Effects of Chromium Picolinate (CrP) on Growth Performance, Carcass Characteristics and Serum Traits in Growing-Finishing Pigs

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ABSTRACT : An experiment was carried out to evaluate the effects of feeding graded levels of chromium in the form of chromium picolinate on growth performance, blood components, carcass grade, *in vitro* lipogenesis and lipolysis, and *in vitro* protein degradation and synthesis in growing-finishing pigs. There were no significant differences for daily weight gain, feed intake and feed conversion among treatments during growing phase, while in the finishing phase, feed intake was lower in groups fed diets with 200 ppb chromium than in other treatment ($p < 0.1$). Feed conversion was improved in the groups fed diets with chromium compared with control. Carcass weight was similar among treatments while carcass length was longer in groups fed diets with 200 ppb chromium ($p < 0.05$). Thinner carcass fat was found with groups fed diets with chromium compared to control. Three A grade of carcasses were from groups fed chromium compared to control. No significant differences were observed with blood glucose, insulin, total cholesterol, triglycerides and non-esterified fatty acid at 60 kg body weight. While, at 100 kg body weight, blood triglyceride was lower in groups with 200 and 400 ppb chromium but higher in groups with 100 ppb chromium ($p < 0.05$). *In vitro* lipolysis and protein synthesis in adipose tissues were increased as dietary chromium was increased from 0 to 200 ppb ($p < 0.1$). As a result, 200 ppb chromium in a growing-finishing diet could improve feed efficiency and carcass traits; an increase to 400 ppb has no further effect.
(**Key Words**: Chromium Picolinate, Growth, Carcass Trait, Blood Component, Pigs)

INTRODUCTION

Various feed additives or growth promotors have been developed to improve growth rate, feed efficiency, production cost and product quality. Chromium has been known as an essential mineral consisting of GTF (glucose tolerance factor) which regulates glucose metabolism. Schwarts and Mertz (1957) found chromium to be a component of GTF, and since then, many studies were carried out to elucidate its importance in nutritional metabolism. It was also suggested that chromium play an important role of animal's carbohydrate and lipid metabolism, and glucose tolerance was impaired by chromium deficiency.

NRC (1980) suggested that maximum allowances of chromium for each animal were ranged from 1,000 to 3,000 ppm depending on its chemical forms. Most ingested chromium by animals was excreted in urine but not retained in the body.

Evans (1989) reported that body fat, plasma total cholesterol, LDL fraction, apolipoprotein B, glucose and hemoglobin decreased while muscle mass increased in human administered daily 200 μg of chromium in chromium picolinate. Several investigations with broiler chickens show that feed conversion was most efficient at 400 ppb chromium picolinate supplemented group (Kim et al., 1995b) and the weight gain was higher when chromium picolinate was supplemented in the diet which contains 80% of crude protein of NRC required than no chromium picolinate supplemented group (Kim et al., 1995a). Meanwhile, feeding excessive chromium picolinate up to 2,400 ppb did not exhibit unfavorable effects on broiler chickens (Kim et al., 1995c). Most grains and meals are deficient in chromium and its utilization depends on the chelating forms (Schroeder, 1971; Giri, 1990; Mertz, 1969, Votava, 1973; Evans and Johnson, 1980). Currently, there is no suggestion on dietary requirement of chromium for pigs. According to recent study by Page et al. (1993), loineye area and muscle mass increases but backfat thickness at 10th rib decreased when growing pigs were fed diets added with

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200 ppb chromium. They also reported that weight gain appeared to decrease while feed intake decreased in quadratic pattern as dietary chromium increased gradually.

Further studies on effects of feeding chromium to pigs are needed to determine the metabolic role of chromium. Therefore, we fed diets containing graded levels of chromium to pigs at growing and finishing stages in order to evaluate the effects of chromium on growth performance, carcass traits and blood components.

MATERIALS AND METHODS

A total of 64 three cross-bred pigs with average body weight of 20 kg (32 male and 32 female) were used as experimental subjects. Experimental diets were formulated to contain graded levels of chromium in the form of chromium picolinate and pigs were randomly alotted into 4 pens consisting of 4 heads each. Commercial diets were fed for 7 days before feeding trial started. Then experimental diets for growing phase were fed to reach 60 kg body weight and experimental diets for finishing phase were fed from 60 kg to market weight (table 1). Feeding trial lasted for 103 days summing growing phase and finishing phase. Experimental animals had free access to experimental diets and water. Body weight and feed intake were recorded to calculate daily weight gain and feed conversion.

Table 1. Ingredients and chemical composition of the basal diets[1]

	Growing	Finishing
Ingredients :	..... %	
Corn, yellow	77.40	80.80
Soybean meal	19.20	16.80
Fish meal	1.20	–
Limestone	0.75	1.00
TCP	0.65	0.92
Salt	0.35	0.35
L-lysine	–	0.13
Vit. & Min. premix[2]	0.20	0.20
Antibiotics	0.15	–
Total	100.00	100.00
Composition :[3]		
ME (kcal/kg)	3,300	3,306
Crude protein (%)	16.00	14.00
Ca (%)	0.60	0.70
P (%)	0.50	0.50
Lysine (%)	0.80	0.70

[1] Formulated to meet the nutrient requirements suggested by NRC (1988).

[2] The vitamin and mineral premix contained the following per kg : vitamin A, 2,000,000 IU; vitamin D_3, 400,000 IU; vitamin E, 250 IU; vitamin K, 200 mg; d-pantothenic acid, 3,000 mg; vitamin B_1, 20 mg; vitamin B_2, 700 mg; vitamin B_6, 200 mg; vitamin B_{12}, 2,200 mg; niacin, 8,000 mg; choline chloride, 30,000 mg; folic acid, 40 mg; BHT, 6,000 mg; Mn, 12,000 mg; Cu, 500 mg; Fe, 4,000 mg; Zn, 15,000 mg; I, 250 mg; Co, 100 mg; Mg, 2,000 mg.

[3] Calculated values.

Body weight was measured twice at the initiation and termination of trial and the mean of each measurement was used as initial body weight and final body weight. During feeding trial, body weight and feed refusals were measured once every three weeks to calculate weight gain, feed intake and feed conversion.

Laboratory analysis

Four randomly selected pigs (2 male and 2 female) from each treatment were slaughtered after 24-hour fasting and kept at freezing temperature for subsequent carcass evaluation. Carcass weight, carcass percentage, dressing percentage, backfat thickness and loineye area were measured for comparison.

Blood were drawn into heparin-treated vacuum tube from cervical artery with syringes (10 ml) one hour after feeding at 60 kg and 100 kg body weight, and then kept on ice for analysis. The blood samples in vacuum tubes were centrifuged at 1,000 × G for 15 minutes, and plasma layer (supernatant) was separated for the subsequent analysis. Plasma total cholesterol, NEFA, triglyceride, glucose and HDL concentration were analyzed using enzyme kits (Asan Co., Ltd). Blood insulin concentration was measured with RIA kit (Diagnostic Products Corporation).

For lipogenesis, 10 to 20 mg of adipose tissue were taken into Krebs-Ringer Bicarbonate (KRB) buffer containing 25 mM HEPES, 5.0 mM glucose, 3% bovine serum albumin (BSA; 4% fatty acid free fraction) and 0.5 μCi [^{14}C] glucose, and then incubated at 37℃ under 95 % O_2 and 5% CO_2 of gaseous pressure for 2 hours. Lipid was extracted with Dole's solution from cultured tissue. Lipid extracts were dried and poured into cocktail solution to measure radioactivity using Liquid Scintilation Counter (LS 100 C, Beckman). For lipolysis, 100 mg of adipose were incubated in 3 ml of KRB buffer containing BSA and 5.56 mM glucose at 37℃ under gaseous pressure (95 % O_2 + 5% CO_2) for 2 hours. Removing adipose tissue, culture medium was kept at −20℃ for termination. NEFA contents in medium was measured according to the method by Kelly (1965).

Liver tissue was collected into BSS (Balanced Salt Solution) including calf serum, and immediately cell dispersion was conducted according to the method by Choi et al. (1988). Tissues, freed from lipid, lymphocyte, connective tissues and blood vessels, were cut into 5 mm^3 in size and treated in 37℃ of collagenase-hyaluronidase solution for 3 hours, and then washed 3 times with BSS and resuspended in 1 × MEM (minimal essential medium). The culture medium were prepared based on Eagle's MEM added with 0.2% glucose, 5% fetal bovine serum, penicillin 10,000 IU/100 ml, Amphotericin-B 250 μg/100 ml, and Streptomycin 10,000 IU/100 ml, with pH 7.4 adjusted with sodium bicarbonate (Smith et al., 1982). [^{3}H]-lysine was incoporated into medium for labelling and incubated at 37℃ for 18 hours. Specific activity of radioisotope-labeled lysine was measured using liquid scitillation counter (LS 100 C, Beckman). Protein synthesis was calucated based on the following formula.

P = [C/C]/A

P : Specific activity (dpm/mg protein)

C : cpm incoporated into protein

E : Isotope counting efficiency

A : Protein amount (mg)

Treatment means were compared accordings to Duncan's method (1955) using SAS (1985) General Linear Model procedure.

RESULTS AND DISCUSSION

Daily weight gain, daily feed intake and feed conversion of growing-finishing pigs fed diets with graded levels of chromium are shown in table 2. There were no significant differences for daily weight gain, daily feed intake and feed conversion among treatments during growing phase. For the finishing phase, daily weight gain and feed conversion were similar among treatments, while feed intake appeared to be lower in groups fed diets with 200 ppb chromium. Over the entire trial period, weight gain and feed intake tended to slightly decrease in animals fed diets with chromium. While feed conversion tended to improve in animals fed diets with chromium without significant difference. Page et al. (1993) reported that weight gain and feed intake decreased in a linear pattern as dietary chromium level increased, while Lindermann et al. (1995) countered that feeding chromium to growing pigs improved weight gain and feed intake at 250 and 500

Table 2. Effects of chromium picolinate (CrP) on growth performance in growing-finishing pigs

Items	CrP[1] (ppb)				SEM[2]
	0	100	200	400	
	Growing phase (56 d)				
Initial wt (kg)	20.1	19.9	19.8	19.8	
Final wt (kg)	64.8	64.8	64.6	64.6	0.91
Average daily gain (g/d)	799	802	799	800	15.6
Feed intake (kg/d)	2.30	2.34	2.32	2.24	0.038
Feed : gain	2.88	2.92	2.91	2.81	0.057
	Finishing phase (47 d)				
Initial wt (kg)	64.8	64.8	64.6	64.6	0.91
Final wt (kg)	106.8	106.0	103.7	106.1	0.96
Average daily gain (g/d)	893	876	832	884	19.2
Feed intake (kg/d)	3.25[a]	3.12[a]	3.00[b]	3.12[a]	0.049
Feed : gain	3.63	3.56	3.61	3.54	0.060
	Growing-finishing phase (103 d)				
Initial wt (kg)	20.1	19.9	19.8	19.8	0.12
Final wt (kg)	106.8	106.0	103.7	106.1	0.96
Average daily gain (g/d)	842	836	814	838	8.9
Feed intake (kg/d)	2.73[a]	2.70[ab]	2.63[b]	2.64[b]	0.024
Feed : gain	3.24	3.23	3.23	3.16	0.031

[1] Values are means of four replicates consisting of 4 pigs each.

[2] Standard error of mean.

[ab] Means with different superscripts within the same row are significantly different ($p < 0.1$).

ppb level in a diet. There is no explanation for the reason that the results were different. However it is noteful that feed conversion could be improved by addition of chromium.

Table 3 shows carcass characteristics of slaughtered pigs fed diets with chromium. Slaughter weight, carcass weight, carcass length and carcass width were similar among treatments. Backfat thickness were 8 to 19% thinner in groups fed diets with chromium than in those fed control diets. The thinnest backfat thickness was found with groups fed diets added at 200 ppb chromium. It was suggested by Page et al. (1993) that decrease of backfat thickness, dressing percentage and loineye area by addition of chromium should be due to improved efficiency of glucose metabolism resulted from inhibition of protein degradation. Likewise, in this experiment, loineye area and carcass percentage appeared to be improved in groups fed diets with chromium. This was similar to the results by Page et al. (1993) and Lindermann et al. (1995). Inorganic form of chromium, chromium trichloride failed to improve carcass characteristics of pigs (Page et al., 1990), but succeeded to increase growth of rats and turkey (Steele et al., 1979; Mertz et al., 1969). Also, in human administered with chromium picolinate, muscle mass increased while fat decreased (Evans, 1989).

Table 3. Effects of chromium picolinate (CrP) on carcass traits in finishing pigs[1]

Items	CrP (ppb)				SEM[4]
	0	100	200	400	
Slaughter wt (kg)	108.8	108.2	105.1	106.2	
Carcass wt (kg)	83.0	82.8	80.5	80.8	3.98
Carcass length (cm)	98.0	98.0	100.4	99.9	3.38
Carcass width (cm)	32.3	32.1	32.5	32.1	0.79
Backfat (cm)	2.69[a]	2.48[ab]	2.18[b]	2.32[ab]	0.15
Backfat[2] (cm)	2.64	2.51	2.22	2.34	0.17
Loineye area (cm^2)	23.2	23.5	23.9	23.3	0.69
Loineye area[3] (cm^2)	22.8	23.2	24.3	23.5	0.73
Carcass percentage	76.3	76.5	76.6	76.1	3.04

[1] Values are means of 8 pigs randomly selected from each treatment.
[2] Corrected backfat thickness based on mean final body weight as a covariate.
[3] Corrected loineye area based on mean final body weight as a covariate.
[4] Standard error of mean.
[ab] Means with different superscripts within the same row are significantly different ($p < 0.05$).

Table 4 represents the outcomes of carcass evaluation on 32 pigs slaughtered at market weight (about 105 kg). Although the number of animals is not sufficient, one pig received A grade from all treatments fed chromium compared to control.

Table 4. Effects of chromium picolinate (CrP) on the carcass grades of finishing pigs

	Carcass grade			
	A	B	C	D
CrP (ppb)	Frequency			
0	0	3	4	1
100	1	2	4	1
200	1	3	3	1
400	1	2	4	1

Blood constituent concentrations of pigs at 60 kg body weight were shown in table 5. Blood glucose concentration gradually appeared to increase up to 200 ppb chromium and then rapidly decreased, and also insulin concentration tended to increase up to 200 ppb chromium, and thereafter, slightly decreased. Study by Mertz et al. (1974) indicated that chromium enhance its association with insulin and insulin receptor. Blood cholesterol concentration tended to be higher in 200 and 400 ppb chromium group than in 0 and 100 ppb chromium group. Blood NEFA concentration tended to increase with increasing chromium levels in diets, implying that chromium inhibit fat synthesis, but increase fat degradation in tissues.

Triglyceride, NEFA, HDL, and ratio of HDL to cholesterol seemed to be higher in groups fed diets with 200 ppb chromium. Riales and Albrink (1981) and Mertz

(1993) suggested that chromium would be related to lipid metabolism in animals.

Table 6 shows blood constituent concentrations of pigs at 100 kg body weight. Blood glucose concentration tended to increase with increasing chromium levels in diets, while blood cholesterol concentration tended to decrease up to 200 ppb chromium and again increase at 400 ppb chromium. Blood triglyceride concentration tended to be lower in 200 and 400 ppb chromium group than in 0 and 100 ppb chromium group, while blood NEFA concentraion tended to be higher in 400 ppb chromium group than in other groups. More studies are needed to verify the effects of chromium on blood constituents of pigs because of inconsistent results, and blood constituents could be easily variable depending on blood collection method, environment, desease, physiological state, diet, time after ingestion, etc.

Table 5. Effects of chromium picolinate (CrP) on serum traits in pigs at 60 kg body weight[1]

Items	CrP (ppb)				SEM[2]
	0	100	200	400	
Glucose (mg/dl)	109.5	113.6	128.5	106.3	5.12
Insulin (μIU/ml)	33.3	33.2	34.7	34.2	2.99
Cholesterol (mg/dl)	76.2	75.6	91.7	87.5	8.85
Triglycerides (mg/dl)	37.0	28.9	38.6	36.5	8.95
NEFA (μEq/l)	201.8	249.3	291.3	189.2	32.89
HDL (mg/dl)	39.9	37.8	53.5	46.5	4.44
HDL : cholesterol	0.54	0.52	0.58	0.57	0.088

[1] Values are means of 4 pigs randomly selected from each treatment.
[2] Standard error of mean.

Table 6. Effects of chromium picolinate (CrP) on serum traits in pigs at 100 kg body weight[1]

Items	CrP (ppb)				SEM[2]
	0	100	200	400	
Glucose (mg/dl)	94.2	93.4	98.7	100.1	9.12
Cholesterol (mg/dl)	79.9	70.1	65.1	73.5	6.16
Triglycerides (mg/dl)	48.1	49.7	43.6	41.6	3.60
NEFA (μeq/l)	153.2	153.2	153.1	189.2	26.18
HDL (mg/dl)	29.5	30.9	20.5	32.2	2.36
HDL : cholesterol	0.37	0.45	0.32	0.44	0.05

[1] Values are means of 4 pigs randomly selected from each treatment.
[2] Standard error of mean.

Lipogenesis and lipolysis responses of adipose tissue of pigs fed experimental diets are presented in table 7. In barrows, amount of NEFA released was highest in 400 ppb chromium group, while, in gilts, amount of NEFA released was highest in 200 ppb chromium group ($p < 0.05$). Summing the barrow and gilt, released amounts of NEFA were 5.08, 6.59, 10.14, 6.05 μeq/mg for 0, 100, 200, 400 ppb chromium group, respectively, indicating 200 ppb chromium group released more NEFA into medium. Also, there was a significant effect of sex × chromium interaction. It implicated that effect of chromium addition was different between sex. No significant differences were found for lipogenesis response between sex or among treatments. In barrows, lipogenetic activity tended to decrease in the order of 100.39, 84.90, 82.20, 79.59 *n*mole/mg for 0, 100, 200, 400 ppb chromium group, respectively. Gilts had higher lipogenic ability than barrows although there was no significant difference and interaction effect of sex × treatment did not exist for the lipogenic activity. NRC (1988) does not suggest the chromium requirement for swine, despite that it is widely recognized that grains and plants do not have enough chromium, and there is a possibility to decrease fat contents by chromium supplementation.

Table 7. Effects of chromium picolinate (CrP) on lipid metabolism of adipose tissue in pigs at 100 kg body weight[1]

Sex	Treatments (CrP, ppb)	Lipogenic activity[1]	Lipolytic activity[2]
Barrow	0	100.39	6.76^{bc}
	100	84.90	5.60^{bc}
	200	82.20	7.07^{b}
	400	79.59	7.66^{c}
Gilt	0	123.70	5.08^{a}
	100	87.64	6.59^{bc}
	200	81.54	10.14^{a}
	400	79.49	6.05^{bc}
Mean		89.93	6.87^{bc}
SEM[3]		4.62	0.34
Probability		0.4054	0.001
Sex			
Barrow		86.77	6.77
Gilt		93.09	6.97
CrP level (ppb)			
	0	112.05	5.93^{b}
	100	86.27	6.10^{b}
	200	81.87	8.61^{a}
	400	79.54	6.86^{b}
Probability (P)			
Sex		NS[4]	NS
CrP		NS	0.0023**
Sex × CrP		NS	0.0045**

[1] nmol glucose incorporation into total lipids/mg.
[2] μeq NEFA released/mg.
[3] Standard error of mean.
[4] Non-significant.
[ab] Means with different superscripts within the same row are significantly different ($p < 0.05$).
** Significant at $p < 0.05$.

Table 8 includes protein retained and protein secreted from liver tissues of pigs fed diets added with chromium. For the secreted protein, there were no significant differences between sex and treatments. Protein retained was significantly higher for the group fed 200 and 400 ppb of chromium ($p < 0.05$). Between sex, retained protein was higher in gilts than in barrows ($p < 0.05$). There was no interaction effect of sex × treatment for the retained protein. Regardless of sex, retained protein increased from 1,203.3 dpm/mg to 1,619.1 dpm/mg with increasing chromium level from 0 to 400 ppb in a diet ($p < 0.05$).

According to report by Roginski and Mertz (1969), chromium would affect utilization of amino acids, and Okada et al. (1983) suggested that chromium had an effect on protein and RNA synthesis within nuclei in the cell. But our experiment did not succeed to provide an evidence that chromium influenced pork production and quality.

Table 8. Effects of chromium picolinate (CrP) on protein synthesis of hepatocytes in pigs at 100 kg body weight

Sex	Treatments (CrP, ppb)	Secreted protein[1] (dpm/mg)	Retained protein[2] (dpm/mg)
Barrow	0	2,465.9	1,002.5^{b}
	100	2,279.8	1,034.3^{b}
	200	2,242.6	1,421.5^{ab}
	400	2,275.9	1,653.4^{a}
Gilt	0	2,356.5	1,404.0^{ab}
	100	2,036.0	1,468.8^{ab}
	200	2,115.2	1,618.1^{a}
	400	2,697.5	1,584.8^{a}
Mean		2,308.70	1,398.14
SEM[3]		82.07	63.77
Probability (P):		0.6413	0.0254
Sex			
Barrow		2,316.1	1,277.9^{b}
Gilt		2,301.3	1,518.9^{a}
CrP level (ppb)			
	0	2,411.2	1,203.3^{c}
	100	2,157.9	1,251.6^{bc}
	200	2,178.9	1,519.8^{ab}
	400	2,486.7	1,619.1^{a}
Probability (P):			
Sex		NS[4]	0.0339**
CrP		NS	0.0295**
Sex × CrP		NS	NS

[1] The amount of secreted protein was determined by the incorporation of [^{3}H]-lysine (0.5 μCi/ml) into TCA-insoluble material.
[2] The amount of retained protein was determined by the incorporation of [^{3}H]-lysine (0.5 μCi/ml) into acini.
[3] Standard error of mean.
[4] Non-significant.
[ab,c] Means values with different superscript with in same column are significantly different ($p < 0.05$).
** Significant at $p < 0.05$.

Considering that chromium enables pigs to utilize energy or protein more efficiently, addition of chromium to the swine diets should be a promising feeding program to improve carcass quality (Schroeder, 1971; Giri, 1990; Mertz, 1969; Votava, 1973). Based upon these results, further studies should be directed toward immune response and amino acid metabolism.

REFERENCES

Choi, Y. J., W. L. Keller, I. E. Berg, C. S. Park and A. G. Mackinlay. 1988. Casein gene expression in bovine mammary gland. J. Dairy Sci. 71:2898.

Evans, G. W. 1989. The effect of chromium picolinate on insulin controlled parameters in humans. Int. J. Biosocial Med. Res. 11:163.

Giri, J., K. Usha and T. Sunitha. 1990. Evaluation of the selenium and chromium content of plant foods. Plant Foods Hum. Nutr. 40:49.

Kelly, T. F. 1965. Improved method for microtitration of fatty acid. Analyt. Chem. 27:251.

Kim, S. W., I. K. Han, Y. J. Choi, Y. H. Kim, I. S. Shin and B. J. Chae. 1995. Effects of chromium picolinate on growth performance and carcass composition of broiler fed dietary different levels of crude proteins. AJAS 8(5):463-470.

Kim, Y. H., I. K. Han, Y. J. Choi, S. W. Kim, I. S. Shin and B. J. Chae. 1996. Effects of dietary levels of chromium picolinate on growth performance, carcass quality and serum traits in broiler chicks. AJAS 9(3):341-347.

Kim, Y. H., I. K. Han, I. S. Shin and B. J. Chae. 1996. Effects of dietary excessive chromium picolinate on growth performance, nutrient utilizability and serum traits in broiler chicks. AJAS 9(3):349-354.

Lindemann, M. D. and C. M. Wood. 1995. Dietary chromium picolinate improve gain : Feed and carcass characteristics in growing-finishing pigs and increase litter size in reporducing sows. J. Anim. Sci. 73:457-465.

Mertz, W. 1969. Chromium occurrence and function in biological systems. Physiol. Rev. 49:163.

Mertz, W. and E. E. Roginski. 1969. Effects of chromium (III) supplementation on growth and survival under stress in rats fed low protein diets. J. Nutr. 97:531.

Mertz, W. 1993. Chromium in human nutrition. A Review. J. Nutr. 123:626.

Moonsie-Shageer, S. and D. N. Mowat. 1993. Effect of level of supplemental chromium on performance, serum constituents, and immune status of stressed feeder calves. J. Anim. Sci. 71:232.

NRC. 1980. Mineral tolerance of domestic animals. National Academy of Sciences. Washington, D.C.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, D.C.

Okada, S., H. Tsukada, H. Ohba. 1983. Enhancement of ribonucleic acid synthesis by chromium (III) in mouse liver. J. Inorg. Biochem. 19:95-103.

Page, T. G., T. L. Ward and L. L. Southern. 1990. Chromium supplementation of corn-soybean meal diets for finishing swine. J. Anim. Sci. 68(Suppl. 1): 39 (Abstr.).

Page, T. G., L. L. Southern, T. L. Ward and D. L. Thompson, Jr. 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71:656.

Rials, R. and M. J. Albrink. 1981. Effect of chromium chloride supplementation on glucose tolerance and serum lipids including high-density lipoprotein of adult men. Am. J. Chin. Nutr. 34:2670.

Roginski, E. E. and W. Mertz. 1969. Effects of chromium III supplementation on glucose and amino acid metabolism in rats fed a low protein diet. J. Nutr. 97:525-530.

SAS. 1985. SAS User's Guide : Statistics (5th Ed.). SAS inst. Inc., NC.

Schroeder, H. A., J. J. Balassa and W. H. Vinton. 1965. Chromium, cadmium and lead in rats : Effects on life span, tumors and tissue levels. J. Nutr. 86:51.

Schroeder, H. A. 1971. Losses of vitamins and trace minerals resulting from processing and preservation of foods. Am. J. Clin, Nutr. 24:562.

Schwarz, K. and W. Mertz. 1959. Chromium (III) and the glucose tolerance factor. Arch. Biochem. Biophys. 85:292-295.

Smith, J. J., S. C. Nickerson and T. W. Keenan. 1982. Metabolic energy and cytoskeletal requirements for synthesis and secretion by acini from rat mammary gland. I. Ultrastructural and biochemical aspects of synthesis and release of milk proteins. Int. J. Biochem. 14:87.

Steele, N. C. and R. W. Rosebrough. 1979. Trivalent chromium and nicotinic acid supplementation for the turkey poult. Sci. 58:983.

Vatava, H. J., C. J. Hahn and G. W. Evans. 1973. Isolation and partial characterizaiton of a Cr complex from Brewer's yeast. Biochem. Biophys. Res. Commun. 55:312.