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Effects of Different Sources of Dietary Chromium on Growth, Blood Profiles and Carcass Traits in Growing-finishing Pigs

J. K. Park, J. Y. Lee, B. J. Chae and S. J. Ohh*

College of Animal Life Science, Kangwon National University, Chuncheon, 200-701, Korea

ABSTRACT : This study was carried out to evaluate the effects of dietary supplementation of different sources of chromium on growth performance, blood profile and carcass trait in growing-finishing pigs. A total of 200 growing pigs (Landrace×Yorkshire)× Duroc, average initial weight 8.5 kg) were allotted to 5 treatments with 4 replicates per treatment and 10 pigs per replicate. Five treatments were designated as follows according to the source of chromium. i) Control (No chromium): corn-soybean meal based basal diet, ii) $CrCl_3$: control diet+200 ppb Cr as $CrCl_3$, iii) CrPic: control diet+200 ppb Cr as Cr picolinate, iv) CrMet-1: control diet+100 ppb Cr as Cr methionine, and v) CrMet-2: control diet+200 ppb Cr as Cr methionine. After the feeding trial, three pigs per replicate (12 pigs per treatment) were slaughtered for the evaluation of carcass traits. Average daily gain (ADG), average daily feed intake (ADFI), and feed: gain ratio (F/G) were not different ($p>0.05$) among dietary Cr sources. However, whole-period ADG of pigs fed CrPic, CrMet-1 and CrMet-2 diets was higher ($p<0.05$) than for the control diet. Nutrient digestibility was not different ($p>0.05$) among dietary Cr sources, but the nutrient digestibility of pigs fed CrPic, CrMet-1 and CrMet-2 diets was higher ($p<0.05$) than for the control diet. BUN level decreased with more magnitude ($p<0.05$) in pigs fed Cr during the 20 to 50 kg period. Although both serum cholesterol and triglyceride were different ($p<0.05$) among treatments, there was no consistent response that could be related to the dietary Cr sources regardless of growth phase. However, the overall data suggested that serum cholesterol level increased as BW of pigs increased. Blood total protein (TP) increased ($p<0.05$) in pigs fed Cr only during the 90-110 kg phase, and blood creatinine (Creat) level was higher in $CrCl_3$ and CrPic treatments than in the control only during the 90-110 kg phase. Backfat thickness was thinner ($p<0.05$) in pigs fed CrMet-2 than in the control treatment. Therefore, lean percentage was higher ($p<0.05$) in CrMet-2 than in control pigs. However, dressing percentage and *Longissimus* muscle area (LMA) were not different ($p>0.05$) among treatments. In conclusion, dietary supplementation of 200 ppb Cr, via either CrPic or CrMet, improved pig growth performance and nutrient digestibility. Moreover, dietary CrMet supplementation for the growing-finishing pig is evidently remarkable for improving both lean percentage of the carcass and backfat thickness. (**Key Words :** Cr Sources, Pig, Growth Performance, Digestibility, Carcass Quality)

INTRODUCTION

Dietary chromium (Cr) is known to influence protein synthesis and nucleic and lipid metabolism in the body of animals, and to be partially responsible for blood cholesterol regulation (Schroeder, 1968; Pi-Sunyer et al., 1984; Mertz, 1993; Ohh and Lee, 2005). However, the efficiency of Cr absorption and utilization is known to be relatively limited and its mechanism is not yet clear. Absorption and utilization of Cr was proposed to be associated with its component organic molecule (Power and Horgan, 2000). In an earlier study of Chen et al. (1973), oxalate was reported to enhance the absorption of chromium in rats. Since then, other synthetic organic forms, such as chromium nicotinate and chromium picolinate (CrPic) have been introduced as readily available sources of chromium. Recently, chromium methionine (Korea patent, 0543107), an amino acid chelate was also introduced to the market. However, there has not been much information with regard to not only the bio-efficacy of the several chromium sources but also appropriate criteria to evaluate the bio-efficacy.

Since Cr is principally related to protein synthesis and lipid partitioning, carcass leanness, including *Longissimus* muscle area (LMA), and backfat thickness have been common evaluation criteria after feeding Cr to growing-finishing pigs (NRC, 1997; Ohh and Lee, 2005). Feeding a CrPic-supplemented diet resulted in carcass leanness (Page et al., 1993; Lindemann et al., 1995; NRC, 1997) and a decrease in backfat thickness (Page et al., 1993; Lindemann

* Corresponding Author: S. J. Ohh. Tel: +82-33-250-8631, Fax: +82-33-255-5482, E-mail: sjohh@kangwon.ac.kr
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et al., 1995; Min et al, 1995). However, there have been several other studies with CrPic or $CrCl_3$ (Evock-Clover et al., 1993; Mooney and Cromwell, 1997) that failed to find such an improvement in carcass quality. The reason why there has been such inconsistency cannot be logically explained yet. The source of Cr could be suggested as one factor for the inconsistent results since most studies were done with just one Cr source. In addition, the growing phase and nutritional status of the pig could be other factors that caused the inconsistency.

There are only a few studies that reported increased growth by dietary Cr in weanling pigs (Harper et al., 1995; van Heugten and Spears, 1997), but others (van de Ligt et al., 2002) showed no effect of CrPic on growth. Therefore, it is too early to explain any bio-efficacy of Cr only on the basis of growth in the weanling pig.

Bio-efficacy of dietary chromium was also evaluated by measuring changes in blood profiles. Cr supplementation was effective (Anderson, 1995) in decreasing total cholesterol and low density lipoprotein (LDL) cholesterol, as well as triglyceride, but increased high density lipoprotein (HDL) cholesterol. However, Matthews et al. (2001) reported that plasma glucose, total cholesterol, urea N, and HDL cholesterol were not affected by dietary supplementation of CrPic or Cr propionate. The reason for these contradictory results is not known yet but certainly evokes further research including comparison among the sources of Cr.

This study was therefore executed to evaluate different sources of supplemental chromium on growth performance, nutrient digestibility, blood profiles and carcass traits in growing-finishing pigs.

MATERIALS AND METHODS

Experimental design and procedures

Sources of chromium employed for this study were chromium chloride ($CrCl_3 \cdot 6H_2O$, Kanto chemical Co., Inc.), chromium tripicolinate (CrPic; Chrom-Pico, TMC products, Korea) and chromium methionine (CrMet, manufactured in the author's laboratory by the patented procedure, Korea patent 0543107). Five treatments were designated as follows according to the source of dietary supplemental chromium: i) Control (No chromium): corn-soybean meal based basal diet, ii) $CrCl_3$: Control+200 ppb Cr as $CrCl_3$, iii) CrPic: Control+200 ppb Cr as CrPic, iv) CrMet-1: Control +100 ppb Cr as CrMet and v) CrMet-2: Control+200 ppb Cr as CrMet.

Four corn-soybean meal based basal diets were prepared for pigs with respective growth phases; 8-20 kg, 20-50 kg, 50-90 kg and 90-110 kg. The corn-soybean meal basal diet was formulated to meet or marginally exceed the nutrient requirements of pigs for the respective growth phase (NRC, 1998).

Formula and calculated nutrient composition of each basal diet are shown into Table 1. A total of 200 crossbred pigs ((Landrace×Yorkshire)×Duroc), comprised of 120 barrows and 80 gilts, were employed for this study. A randomized complete block design was employed and pigs were allotted on the basis of similar initial weight. All treatments at each phase had four replicates with ten pigs per replicate. The average initial weight of the pigs was 8.5 kg. Body weight gain and feed consumption were recorded every 2 weeks until the end of the experiment. Pigs were allowed *ad libitum* access to the experimental diets and tap water. The protocol for experimental animal care was approved by the Laboratory Animal Care and Use Committee of Kangwon National University.

Nutrient digestibility trial and analysis

Acid insoluble ash (AIA), which is celite, was used as an indigestible marker for the nutrient digestibility trial. AIA was determined according to the method of McCarthy et al. (1974). Nutrient analysis of feed and feces was performed according to the official methods of the AOAC (1990). Apparent nutrient digestibility was calculated from the concentration of AIA and nutrient in the feed and feces (%, dry matter) according to the following formula:

$$\text{Apparent nutrient digestibility (\%)} = 100 \times \left(1 - \frac{\text{AIA in feed}}{\text{AIA in feces}} \times \frac{\text{nutrient in feces}}{\text{nutrient in feed}}\right)$$

Blood analysis

Blood samples were collected from two pigs per replicate, totaling 8 pigs per treatment, at the termination of each growth phase. All blood samples were obtained via the anterior vena cava and then stored on ice for approximately 4 to 6 h until they were centrifuged at 3,000 rpm for 15 min at 4°C for serum separation. The serum was then frozen (-80°C) and eventually analyzed for blood urea nitrogen (BUN), creatinine (Creat), total protein (TP), cholesterol (Chol), and triglyceride (TG) using a VETEX analyzer (Bayer, Leverkusen, Germany) with laboratory grade reagents (Alfa Wassermann, Netherland).

Carcass evaluation

Upon termination of the feeding experiment, three pigs per replicate, totaling 12 pigs per treatment, were slaughtered for evaluation of carcass traits. All pigs were humanely killed (electrically stunned followed by exsanguination), dehaired, and eviscerated. The head was removed and the carcass was split longitudinally. All pigs were slaughtered in a commercial facility and hot carcass weights were obtained to calculate dressing percentage by

Table 1. Formula and chemical composition of basal diets

Ingredient	Growth phase of pigs (body weight)			
	8-20 kg	20-50 kg	50-90 kg	90-110 kg
Corn	33.42	37.30	41.03	41.03
Soybean meal	18.00	16.50	-	-
Dehulled soybean meal	15.00	10.00	25.05	25.05
Wheat middling	20.00	22.70	22.00	22.00
Rice bran	1.70	1.00	-	-
Cotton seed meal	1.00	2.00	3.00	3.00
Fish meal	2.00	1.00	-	-
Molasses	1.00	2.00	2.00	2.00
Beef tallow	5.70	5.50	5.35	5.35
Dicalcium phosphate	0.79	0.59	0.71	0.71
Limestone	0.50	0.68	0.15	0.15
Salt	0.26	0.30	0.30	0.30
Trace minerals premix[1]	0.15	0.15	0.15	0.15
Vitamins premix[2]	0.15	0.15	0.15	0.15
DL-methionine	0.07	0.02	-	-
L-lysine	0.10	0.11	0.11	0.11
Lincomycin	0.08	-	-	-
Colistin	0.08	-	-	-
Calculated composition				
Crude protein (%)	22.43	19.83	19.22	19.22
Crude fat (%)	7.76	7.62	7.25	7.25
Ash (%)	5.00	4.59	4.29	4.29
Ca (%)	0.64	0.61	0.57	0.57
Total P (%)	0.56	0.50	0.49	0.49
Lysine (%)	1.29	1.12	1.06	1.06
Methionine+cystein (%)	0.79	0.68	0.64	0.64
ME (kcal/kg)	3,492	3,452	3,452	3,452

[1] Trace mineral premix provided the following per kilogram of diet: 150 mg Fe as ferrous sulfate; 75 mg Cu as copper sulfate; 97.5 mg Zn as zinc sulfate; 60 mg Mn as manganese sulfate; 1.05 mg I as ethylenediamine dihydriodide; 0.3 mg Co as cobalt sulfate; 0.3 mg Se as sodium selenite with calcium carbonate as the carrier.

[2] Vitamin premix provided the following per kilogram of diet: Vitamin A, 18,000 IU; vitamin D_3, 4,500 IU; vitamin E, 60 mg; vitamin K_3, 3.6 mg; thiamin, 1.8 mg; riboflavin, 6 mg; niacin, 22.5 mg; pantothenic acid, 15 mg; pyridoxine, 3 mg; folic acid, 0.6 mg; vitamin B_{12}, 30 μg.

hot carcass weight/live weight×100%. Selected carcass measurements were executed following a 24-h chill at 2°C. The right side of the carcass was split between the 10th and 11th ribs to obtain backfat thickness and LMA. Tenth-rib backfat thickness was measured at three-fourths of the distance from the midline to the end of the *Longissimus* muscle, and LMA was traced as the area after perpendicular cut between the 10th and 11th ribs. The percentage of lean in hot carcass weight was estimated using the equation and procedure outlined by the NPPC (1991).

Statistical analysis

For statistical analysis, all of the collected data were processed by comparing means according to Duncan's multiple range test, using the General Liner Model (GLM) procedure of SAS program (1999).

RESULTS AND DISCUSSION

Growth performance

Growth performance of the pigs is shown in Table 2. There was a difference in growth performance between control and Cr-supplemented groups and sometimes within the Cr-supplemented groups. The difference also varied from phase to phase. Average daily gain (ADG) of pigs fed the CrPic- or CrMet-supplemented diet was higher ($p<0.05$) than that of pigs fed the control diet. Within the sources of Cr, body weight gain of pigs fed $CrCl_3$ was lower than CrPic and CrMet with more magnitude on CrPic ($p<0.05$) than CrMet. In overall terms, average daily feed intake (ADFI) was not different among treatments although there was a difference in ADFI in a certain phase. Therefore, Feed/Gain (F/G) was improved ($p<0.05$) by dietary Cr supplementation compared to the control but with only numerical ($p>0.05$) improvement by inorganic $CrCl_3$ supplementation. Within the CrMet supplementation group, F/G was better with 200 ppb (CrMet-2) supplementation than with 100 ppb (CrMet-1). However, there was no such difference in ADG and ADFI between CrMet-2 and CrMet-1.

Growth performance data indicated that dietary Cr acted as a growth enhancer as previously reported (Lindemann et

Table 2. Effects of different sources of dietary chromium on growth performance in growing-finishing pigs[1]

Growth phase	Items	Treatments[2]					SEM
		Control	$CrCl_3$	CrPic	CrMet-1	CrMet-2	
8-20 kg	ADG (kg)	0.47^{ab}	0.45^{b}	0.50^{a}	0.49^{ab}	0.44^{b}	0.03
	ADFI (kg)	0.69^{ab}	0.67^{ab}	0.72^{a}	0.69^{ab}	0.66^{b}	0.04
	Feed:gain	1.48^{ab}	1.50^{a}	1.44^{ab}	1.42^{b}	1.48^{ab}	0.04
20-50 kg	ADG (kg)	0.60^{c}	0.66^{a}	0.66^{a}	0.63^{b}	0.67^{a}	0.02
	ADFI (kg)	1.22^{bc}	1.29^{a}	1.25^{ab}	1.20^{c}	1.22^{bc}	0.03
	Feed:gain	2.04^{a}	1.96^{b}	1.90^{bc}	1.91^{bc}	1.86^{c}	0.04
50-90 kg	ADG (kg)	0.71^{c}	0.72^{bc}	0.77^{ab}	0.78^{a}	0.79^{a}	0.05
	ADFI (kg)	2.03	2.05	2.11	2.13	2.16	0.10
	Feed:gain	2.85	2.84	2.74	2.72	2.76	0.12
90-110 kg	ADG (kg)	0.77^{b}	0.80^{ab}	0.84^{a}	0.78^{ab}	0.83^{ab}	0.05
	ADFI (kg)	2.88	2.96	2.95	2.96	2.91	0.12
	Feed:gain	3.82^{a}	3.70^{ab}	3.49^{b}	3.84^{a}	3.48^{b}	0.14
Whole period	ADG (kg)	0.64^{c}	0.66^{bc}	0.69^{a}	0.67^{ab}	0.68^{ab}	0.02
(8-110 kg)	ADFI (kg)	1.72	1.75	1.76	1.75	1.73	0.04
	Feed:gain	2.55^{a}	2.50^{ab}	2.40^{c}	2.47^{b}	2.40^{c}	0.05

[1] Data are means of four replicates with ten pigs per replicate.

[2] Treatments were designated by the source of Cr and supplementation levels (μg/kg diet): control (no chromium), $CrCl_3$ (200 ppb $CrCl_3$), CrPic (200 ppb Cr-picolinate), CrMet-1 (100 ppb Cr-methionine), and CrMet-2 (200 ppb Cr-methionine).

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

al., 1995; Mooney and Cromwell, 1995; Lindemann et al., 2008). However, the weight gain was not related to an increase in feed intake. No difference in feed intake by dietary Cr supplementation was also reported previously (Amoikon et al., 1995; Mooney and Cromwell, 1999; Matthew et al., 2003; Shelton et al., 2003; Matthew et al., 2005). Since the F/G was improved by dietary Cr in this study, it was predicted that the body weight gain could be induced by either nutrient partitioning or digestibility improvement or both. To our knowledge, there have been no direct studies that compared sources of Cr between inorganic and organic or within organic sources. The results of this study suggested that there could be a difference in bio-efficacy among Cr sources. Organic Cr sources such as CrPic and CrMet were evaluated as generally more efficient than inorganic $CrCl_3$ in regards to gain and F/G of pig. Within the organic Cr sources, growth performance did not show any difference between CrPic and CrMet, but 100ppb CrMet is supposed to have been insufficient since overall F/G was inferior ($p<0.05$) to 200 ppb CrMet.

Nutrient digestibility was improved ($p<0.05$) by dietary Cr supplementation (Table 3). Although there was some inconsistency in the digestibility of the same Cr-supplemented diet from phase to phase, all nutrients were generally more digestible with dietary Cr supplementation as previously reported by Kornegay et al. (1997). Among Cr sources, diets supplemented with CrPic and CrMet were more digestible than the $CrCl_3$-supplemented diet. In this study, there was no evident and consistent difference in nutrient digestibility between 100 ppb and 200 ppb CrMet supplementation. However, nutrient digestibility of the CrMet-1 supplemented diet was numerically less overall and statistically less ($p<0.05$) during both the 20-50 kg and 50-90 kg phases than the CrMet-2 supplemented diet. This result might partially explain the relatively poorer F/G by CrMet-1 (Table 2). Improved nutrient digestion by dietary Cr supplementation (Table 3) could also partially explain why there was an improved F/G by dietary Cr supplementation. Overall average digestibility of each diet (Table 3) was well matched to the F/G of each diet even with its scale of magnitude.

Since there have been only a limited number of studies that evaluated nutrient digestibility with dietary Cr supplementation, it is too early to say this digestibility improvement by Cr supplementation is evident and consistent. Other unpublished studies from the author's laboratory found an improvement in digestibility by CrMet supplementation compared to $CrCl_3$ supplementation. Therefore, it has become quite evident that dietary Cr could enhance the digestibility of nutrients and that enhancement could be varied by Cr source.

Blood profiles

To find any effect of dietary Cr on blood components, serum of pigs at each phase were compared with the control treatment. The serum profiles including BUN, Chol, Creat, TP and TG were measured and only meaningful items were tabulated in Table 4. BUN levels were generally lower ($p<0.05$) in pigs fed Cr-supplemented diets, but the levels were not evident and not consistent within the Cr-supplemented group. The decrease in BUN by Cr supplementation was similar to previous results (Amoikon et al., 1995; Mooney and Cromwell, 1997) but differed from other studies (Page et al., 1993; Ward et al., 1997;

Table 3. Effects of different sources of dietary chromium on nutrient digestibility in pigs[1]

Growth phase	Items	Treatments[2]					SEM
		Control	$CrCl_3$	CrPic	CrMet -1	CrMet-2	
8-20 kg	CP (%)	72.3^{b}	73.6^{b}	75.6^{a}	76.8^{a}	72.7^{b}	1.2
	EE (%)	72.3^{c}	71.4^{c}	75.5^{b}	79.3^{a}	77.3^{b}	1.5
	Ash (%)	45.0^{b}	42.4^{c}	41.6^{c}	49.5^{a}	41.6^{c}	1.5
	Energy (%)	74.4^{c}	73.9^{c}	77.3^{b}	79.4^{a}	77.8^{b}	1.1
	TCHO (%)	80.7^{c}	80.2^{c}	82.8^{b}	84.8^{a}	84.6^{a}	0.8
20-50 kg	CP (%)	77.0^{c}	81.2^{a}	79.3^{ab}	77.7^{bc}	80.8^{a}	1.6
	EE (%)	78.0^{c}	83.3^{a}	81.0^{b}	79.7^{bc}	83.6^{a}	1.6
	Ash (%)	47.9^{c}	51.5^{b}	52.1^{ab}	45.5^{c}	54.4^{a}	2.2
	Energy (%)	78.6^{b}	80.8^{a}	81.0^{a}	79.4^{ab}	80.6^{a}	1.7
	TCHO (%)	83.8^{b}	84.7^{ab}	85.4^{a}	84.7^{ab}	85.5^{a}	1.3
50-90 kg	CP (%)	76.3^{c}	73.8^{d}	80.5^{a}	78.4^{b}	82.1^{a}	1.4
	EE (%)	74.3^{d}	76.1^{c}	83.7^{b}	82.5^{b}	86.2^{a}	1.3
	Ash (%)	50.3^{b}	50.3^{b}	56.0^{a}	49.8^{b}	57.7^{a}	2.3
	Energy (%)	81.0^{c}	79.9^{c}	85.0^{a}	83.2^{b}	86.0^{a}	1.3
	TCHO (%)	87.2^{d}	87.5^{cd}	89.6^{ab}	88.6^{bc}	90.3^{a}	1.1
90-110 kg	CP (%)	78.4^{b}	82.3^{a}	81.6^{a}	80.8^{a}	81.3^{a}	1.6
	EE (%)	80.4^{c}	82.4^{bc}	86.9^{a}	86.9^{a}	82.7^{b}	1.8
	Ash (%)	47.2^{d}	54.0^{bc}	55.9^{b}	52.0^{c}	58.6^{a}	1.9
	Energy (%)	83.1^{b}	84.0^{ab}	84.9^{a}	84.4^{ab}	85.4^{a}	1.6
	TCHO (%)	88.1^{c}	89.8^{a}	89.0^{ab}	88.7^{ab}	89.1^{ab}	1.4
Whole period	CP (%)	76.0^{c}	77.7^{b}	79.2^{a}	78.4^{ab}	79.2^{a}	0.9
(8-110 kg)	EE (%)	76.2^{c}	78.3^{b}	81.8^{a}	82.1^{a}	82.5^{a}	0.8
	Ash (%)	47.6^{d}	49.6^{c}	51.4^{b}	49.2^{c}	53.1^{a}	0.9
	Energy (%)	79.3^{b}	79.6^{b}	82.1^{a}	81.6^{a}	82.4^{a}	0.8
	TCHO (%)	84.9^{b}	85.5^{b}	86.7^{a}	86.7^{a}	87.4^{a}	0.6

[1] Data are means of four replicates with ten pigs per replicate.

[2] Treatments were designated by the source of Cr and supplementation levels (μg/kg diet): control (no chromium), $CrCl_3$ (200 ppb $CrCl_3$), CrPic (200 ppb Cr-picolinate), CrMet-1 (100 ppb Cr-methionine), and CrMet-2 (200 ppb Cr-methionine).

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

Table 4. Effects of different sources of dietary chromium on serum profiles in pigs[1]

Growth phase	Items	Treatments[2]					SEM
		Control	$CrCl_3$	CrPic	CrMet-1	CrMet-2	
8-20 kg	BUN (mg/dl)	12.22^{a}	9.14^{b}	9.46^{b}	11.06^{ab}	10.26^{ab}	2.03
	Chol (mg/dl)	101.00	109.40	111.00	107.40	103.40	8.36
	Creat (mg/dl)	0.79^{ab}	0.78^{b}	0.77^{b}	0.85^{a}	0.81^{ab}	0.06
	TP (g/dl)	6.62^{b}	6.74^{b}	6.62^{b}	6.94^{ab}	7.20^{a}	0.29
	TG (mg/dl)	54.80^{ab}	56.60^{ab}	49.00^{b}	55.40^{ab}	64.20^{a}	7.22
20-50 kg	BUN (mg/dl)	18.80^{a}	13.78^{b}	14.44^{b}	14.32^{b}	12.38^{b}	1.58
	Chol (mg/dl)	108.60^{a}	100.20^{ab}	98.40^{b}	104.40^{ab}	105.80^{ab}	7.26
	Creat (mg/dl)	0.91	0.93	0.92	0.89	0.93	0.08
	TP (g/dl)	7.74	7.86	7.66	7.78	8.26	0.46
	TG (mg/dl)	46.60^{cd}	64.80^{a}	39.80^{d}	55.60^{b}	51.60^{bc}	6.31
50-90 kg	BUN (mg/dl)	17.74^{a}	14.06^{b}	14.24^{ab}	15.60^{ab}	13.52^{b}	2.68
	Chol (mg/dl)	108.40^{ab}	107.60^{ab}	101.60^{b}	115.80^{a}	98.00^{b}	8.02
	Creat (mg/dl)	1.09	1.18	1.16	1.18	1.18	0.08
	TP (g/dl)	7.62	7.90	7.48	7.68	7.54	0.39
	TG (mg/dl)	45.20^{a}	50.20^{a}	37.40^{b}	47.00^{a}	37.20^{b}	5.46
90-110 kg	BUN (mg/dl)	15.86^{ab}	16.82^{ab}	17.58^{a}	18.10^{a}	14.56^{b}	2.21
	Chol (mg/dl)	108.80^{c}	123.00^{b}	136.00^{a}	127.00^{ab}	116.40^{c}	8.82
	Creat (mg/dl)	1.29^{c}	1.52^{ab}	1.72^{a}	1.41^{bc}	1.41^{bc}	0.15
	TP (g/dl)	7.98^{c}	9.40^{ab}	9.86^{a}	8.90^{ab}	8.52^{ab}	1.09
	TG (mg/dl)	50.80^{ab}	42.00^{b}	50.40^{ab}	48.20^{ab}	56.40^{a}	6.96

[1] Data are means of four replicates with two pigs per replicate.

[2] Treatments were designated by the source of Cr and supplementation levels (μg/kg diet): control (no chromium), $CrCl_3$ (200 ppb $CrCl_3$), CrPic (200 ppb Cr-picolinate), CrMet-1 (100 ppb Cr-methionine), and CrMet-2 (200 ppb Cr-methionine).

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

Table 5. Effects of different sources dietary chromium on carcass traits of slaughtered pigs[1]

Items	Treatments[2]					SEM
	Control	$CrCl_3$	CrPic	CrMet-1	CrMet-2	
Dressing (%)	79.01	77.91	79.76	79.94	79.60	1.73
Backfat thickness (cm)	2.77[a]	2.42[ab]	2.39[ab]	2.34[ab]	1.90[b]	0.30
Loin muscle area (cm^2)	51.16	48.27	52.00	52.22	52.42	4.86
Estimated percent lean (%)	58.24[b]	59.18[ab]	60.08[ab]	60.03[ab]	63.38[a]	2.56

[1] Data are means of four replicates with three pigs per replicate.

[2] Treatments were designated by the source of Cr and supplementation levels (μg/kg diet): control (no chromium), $CrCl_3$ (200 ppb $CrCl_3$), CrPic (200 ppb Cr-picolinate), CrMet-1 (100 ppb Cr-methionine), and CrMet-2 (200 ppb Cr-methionine).

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

Matthews et al., 2001) that reported no differences. Decreased BUN by Cr supplementation could be associated with the increased body weight gain (Table 2) especially with a stronger relationship in both 20-50 kg and 50-90 kg phases. The increase of body weight gain by Cr supplementation was also matched by increased serum TP as well as Creat (Table 4). Creatinine is a product of muscle catabolism (Doornenbal et al., 1986) and has been suggested as an index of lean tissue mass in the body (Meador et al., 1968). Doornenbal et al. (1986) also demonstrated that BUN, Creat, and blood TP were related to performance and carcass traits, which supports the results of this study.

Although several studies (Page et al., 1993; Shelton et al., 2003) have shown that Cr supplementation decreases serum TG and Chol and increases HDL cholesterol in pigs and sometimes (Amoikon et al., 1995) increases plasma cholesterol, this study failed to find any consistent results in serum cholesterol and TG levels among treatments. Since the levels of blood glucose, cholesterol and TG generally fluctuate, it was difficult for this study to avoid such fluctuation. However, considering the number of observations and inconsistent values in this study, it is suggested that dietary Cr may not be directly associated with serum levels of cholesterol and TG. This suggestion is consistent with earlier studies in humans (Uustitupa et al., 1992; Hermann et al., 1994) and in pigs (Matthew et al., 2001). Therefore, the increase in body weight gain by Cr supplementation could be primarily associated with protein metabolism but is not likely to have been associated with lipid metabolism.

Carcass traits

The effect of dietary Cr supplementation on pig carcass traits is shown in Table 5. Cr supplementation decreased ($p<0.05$) backfat thickness with the highest decrease by CrMet-2 and a numerical decrease by $CrCl_3$, CrPic and CrMet-1 compared to the control. Due to the decrease of backfat thickness, the estimated lean percentage was also increased ($p<0.05$) by Cr supplementation. However, there was no such difference between control and Cr-supplemented groups in both dressing percentage and *Longissimus* muscle area (LMA).

Carcass results as well as the increased ADG (Table 2) together indicated that dietary Cr could be strongly responsible for muscular body weight gain by limiting the deposition of fatty tissue in the body. However, the increase in muscular body weight gain represented mainly the changes in proportion between muscular and fatty tissues. This meant that dietary Cr supplementation relatively weakly affected the increase of physical body size since there was no notable difference in dressing percentage and LMA.

Results of other studies (Mooney and Cromwell, 1995; Mooney and Cromwell, 1997; Matthew, 2001; Matthew et al., 2005) of dietary Cr on carcass traits varied without evident consistency. However, the relatively higher numbers of studies with pigs showed a positive response in carcass quality including decrease in backfat thickness and increase in lean percentage. The current study also suggested a beneficial effect of dietary Cr on carcass trait improvement, and there was also some difference among the sources of Cr in backfat thickness with the lowest backfat thickness observed with 200 ppb CrMet supplementation. However, it was still difficult to state there could be a significant difference between inorganic and organic Cr sources since the organic CrPic and CrMet exerted only a numerical advantage over $CrCl_3$.

In overall terms, this study showed that dietary Cr supplementation improved growth performance, diet digestibility and carcass traits, and this improvement was relatively more marked with organic Cr sources compared to an inorganic Cr source. However, there was virtually no difference between CrPic and CrMet in regards to growth performance and carcass quality. CrMet was more effective in decreasing backfat thickness compared to other Cr sources. In addition, the 200 ppb CrMet supplementation appeared to be more adequate than the 100 ppb CrMet supplementation.

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