Effects of Different Levels of Vitamin-Mineral Premixes on Growth Performance, Nutrient Digestibility, Carcass Characteristics and Meat Quality of Growing-Finishing Pigs**

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ABSTRACT : Two experiments using growing and finishing pigs (Landrace×Duroc×Yorkshire) were conducted to determine the effects of different levels of vitamins and trace minerals (VTM) on growth performance, nutrient digestibility, carcass characteristics and meat quality of growing-finishing pigs, and to evaluate the suitability of vitamin-mineral levels commonly used in the swine industry in Korea. A total of 120 three crossbred (Landrace×Duroc×Yorkshire) growing (Experiment I: 20.90±0.44 kg average initial body weight) and finishing (Experiment II: 53.55±0.97 kg average initial body weight) were used in 6 and 9 weeks feeding trials, respectively. Pigs were allotted on the basis of sex and weight to 5 treatments with 6 replications per treatment with 4 pigs per pen in a completely randomized block design. Treatments were: 1) control, 2) fat soluble vitamin 200% vs. control, 3) water soluble vitamin 200% vs. control, 4) trace mineral 50% vs. control, 5) trace mineral 200% vs. control. In experiment I, during the overall experimental period (0 to 6 weeks, 21 to 54 kg body weight), ADG of the 200% trace mineral supplemented group was significantly higher than that of the 50% trace mineral supplemented group. There were no significant differences among other the treatments. Digestibility of crude protein was lowest in mineral 50% supplemented group ($p<0.05$). Calcium digestibility was significantly higher in the 200% fat soluble vitamin supplemented group than in the other treatments ($p<0.05$). In experiment II, during the overall experimental period (0 to 9 weeks, 54 to 106 kg body weight), growth performance was not significantly affected by dietary vitamin and trace mineral levels. However, increasing level of water soluble vitamins at the level of 200% compared to control had a tendency to improve the overall growth performance. Overall carcass characteristics except for carcass length did not differ among pigs fed the dietary treatments. Loin eye area, pH, drip loss and shear force of meat were not affected by dietary vitamin and trace mineral levels. There was a trend for less fat content (%) in pork when the level of vitamin and trace mineral was increased, but the difference was not significant. Flavor score was the lowest in control and highest in the 200% fat soluble vitamin supplemented group ($p<0.05$). Juiciness of muscle was lower in the 200% fat soluble vitamin supplemented group than other dietary treatments, except for trace mineral 50% supplemented group ($p<0.05$). Based on these results, it is suggested that "typical" commercial levels of vitamin and trace minerals used by feed companies in Korea are sufficient to meet requirement for the maximum growth of growing-finishing pigs. Our results suggests that a reduction in trace mineral levels in commercial diets could be considered to reduce feed cost and nutrient excretion with economic and environmental benefits. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 4 : 515-524)*

Key Words : Pigs, Vitamin, Trace Mineral, Growth, Nutrient Digestibility, Carcass Characteristic, Meat Quality

INTRODUCTION

Vitamins and trace minerals are essential for the support of normal maintenance and performance. The requirements for vitamins and minerals can vary widely due to environmental conditions such as temperature (Lucas and Calder, 1957), humidity (Coehlo, 1991), management and severity of stresses on pigs (Cunha, 1982) and the physiological status of pigs (Mahan and Kim, 1999). Therefore, it is not easy to establish the optimum requirements of vitamins and trace minerals related to their requirements along with the production stages of pigs. The National Research Council (NRC, 1998) has been established vitamin and trace mineral requirements for pigs based on experimental conditions in which stressors on the pigs were minimized. Therefore, in practical conditions vitamin and trace mineral requirements may be underestimated. Consequently, the levels of vitamins and trace minerals recommended by breeding or feed companies, suppliers or universities are substantially higher than those suggested by the NRC (1988). There have been several studies to investigate the effect of vitamin and trace mineral supply on the growth performance of pigs. Cline and Mahan (1972) reported

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that deficiencies of vitamins and minerals caused low growth rate when they compared various vitamin and mineral levels in diets for growing-finishing pigs. Some studies have suggested that NRC (1988) levels of one or more of the commonly supplemented B-vitamins (riboflavin, niacin, pantothenic acid and vitamin B_{12}) are inadequate for maximal performance of newly weaned pigs (Wilson et al., 1991a, b, 1993) or high-lean growing pigs (Stahly et al., 1995). Wilson et al. (1992a, b) reported that the addition of B-vitamin groups at levels of ten times the estimated requirements have a tendency to improve the growth rate or feed efficiency of pigs.

In addition to the growth performance, main concerns have been focused on the effect of vitamins (i.e., vitamin E) and trace minerals (i.e., selenium and chromium) on pork quality. It is reported that additional vitamin and trace mineral supplements over the requirements suggested by NRC (1988 and 1998) improve pork quality (Edmond and Arentson, 1999). Some studies also reported that the addition of vitamin E and selenium at the high levels could reduce the drip loss and lipid oxidation in pork and improve the meat color and quality (Asphar et al., 1991; Monohan et al., 1994; Buckley et al., 1995; Munoz et al., 1996; Mahan and Kim, 1999). However, these data are not in agreement with some researchers, who observed no negative effect on growth performance and carcass quality of pigs when vitamin and (or) trace mineral premixes were omitted from wheat-barley-canola meal based diets (Patience and Gillis, 1995, 1996) and corn-soybean meal based diets (Mavromichalis et al., 1999) during the late finishing period.

There is still insufficient information available on optimal vitamin and trace mineral levels in diets for pigs, and the levels recommended by feed companies and universities are also variable. Recently, Chae et al. (2000a) reported that increasing vitamins and trace minerals at 150 to 200% of NRC (1998) improved the daily gain and feed efficiency. However, they could not suggest the optimal inclusion levels of each vitamin or trace mineral for modern genotype growing pigs.

Therefore, two experiments were conducted to determine the effects of different vitamin and trace mineral (VTM) levels in diets on growth performances, nutrient digestibilities, carcass characteristics and meat quality of growing-finishing pigs, and to evaluate the suitability of vitamin-mineral level commonly used in swine industry in Korea.

MATERIALS AND METHODS

Experiment I

A total of 120 three crossbred (Landrace × Duroc × Yorkshire) growing (20.90 ± 0.44 kg average initial body weight) were used in a 6 weeks feeding trial in Seoul National University experimental farm. During the spring experimental pigs were housed and adjusted to a commercial diet for 3 days before the beginning of experiment and allotted on the basis of sex and weight to 5 treatments with 6 replications per treatment with 4 pigs per pen in a completely randomized block design. Treatments were 1) control, 2) fat soluble vitamin 200% vs. control, 3) water soluble vitamin 200% vs. control 4) trace mineral 50% vs. control 5) trace mineral 200% vs. control. For the control group, vitamin-trace mineral premixes were formulated to contain "typical" commercial levels of vitamin-trace mineral for grower diets in Korea. This level was chosen to evaluate the suitability of the vitamin-mineral level commonly used in the swine industry in Korea and, as shown in table 3, levels of vitamins and trace minerals in the control diet are much higher than the NRC (1998) recommendation. For the experiment, a corn-wheat-soybean meal-based diet (3,360 ME kcal/kg, 18.0% crude protein (CP) and 1.03% lysine) was fed in meal form as the control with all other nutrients except for vitamins and trace minerals meeting or exceeding NRC (1998) nutrient recommendations (table 1). Vitamin and trace mineral premixes were formulated to contain 5 different levels corresponding to treatments intended. Pigs were housed

Table 1. Formula and chemical composition of the basal experimental diets for growing pigs

	%
Ingredients:	
Corn	52.62
Soybean meal	26.03
Wheat	15.00
Canola meal	1.00
Animal fat	2.76
Limestone	1.20
Tricalcium phosphate	0.51
L-lysine-HCl	0.15
DL-methionine	0.03
Vitamin-mineral mixture	0.20
Antibiotics	0.20
NaCl	0.30
Total	100.00
Chemical composition[1]:	
ME (kcal/kg)	3,360
Crude protein	18.01
Calcium	0.70
Phosphorus	0.60
Lysine	1.03
Methionine+cystine	0.62
Threonine	0.66

[1] Calculated value.

in concrete-slatted slurry pens (1.5×2.5 m^2) and were allowed *ad libitum* access to water and diets during entire experimental periods. Body weight and the amount of feed consumed were recorded every two weeks for the entire experimental period and the average daily gain (ADG) was calculated by the difference between the initial and final body weight. Feed conversion ratio (F/G) was calculated by dividing the amount of feed consumption with the corresponding body weight gain.

For the determination of fecal nutrient digestibility, pigs were fed diets containing 0.25% Cr_2O_3 as an indigestible marker. in the 3rd week of the experiment for growing pigs, fecal samples were collected by rectal stimulation of each pig (six pigs per treatment) twice daily for four consecutive days, placed in plastic bags, and frozen at -25℃ until they were dried in an air forced drying oven at 60℃ for 72 hours. Dried fecal samples were ground with 1 mm Wiley Mill for chemical analyses.

Chemical analyses of proximate nutrients in diets and feces were according to the method of AOAC (1990) and chromium was measured by atomic absorption spectrophotometer (Shimadzu, AA625). Gross energy content of feed and feces were measured using an adiabatic bomb calorimeter (Parr Instrument, Moline, IL).

Experiment II

A total of 120 three crossbred (Landrace×Duroc×Yorkshire) finishing pigs (53.55±0.97 kg average initial body weight) were used in a 9 weeks feeding trial conducted in the autumn months. Experimental design was the same as in experiment I. Finisher diets supplied 3,350 ME kcal/kg, 16.0% crude protein (CP), 0.91% lysine for early finisher (0~4 weeks), and 3,350 ME kcal/kg, 14.0% CP, 0.80% lysine for late finisher (5~9 weeks). Formulas and chemical composition of experimental diets are shown in table 2 and the calculated values of vitamin and trace minerals in experimental diets are presented in table 4. Pigs were housed in concrete-slatted slurry pens (1.8×2.5 m^2) and were allowed *ad libitum* access to water and diets during the entire experiment. Body weights and the amounts of feed consumed were recorded in the 4th (early finisher) and 9th (late finisher) weeks of the finishing period. Management of experimental pigs was the same as experiment I.

For analysis of carcass characteristics of finishing pigs, all experimental pigs were slaughtered a commercial slaughter house. Hot carcass weight was recorded to allow calculation of dressing percentage. Of all experimental pigs, 30 pigs with the same body weight (6 pigs per treatment) were used for meat quality analysis. After overnight chilling (2℃), the right loin was collected and transported from the slaughter plant to our meats laboratory. The longissmus (at 10th rib) was traced and scored for color, firmness and marbling according to procedures suggested by the National Pork Producer Council (NPPC, 1991). Water holding capacity of the fresh meat was evaluated using the expressible moisture test (filter paper press method) described by Grau and Hamm (1956). Meat quality was determined using a second loin chop (approximately 5.0 cm thick) from 10th rib location. Water loss was determined after letting the chop thaw on an aluminium tray, under butcher paper, for 24 h at 2℃ (AMSA, 1995). To calculate cooking loss, the chops were grilled to an internal temperature of 71℃, placed in an aluminium tray, and left to reach room temperature before weighing (AMSA, 1995).

Statistical analysis was carried out by comparing means according to Duncan's multiple range test (Duncan, 1955), using General Linear Model (GLM) procedure of SAS (1985). Data were analyzed as a randomized complete block design. Pigs were blocked by initial weight with pen as the experimental unit. The initial and final weights were included in the model as covariates for growth performance data. In experiment II, the final weight was used as covariate for criteria of carcass characteristics.

Table 2. Formula and chemical composition of the basal experimental diets for finishing pigs

	Early finisher	Late finisher
Ingredients (%):		
Corn	73.17	78.54
Soybean meal	23.22	17.80
Animal fat	1.22	1.10
Tricalcium phosphate	1.36	1.52
Limestone	0.39	0.31
L-lysine · HCl	0.12	0.16
DL-methionine	0.04	0.04
Threonine	0.04	0.07
Vitamin-mineral mixture	0.15	0.15
Antibiotics	0.06	0.06
Choline chloride	0.06	0.06
NaCl	0.20	0.20
Total	100.00	100.00
Chemical composition[1]:		
ME (kcal/kg)	3,350	3,350
Crude protein (%)	16.00	14.00
Calcium (%)	0.70	0.70
Phosphorus (%)	0.60	0.60
Lysine (%)	0.91	0.80
Methione+cystine (%)	0.58	0.52
Threonine (%)	0.63	0.56

[1] Calculated value.

RESULTS

Experiment I

Effects of different vitamin-trace mineral levels on the growth performance of growing pigs are presented in table 5. During the first 2 weeks (21 to 30 kg BW), average daily gain (ADG) in the 200% mineral supplemented group was highest, and lowest in the 200% water soluble vitamin supplemented group ($p<0.05$). Average daily feed intake (ADFI) was not affected by dietary treatments. Feed/gain (F/G) was lowest in the 200% vitamin supplemented group, but there was no significant difference among treatments. During the 2nd week (30 to 42 kg BW) and the last 2 weeks (42 to 53 kg BW), overall growth performances were not affected by dietary treatments. During the overall experimental period (0 to 6 weeks, 21 to 54 kg body weight), ADG in the 200% of trace mineral supplemented group was significantly higher than that of trace mineral 50% supplemented group. However, there were no significant differences among treatments. Feed intake was highest in the control group and lowest in the 50% trace mineral supplemented group. F/G was not affected by dietary treatment during the overall experimental period.

The effect of different vitamin and trace mineral premixes formulas on proximate nutrient digestibilities of growing pigs is given in table 7. There was no significant difference in dry matter and crude ash digestibilities among the dietary treatments ($p>0.05$). However, digestibility of crude protein was lowest in the 50% mineral supplemented group ($p<0.05$) but no significant difference was observed among the other treatments. Calcium digestibility was significantly higher in the 200% fat soluble vitamin supplemented group than in other treatments ($p<0.05$), and the 200% trace mineral supplemented group had a tendency to have higher calcium digestibility than the 50% trace mineral supplemented group, but not significantly ($p<0.05$).

During the growing period (21 to 53 kg), total feed cost per pig was a little higher in control group than other treatment groups, but the difference was not significant. There was no significant difference in feed

Table 3. Calculated values* of vitamin and trace minerals in experimental diets for growing pigs

Vitamin and mineral mixture	Control (vit.-min. mix. 100%)		Vitamin mixture (%)		Mineral mixture (%)	
			Fat-soluble vit. 200	Water-soluble vit. 200	50	200
Vitamin mixture:						
Vitamin A (IU)	8,000	(1300)[†]	16,000	8,000	8,000	8,000
Vitamin D_3 (IU)	1,500	(150)	3,000	1,500	1,500	1,500
Vitamin E (mg)	40	(7.37)	80	40	40	40
Vitamin K (mg)	1.50	(0.50)	3.0	1.5	1.5	1.5
Biotin (mg)	0.1	(0.05)	0.1	0.2	0.1	0.1
Choline (mg)	240	(300)	240	480	240	240
Folic acid (mg)	0.6	(0.3)	0.6	1.2	0.6	0.6
Niacin (mg)	20	(10)	20	40	20	20
Pantothenic acid (mg)	12	(8)	12	24	12	12
Vitamin B_1 (mg)	1.0	(1.0)	1.0	2.0	1.0	1.0
Vitamin B_2 (mg)	4.0	(2.5)	4.0	8.0	4.0	4.0
Vitamin B_6 (mg)	2.0	(1.0)	2.0	4.0	2.0	2.0
Vitamin B_{12} (mg)	0.02	(0.01)	0.02	0.04	0.02	0.02
Mineral mixture:						
Zinc (mg)	60	(60)	60	60	30	120
Iron (mg)	60	(60)	60	60	30	120
Manganese (mg)	25.5	(2)	25.5	25.5	12.25	50
Copper (mg)	150	(4)	150	150	75	300
Iodine (mg)	0.2	(0.14)	0.2	0.2	0.1	0.4
Selenium (mg)	0.25	(0.15)	0.25	0.25	0.125	0.5

* Amount/kg of diet (vitamin and trace mineral concentrations in feed ingredients were not considered in calculation).

* Vitamin and trace mineral concentrations from feed ingredients in the basal diet (amount/kg of diet; calculated by NRC (1998) estimates) : vitamin A 123.3 IU, vitamin D_3 0 IU, vitamin E 4.97 mg, vitamin K 0 mg, biotin 0.1 mg, choline 1,054 mg, folic acid 0.44 mg, niacin 21.5 mg, pantothenic acid 7.3 mg, vitamin B_1 3.0 mg, vitamin B_2 1.4 mg, vitamin B_6 4.2 mg, vitamin B_{12} 0 mg, zinc 22.5 mg, iron 67.9 mg, manganese 11.2 mg, copper 6.8 mg, iodine 0 mg, selenium 0.12 mg.

† NRC requirement (1998).

Table 4. Calculated values* of vitamin and trace minerals in experimental diets for finishing pigs

Vitamin and mineral mixture	Control (vit.-min. mix. 100%)		Vitamin mixture (%)		Mineral mixture (%)	
			Fat-soluble vit. 200	Water-soluble vit. 200	50	200
Vitamin mixture:						
Vitamin A (IU)	6,000	(1300)†	12,000	6,000	6,000	6,000
Vitamin D_3 (IU)	1,125	(150)	2,250	1,125	1,125	1,125
Vitamin E (mg)	30	(7.37)	60	30	30	30
Vitamin K (mg)	1.125	(0.50)	2.25	1.125	1.125	1.125
Biotin (mg)	0.075	(0.05)	0.075	0.15	0.075	0.075
Choline (mg)	180	(300)	180	360	180	180
Folic acid (mg)	0.45	(0.3)	0.45	0.9	0.45	0.45
Niacin (mg)	15	(7)	15	30	15	15
Pantothenic acid (mg)	9	(7)	9	18	9	9
Vitamin B_1 (mg)	0.75	(1)	0.75	1.5	0.75	0.75
Vitamin B_2 (mg)	3	(2)	3	6	3	3
Vitamin B_6 (mg)	1.5	(1.0)	1.5	3	1.5	1.5
Vitamin B_{12} (mg)	0.015	(0.005)	0.015	0.03	0.015	0.015
Mineral mixture:						
Zinc (mg)	45	(50)	45	45	22.5	90
Iron (mg)	45	(50)	45	45	22.5	90
Manganese (mg)	19.13	(2)	19.13	19.13	9.56	38.25
Copper (mg)	112.5	(3.5)	112.5	112.5	56.25	225
Iodine (mg)	0.15	(0.14)	0.15	0.15	0.075	0.3
Selenium (mg)	0.19	(0.15)	0.19	0.1875	0.09	0.375

* Amount/kg of diet (vitamin and trace mineral concentrations from feed ingredients were not considered in calculation).

[1] Vitamin and trace mineral concentrations from feed ingredients in the basal diet for early finishing pigs (amount/kg of diet; calculated by NRC (1998) estimates) : vitamin A 168.7 IU, vitamin D_3 0 IU, vitamin E 6.61 mg, vitamin K 0 mg, biotin 0.1 mg, choline 1,102 mg, folic acid 0.43 mg, niacin 25.5 mg, pantothenic acid 8.1 mg, vitamin B_1 3.6 mg, vitamin B_2 1.6 mg, vitamin B_6 5.1 mg, vitamin B_{12} 0 mg, zinc 24.8 mg, iron 68.1 mg, manganese 11.9 mg, copper 6.8 mg, iodine 0, selenium 0.13 mg.

[2] Vitamin and trace mineral concentrations from feed ingredients in the basal diet for late finishing pigs (amount/kg of diet; calculated by NRC (1998) estimates) : vitamin A 169.7 IU, vitamin D_3 0 IU, vitamin E 4.86 mg, vitamin K 0 mg, biotin 0.05 mg, choline 471.5 mg, folic acid 0.14 mg, niacin 15.2 mg, pantothenic acid 4.1 mg, vitamin B_1 2.2 mg, vitamin B_2 0.8 mg, vitamin B_6 3.1 mg, vitamin B_{12} 0 mg, zinc 12.4 mg, iron 25.0 mg, manganese 5.2 mg, copper 2.6 mg, iodine 0 mg, selenium 0.05 mg.

† NRC requirement (1998).

cost per kg weight gain among treatments (table 9).

Experiment II

During the early finishing period (54 to 75 kg), ADG, ADFI and F/G were not significantly affected by dietary treatments ($p>0.05$) (table 6). However, an increased level of water soluble vitamins at 200% compared to control had a tendency to improve the overall growth performances. During the late finishing period (75 to 106 kg), dietary treatments did not significantly affect the overall growth performances. During the overall experimental period (0 to 9 weeks, 54 to 106 kg body weight), an increased level of water soluble vitamins at 200% compared to control had a tendency to improve the overall growth performances, but the difference was not significant.

Effects of different dietary vitamin-mineral levels on carcass characteristics and pork quality of finishing pigs are summarized in table 8. As shown in this table, overall carcass characteristics except for carcass length did not differ among pigs fed the dietary treatments. There was a trend for better carcass grade when the fat soluble vitamins were added at the level of 200% of control, but the difference was not significant. Loin eye area, pH, drip loss and shear force of meat were not affected by dietary vitamin and trace mineral levels. There was a trend for less fat content (%) in pork when the level of vitamin and trace mineral was increased, but difference was not significant. Flavorness was lowest in control group and highest in the 200% fat soluble vitamin supplemented group ($p<0.05$). Juiciness of in muscle was lower in the 200% fat soluble vitamin supplemented group than the other dietary treatments except for the 50% trace

Table 5. Effects of different dietary vitamin-mineral levels[1] on growth performance of growing pigs[2]

Treatments	Control	Fat soluble vitamin 200%	Water soluble vitamin 200%	Mineral (%)		SE[3]
				50	200	
21 to 30 kg:						
ADG (kg)	0.681[ab]	0.647[b]	0.579[c]	0.669[ab]	0.756[a]	0.0152
ADFI (kg)	1.47	1.36	1.39	1.43	1.41	0.029
FCR	2.15[b]	2.09[b]	2.46[a]	2.14[b]	1.94[b]	0.0463
30 to 42 kg:						
ADG (kg)	0.820	0.802	0.868	0.809	0.842	0.0226
ADFI (kg)	1.93	1.78	1.90	1.83	1.83	0.046
FCR	2.35	2.24	2.25	2.30	2.19	0.061
42 to 53 kg:						
ADG (kg)	0.869	0.852	0.874	0.797	0.895	0.0150
ADFI (kg)	2.27	2.26	2.10	2.14	2.40	0.056
FCR	2.67	2.67	2.42	2.68	2.69	0.075
Overall (21 to 53 kg):						
ADG (kg)	0.790[ab]	0.767[ab]	0.778[ab]	0.752[b]	0.813[a]	0.0118
ADFI (kg)	1.89	1.80	1.83	1.80	1.88	0.035
FCR	2.39	2.35	2.35	2.30	2.27	0.039

[a,b] Means with different superscripts in the row differ ($p<0.05$).
[1] Refer to table 3.
[2] Total of 120 pigs; average initial body weight was 20.91 kg and final body weight was 53.66 kg, four pigs/pen, six pens/treatment.
[3] Pooled standard error.

mineral supplemented group ($p<0.05$). Meat color revealed no effect of diet.

During the finishing period (54 to 106 kg), the addition of vitamin and trace minerals at a high level had a tendency to increase the total feed cost per pig as well as feed cost per kg weight gain (table 9).

DISCUSSION

In experiment I, even though the difference was not significant, there was a trend for better overall growth performances when the levels of trace minerals were increased, and a reduction in the level of trace minerals in diet to 50% of control reduced growth performance compared with the 200% trace mineral supplemented group. This is partially in agreement with Chae et al. (2000a), who observed that increasing the dietary level of vitamin and trace mineral to 150 to 250% of NRC (1998) requirements improved growth performance of growing pigs. Several studies have indicated that the NRC (1998) requirement for vitamin and trace minerals may be too low. Lindemann et al. (1995) fed weanling pigs diets containing 0.5, 1, 2, 2.5 and 5 times as much as the NRC (1988) requirements for vitamin A, D, E, K, niacin, pantothenic acid, riboflavin and vitamin B_{12}, and reported that pigs fed diet with 0.5 times as much as the NRC (1988) requirements had reduced growth performance and feed intake, whereas pigs fed five times higher requirements had the highest ADG and ADFI. Stahly et al. (1995) and Stahly and Cook (1997) also reported that additional feeding of B-vitamins or vitamin A, E and C over NRC (1988) requirement improved growth performance of growing pigs. However, in the present study, feeding higher levels of fat soluble or water soluble vitamins did not affect overall growth performance of growing pigs. This result may be attributed to the fact that the levels of vitamin and trace mineral premixes in the control diet used in the present study are much higher than that of NRC (1988, 1998). This might be supported by the results from Wilson et al. (1993), who observed no benefits from additional B-vitamins levels in diets when control diets (corn-soybean meal-milk products based) contained B-vitamin concentrations similar to industry average levels (three to four times as much as NRC (1988) requirement). This result indicates that "typical" commercial levels of vitamin-trace minerals used in the present study might be enough to meet requirements for maximum growth of growing pigs.

Chae et al. (2000a) reported that neither vitamin nor trace mineral addition at the level of 150% of NRC (1998) requirement improved growth performance of growing pigs, but addition of both vitamins and trace minerals at the level of 150% of NRC (1998) requirement improved the growth performance compared to control. They suggested that both vitamins and trace minerals may affect growth performance of pigs. In the present study, because the

Table 6. Effects of different dietary vitamin-mineral levels[1] on growth performance of finishing pigs[2]

Treatments	Control	Fat soluble vitamin 200%	Water soluble vitamin 200%	Mineral (%)		SE[3]
				50	200	
54 to 75 kg:						
ADG (kg)	0.793	0.837	0.844	0.775	0.798	0.0130
ADFI (kg)	2.13	2.11	2.13	2.16	2.20	0.049
F/G	2.68	2.53	2.52	2.80	2.75	0.052
75 to 106 kg:						
ADG (kg)	0.777	0.755	0.825	0.833	0.799	0.0164
ADFI (kg)	2.75	2.76	2.91	2.91	2.87	0.057
F/G	3.55	3.70	3.70	3.51	3.52	0.089
Overall (53 ~ 106 kg):						
ADG (kg)	0.784	0.789	0.833	0.809	0.789	0.0119
ADFI (kg)	2.49	2.49	2.61	2.60	2.59	0.050
F/G	3.18	3.17	3.33	3.22	3.13	0.063

[1] Refer to table 4.
[2] Total of 120 pigs, averaging initial body weight was 53.58 kg and final body weight was 105.62 kg, four pigs/pen, six pens/treatment.
[3] Pooled standard error.

amounts of vitamins and minerals were both increased, it is not possible to determine whether additions of vitamins and trace minerals separately at a high level could affect the growth response in growing pigs.

In experiment II for finishing pigs, the trend in overall growth performances was different from that of experiment II for growing pigs. During the entire experimental period (0 to 9 weeks, 54 to 106 kg body weight), even though the difference was not significant, increasing level of water soluble vitamins at the level of 200% compared to control had a constant tendency to improve the overall growth performances. Because of their role in energy and protein metabolism, it has been suggested that vitamins, particularly the B vitamins, are key elements in protein accretion rates potentially resulting in greater dietary vitamin requirement (Simmins and Dussert, 1998). Stahly et al. (1995) suggested that higher dietary concentrations of B vitamins are needed to optimize the growth rate and efficiency in higher lean growth genotypes. They reported that average daily gain increased (15.8% improvement) and feed efficiency increased linearly (11.5% improvement) when the concentrations of B vitamins in the diet of higher lean growth genotype pigs were increased from 170% to 470% of the NRC (1988) requirements. Wilson et al. (1992a, b) also reported that dietary additions of various B-vitamins at 2 to 10 times as much as NRC (1988) requirement was beneficial to growth performance of weanling pigs.

Unfortunately, it is not easy to compare the present results with others because there have been few data showing effects of dietary additions of various B-vitamins at higher levels than NRC (1988, 1998) on growth performances in growing or finishing pigs. In addition, in the present study, because the amount of the entire vitamin premixes was increased, it is not possible to determine whether the response was due to a single vitamin or to a combination.

In experiment II for finishers, reduction of level in trace mineral to 50% of control had no effect on growth performance compared to other treatments. For early finishing period (54 to 75 BW kg), pigs fed the diet containing 50% of trace mineral levels had a tendency to poorer growth performance, but for the late finishing period (75 to 106 kg BW), feeding that

Table 7. Effects of different dietary vitamin-mineral levels[1] on nutrient digestibility of growing pigs (%)

Treatments	Control	Fat soluble vitamin 200%	Water soluble vitamin 200%	Mineral (%)		SE[2]
				50	200	
Dry matter	83.53	84.11	81.49	79.89	79.29	0.789
Crude ash	49.38	54.08	47.78	52.14	52.32	1.660
Crude protein	81.14[a]	83.00[a]	76.72[ab]	73.13[b]	82.10[a]	1.243
Calcium	58.35[b]	66.15[a]	57.12[b]	56.50[b]	59.12[b]	1.093
Phosphorus	47.44[ab]	56.13[a]	44.16[a]	46.67[ab]	50.12[ab]	1.659

[a,b] Means with different superscripts in the row differ ($p<0.05$).
[1] Refer to table 3.
[2] Pooled standard error.

Table 8. Effects of different vitamin-mineral mixtures levels[1] on carcass characteristics and meat quality of finishing pigs

Treatments	Control	Fat soluble vitamin 200%	Water soluble vitamin 200%	Mineral		SE[6]
				50	200	
Carcass characteristics[2]:						
Carcass length (cm)	100.4[ab]	99.0[b]	102.8[a]	100.5[ab]	99.0[b]	0.65
Backfat thickness (mm)	24.6	24.6	24.6	25.1	25.7	0.574
Carcass percentage (%)	74.0	75.1	75.6	75.3	75.4	0.49
Carcass grade[3]	2.04	1.97	2.42	2.08	2.17	0.10
Meat qaulity[4]:						
Loin eye area (cm^2)	51.25	48.55	46.67	48.37	50.27	0.898
pH	5.59	5.65	5.57	5.59	5.67	0.022
Drip loss (%)	4.61	3.98	3.64	3.50	3.35	0.272
FPW[5] (g)	0.059[a]	0.030[b]	0.033[b]	0.040[ab]	0.033[b]	0.0036
Shear force (kg)	3,153.7	2,571.4	3,250.8	2,644.7	3,243.4	116.59
Fat (%)	3.51	3.13	3.32	3.23	3.03	0.188
Cooking loss (%)	26.32	24.22	25.38	25.59	24.78	0.385
Flavorness	3.68[b]	3.94[a]	3.79[ab]	3.92[a]	3.87[a]	0.031
Tenderness	3.68	3.69	3.65	3.70	3.45	0.055
Juiciness	3.54[a]	3.06[c]	3.56[a]	3.17[bc]	3.35[ab]	0.053
Total acceptability	3.68	3.33	3.53	3.39	3.45	0.051
a*	5.02	6.33	5.27	5.69	6.15	0.222
b*	11.15	11.41	11.14	10.90	11.45	0.19

[a,b] Means with different superscripts in the row differ ($p<0.05$).
[1] Refer to table 4.
[2] Total 120 pigs (24 pigs per treatment) were slaughtered at the end of experiment and measured for carcass characteristics.
[3] Based on a scale with 1 = grade A, 2 = grade B, 3 = grade C, 4 = grade D.
[4] Total 30 pigs with same body weight (6 pigs per treatment) were slaughtered for meat quality analysis.
[5] Filter paper wetness.
[6] Pooled standard error.
* a: Redness, b: yellowness (higher value means higher colorness).

diet did not result in any deterioration of growth. This result is in agreement with Mavromichalis et al. (1999), who observed no effect on growth performance when vitamin and/or trace mineral premixes were omitted from corn-soybean meal based diets during the final 4 to 5 week before slaughter. Patience and Gillis (1995, 1996) also reported that there was no negative effect on growth performance when trace mineral premixes were omitted from wheat-barley-canola meal based diets during the last 3 to 5 weeks before market. These results may indicate that for late finishing period, industry average trace mineral levels could be reduced by 50% for reducing environmental pollution without deterioration of growth performance in finishing pigs.

In experiment I, additional feeding of fat soluble vitamins at the level of 200% compared to control improved calcium digestibility. This is in close agreement with the result from Chae et al. (2000a) who reported that calcium and phosphorus digestibility was improved when dietary vitamin and trace minerals were increased up to 250% of the requirement suggested by NRC (1988, 1998). Chae et al. (2000a) suggested that one of the possible explanations is the interaction among nutrients. It has been suggested that vitamin D and some minerals are related to the metabolism of calcium and phosphorus (Peo, 1991). Soares (1995) reported that adding 5 to 10 μg of dihydroxycholecalciferol to a vitamin D-adequate diet increased phytate phosphorus bioavailability by 50%.

In experiment II, reduction of dietary trace mineral by 50% compared with the control, "typical" commercial levels, had no negative effect on overall carcass characteristic and pork quality. These data are in agreement with Patience and Gillis (1995) and Mavromichalis et al. (1999) who observed no effect on carcass characteristics and meat quality of pigs when dietary vitamin and trace mineral premixes were omitted or the levels was reduced for the latter part of finishing period. Meanwhile, Chae et al. (2000b) reported that increasing dietary vitamins and trace minerals in excess of NRC (1998) recommendations improved growth performance and pork stability of finishing pigs. However, in the present study, feeding high levels of fat and water soluble vitamins or trace mineral did not affect overall carcass characteristics and pork quality of pigs. This result may be attributed to the fact that the level of vitamin and trace mineral

Table 9. Effects of different dietary vitamin-mineral levels[1] on the feed cost per gain in growing-finishing pigs

Treatments	Control	Fat soluble vitamin 200%	Water soluble vitamin 200%	Mineral (%)		SE[2]
				50	200	
Exp. I : growing pigs:						
Total weight gain (kg)	33.2[ab]	32.3[ab]	32.7[ab]	31.6[b]	34.2[a]	0.50
Total feed cost/pig (USD)	14.0	13.7	13.86	13.31	13.93	0.26
Feed cost/ton weight gain (USD)	421.8	425.7	426.9	421.9	407.4	6.52
Exp. II : finishing pigs:						
Total weight gain (kg)	50.9	51.3	54.1	52.6	51.3	0.77
Total feed cost/pig (USD)	26.0	27.7	26.6	27.1	27.0	0.53
Feed cost/kg weight gain (USD)	510.6	519.7	511.9	515.1	529.6	8.84

[a,b] Means in the same row with different superscripts differ ($p<0.05$).
[1] Refer to tables 3 and 4.
[2] Pooled standard error.
* 1) Feed cost of each diets for growing pigs were 176.4 USD/ton for control diet, 181.2 USD/ton for diet with fat soluble vitamin 200%, 179.8 USD/ton for diet with water soluble vitamin 200%, 176.2 USD/ton for diet with trace mineral 50%, 176.7 USD/ton for diet with trace mineral 200%, respectively.
2) Average feed cost of each diets for early and late finishers were 161.8 USD/ton for control diet, 165.4 USD/ton for diet with fat soluble vitamin 200%, 164.4 USD/ton for diet with water soluble vitamin 200%, 161.6 USD/ton for diet with trace mineral 50%, 162.0 USD/ton for diet with trace mineral 200%, respectively.

premixes in the control diet used in the present study is much higher than that of NRC's (1988, 1998). The lack of negative effects on the traits evaluated in the present study indicates that commercial levels of trace minerals in the diet for finishing pigs could be reduced by 50% and suggests little justification for adding fat or water soluble vitamin and trace mineral in excess of control level during the finishing period.

As shown in table 9, during the growing period (21 to 53 kg), total feed cost per pig was a little higher in the control than the other treatment groups, but the difference was not significant. There was no significant difference in feed cost per kg weight gain among treatments. However, the supplementation with fat or water soluble vitamins at a high level increased feed cost per kg weight gain by 0.9 to 1.2% compared to the control group. During the finishing period (54 to 106 kg), the addition of vitamin and trace minerals at a high level had a tendency to increase the total feed cost per pig as well as feed cost per kg weight gain. Although it was not significant, addition of fat soluble vitamins and trace minerals at 200% of control increased feed cost per kg weight gain by 1.8 and 3.8%, respectively. Generally, a reduction in feed cost should not be the only criterion for making decision in feed production. Improvements in carcass lean content and carcass grade or meat quality can result in improvements in economic returns. However, in the present study, a diet with a high level of vitamin and trace mineral did not have favorable effects on carcass and meat quality. Therefore, we suggest that from the economical point of view, feeding diets with higher levels of vitamin and trace minerals than the "typical" commercial level is not a good strategy for growing-finishing pigs.

Based on these results from the present study, it is suggested that "typical" levels of vitamin and trace minerals used by feed companies in Korea are enough to meet requirement for maximum growth of growing-finishing pigs. The results suggest that a reduction in trace mineral levels in pig diets could be considered to reduce feed cost and nutrient excretion, giving economic and environmental benefits.

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