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Effects of Supplemental Chromium Source and Concentration on Growth Performance, Carcass Traits, and Meat Quality of Broilers Under Heat Stress Conditions

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Abstract The objective of this study was to investigate the effects of dietary supplemental chromium (Cr) on growth performance, carcass traits, and meat quality of broilers reared under heat stress. A total of 252 1-d-old Cobb 500 commercial female broilers were randomly allotted by body weight (BW) to one of six replicate cages (six broilers per cage) for each of seven treatments in a completely randomized design involving a 2 × 3 factorial arrangement of treatments with three Cr sources (Cr propionate, CrPro; Cr picolinate, CrPic; Cr chloride, $CrCl_3$) and two concentrations of added Cr (0.4, or 2.0 mg of Cr/kg) plus a Cr-unsupplemented control group. Feed and distilled-deionized water were available ad libitum for an experimental phase of 42 days. For induction of heat stress, the house temperature was set at 33 ± 2 °C from 15 to 42 days of age. Results showed that birds supplemented with Cr, regardless of Cr source, had increased ADG ($P = 0.032$) than controls. Birds fed 2.0 mg Cr/kg diet had greater ADG ($P = 0.005$) than birds fed 0.4 mg Cr/kg diet. Compared to controls, birds fed with Cr had greater dressing percentage ($P = 0.021$). Percentage of abdominal fat decreased ($P = 0.013$), whereas, breast intramuscular fat (IMF) remained unaffected ($P = 0.147$) in Cr supplemented vs control broilers. Broilers supplemented Cr had decreased b^* values of meat color ($P = 0.042$) in breast muscle. B^*values were also lesser ($P = 0.049$) in birds fed CrPro than birds supplemented with $CrCl_3$ or CrPic. Regardless of Cr source, the percentage of cooking loss was decreased ($P = 0.025$) with Cr supplementation in breast muscle when compared to controls. Results from this study indicate that Cr supplementation, independent of its source, could promote growth and improve carcass traits and meat quality of broilers under heat stress conditions. Chromium propionate seems to have greater beneficial effects on meat color in comparison with CrPic and $CrCl_3$.

Keywords Chromium · Growth performance · Carcass characteristics · Meat quality · Broilers · Heat stress

Introduction

Chronic heat stress is of great concern in all aspects of poultry production due to decreases in weight gain [1] and feed intake [2]. Exposure to high ambient temperatures has been shown, as well, to cause undesirable changes in meat quality [3] and a deterioration in antioxidants status which can lead to depressed immunity [4, 5] in broilers. Alleviating the negative effects of high environmental temperatures on performance and meat quality of broilers by nutritional means may increase profitability, and in addition, enhance animal well-being.

Chromium functions by potentiating the action of insulin. Research suggests that Cr enhances insulin action by binding to an oligopeptide (chromodulin) that amplifies insulin receptor tyrosine kinase activity [6]. Although there is no established Cr requirement for poultry (NRC, 1997) [7], various studies involving broilers fed supplemental Cr have shown a positive effect on growth performance [8–10], carcass traits [8, 9], and immunity [11, 12] when under heat stress conditions. Dietary supplementation with CrMet to broilers subjected to heat stress increased feed intake and body weight gain, resulting in an improvement in performance. Moreover, supplemental CrMet modulated suppressive effects of heat

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stress on cellular and humoral immune responses [12]. In most of the studies, beneficial effects of supplemental Cr were obtained under heat stress; however, the results have been inconsistent. Ghazi et al. [13] reported that growth performance of heat-stress broilers were not affected by dietary Cr supplementation (0, 0.6, 1.2 mg Cr/kg from $CrCl_3$ or CrMet). Moeini et al. [14] also showed no difference in body mass, feed intake, and conversion ratio of heat-stress broilers fed diets containing 0, 0.8, or 1.2 mg Cr/kg from $CrCl_3$ or CrMet. The lack of agreement among these studies may be partially explained by the Cr sources, supplemental Cr concentration, and/or Cr concentration in the basal diets.

The Cr sources used in most of the studies include inorganic Cr Chloride, ($CrCl_3$), and organic sources (Cr nicotinate, CrNic; Cr yeast, CrY; Cr methionine, CrMet; and Cr picolinate, CrPic). In most studies, organic Cr has been added in the form of CrPic or CrMet [8–14]. Chromium propionate (CrPro), as a new organic Cr additive, is permitted as a source of supplemental Cr for swine and cattle feed by the US Food and Drug Administration (FDA) [15]. Chromium propionate has not been evaluated as a source of Cr for broilers under heat stress. Therefore, the objective of this study was to compare the efficacy of different concentrations (0.4 or 2.0 mg/kg diet) of supplemental organic (CrPic, CrPro) and inorganic Cr ($CrCl_3$) in heat-stress broiler chickens.

Materials and Methods

Birds, Diets, and Treatments

All experimental procedures described herein were approved by the Chinese Southwest University for Nationalities Animal Care and Use Committee. The experiment was conducted using 252 commercial 1-day-old Cobb 500 female broilers. Birds were individually weighed and randomly allotted by BW to one of seven dietary treatments, in order to have similar BW averages across treatments and cages. Each treatment consisted of six replicate cages that contained six birds per cage. Broilers were housed in electrically heated, thermostatically controlled cages (length 100 cm × width 50 cm × height 45 cm) with each containing fiberglass feeders and water troughs. Temperature was set at 34 °C during the first week of age. For induction of heat stress, the house temperature was set at 33 ± 2 °C from 15 days of age until the end of the trial at day 42 [8, 11, 16] and relative humidity at 67 %, while the lighting program consisted of 23 h of light and 1 h of darkness. Birds were allowed ad libitum access to experimental diets and water during the 42-day study. Body weight and feed consumption of each replicate cage were recorded every 21 days.

The corn-soybean meal basal diets (Table 1) were formulated to meet or exceed the nutrient requirements of broilers (NRC, 1994) [17]. A starter diet was fed from days 1–21 and a grower diet was fed the last 21 days of the study. The seven dietary treatments included the unsupplemented basal control diet, and the basal diet supplemented with Cr at 0.4, or 2.0 mg Cr/kg from Cr chloride ($CrCl_3$, contained 19.32 % Cr, reagent grade), Cr propionate (CrPro, contained 0.120 % analyzed Cr, Kemin Industries (Zhuhai), Inc. Zhuhai, P. R. China), or Cr picolinate (CrPic, contained 0.113 % analyzed Cr, Mianyang Sinyiml Chemical Co., Ltd. Mianyang, P. R. China). Thus, the experimental design was a 3 × 2 factorial arrangement of treatments involving three sources of Cr offered at two concentrations plus a basal unsupplemented control. Briefly, first a single batch of basal feed was mixed and then divided into seven aliquots for each experimental treatment. Each Cr

Table 1 Composition of the basal diets for broilers

Item[a] (% unless noted)	Starter (days 1–21)	Grower (days 22–42)
Ingredient		
Ground yellow maize	56.37	62.40
Soybean meal (43.81 % CP)	32.05	25.32
Soybean oil	3.00	3.60
Corn gluten meal	4.50	5.10
Calcium hydrogen phosphate[b]	1.90	1.34
Ground limestone[b]	1.23	1.36
Salt	0.30	0.30
L-Lysine HCl	0.07	0.13
DL-Methionine	0.18	0.05
Micronutrients[c]	0.20	0.20
Maize starch + Cr[d]	0.20	0.20
Nutrient composition (calculated)		
ME (MJ/kg)	12.55	13.01
CP	21.52	19.43
Lysine	1.10	1.00
Methionine	0.54	0.38
Methionine + cysteine	0.90	0.72
Calcium	1.00	0.90
Available phosphorus	0.45	0.35
Chromium analyzed (mg/kg)	0.35	0.37

[a] Ingredient and nutrient composition are reported on as-fed basis

[b] Reagent grade

[c] Provided the following per kilogram of diet: vitamin A (all-trans retinol acetate), 15,000 IU; cholecalciferol, 3900 IU; vitamin E (all-rac-α-tocopherolacetate), 30 IU; vitamin K (menadione sodium bisulfate), 3.0 mg; thiamin (thiamin mononitrate), 2.4 mg; riboflavin, 9.0 mg; vitamin B_6, 4.5 mg; vitamin B_{12}, 0.021 mg; calcium pantothenate, 30 mg; niacin, 45 mg; folic acid, 1.2 mg; biotin, 0.18 mg; choline (choline chloride), 500 mg; Cu ($CuSO_4$·5H2O), 8 mg; Mn ($MnSO_4 \cdot H_2O$), 80 mg; Fe ($FeSO_4 \cdot 7H_2O$), 80 mg; Zn (ZnSO4·7H2O), 40 mg; I ($Ca(IO_3)_2$), 0.35 mg; Se (Na_2SeO_3), 0.15 mg; and antioxidant, 100 mg

[d] Cr supplements were added in replacement of equivalent weights of maize starch

source was then mixed with corn starch to the same weight and then mixed with each aliquot of the basal diets to provide their appropriate concentrations. Chromium concentration in organic Cr sources (CrPro and CrPic) and basal diet were initially analyzed by atomic absorption spectrophotometry using a graphite furnace (SOLAAR S2 Series; Thermo Electron, Cheshire, CT) according to Padmavathi et al. (2010) [18] after being digested on a hotplate using 50-ml beakers with 20 ml trace metal grade nitric acid.

Sample Collection and Analysis

On day 42 of the experiment, two broilers from each cage were selected, according to the average BW, within the cage following a 12-h fast, weighed individually, and harvested according to the welfare of animal slaughter regulations of China. Carcass weight measurements were collected after defeathering. The heads, necks, and feet were removed, carcasses were eviscerated, and then carcasses were weighed to determine the eviscerated yield percentage. Dressing percentage was calculated by dividing the carcass weight by live BW. Abdominal fat (leaf fat surrounding the cloaca and abdominal fat surrounding the gizzard) and the left breast and leg muscles were removed and weighed to determine the amount of each tissue type. The percentage of abdominal fat was calculated by dividing the weight of abdominal fat by (eviscerated weight + abdominal fat weight); the percentage of breast and leg muscles were calculated by dividing the breast and leg weight by eviscerated weight. After being weighed, the left and right breast muscles were separated and used for pH, color, intramuscular fat (IMF) content, cooking loss, and shear force determination as described below.

Muscle pH and Color Measurements

Fifteen minutes post harvest, the left breast muscle pH was measured on each specimen at three different locations at a depth of 2.5 cm below the muscle surface using a Model R. Matthaus PH-STAR meter (MATTHAUS Corporation, Germany) equipped with a spear electrode. Then the left breasts were placed in individual polyethylene bags and stored at 4 °C for 24 h. The 24-h pH was then measured in the same manner as the pH 15 min. The color of meat was measured by three variables in triplicate at 24 h postmortem using a portable colorimeter (model: CR-400, Konica Minolta Investment Ltd., Japan) and then reported using the CIE system values of L^* (brightness; 0 = black, 100 = white), a^* (redness/greenness; positive values = red, negative values = green), and b^* (yellowness/blueness; positive values = yellow, negative values = blue) [19].

Cooking Loss and Shear Force Determinations

The right breast subsample was weighed and heated in plastic bags in a water bath at 80 to 85 °C until the temperature of the meat center reached 75 °C. After cooking, the samples were removed from the water bath, blotted dry, allowed to remain at room temperature for 15 min, and then weighed. Cooking loss was calculated as the difference in sample weight before and after cooking and expressed as a percentage of the initial sample weight [20].

Samples from cooking loss determination were then used for tenderness analysis. Muscles were cut into 3 × 0.5 × 0.5 cm small pieces parallel with the muscle fibers. Shear force was measured using a Ta-XT-Plus Texture Analyzer (No. 11056, Stable Micro Systems, Vionna Court, Lammas Road, Godalming, Surrey, GU7 1YL UK) with a blade probe. The measurement pattern of the probe was force in compression. The mode of operation for the probe was total cycle consisting of a downstream speed at 2.00 mm/s, return speed at 10.00 mm/s, and down distance at 20 mm. The texture analyzer was controlled via Texture Expert V1 Software and was utilized to record compression data and generate force determination curves [21].

Intramuscular Fat Determination

Intramuscular fat was determined on air dry basis using the Soxtec Avanti System (Foss tecator, model 2055, Foss North America, Eden Prairie, MN, USA) according to the AOAC (1990) [22].

Statistical Analysis

To test the effect of Cr supplementation, data were analyzed using single degree of freedom contrast to compare all supplemental Cr treatments with the control [23]. Data excluding the control were further analyzed by ANOVA using the MIXED procedure of the SAS software [24]. Replicate cage served as the experimental unit. The model included the main effects of Cr source and Cr concentration and their interaction. Significance was declared at $P \le 0.05$ and tendencies are discussed at $0.05 < P < 0.10$ [24]. Treatment effects were separated using least squares means with the PDIFF option. Data are presented as means ± SE.

Results

Growth Performance

No interactions between Cr source and Cr concentration were observed on overall growth performance of broilers ($P > 0.14$) (Table 2). Birds supplemented with Cr, regardless of Cr

Table 2 Effects of Cr source and concentration on performance of broilers during 0–6 weeks of age

Item	Cr concentration (mg/kg)	ADG (g/day)	ADFI (g/day)	FCR
Control	0	35.10 ± 0.95*	65.44 ± 3.14	1.86 ± 0.01
CrPro	0.4	35.53 ± 0.97	66.72 ± 3.35	1.88 ± 0.09
	2.0	37.33 ± 1.88	67.14 ± 2.39	1.80 ± 0.01
CrPic	0.4	35.71 ± 1.99	64.73 ± 4.39	1.82 ± 0.11
	2.0	36.60 ± 1.00	66.61 ± 3.10	1.82 ± 0.05
$CrCl_3$	0.4	35.56 ± 0.61	64.81 ± 2.55	1.82 ± 0.04
	2.0	37.27 ± 1.64	65.09 ± 2.19	1.75 ± 0.04
Source	CrPro	36.43	66.93	1.84
	CrPic	36.16	65.672	1.82
	$CrCl_3$	36.42	64.95	1.79
SEM		0.416	0.923	0.027
Concentration	0.4	35.60[a]	65.429	1.84
	2.0	37.07[b]	66.28	1.79
SEM		0.340	0.754	0.022
P value				
Control vs added Cr		0.032	0.764	0.228
Source		0.872	0.320	0.399
Concentration		0.005	0.426	0.107
Interaction		0.700	0.794	0.487

Data are means ± SE. Each value represents the mean of 6 cages with 6 broilers/cage (2 broilers harvested/cage) of individual treatment

ADG average daily gain, *ADFI* average daily feed intake, *FCR* feed conversion ratio = feed/gain, *CrPro* supplemented with Cr propionate (0.120 % Cr), *CrPic* supplemented with Cr picolinate (0.113 % Cr), *$CrCl_3$* supplemented with Cr chloride (19.32 % Cr, reagent grade)

*Means different ($P < 0.05$) from all Cr-supplemental groups

[a, b] Means within a row without a common superscript letter are different ($P < 0.05$)

source, had increased ADG ($P = 0.032$) than controls. Birds fed 2.0 mg Cr/kg diet had greater ADG ($P = 0.005$) than birds fed 0.4 mg Cr/kg diet. Average daily feed intake (ADFI) was not affected by dietary treatments ($P = 0.135$).

Carcass Characteristics and Breast Intramuscular Fat

The carcass traits determined in this study were not affected by Cr source ($P > 0.28$) or the interaction ($P > 0.25$) between Cr source and supplemental Cr concentration (Table 3). Supplemental Cr concentration did not affect ($P > 0.45$) live body weight, percentage of eviscerated yield, and percentage of breast muscle or thigh muscle, but did affect dressing percentage and percentage of abdominal fat (Table 3). Birds fed diets supplemented with 0.4 or 2.0 mg Cr/kg had greater dressing percentage ($P = 0.021$) and lesser abdominal fat percentage ($P = 0.013$) than birds fed the control diet, but no differences ($P > 0.12$) were observed in broilers fed 0.4 mg Cr/kg vs those fed 2.0 mg Cr/kg treatment for the same parameters. Breast IMF was not affected ($P > 0.64$) by Cr concentration and the interaction between Cr source and supplemental Cr concentration (Table 3), but tended to be affected by Cr source. Broilers fed Cr from CrPro tended to ($P = 0.071$) have a greater IMF compared with those fed Cr from CrPic or $CrCl_3$.

Breast Muscle Meat Quality

None of the meat quality indices measured in this study were affected by Cr source or the interaction between Cr sources and supplemental Cr concentration (Table 4). The L^* and a^* meat color values, 15-min and 24-h pH values, and shear force were not affected by supplemental Cr concentration ($P > 0.37$) or source ($P > 0.33$). However, the b^* values and cooking loss percentage were affected by supplemental Cr concentration (Table 4). Birds fed supplemental Cr had lesser b^* values ($P = 0.042$), as well as lesser cooking loss percentage ($P = 0.025$) than birds fed with control diets. However, there were no significant differences ($P > 0.49$) observed in these same parameters between the broilers fed the 0.4 or 2.0 mg Cr/kg treatments. Birds supplemented with CrPro had lower ($P = 0.049$) b^* meat color scores than those supplemented with CrPic or $CrCl_3$.

Table 3 Effects of Cr source and concentration on the carcass characteristics of broilers at age of 42 days

Treatment	Cr concentration (mg/kg)	Dressing (%)	Eviscerated yield (%)	Breast muscle (%)	Leg muscle (%)	Abdominal fat (%)	Breast IMF (%)
Control	0	92.98 ± 1.43*	82.13 ± 0.17	17.28 ± 2.56	15.78 ± 0.81	2.58 ± 0.35*	3.65 ± 0.50
CrPro	0.4	93.98 ± 0.79	81.76 ± 0.73	18.21 ± 2.57	15.25 ± 1.09	2.43 ± 0.17	3.51 ± 0.62
	2.0	93.69 ± 0.84	82.12 ± 0.74	17.77 ± 1.33	16.18 ± 1.10	2.25 ± 0.27	3.67 ± 0.70
CrPic	0.4	93.89 ± 0.85	82.44 ± 0.48	18.95 ± 1.51	16.37 ± 0.78	2.28 ± 0.18	3.38 ± 0.86
	2.0	93.97 ± 0.69	81.96 ± 0.34	18.10 ± 1.69	16.31 ± 0.57	2.26 ± 0.24	3.06 ± 0.50
$CrCl_3$	0.4	93.58 ± 0.52	81.78 ± 0.64	17.51 ± 1.65	15.82 ± 1.13	2.28 ± 0.32	2.99 ± 0.61
	2.0	93.83 ± 0.39	81.86 ± 0.70	18.20 ± 1.15	15.73 ± 1.07	2.26 ± 0.20	2.98 ± 0.29
Source	CrPro	93.84	81.94	17.99	15.72	2.34	3.59
	CrPic	93.93	82.20	18.53	16.34	2.27	3.22
	$CrCl_3$	93.71	81.82	17.86	15.78	2.27	2.99
SEM		0.202	0.179	0.493	0.292	0.08	0.09
Concentration	0.4	93.82	81.99	18.22	15.81	2.33	3.29
	2.0	93.83	81.98	18.02	16.07	2.26	3.24
SEM		0.165	0.146	0.403	0.240	0.102	0.143
P value							
Control-added Cr		0.021	0.437	0.652	0.528	0.013	0.147
Source		0.735	0.328	0.603	0.281	0.946	0.071
Concentration		0.954	0.936	0.727	0.453	0.124	0.780
Interaction		0.630	0.256	0.531	0.405	0.337	0.644

Data are means ± SE. Each value represents the mean of six cages with six broilers per cage (two broilers harvested/cage) of individual treatment

IMF intramuscular fat, *CrPro* supplemented with Cr propionate (0.120 % Cr), *CrPic* supplemented with Cr picolinate (0.113 % Cr), *$CrCl_3$* supplemented with Cr chloride (19.32 % Cr, reagent grade)

*Means different ($P < 0.05$) from all Cr-supplemental groups

Discussion

The current study was conducted under heat stress conditions and the results indicate that dietary Cr supplementation, regardless of Cr source, increased ADG. Similar observations have been demonstrated in previous studies examining the influence of Cr under heat stress conditions [8–10]. Several studies in broilers showed improvement in weight gain and feed conversion with Cr supplementation under conditions of induced stress. Dietary supplementation with CrMet to broilers subjected to heat stress increased feed intake and improved weight gain and feed efficiency [12]. In contrast, other studies had demonstrated no effect of dietary Cr supplementation on broiler growth performance under heat stress conditions. Ghazi et al. [13] and Moeini et al. [14] reported that growth performance of heat-stress broilers was not affected by dietary Cr supplementation from either $CrCl_3$ or CrMet. The lack of agreement among these studies may be partially explained by one or a combination of the following: (1) the source of Cr, (2) the concentration of the supplemental Cr, (3) the concentration of Cr in the basal diets, and (4) the duration and type of induced stress.

The Cr concentration in the basal diet in the studies by Ghazi et al. [13] and Moeini et al. [14] analyzed over 3.0 mg Cr/kg diet, and the lack of improvement in growth performance in these studies may be due to the high Cr concentration in the basal diets. High Cr concentration in basal diets may decrease the growth performance response to supplemental Cr in broilers. Most feed grade calcium carbonate and dicalcium phosphate, which are common additives to poultry regimens, contain high concentrations of Cr [25]. In order to reduce the Cr concentration in the basal diets of our present trial, we used reagent grade calcium carbonate and dicalcium phosphate in our study, and our diets analyzed 0.35–0.37 mg Cr/kg.

Birds fed 2.0 mg Cr/kg diet had greater ADG than birds fed 0.4 mg Cr/kg diet in the present study. Consistent with the current finding, Toghyani et al. [8] found that supplements of organic and inorganic Cr at various levels (0, 0.5, 1.0, 1.5 mg Cr/kg diet), particularly at 1.5 mg/kg, increased ADG of broilers reared under heat stress. It has also been found that increased supplemental Cr (0, 0.2, 0.4, 0.8, or 1.2 mg/kg of diet) resulted in a linear increase in body weight in broilers exposed to heat stress [26]. Stress increases Cr mobilization from tissues and its excretion by urinary output, and thus may increase Cr requirements [8]. Recently, high doses of Cr were proposed to have a pharmacological effects rather than acting as a nutritional agent [27]. Di Bona et al. [27] stated that nutritionally relevant amounts of Cr in the diet seemed to have no effect

Table 4 Effects of Cr source and concentration on meat quality of breast muscle in broilers at age of 42 days of age

Item	Cr concentration (mg/kg)	Meat color			pH value		Shear force (kg)	Cooking loss (%)
		*L**	*a**	*b**	pH 15 min	pH 24 h		
Control	0	46.26 ± 2.14	2.28 ± 0.55	9.59 ± 1.49*	6.05 ± 0.16	6.42 ± 0.26	3.47 ± 0.68	28.49 ± 1.16*
CrPro	0.4	45.36 ± 2.31	1.90 ± 0.23	7.23 ± 1.11	6.13 ± 0.25	6.47 ± 0.48	3.73 ± 0.56	26.88 ± 1.39
	2.0	47.47 ± 3.09	2.25 ± 0.50	7.42 ± 0.98	6.22 ± 0.22	6.70 ± 0.13	3.09 ± 0.72	26.56 ± 1.08
CrPic	0.4	48.61 ± 2.13	2.46 ± 0.46	8.40 ± 0.50	6.31 ± 0.12	6.35 ± 0.44	3.78 ± 0.78	27.54 ± 1.55
	2.0	45.73 ± 2.64	2.44 ± 0.76	8.38 ± 1.52	6.24 ± 0.10	6.53 ± 0.17	3.63 ± 0.65	27.53 ± 1.44
$CrCl_3$	0.4	46.67 ± 1.55	2.19 ± 0.45	9.32 ± 1.51	6.27 ± 0.14	6.36 ± 0.28	3.66 ± 0.82	26.89 ± 0.60
	2.0	48.07 ± 1.43	2.40 ± 0.80	8.42 ± 1.88	6.25 ± 0.22	6.42 ± 0.38	3.53 ± 0.64	26.81 ± 1.40
Source	CrPro	46.42	2.08	7.33^b	6.18	6.59	3.41	26.72
	CrPic	47.17	2.45	8.39^a	6.28	6.44	3.71	27.54
	$CrCl_3$	47.37	2.301	8.87^a	6.26	6.39	3.60	26.85
SEM		0.678	0.171	0.422	0.053	0.101	0.206	0.422
Concentration	0.4	46.88	2.18	8.32	6.24	6.39	3.72	27.10
	2.0	47.09	2.36	8.07	6.24	6.55	3.42	26.97
SEM		0.549	0.138	0.336	0.044	0.082	0.167	0.335
P value								
Control-added Cr		0.358	0.296	0.042	0.631	0.247	0.276	0.025
Source		0.578	0.337	0.049	0.368	0.396	0.602	0.329
Concentration		0.79	0.373	0.551	0.964	0.19	0.196	0.493
Interaction		0.270	0.745	0.611	0.545	0.833	0.606	0.803

Data are means ± SE. Each value represents the mean of six cages with six broilers/cage (two broilers harvested/cage) of individual treatment

CrPro supplemented with Cr propionate (0.120 % Cr), *CrPic* supplemented with Cr picolinate (0.113 % Cr), *$CrCl_3$* supplemented with Cr chloride (19.32 % Cr, reagent grade)

*Means different ($P < 0.05$) from all Cr-supplemental groups

[a, b] Means within a row without a common superscript letter are different ($P < 0.05$)

on plasma insulin concentrations in response to a glucose challenge in healthy Zucker lean rats; however, the highest dose of Cr (1.0 mg Cr/kg) led to lesser concentration of insulin required to restore normal glucose concentrations. Further work is required to evaluate the effect of high doses of Cr supplementation on broilers reared under stress.

Exposure of birds to high ambient temperatures has reportedly altered their carcass composition. Decreased body protein content and increased fat deposition in heat-exposed broiler chickens have been reported [1]. Previous studies performed under heat stress conditions indicated that dietary Cr supplementation had a positive effect on carcass traits [8, 9]. Toghyani et al. [8] observed that Cr supplementation from $CrCl_3$ and CrNic increased carcass yield and decreased abdominal fat. Sahin et al. [5] also reported that the hot and chilled carcass weights and yields increased, while abdominal fat decreased with dietary supplementation of CrPic (0.4 mg Cr/kg diet) fed to broilers exposed to a high ambient temperature (32 °C). Similar to the results of others, in the present study, birds fed diets supplemented with 0.4 or 2.0 mg Cr/kg had greater dressing percentage and lesser percentage of abdominal fat than birds fed with the control diets. No differences, however, were observed in broilers fed 0.4 mg Cr/kg vs those fed 2.0 mg Cr/kg treatment for the same parameters. Thus, indicating carcass traits in broilers chicks, under heat stress conditions, could improve with that relatively low supplementation of Cr (0.4 mg Cr/kg).

The effect of Cr supplementation on IMF deposition of broilers has been variable. Samanta et al. [16] reported that broilers receiving dietary $CrCl_3$ supplementation (0.5 mg/kg diet) in normal conditions had lesser meat fat content. A similar result was observed by Motozono et al. [28] who reported that crude fat content of skin-off breast meat in the 0.4 mg/kg CrPic group was lesser compared with that in 0 and 0.2 mg/kg groups. Inconsistent with aforementioned reports, Toghyani et al. [29] stated that the lipid content of meat was not affected by either supplemental Cr concentration (0, 0.5, 1.0, or 1.5 mg/kg diet) or Cr source (CrNic and $CrCl_3$) when fed to broilers reared under heat stress conditions. Similar to the results of Toghyani et al. [29], in the current heat stress study, breast IMF was not affected by Cr concentration, however, tended to be affected by Cr source in broilers. Broilers fed Cr from CrPro tended to have greater IMF compared with those fed Cr from CrPic or $CrCl_3$.

Chronic heat stress has been reported to increase the production of lactate in muscle, which in turn increased the rate of pH decline and subsequently decreased the quality of breast meat in broilers [19]. The breast and thigh muscles of birds grown under constant high temperature conditions had significantly higher lightness, cook loss, and shear force, whereas with significantly lower initial pH, ultimate pH, and redness when compared with birds reared under standard normal temperatures [19]. Little information is available on the effect of Cr supplementation on pH value, meat color, meat shear force, and cooking loss percentage in breast muscle of broilers. Some studies have been conducted in swine examining the influence of Cr supplementation on meat quality, but results have been variable. Tian et al. (2015) [30] reported supplemental Cr at 0.1, 0.4, and 0.8 mg/kg from CrMet decreased drip loss but increased shear force in growing-finishing pigs. A meta-analysis designed to quantitatively describe effects of dietary Cr supplementation on meat quality of growing-finishing swine showed no effects were detected in characteristics related to meat quality (CIE color, drip loss, cook loss, shear force) [31]. Toghyani et al. [29] observed that diets supplemented with Cr (0, 0.5, 1.0, or 1.5 mg Cr/kg diet) either in the forms of CrNic or $CrCl_3$ fed to chicks fed in heat stress conditions had no effects on pH of meat, but did increase breast meat protein especially in the organic source of Cr (CrNic). In the current experiment, birds fed supplemental Cr at both 0.4 or 2.0 mg/kg diet had lower b^* values and lesser cooking loss percentage than birds fed with control diets. Whereas the L^* and a^* values, 15-min and 24-h pH readings, and shear force were not affected by supplemental Cr. The current results indicated that as little as 0.4 mg Cr/kg supplementation could improve meat quality of heat stressed broilers by decreasing b^* values and cooking loss percentage. With the heightened awareness of meat quality in the poultry industry, the effects of Cr on meat quality need to be explored further.

Conclusions

In summary, dietary Cr supplementation increased growth performance, carcass traits, and breast meat quality of broiler chicks under heat stress conditions regardless of the source of Cr. For growth performance, Cr supplementation at 2.0 mg Cr/kg diet is more effective than 0.4 mg Cr. While Cr supplementation at either 0.4 or 2.0 mg Cr/kg diet could improve carcass traits and breast meat quality of broilers raised under heat stressed environment.

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