Effect of antibiotics, enzyme, yeast culture and probiotics on the growth performance of Israeli carp. Kor. J. Anim. Sci. 35:480-486.

NRC. 1998. Nutrient requirements of swine (10th Ed.). National Academy Press, Washington DC., USA.

SAS. 1989. SAS/STAT® User's guide (Version 6, 4th Ed.). SAS Inst. Inc., Cary, NC, USA.

Simons, P. C. M. and H. A. J. Versteegh. 1990. Phytase in feed reduces phosphorus excretion. Poultry-Misset June/July:15-17.

Thacker, P. A., G. L. Campbell and J. W. D. Groot-Wassink. 1991. The effect of enzyme supplementation on the nutritive value of rye-based diets for swine. Can. J. Anim. Sci. 71:489-496.

Walker, W. R., G. L. Morgan and C. V. Maxwell. 1986. Ileal cannulation in pigs with a simple T-cannula. J. Anim. Sci. 62:407.