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Effect of Chromium Picolinate Supplementation on Growth Performance and Meat Characteristics of Swine

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Abstract The purpose of this study was to evaluate the effect of supplemental chromium (Cr) in the form of chromium picolinate (CrPic) on swine growth performance, meat quality, and protein deposition in skeletal muscle. Forty-eight piglets were divided into three groups randomly, fed with three different dietary levels of Cr (common basal feedstuff supplemented with a dose of 1.61 μg/g or 3.22 μg/g CrPic, which corresponded to 0.2 and 0.4 μg/g Cr). Results indicated that during the growing period (1–35 days), pigs fed with the diet supplemented with CrPic showed no improvement in body mass, average daily gain (ADG), feed consumption, or feed conversion rate (FCR) ($P>0.05$). During the finishing period, a supplementary dose of 0.2 μg Cr/g improved daily weight gain significantly ($P<0.05$), while the situation had no significance with 0.4 μg Cr/g ($P>0.05$) supplemented. For the entire growing-finishing period, body mass increased by 3.86%, ADG rose by 6.08%, and the FCR decreased by 3.30%; levels of total muscular pigment and that in the ribeye areas significantly improved ($P<0.05$) when supplementation with 0.2 μg Cr/g ($P<0.05$) was employed. However, there were no significant changes when supplemented with 0.4 μg Cr/g. While there were no changes in yield of carcass, back fat, water holding capacity, or levels of muscular crude protein and fat ($P>0.05$) in treatment, the ratio of fat-lean and RNA/DNA increased significantly supplemented with 0.2 μg Cr/g ($P<0.05$), but there were no significance with 0.4 μg Cr/g supplementation. In addition, the muscular levels of cholesterol had slightly decreased and the content of DNA in skeletal muscle showed no marked changes with 0.2 or 0.4 μg/g Cr supplementation. In conclusion, the present results suggested that dietary Cr supplementation in the dose of 0.2 μg/g could promote the growth performance, carcass characteristics, and protein deposition.

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Introduction

Chromium is an essential trace element required by both humans and animals. The dietary chromium requirement of livestock has not yet been defined. However, it is clear that strenuous exercise, transportation, and other stress conditions may increase the organism's requirement for chromium due to the increase in its excretion (mainly in urine) [1]. A diet deficient in Cr leads to abnormalities of organic glucose and lipid metabolism [2]. Cr is used as a dietary supplement in its trivalent form as the chloride ($CrCl_3$). Low-molecular-weight organic–Cr complexes such as picolinic acid and nicotinate salt [3] have a myriad of benefits and higher organic bioavailability than inorganic forms [4], which are most often used as dietary supplements. Chromium nanocomposite (CrNano) proved to have even higher bioavailability than chromium picolinate (CrPic). However, its high cost has prevented its widespread application. Hence, the most thoroughly investigated organic Cr source is CrPic, which is used in animal husbandry for industrial production.

Several studies have claimed that Cr is an essential nutrient for body growth [5, 6]. Dietary Cr supplementation has been found to accelerate body growth and increase lean body mass in humans, experimental animals, and domestic livestock. Supplementing the diet with 0.2–0.4 μg Cr/g each day had favorable effects on body composition, reducing fat mass and weight without significantly changing lean mass [7]. Mooney reported that growth performance in piglets had improved with CrPic supplementation for 35 days [8]. Administration of Cr yeast enhanced carcass quality and protein retention in finishing lambs [9]. Some studies have reported negative results after demonstrating that dietary supplementation with CrPic had no definite effect on the growth of piglets [10, 11]. Matthews reported that supplementing the diet with 0.2 μg Cr/g in form of CrPic had only modest effects on swine growth [12]. Studies conducted on broilers receiving Cr-yeast supplements showed no significant effect on either growth or the feed conversion rate [13]. Inconsistent results regarding the beneficial effects of dietary Cr supplementation on animal growth have made this micronutrient somewhat controversial.

The factors that determine meat quality include those which affect visual quality, such as color, marbling, firmness, and maturity; factors that affect processing or packaged display quality, such as pH, color, water holding capacity, and antioxidant potential; sensory traits of tenderness, juiciness, and flavor; safety; or characteristics of the meat which affect human nutritional quality. In this study, meat quality will be emphasized more than carcass composition and percentage meat yield. A diet with supplemented CrPic can improve the quality of swine carcass [5]. Boleman et al. [11] found that the fat-lean ratio increased and back fat decreased when dietary levels of CrPic were increased in pigs, while no effect could be found on tenderness or sensory traits. However, others reported no response in carcass leanness to supplemental Cr in this form [14, 15]. Nowadays, consumers increasingly choose meat with lower levels of fat and cholesterol, higher levels of protein, and a higher fat-lean ratio for the beneficial effects of these characteristics in preventing cardiovascular diseases. Whether such indexes in meat can be improved with CrPic supplementation remains enigmatic. Nucleic acid synthesis is modified by nutritional conditions including the concentration of trace elements and the levels of protein [16]. The ratio of RNA/DNA is always employed to elevate the efficiency of protein synthesis and cellular proliferation. We attempted to determine whether under these conditions protein deposition in skeletal muscle and the fat-lean ratio could be improved with CrPic supplementation.

Currently, Cr supplements are often highly concentrated, and it is possible to accidentally overdose the diet during feed preparation [17]. In swine, Page et al. [18] found that changes in body composition took place at different levels of dietary Cr. The optimum dose of Cr for supplementation to enhance body growth and meat quality has yet to be determined.

In order to draw conclusions regarding growth and meat quality, CrPic was added to the diet during growing and finishing periods in this study. The aim was to elucidate the effect of CrPic supplementation on the growth performance and meat characteristics of swine for the entire period, in order to provide guidance to those engaged in animal husbandry on the levels of CrPic, which can usefully be added to feeds. In addition, the digestive and respiratory systems [19] of humans and swine are similar, and because of this, pigs are often used as animal models for the study of potential metabolic mechanisms of action of drugs and additives. Our study also provides data regarding the effect of Cr supplementation on growth that can be applied to children.

Materials and Methods

Animals and Groups

Forty-eight male piglets (Duroc×Landrace×Yorkshire hybrid) with an initial live average body mass of 35.72 kg were obtained from Changping experimental base of the Chinese Academy of Agricultural Sciences (CAAS), Beijing, China. Animals were quarantined for a minimum of 5 days prior to testing. All animals were asymptomatic and were released from quarantine prior to the start of the study. Piglets were housed in clean cages. The temperature and humidity were centrally controlled and recorded daily. The temperature readings ranged from 16°C to 24°C and humidity from 41% to 50%. Animals remained healthy during the period of study when normal immunization procedures were implemented. The research was approved by Institution of Animal Science and Welfare. Forty-eight piglets were divided into three groups randomly, fed with (1) common basal feedstuff, (2) basal feedstuff supplemented with 1.61 μg CrPic/g (0.26 μg Cr/g), and (3) basal feedstuff supplemented with 3.22 μg CrPic/g (0.46 μg Cr/g). The basal diets (Table 1) met or exceeded recommended nutrition levels for growing and finishing pigs of the National Research Council. Experimental periods were divided into growing (1–35 days) and finishing stages (days 36–80) by live mass.

Growth Performance and Samples Collection

Initial body mass, the slaughter live mass, and feed consumption were recorded. Average daily gain (ADG) and feed conversion rate (FCR) were calculated by the following equations.

$$\mathrm{ADG} = \text{mass increase(g)}/\text{number of days}$$
$$\mathrm{FCR} = \text{mass of food intake(g)}/\text{mass increase(g)}$$

The entire trial ended 80 days after the beginning of the administration. The animals were partially skinned lying on their back on the floor. Thereafter, the animals were suspended by the hind legs for further skinning. Carcass and noncarcass components were weighed immediately after slaughter, and carcasses were chilled at 4°C. Noncarcass components included head, skin, feet, digestive tract, liver, spleen, pancreas, and pluck. The

Table 1 Ingredient Inclusion and Chemical Composition of Basal Diet (as 2 Fed Basis) %

	Growing stage (30–60 kg)	Finishing stage (60–90 kg)
Ingredients (%)		
Corn	73.7	78.7
Soybean meal	23	18
Limestone	0.9	1
Calcium phosphate	1.1	0.9
Salt	0.3	0.4
Premix	1[a]	1[b]
Total	100	100
Nutrient levels		
Me (MJ/kg)	13.4	13.53
Crude protein (%)	15.64	13.88
Calcium (%)	0.63	0.61
Phosphorus (%)	0.52	0.47
Lysine (%)	0.83	0.68
Methionine+cystine	0.52	0.47
Threonine	0.65	0.57

[a] The premix provides vitamins and trace elements per kg diet: vitamin A 4,600 IU, vitamin D_3 3,000 IU, vitamin E 12 IU, menadione 2.5 mg, vitamin B_{12} 0.013 mg, thiamin 1.0 mg, riboflavin 3.0 mg, biotin 0.1 mg, folacin 0.5 mg, niacin 16 mg, pantothenic acid 11.0 mg, and pyridoxine 3.0 mg, Cr 60 μg, Mn 20 mg, Zn 120 mg, Fe 120 mg, Cu 145 mg, I 0.50 mg, Se 0.35 mg, and Lys 1.2 g

[b] The premix provides per kilogram completed feed included: vitamin A 3,000 IU, vitamin D_3 3,800 IU, vitamin E 10 IU, menadione 1.5 mg, vitamin B_{12} 0.008 mg, thiamin 1.0 mg, riboflavin 2.0 mg, biotin 0.1 mg, folacin 0.5 mg, niacin 10 mg, pantothenic acid 9.0 mg, and pyridoxine 3.0 mg, Cr 60 μg, Mn 50 mg, Zn 110 mg, Fe 110 mg, Cu 110 mg, I 0.50 mg, Se 0.35 mg, and Lys 1.0 g

dressed carcass was then split into fore and hind quarters and loin eye area (cm^2). The carcass was then split along the vertebral column into left and right halves using a band saw. The left half was cut into leg, loin, rack, neck and shoulder, and breast and fore shank specifications. The composition (lean, subcutaneous, and inter-muscular fat and bone content) of the overnight chilled cuts was carried out by manual dissection, and percent distribution was calculated on the basis of chilled (4°C) carcass mass.

Musculus glutaeus medius and psoas mucles samples were obtained and stored at −70°C. All muscles were judged to be of normal meat quality (no PSE or DFD meat; pale, soft, exudative (PSE); dark, firm, dry (DFD)) by visual inspection, pH, and fiber-optic probe (FOP) measurements.

Carcass Quality

Back fat (sixth and 10th ribs) was measured with a ruler. The ribeye (longissimus thoracis) area (12th rib; cm^2) was measured using the method described by the Iowa Cooperative Extension Service (Iowa State University, November, 1988; As-235).

Yield of carcass were calculated : Yield of carcass = mass of carcass/live body mass × 100%.

Fat-lean ratio was defined that the percentage of lean mass to total mass of skeletal, skin, superficial adipose tissue, and lean.

Meat Composition Assay

Levels of fat and protein in meat were calculated according to previous methods [20, 21]. Water holding capacity (WHC) was measured using drip loss method. Drip loss was assessed as the proportionate mass loss of a slice of muscle (175–185 g with thickness of 2.54 cm) that had been suspended in a plastic bag for 24 h at 2°C [22].

Level of pork cholesterol was analyzed with gas chromatography (HP-6890) [23] that contained a procedure of inlet, 350°C; Det, 3,600C; oven, 2, 500°C, 5 min, 10°C/min, 300°C, 5 min (the type of column: HP-5, phenyl methyl siloxane).

Meat color was measured by total pigment assay [24]. Immediately following carcass washing, each 10 g tissue sample was homogenized. Then, 40 ml acetone and 2 ml distilled water were added. The mixture was put into an extraction flask. After 1 ml muriatic acid (12 M) was added, the mixture was laid in a dark area for 24 h. Plained filtrate was collected with colorimetric tubes (optical path, 1 cm) after filtration. The absorbance of total pigment was read at 640 nm using a spectrophotometer (721 type, Shanghai, China); 80% acetone solution was used as a control in this assay.

Total DNA Extraction

The total DNA was extracted from tissues using the following procedures. First, samples of tissue were homogenized and placed into centrifuge tubes, to which 500 μl DNA extraction buffer [50 mM Tris–Cl (pH 8.0), 100 mM EDTA (pH 8.0), 100 mM NaCl], and proteinase K 100 μg/ml were added. The tubes were then covered with parafilm and incubated at 55°C overnight. After cooling to room temperature, an equal volume of phenol was added to form an emulsion which then separated out into two phases. The upper phase was centrifuged at 12,000×*g* for 10 min, and the precipitate was collected. The same volume of a phenol and chloroform mixture (1:1 in volume) was added to the precipitate, and the mixture was blended gently. The solid was obtained from the upper phase by precipitation (12,000×*g* for 10 min) and was then mixed with an equal volume of chloroform and re-centrifuged (12,000×*g* for 10 min) to obtain another precipitate. Following this process, the volume of ethanol was used twice to extract the total DNA. The pellet was obtained after precipitation by centrifugation at 12,000×*g* for 10 min. The upper aqueous phase was discarded, and the pellet was washed twice with 70% ethanol at 4°C. Finally, the DNA pellet was dried and then dissolved in 80 μl double distilled water and stored at −80°C until use.

Extraction of Total RNA

Extraction of RNA from tissues was carried out using trizol kits according to manufacturer's protocol (GIBCOL Company). All the instruments used to extract RNA were saturated with 0.1% diethyl-pyrocarbonate (DEPC) solution then sterilized and baked in an oven at 200°C. The dried RNA pellet was suspended in 40 μl of DEPC-treated water.

DNA and RNA Assays

Levels of muscular DNA and RNA were determined as described by Munro et al. Briefly, 10 μl of various dilutions of the DNA and RNA solutions, which had first been diluted 300× and 100×, were centrifuged, and their concentrations and purity were determined using spectrophotometry (TU-1810 Spectrometer, Pgeneral, China) to measure the OD_{260} and OD_{280} of the samples.

Results

Effect of CrPic Supplementation on Growth Performance

Results of growth performance were shown in Table 2.

There were no marked differences in growth indexes ($P>0.05$) in the period of growing. While there was an increasing tendency in ADG and a decrease in FCR, there were no significant differences ($P>0.05$).

During the finishing stage, the final body mass of swine supplemented with 0.2 μg Cr/g increased approximately 3.72 kg compared with that of control ($P<0.05$). There was no significance between pigs of high dose and control groups also in two treatments. Average body mass, daily feed consumption, and feed/gain ratio had no significant changes when supplemented with two doses of Cr ($P>0.05$) (Table 2).

For the entire period, the results indicated that the addition of 0.2 μg Cr/g increased body mass by 3.86% and ADG by 6.08% and decreased FCR by 3.30% compared to the control group, while there were no differences between high dose and control groups ($P<0.05$). As seen in Table 2, the addition of 0.2 or 0.4 μg Cr/g in diet had no effect on daily feed consumption ($P>0.05$).

Effect of CrPic Supplementation on Carcass Quality and Composition of Skeletal Muscle

As seen in Table 3, results of fat-lean ratio improved with 0.2 μg Cr/g supplementation ($P<0.05$). Compared with control, it increased by 2.92%. Supplemental 0.4 μg Cr/g had no differences on ratio of fat-lean ($P>0.05$). The ribeye area used to evaluate the meat quality improved by 2.97 cm^2 with 0.2 μg Cr/g supplementation. No significance could be observed between pigs of control group and those with 0.4 μg Cr/g supplied. In comparison to basal diet, addition of 0.2 and 0.4 μg Cr/g had no significant changes on yield of carcass and back fat in entire experimental period.

Table 2 Effect of Cr Supplementation on Growth Performance in Two Different Stages

Groups	Initial body mass (kg)	Middle/final body mass (kg)	ADG (g)	Daily feed consumption	FCR
Effect of CrPic supplementation on growth performance in growing-finishing pigs					
Control	35.77±0.47	62.32±0.40	663.75±14.50	2.02±0.04	3.04±0.01
0.2 μg/g	35.56±0.58	63.57±0.43	700.25±13.68	2.08±0.05	2.97±0.01
0.4 μg/g	35.83±0.60	62.76±0.70	673.25±13.87	2.07±0.06	2.99±0.11
Effect of CrPic supplementation on growth performance in fatting pigs					
Control	62.32±0.40	96.38±0.58 a	810.95±23.00	2.85±0.08	3.51±0.07
0.2 μg/g	63.57±0.43	100.10±0.23 b	869.76±8.72	2.91±0.07	3.35±0.02
0.4 μg/g	62.76±0.70	98.63±1.23 ab	854.05±17.41	2.94±0.19	3.44±0.08
Effect of CrPic supplementation on growth performance in entire period					
Control	35.77±0.47	96.38±0.58 c	739.15±10.53 e	2.44±0.02	3.30±0.03 g
0.2 μg/g	35.56±0.58	100.10±0.23 d	787.07±7.37 f	2.52±0.04	3.19±0.03 h
0.4 μg/g	35.83±0.60	98.63±1.23 cd	765.85±12.38 ef	2.48±0.05	3.24±0.02 gh

Means in the same column with different letters are significantly different ($P<0.05$)

Table 3 Influence of Different Doses of Cr Supplementation on Meat Quality of Pigs Expressed by Carcass Quality and Composition of Skeletal Muscle

Indexes	Control	0.2 μg/g	0.4 μg/g
Carcass quality			
Yield of carcass %	73.18±1.41	73.89±0.36	72.91±0.25
Fat-lean ratio %	54.19±0.56 b	57.11±0.53 a	55.70±0.47 ab
Back fat (cm)	3.05±0.02	2.90±0.07	2.96±0.03
The ribeye area (cm^2)	38.24±0.65 c	41.21±0.64 d	39.56±0.52 cd
Composition of skeletal muscle			
Crude protein %	21.98±0.32	22.95±0.15	22.41±0.42
Crude fat %	3.91±0.09	3.82±0.09	3.73±0.06
Cholesterol (mg/100 g)	57.69±1.52	53.30±1.68	56.52±2.84
Total pigment (OD)	0.1456±0.0042 e	0.1611±0.0031 f	0.1535±0.0054 ef
WHC	5.56±0.03	5.51±0.05	5.51±0.02

Means in the same line with different letters are significantly different ($P<0.05$)

The result show that there were no statistical significance when the supplemental dose reached 0.4 μg Cr/g. Total pigment of skeletal muscle was significantly increased when administered with 0.2 μg Cr/g (Table 3) ($P<0.05$). There were no differences on proportions of crude protein, crude fat, or cholesterol in skeletal muscle and also its water holding capacity after administration of CrPic to pigs.

Levels of Total DNA and RNA in Skeletal Muscle

DNA and RNA were extracted from skeletal muscle. There was no significant variation in level of total DNA among two supplements and control groups ($P>0.05$) (Table 4). Total content of RNA was significantly increased by 0.036 μg/g with 0.2 μg Cr/g supplementation compared with that of control, and its ratio of RNA/DNA was also significantly improved ($P<0.05$), while there was no significance on RNA level and ratio of RNA/DNA with 0.4 μg Cr/g supplied in diet.

Discussion

Cr (III) helps insulin to metabolize fat, turn protein into muscle, and convert sugar into energy. The results obtained from our study showed that dietary supplementation with

Table 4 Influence of Different Doses of Cr Supplementation on Level of Nucleic Acid in Skeletal Muscle

Groups	Concentration (μg/ml)		Ratio of RNA/DNA
	RNA	DNA	
Control	0.5211±0.009 a	2.0473±0.0047	0.2545±0.0047 c
0.2 μg/g	0.5570±0.0059 b	2.0701±0.0352	0.2693±0.0044 d
0.4 μg/g	0.5430±0.0081 ab	2.0550±0.0419	0.2644±0.0023 cd

Means in the same column with different letters are significantly different ($P<0.05$)

CrPic had no significant effect on growth performance in growing pigs. Based on the values obtained for certain indexes in growing pigs, there were no effects on mass gain, ADG, daily food consumption, or FCR. In contrast, differences in final body mass were observed in finishing pigs fed on diets supplemented with 0.2 μg Cr/g. During the growing-finishing period, administration of 0.2 μg Cr/g lowered FCR and improved the final body mass and ADG in swine. Similar results have been reported in Cr-treated growing-finishing pigs. The addition of 0.2 μg Cr/g of to the diet increased the average daily gain and feed intake but did not alter FCR [8], while contrasting results indicated that supplementation of the basal diet with 0.3 μg Cr/g did not affect growth performance in young growing pigs [10].

Several reports [8, 18] have indicated that supplemental Cr may be beneficial to swine and sheep by decreasing body fat and increasing lean meat production. Increasing the $CrCl_3$ level from 25 to 200 mg/kg in the feed for turkeys [25] generally improved breast size. In broilers [26], supplementation of the feed with 0.4 μg/g in the form of Cr-yeast increased the yield of breast muscle. The ribeye area showed a significant improvement in yield with the addition of 0.2 μg CrPic/g. However, there were no changes in the yield of carcass when compared with controls. Chromium enhances the action of insulin by facilitating its binding to target cell receptors and also by improving its post-receptor signaling. Insulin increases protein synthesis; carbohydrate and lipid utilization also has an effect on amino acid transport leading to a reduction in the rate of protein degradation [27]. Results showed that the fat-lean ratio had increased after dietary supplementation with 0.2 μg Cr/g. Energy metabolism during the two periods of body growth is different in swine. During the growing period, dietary nutrients were mainly used to synthesize protein for body development. As the growth rate decreased, excess energy was converted into fat, which was deposited in the subcutaneous tissue. After supplementation of the diet with CrPic, a slight decrease both in back fat and fat composition of the carcass was observed together with a modest increase in crude protein. The level of cholesterol in skeletal muscle decreased slightly. Addition of Cr to the diet was reported to increase carcass leanness and decrease carcass fatness [26]. It has been reported that the area of the longissimus muscle and the percentage of muscle increased and that fat around the 10th rib was reduced when CrPic was added to the diets of growing-finishing pigs [18]. However, inconsistent or negative results regarding the effect of CrPic or $CrCl_3$ supplementation on carcass traits have also been reported [8, 10]. O'Quinnb et al. [28] reported that CrPic decreased drip loss and marbling and that Cr nicotinate decreased subjective color of loin muscle and the saturation index in gilts. Sensory and shear force values were not affected by the administration of 0.2 μg Cr/g in growing-finishing pigs [11]. Our data indicated that the total pigment of the skeletal muscle had markedly increased and that changes in the WHC were not significant. There have also been studies which have reported on the influence of Cr supplementation on muscle mass and body fatness in humans; it was found that supplementing the diet with 0.2 μg Cr/g in the form of CrPic did not promote mass loss or changes in body composition [29, 30]. Another study concluded that CrPic supplementation (3.22 μg/day nearly 0.4 μg Cr/g for 9–12 weeks) failed to favorably influence body composition changes during weight-loss interventions [31]. The effect of Cr supplementation on body composition is influenced by the in vivo conditions, such as general nutrition, environment, and levels of organic Cr. The organism would not be expected to respond to excessive supplementation.

The level of DNA in the tissue was used as an estimate of cellular development and in particular as an index of the cell number. Generally, a high concentration of DNA indicates that there are a large number of cells of small volume. Supplemental CrPic in feedstuff did not increase the total DNA concentration of the tissue, which indicates that Cr has only a moderate effect on cellular proliferation. The total RNA concentration is an indicator of the

level of protein synthesis taking place in the cells [32]; because ribosomal RNA accounts for most of the total RNA, an increase in this parameter does not necessarily reflect a significant increase in tissue protein content [33]. In this respect, the level of RNA indicates the potential substrate or energy availability for protein synthesis, the hormone and metabolite concentration, and the previous nutritional status of the animal [34]. The ratio of RNA/DNA reflects recent growth and is an index of the cell's synthetic capacity [30]. In response to 0.2 μg Cr/g supplementation, the level of muscular RNA and the ratio of RNA/DNA increased, which demonstrates that Cr contributes to the promotion of RNA synthesis and regulates the translation process for proteins in muscle cells. Our conclusions concur with a previous report which suggests that protein metabolism was improved by Cr^{3+} supplementation [35]. Overuse of Cr may not benefit nucleic acid synthesis. The results indicated that the concentration of RNA and ratio of RNA/DNA did not change significantly when dietary Cr was increased to 0.4 μg/g. Since the fat-lean ratio increased in our study, protein deposition in growing-finishing pigs may be attributable to CrPic supplementation. Previous results conducted in longissimus muscle showed that the concentration of RNA and ratio of RNA/DNA increased with 0.2 μg Cr/g supplementation [6].

Overuse of Cr is not beneficial to either humans or animals. Dietary intake of Cr in the USA and most industrialized countries is suboptimal [36]. Results showed that indexes of growth performance and carcass characteristics were favorably regulated when the supplemental dose of CrPic was set at 0.2 μg Cr/g [11, 18, 37]; however, there were no significant differences in these characteristics when the concentration of CrPic was increased to 0.4 μg Cr/g. Therefore, a suitable concentration of Cr in the form of CrPic for supplementation of the diet for pigs was concluded to be 1.61 μg/g (nearly 0.2 μg Cr/g).

In conclusion, the present results suggested that dietary Cr supplementation in the dose of 0.2 μg/g could promote the growth performance, carcass characteristics, and protein deposition.

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