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Quality of meat from chickens supplemented with Chromium-Methionine

Qualidade da carne de frangos suplementados com Cromio-Metionina

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Highlights

The use of CrMet influenced meat color and ash content.
The use of CrMet in the diet did not affect the severity of myopathies.
The use of CrMet did not affect carcass characteristics and lipid peroxidation.
A higher occurrence of a Wooden Breast score of 0 was observed with the use of CrMet.

Abstract

The use of Cr has shown potentially beneficial effects when added to broiler diets. Therefore, this study was conducted to evaluate the effects of increasing levels of chromium methionine (CrMet) supplementation in broiler diets from 1 to 42 days of age on carcass traits, breast myopathies, meat quality, and composition. The study involved one-day-old male Cobb 500® broiler chickens with initial weights ranging from 45.7 to 48.5 g. The birds were distributed in a completely randomized design comprising five dietary treatments, with 10 replicate pens per treatment and 20 animals per pen, which served as the experimental unit. Treatments consisted of diets supplemented with graded levels of CrMet (0, 0.25, 0.50, 1.0, and 2.0 mg kg^{-1}). CrMet supplementation did not significantly affect (P>0.05) carcass

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traits, lipid peroxidation, or the severity of wooden breast and white striping. However, it influenced the occurrence of score 0 for wooden breast and scores 2 and 3 for white striping. Additionally, meat color and ash content were affected.
Key words: Antioxidant. Carcass. Color. Lipid oxidation. Myopathy. Organic chromium.

Resumo

Este estudo foi realizado para avaliar os efeitos de níveis graduais de inclusão de metionina-cromo (CrMet) nas dietas de frangos de corte de 1 a 42 dias de idade sobre as características da carcaça, miopatias do peito, qualidade e composição da carne do peito. O estudo envolveu frangos de corte machos de um dia, da linhagem Cobb 500®, com peso inicial entre 45,7 e 48,5 g. Os animais foram distribuídos em um delineamento inteiramente randomizado, composto por cinco tratamentos, com 10 repetições e 20 aves por repetição, que serviram como unidade experimental. Os tratamentos consistiram em dietas suplementadas com níveis graduais de CrMet (0, 0,25, 0,50, 1,0 e 2,0 mg kg^{-1}). A inclusão de CrMet nas dietas de frangos de corte não resultou em efeitos (P>0,05) nas características da carcaça, peroxidação lipídica ou severidade de *wooden breast* e *white striping.* No entanto, influenciou a ocorrência da pontuação 0 para *wooden breast* e das pontuações 2 e 3 para *white striping,* além disso, afetou a cor da carne e o teor de cinzas.
Palavras-chave: Antioxidante. Carcaça. Cor. Oxidação lipídica. Miopatia. Cromo orgânico.

Introduction

The growth of poultry production has been driven by the high development potential of chickens, achieved through genetic selection programs. However, the rapid growth rate over a short period and the large size of modern birds have led to the emergence of cardiovascular diseases, as well as various metabolic and musculoskeletal disorders. Among the abnormalities in the pectoral muscle, the most notable are white striping, wooden breast, and spaghetti meat (Hartcher & Lum, 2020; Soglia et al., 2021; Che et al., 2022).

These myopathies are also associated with a reduction in the nutritional and organoleptic quality of the meat, characterized by higher fat content and lower protein concentration (Wold et al., 2017; Baldi et al., 2019). Consequently, they compromise meat processability, resulting in undesirable texture, increased drip and cooking losses, and reduced marinade absorption capacity (Bowker & Zhuang, 2016; Dalgaard et al., 2018).

Given these challenges, poultry nutrition studies aim to identify additives and dietary strategies that reduce the incidence of myopathies without compromising performance or carcass yield at slaughter (Castilho Heiss et al., 2024).

Among these alternatives, trivalent chromium (Cr) is an essential trace element for all living organisms, playing a fundamental role in several physiological processes in animals (Han et al., 2021). Its main functions include the activation of specific

enzymes, enhancement of insulin efficiency, stabilization of proteins and nucleic acids, and regulation of carbohydrate, lipid, and amino acid metabolism (Safwat et al., 2020). As a result, Cr supplementation can contribute to improving broiler performance, meat quality, and immune function (Tian et al., 2014).

Various organic Cr sources are available, including chromium propionate (CrPro), chromium yeast (Cr-yeast), chromium nicotinate (CrNic), chromium histidine (CrHis), chromium picolinate (CrPic), and chromium methionine (CrMet) (Han et al., 2021). Youssef et al. (2022), studying chromium methionine chelate levels of 0, 50, and 100 g t^{-1} in broiler diets, reported increased carcass yield and reduced abdominal fat percentage.

Chromium (Cr) supplementation, especially in its organic forms, has shown potential benefits in improving chicken meat quality. Therefore, this study was conducted to evaluate the effects of increasing levels of chromium methionine (CrMet) in broiler diets from 1 to 42 days of age on carcass and cut yields, meat quality, breast proximate composition, and the incidence of breast myopathies.

Material and Methods

The experiment was conducted at the Poultry Research Centre of the Universidade Estadual do Oeste do Paraná (Unioeste, Marechal Cândido Rondon, PR, Brazil). All experimental procedures followed Normative Act No. 37, dated February 15, 2018, from the National Committee for the Control of Experimental Animals (CONCEA), which establishes the Euthanasia Practice Guidelines. The study also complied with the U.K. Animals (Scientific Procedures) Act, 1986, and associated guidelines, as well as EU Directive 2010/63/EU for animal experiments.

Birds, experimental design, and diets

This study involved one-day-old male Cobb 500® broiler chickens (n = 1,000) obtained from a commercial hatchery (Globoaves, Cascavel, PR, Brazil), with an initial average weight of 46.80 ± 0.59 g. The birds were assigned to a completely randomized design comprising five dietary treatments, with 10 replicate pens per treatment and 20 birds per pen, which served as the experimental unit. Treatments consisted of diets supplemented with graded levels of CrMet (0, 0.25, 0.50, 1.0, and 2.0 mg kg^{-1}). Feed and water were provided ad libitum throughout the experimental period. The diets, offered in mash form, were formulated to meet the nutritional requirements (except for selenium) according to Rostagno et al. (2017) for different phases: pre-starter, 1 to 7; starter, 8 to 21; grower, 22 to 33; and finisher, 34 to 42 days of age (Table 1). Chromium methionine was added by replacing an equivalent amount (g g^{-1}) of inert material (kaolin).

Table 1
Proximate composition, calculated, and analyzed values of basal diets. Pre-starter (days 1 to 7), starter (days 8 to 21), grower (days 22 to 33), and finisher (days 34 to 42)

Ingredients g kg^{-1}	Pre-starter	Starter	Grower	Finisher
Corn (78.8 g kg^{-1} CP)	509.10	528.00	585.90	640.00
Soybean meal (460 g kg^{-1} CP)	429.50	405.00	343.40	292.70
Soybean oil	24.49	32.55	35.01	36.79
Dicalcium phosphate	19.01	16.79	14.42	10.60
Salt	5.32	5.15	3.70	3.46
DL-Methionine (990)	3.28	3.12	2.66	2.27
Limestone	3.09	2.99	7.24	6.87
Inert	2.00	2.00	2.00	2.00
Byo-Lysine (540)	1.84	2.02	2.19	2.40
Sodium bicarbonate	-	-	1.50	1.50
Vitamin premix[1]	0.50	0.50	0.50	0.50
Mineral premix[2]	0.50	0.50	0.50	0.50
Choline Chloride	0.50	0.50	0.40	-
L-Threonine	0.45	0.44	0.33	0.24
Salinomycin (120)	0.20	0.20	0.15	-
BHT	0.10	0.10	-	-
Avilamicyn (100)	0.05	0.05	0.05	-
Calculated chemical composition, g kg^{-1}				
Met. En. (MJ)	12.46	12.77	13.08	13.40
Crude protein	242	232	209	189
Calcium	9.71	8.78	7.58	6.34
Total phosphorus	7.18	6.68	6.10	5.22
Available phosphorus	4.63	4.19	3.74	2.96
Sodium	2.25	2.18	2.00	1.90
Potassium	9.49	9.10	8.16	7.46
Digestible Lysine	13.07	12.56	11.24	10.14
Digestible Methionine	6.63	6.37	5.47	4.87
Digestible Met + Cis	9.67	9.29	8.32	7.50
Digestible Threonine	8.63	8.29	7.42	6.69
Digestible Tryptophan	2.84	2.71	2.38	2.11
Digestible Arginine	12.9	14.67	12.91	11.49
Digestible Valine	10.13	9.70	8.65	7.81
Digestible Isoleucine	9.51	9.08	8.03	7.19

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	Analyzed composition, g kg-1			
Dry matter	890.0	888.9	899.5	896.7
Crude protein	249	200	183	182
Total ash	57.0	56.4	61.5	58.6
Crude fat	45.7	43.8	56.2	54.9

[1]Content per kilogram of diet: Retinol acetate (4.8 mg); Cholecalciferol (200 mg); D-Alpha tocopherol (44.7 mg); Menadione nicotinamide bisulfite (3 mg); Thiamine (3.6 mg); Riboflavin (10 mg); Pyridoxine (4.8 mg); Cyanocobalamin (0.02 mg); Nicotinamide (54 g); Calcium pantothenate (18 mg); Folic Acid (1.65 mg); Biotin (80.0 mg)
[2]Content per kilogram of diet: Manganese sulfate (70 g); Zinc sulfate (60 g); Iron sulfate (50 g); Copper sulfate (8 g); Calcium iodate (0.8 g).

Experimental facility and housing management

The experimental house was divided into pens, each measuring 1.96 m^2, covered with wood shavings as litter material, and equipped with a semi-automatic feeder and a nipple-type drinker. Environmental control was ensured through exhaust fans, inlets, and evaporative cooling pads, while heating was provided by a commercial pellet stove. Regarding lighting, birds were exposed to 24 h of continuous light on the first day of life. From day 2 onward, lighting schedules were adjusted as follows: 23 h light and 1 h dark until day 3; 21 h light and 3 h dark until day 8; and 18 h light and 6 h dark from day 9 to day 42. Light intensity was maintained at 20 lux throughout the experiment. Environmental conditions were monitored every 5 min using a control panel (SMAAI 4, InoBram Automations, Pato Branco, Brazil).

Carcass and cut yields, and relative weights of liver and fat pad

At 42 days of age, four broilers per pen were randomly selected and fasted for 6 h. After fasting, birds were weighed, stunned by electronarcosis, and bled via a ventral neck incision. Carcasses were scalded at 60 °C for 30 s, mechanically defeathered, and eviscerated, with the removal of feet and neck. The eviscerated hot carcass and organs were weighed, then carcasses were cooled in a static ice-water mixture for 1 h and drained for 10 min. Subsequently, the carcasses were weighed again to obtain cold carcass weight.

The carcass yield was determined by dividing the absolute weight of the eviscerated carcass (without head, feet, and neck) by the live broiler weight. The yields of the breast (Pectoralis major), legs, wings, and tenders (Pectoralis minor) were obtained by dividing the absolute weight of each cut by the cold eviscerated carcass weight. The relative weights of the liver and fat pads were calculated relative to the live broiler weight.

Incidence and severity of breast muscle (Pectoralis major) myopathies

The incidence of Wooden Breast (WB) was assessed using an adaptation of the methodology described by Tijare et al. (2016),

based on a four-point scoring system. The criteria were as follows: normal (score 0, no areas of hardness or pallor); mild to moderate (score 1, slight hardness in the cranial and/or caudal areas); moderate to severe (score 2, moderate hardness throughout the muscle); and severe (score 3, characterized by superficial hemorrhage and the presence of a sterile exudate on the muscle surface).

For white striping (WS), the evaluation followed the methodology proposed by Souza et al. (2021). Striations were classified as: normal (score 0, fillets with no distinct white lines); moderate (score 1, small white lines, generally < 1 mm thick, visible on the surface); severe (score 2, thick white lines, 1 to 2 mm thick, very visible, covering less than 50% of the fillet); and extreme (score 3, whitish streaks running parallel to muscle fibers, > 2 mm thick, covering almost the entire fillet surface).

Incidence was determined by calculating the percentage of samples assigned to each score category for each treatment. For severity, mean scores were calculated per replicate, resulting in the overall severity score for each treatment.

Breast meat quality

To assess breast meat quality, various analyses were conducted on samples of the Pectoralis major, including pH, instrumental color (IC), water holding capacity (WHC), cooking loss (CL), shear force (SF), and thiobarbituric acid reactive substances (TBARS). pH and IC were measured directly on the right breast fillet at 15 min and 24 h postmortem (Olivo et al., 2001), using a portable pH meter (HI99163, HANNA Instruments, Woonsocket, RI, USA), as described. Color was measured with a colorimeter (Konica Minolta Sensing CR-400) and expressed in the CIELAB system, where L* represents lightness (higher values indicate a lighter tone), a*, redness (higher values indicate redder tone), and b*, yellowness (higher values indicate yellower tone).

Water holding capacity was determined following the methodology of Nakamura and Katoh (1981). Two rectangular samples were cut from the left breast muscle, weighed on an analytical balance, wrapped in filter paper, and centrifuged at 2,000 g for 4 min. After centrifugation, samples were dried in a forced-air oven, and WHC was calculated as the difference between initial and final weight.

Cooking loss was measured using samples from the right Pectoralis major. After initial weighing, samples were wrapped in laminated paper and cooked on a commercial electric plate at 180 °C until reaching an internal temperature of 80 °C. Once cooled to room temperature, they were reweighed, and CL was calculated based on weight loss, following the method of Honikel (1998).

Shear force was determined using the same cooked samples from the CL analysis. Three pieces (approximately 1.0 × 1.0 × 4.0 cm) were cut and analyzed using a texture analyzer (CT3™, Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA) equipped with a TA 3/100 probe and TA-SBA fixture. The equipment was calibrated at 0.01 kg force, with 20 mm deformation and 2.5 mm s^{-1} test speed. Shear force was expressed in kgf cm^{-1}, representing the force required to cut each sample.

Lipid peroxidation in the breast muscle was evaluated by TBARS analysis at 10, 30, and 60 d of storage at -20 ºC, using a method adapted from Vyncke (1975) and Sorensen and Jorgensen (1996). A 2.5 g meat sample was homogenized with 10 mL of trichloroacetic acid (7.5%) and BHT (0.2%), filtered through qualitative paper, and centrifuged (Centrifuge Kasvi K14-4000, Kasvi, São Paulo, Brazil) at 4,000 g for 10 min. A 3 mL aliquot of the filtrate was then mixed with 3 mL of thiobarbituric acid solution (0.02 M) and heated in a water bath at 80 ºC for 40 min. Absorbance was read at 538 nm using a spectrophotometer (600S, FEMTO, São Paulo, Brazil). A standard curve using 1,1,3,3-Tetraethoxypropane was used to quantify MDA concentration in the sample.

Chemical composition of breast meat (Pectoralis major)

Dry matter (DM) was determined according to AOAC method 934.01 (Association of Official Analytical Chemists [AOAC], 2012). Samples were homogenized, weighed, and oven-dried at 102 ± 2 °C for 16 to 18 h. The samples were then reweighed to calculate moisture loss and DM content.

Total ash (TA) was determined following AOAC method 942.05 (AOAC, 2012). Samples were weighed and incinerated in a muffle furnace at 600 °C to remove all organic matter, then cooled and reweighed to obtain TA content.

Crude fat (CF) was determined according to AOAC method 960.39 (AOAC, 2012). Ground and weighed samples were placed in paper cartridges in a Soxhlet extractor and washed repeatedly with petroleum ether to extract the lipids. After extraction, the cartridges were dried at room temperature for approximately one hour and subsequently in an oven, and reweighed to determine fat content by difference.

Crude protein (CP) was analyzed using the Kjeldahl method (AOAC, 2012). Samples were homogenized, digested with sulfuric acid, and distilled to release ammonia gas. Nitrogen content was determined by titration with hydrochloric acid.

Statistical procedures

The UNIVARIATE procedure was used to test data for homogeneity (Levene's test) and normality (Shapiro-Wilk test). After removing outliers, the General Linear Model (GLM) procedure was applied to perform a one-way ANOVA to test for variance among the data. When statistically significant differences were observed, Tukey's test, as well as polynomial and broken-line regression analyses, were conducted. Polynomial, broken-line, or combined equations were used individually or in combination to determine the optimal inclusion level. In cases where results did not align, the equation with the highest R^2 value was selected as the criterion for determining the most accurate predictive equation.

Data on the severity and incidence of myopathies were grouped, and the percentage of scores within each replicate was calculated. Subsequently, a nonparametric test (Kruskal-Wallis) was performed using the NPAR1WAY procedure. Mean scores were compared using the Dunn test. All analyses were conducted using the Statistical Analysis System (SAS, OnDemand Edition for Academics) at a 5% probability level.

Results and Discussion

The analysis of the experimental diets (Table 2) showed the presence of chromium (Cr) in the basal diets at concentrations of 0.02, 0.03, 0.01, and 0.02 mg kg^{-1} for the pre-starter, starter, grower, and finisher phases, respectively. The total Cr concentrations analyzed in the experimental diets were slightly higher than the calculated values for each treatment. This slight increase may be attributed to the inclusion of CrMet, an organic form of chromium that enhances its absorption and bioavailability (Barzegar Yarmohammadi et al., 2020).

Table 2
Analyzed chromium (Cr) concentrations in the experimental diets

Inclusions of CrMet, mg kg^{-1}	Cr, mg kg^{-1} (as-fed basis)			
	Pre-starter	Starter	Grower	Finisher
0.00	0.02	0.03	0.01	0.02
0.25	0.28	0.30	0.29	0.31
0.50	0.57	0.55	0.53	0.56
1.00	1.07	1.09	1.04	1.05
2.00	2.05	2.04	2.01	2.10

Pre-starter: d 1 to 7; starter: d 8 to 21; grower: d 22 to 33; finisher: d 34 to 42.

No significant effects were observed on carcass traits or the relative weights of the liver and fat pads in response to CrMet supplementation ($P \geq 0.306$; Table 3). The study was conducted under optimal conditions, without experimental challenges, and with birds kept in a fully controlled environment, which likely contributed to the absence of differences in carcass yield among treatments. Chromium contributes to improving animal performance by stimulating the secretion of digestive enzymes, thereby optimizing nutrient absorption and utilization. Furthermore, this element is a component of the glucose tolerance factor, which enhances cellular sensitivity to insulin and promotes greater uptake of glucose and amino acids by muscle tissue (Safwat et al., 2020).

Table 3
Chromium-methionine (CrMet) in diets of broiler chickens and its effects on carcass and parts yields, and liver and fat pad relative weights at 42 days of age

CrMet mg kg^{-1}	HCY[2]	CCY[2]	BFY[3]	LGY[3]	WNY[3]	TRY3	LIY[2]	FPY[2]
0	69.78	70.63	28.03	30.60	10.16	5.65	1.83	1.16
0.25	69.41	70.11	28.01	30.39	9.99	5.40	1.83	1.16
0.50	69.37	70.21	28.20	30.13	9.90	5.50	1.68	1.22
1.0	69.73	70.60	28.01	30.22	9.71	5.35	1.74	1.30
2.0	69.72	70.53	27.52	30.64	9.92	5.43	1.76	1.17
SEM	1.17	1.18	1.03	0.89	0.46	0.33	0.18	0.23
CV (%)	1.69	1.67	3.78	2.91	4.66	6.00	10.27	18.81
P-value[1]	0.915	0.866	0.439	0.636	0.306	0.306	0.322	0.627

[1]: ANOVA P value
[2]: percentage in relation to the live broiler weight (without head, feet, and neck)
[3]: percentage in relation to the cold eviscerated carcass weight
HCY: hot carcass yield; CCY: cold carcass yield; BFY: breast fillet yield; LGY: legs yield;
WNY: wings yield TRY: tenders yield; LIY: liver relative weight; FPY: fat pads relative weight
SEM: pooled standard error of the mean
CV: coefficient of variation.

It is important to note that the bioavailability and physiological effects of chromium tend to be more evident under stress conditions (Hayat et al., 2020). Therefore, the absence of stress in this study may explain the lack of observable effects from CrMet supplementation. This finding is consistent with results reported by Zheng et al. (2016), who found no significant differences in carcass traits following supplementation with different Cr sources (CrPro, CrPic, and CrCl3). In contrast, Piray and Foroutanifar (2022) reported that supplementation with 1.9, 1.6, 1.7, and 2.5 mg kg^{-1} of Cr reduced the fat percentage in the carcass, breast, legs, and abdominal region of broilers, respectively. However, inclusion levels of 0.9 and 0.8 mg kg^{-1} showed beneficial effects on carcass, breast, and leg yields, while 1.0 mg reduced abdominal fat.

Table 4 shows the incidence of breast myopathies. A higher proportion of normal breasts (score 0) for wooden breast (WB) was observed in birds that received 1.0 and 2.0 mg kg^{-1} of CrMet compared to those that received 0.50 mg kg^{-1} ($P = 0.007$). No significant differences were found among treatments for scores 1, 2, and 3 ($P > 0.05$).

Table 4
Chromium-methionine (CrMet) in diets of broiler chicken and its effects on the incidence scores of wooden breast and white striping myopathies in the breast muscle (Pectoralis major) at 42 days of age

CrMet mg kg^{-1}	Wooden breast				White striping			
	Scores (%)				Scores (%)			
	0	1	2	3	0	1	2	3
0	23.07^{ab}	38.46	15.38	23.09	7.69	53.84	25.64^{b}	12.83^{a}
0.25	20.73^{ab}	43.89	20.00	15.38	20.52	43.58	35.90^{ab}	0.00^{b}
0.50	17.50^{b}	35.00	22.50	25.00	15.00	45.00	35.00^{ab}	5.00^{ab}
1.0	30.00^{a}	30.00	17.50	22.50	12.50	37.50	40.00^{a}	10.00^{a}
2.0	32.50^{a}	40.00	12.50	15.00	12.50	47.50	25.00^{b}	15.00^{a}
P-value[1]	0.007	0.317	0.380	0.249	0.116	0.222	0.008	0.001

1: Kruskal-Wallis P-values
a-b: means with no common superscript differ for each treatment.

Regarding White Striping (WS), birds fed 1.0 mg kg^{-1} of CrMet showed the highest incidence for score 2 (P = 0.008), while no cases of score 3 were observed in birds supplemented with 0.25 mg kg^{-1} (P = 0.001). No significant differences were observed for scores 0 and 1 (P > 0.05). Additionally, no differences were found for the severity scores of WB and WS (P > 0.05; Table 5).

Table 5
Chromium-methionine (CrMet) in diets of broiler chickens and its effects on the scores of severity of wooden breast and white striping myopathies in the breast muscle (*Pectoralis major*) at 42 days of age

	Average scores	
CrMet mg kg^{-1}	WB	WS
0	1.22	1.36
0.25	1.31	1.16
0.50	1.55	1.30
1.0	1.28	1.45
2.0	1.10	1.43
SEM	0.63	0.41
CV (%)	49.09	30.08
P-value[1]	0.614	0.531

[1]: chi-squared P-values
SEM: pooled standard error of the mean.

Pectoralis major muscle myopathies, such as WB and WS, are muscular disorders in broiler chickens associated with multiple factors, particularly fast-growing genetic strains and high breast meat yield. The prevailing hypothesis suggests that these conditions are caused by an imbalance between rapid muscle growth and the tissue's vascularization capacity, which compromises the delivery of oxygen and nutrients to the muscle, leading to hypoxia, inflammation, and muscle fiber degeneration (Barbut et al., 2024).

In this context, supplementation with chromium methionine (CrMet) was employed in the present study to reduce the incidence of such myopathies, as chromium may modulate oxidative stress and improve muscle metabolism (Gencoglu et al., 2024). However, given the multifactorial origin of these disorders, nutritional intervention alone through CrMet supplementation was not sufficient to significantly influence their incidence in this experiment.

Table 6 displays the outcomes of the impact of CrMet inclusion on pH and IC at 15 min and 24 h postmortem, WHC, CL, and SF. A significant difference was observed for IC at 24 h postmortem. Breast fillets from animals that consumed 0.50 mg kg^{-1} of CrMet were more yellow (b*, P = 0.004) than those from animals fed 0.25 or 2.0 mg kg^{-1} of CrMet or the control diet. Additionally, the inclusion of 1.04 mg kg^{-1} of CrMet was estimated to increase the yellow coloration in breast meat. Breasts from animals fed 2.0 mg kg^{-1} of CrMet were darker (L*, P = 0.016) than those that received the control diet. The data also fit a linear decreasing equation. No significant differences were observed for pH (P = 0.830) and IC at 15 min postmortem (P ≥ 0.185), nor for WHC (P = 0.112), CL (P = 0.290), or SF (P = 0.520).

Table 6
Chromium methionine (CrMet) in diets of broiler chickens and its effects on breast meat quality (*Pectoralis major*) at 42 days of age

CrMet mg kg^{-1}	15 min *postmortem*				24 h *postmortem*						
	pH	a*	b*	L*	pH	a*	b*	L*	WHC	CL	SF
0.00	7.53	3.97	4.19	59.86	5.45	2.84	6.21^{b}	57.70^{a}	61.37	27.89	2.25
0.25	7.40	2.74	5.42	59.46	5.42	4.13	6.34^{b}	56.17^{ab}	59.52	29.09	2.16
0.50	7.54	3.05	5.41	58.14	5.49	2.62	8.93^{a}	59.55^{a}	60.08	29.28	2.71
1.00	7.51	3.17	4.06	53.12	5.48	3.06	7.41^{ab}	56.03^{ab}	63.56	27.91	2.22
2.00	7.54	2.92	3.06	55.75	5.43	3.40	6.70^{b}	53.91^{b}	61.22	26.50	2.57
SEM	0.29	1.64	2.48	7.23	0.22	1.43	1.57	4.20	3.05	3.20	0.67
CV (%)	3.81	52.32	55.81	12.64	4.06	44.23	22.07	7.42	4.99	11.35	28.06
P-value[1]	0.830	0.637	0.185	0.260	0.933	0.179	$0.004^{(Q)}$	$0.016^{(L)}$	0.112	0.315	0.520
Polynomial regression equations							R^2		CrMet		Response
$^{(Q)}$ b^*_{24h} = 6.22802 + 0.00355 * CrMet – 0.00000168 * $CrMet^2$							0.44		1.04		8.05
$^{(L)}$ L^*_{24h} = 58.35 – 0.00246 * CrMet							0.13		-		-

[1]: ANOVA P values; a*: redness; b*: yellowness; L*: lightness; WHC: water holding capacity, %; CL: cooking loss, %; SF: shear force, kgf cm^{-1}; $^{a-b}$: means with no common superscript differ for each treatment; ^{Q}: quadratic regression equation ^{L}: linear; SEM: pooled standard error of the mean; CV: coefficient of variation.

The results of this study demonstrate that CrMet supplementation had a quadratic effect on b* values, ranging from 6.21 to 8.93, with the inclusion of 1.04 mg kg^{-1} of CrMet resulting in a b* value of 8.1. L* values decreased linearly at 24 h postmortem, with no effects observed on the other meat quality variables (pH, WHC, CL, SF). The pH observed in this study was slightly lower than the values considered normal for chicken meat (Petracci et al., 2015), which may have influenced meat color. When pH values were considered alongside L*, some breast fillets evaluated could be classified as PSE, with L* values above 53 and pH below 5.7 (Zhang & Barbut, 2005).

In the study by Dalólio et al. (2021), the inclusion of 0.59 mg CrMet was estimated to optimize WHC, with no effects on other meat quality variables. Huang et al. (2016) reported a reduction in b* and CL in the breast meat of broilers fed 2.0 mg CrPro kg^{-1}. According to Neethling et al. (2017), in addition to nutritional factors, meat color can be influenced by several factors such as antemortem stress, processing procedures, storage temperature, pH, animal-to-animal variation, and lipid oxidation, among others, which may help explain the increased b* value observed in the present study. One possible explanation for the decrease in L* could be related to chromium's role in fat metabolism.

The inclusion of CrMet did not significantly affect ($P \geq 0.118$) lipid peroxidation in the pectoral muscle at 10, 30, and 60 days of storage (Table 7). Chromium is known for its indirect antioxidant potential, primarily by enhancing insulin action and reducing free radical production under physiological stress conditions (Untea et al., 2019). Thus, it would be expected that CrMet supplementation might reduce lipid oxidation, particularly in fat-rich tissues like the pectoral muscle. However, the effectiveness of chromium in this context appears to be highly dependent on the presence of oxidative stress, which was not evident under the controlled conditions of this experiment. Similar results were found by Han et al. (2021), who observed no differences in serum, mammary, or hepatic MDA concentrations when evaluating various chromium sources (CrMet, CrPic, CrNic, and Cr yeast). In contrast, Youssef et al. (2022) reported a linear decrease in plasma MDA concentrations with increasing CrMet supplementation.

Table 8 describes the effects of CrMet inclusion on meat composition. The variables DM, CF, and CP were not influenced by the treatments ($P \geq 0.184$). However, total ash (TA) was lower in all groups fed CrMet compared to those that received control diet ($P = 0.001$). A quadratic effect was also observed for TA, with the inclusion of 1.0 mg kg^{-1} of CrMet resulting in 1.34%, thereby reducing TA content in the pectoral muscle.

Table 7
Chromium-methionine (CrMet) in diets of broiler chickens and its effects on the thiobarbituric acid reactive substances (TBARS, mg MDA kg^{-1} of breast meat) in the breast muscle (*Pectoralis major*) at different days of storage

CrMet mg kg^{-1}	Days of storage		
	10	30	60
0.00	0.018	0.031	0.037
0.25	0.031	0.035	0.044
0.50	0.030	0.038	0.036
1.00	0.033	0.031	0.034
2.00	0.022	0.031	0.025
SEM	0.01	0.01	0.01
CV (%)	50.07	24.6	29.0
P-value[1]	0.368	0.604	0.118

[1]: ANOVA P values
[a-b]: means with no common superscript differ for each treatment
SEM: pooled standard error of the mean
CV: coefficient of variation.

Table 7
Chromium-methionine (CrMet) in diets of broiler chicken and its effects on the proximate composition of the breast meat (*Pectoralis major*) at 42 days of age

CrMet mg kg^{-1}	Breast composition (%)			
	DM	TA[2]	CF[2]	CP[2]
0.00	27.26	2.91[a]	3.37	23.25
0.25	25.71	1.61[b]	2.79	23.25
0.50	25.99	1.72[b]	3.03	21.93
1.00	25.99	1.56[b]	2.38	23.14
2.00	26.22	1.59[b]	2.71	22.93
SEM	0.86	0.40	0.69	1.04
CV (%)	3.28	21.07	24.49	4.55
P-value[1]	0.204	0.001[(Q)]	0.422	0.294

Polynomial regression equation	R^2	CrMet	Response
[(Q)] TA=2.53892 – 0.00241 * CrMet^2 + 0.00000121 * CrMet^2	0.66	1.0	1.34

[1]: ANOVA P value
[2]: expressed as fed-basis
DM: dry matter; TA: total ash; CF: crude fat; CP: crude protein
[a-b]: means with no common superscript differ for each treatment
[Q]: quadratic
SEM: pooled standard error of the mean
CV: coefficient of variation.

Chromium activates the glucose tolerance factor in the body, enhancing insulin's metabolic action (Arif et al., 2019). Improved metabolic efficiency can reduce the need to accumulate certain minerals, significantly affecting ash content. In this study, CrMet supplementation led to reduced TA in breast muscle, reflecting this metabolic influence. However, no differences were observed for DM, CF, or CP. While some studies report improvements in meat composition with Cr supplementation in broilers (Untea et al., 2019), others, such as Kumari et al. (2021), found no differences in DM, CP, or TA when evaluating Cr-Nano, although CF was significantly reduced. Al-Mashhadani et al. (2010) investigated Cr-yeast supplementation at different levels (0.5, 1.0, 1.5, and 2.0 mg kg^{-1}) and observed significant increases in CP and reductions in CF in breast and thigh meat at higher inclusion levels, though no effects were found on DM or TA.

Conclusion

The inclusion of CrMet in broiler diets did not significantly affect carcass traits, lipid peroxidation, or the severity of wooden breast and white striping. However, it influenced the frequency of score 0 for wooden breast and scores 2 and 3 for white striping. Additionally, CrMet affected meat color and ash content, improving overall meat quality.

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References

Al-Mashhadani, E. H., Ibrahim, D. K., & Al-Bandr, L. K. (2010). Effect of supplementing different levels of chromium yeast to diet on broiler chickens performance. *International Journal of Poultry Science, 9*(4), 376-381. doi: 10.3923/ijps.2010.376.381

Association of Official Analytical Chemists (2012). *Official methods of analysis* (19nd ed.). AOAC.

Arif, M., Hussain, I., Mahmood, M. A., Abd El-Hack, M. E., Swelum, A. A., Alagawany, M., Mahmoud, A. H., Ebaid, H., & Komany, A. (2019). Effect of varying levels of chromium propionate on growth performance and blood biochemistry of broilers. *Animals, 9*(11), 935. doi:10.3390/ani9110935

Baldi, G., Soglia, F., Laghi, L., Tappi, S., Rocculi, P., Tavaniello, S., Prioriello, D., Mucci, R., Maiorano, G., & Petracci, M. (2019). Comparison of quality traits among breast meat affected by current muscle abnormalities. *Food Research International, 115,* 369-376. doi: 10.1016/j.foodres.2018.11.020

Barbut, S., Mitchell, R., Hall, P., Bacon, C., Bailey, R., Owens, C. M., & Petracci, M. (2024). Review: myopathies in broilers: supply

chain approach to provide solutions to challenges related to raising fast growing birds. *Poultry Science, 103*(8), 103801. doi: 10.1016/j.psj.2024.103801

Barzegar Yarmohammadi, A., Sharifi, S. D., & Mohammadi-Sangcheshmeh, A. (2020). Efficacy of dietary supplementation of nanoparticles-chromium, chromium-methionine and zinc-proteinate, on performance of Japanese quail under physiological stress. *Italian Journal of Animal Science, 19*(1), 1122-1133. doi: 10.1080/1828051X.2020.1822763

Bowker, B., & Zhuang, H. (2016). Impact of white striping on functionality attributes of broiler breast meat. *Poultry Science, 95*(8), 1957-1965. doi: 10.3382/ps/pew115

Castilho Heiss, V. A. R., Komiyama, C. M., Barbosa, D. K., Burbarelli, M. F. C., Garcia, R. G., & Caldara, F. R. (2024). A systematic review of nutritional strategies to mitigate pectoral myopathies in broiler chickens. *World's Poultry Science Journal, 80*(3), 897-914. doi: 10.1080/00439339.2024.2338350

Che, S., Wang, C., Iverson, M., Varga, C., Barbut, S., Bienzle, D., & Susta, L. (2022). Characteristics of broiler chicken breast myopathies (spaghetti meat, woody breast, white striping) in Ontario, Canada. *Poultry Science, 101*(4), 101747. doi: 10.1016/j.psj.2022.101747

Dalgaard, L. B., Rasmussen, M. K., Bertram, H. C., Jensen, J. A., Møller, H. S., Aaslyng, M. D., Hejbøl, E. K., Pedersen, J. R., Elsser-Gravesen, D., & Young, J. F. (2018). Classification of wooden breast myopathy in chicken pectoralis major by a standardised method and association with conventional quality assessments. *International Journal of Food Science & Technology, 53*(7), 1744-1752. doi: 10.1111/ijfs.13759

Dalólio, F. S., Albino, L. F. T., Fireman, A. K. B. A. T., Burin, A. M., Jr., Busanello, M., Calderano, A. A., Ribeiro, V., Jr., & Rostagno, H. S. (2021). Effect of chromium-methionine supplementation on meat quality of broilers reared under heat stress. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 73*(4), 995-999. doi: 10.1590/1678-4162-12235

Gencoglu, H., Orhan, C., & Sahin, K. (2024). Understanding Cr(III) Action on mitochondrial ATP synthase and AMPK efficacy: insights from previous studies a review. *Biological Trace Element Research, 202*(4), 1325-1334. doi: 10.1007/s12011-023-04010-6

Han, M., Chen, Y., Li, J., Dong, Y., Miao, Z., Li, J., & Zhang, L. (2021). Effects of organic chromium sources on growth performance, lipid metabolism, antioxidant status, breast amino acid and fatty acid profiles in broilers. *Journal of the Science of Food and Agriculture, 101*(9), 3917-3926. doi: 10.1002/jsfa.11053

Hartcher, K. M., & Lum, H. K. (2020). Genetic selection of broilers and welfare consequences: a review. *World's Poultry Science Journal, 76*(1), 154-167. doi: 10.1080/00439339.2019.1680025

Hayat, K., Bodinga, B. M., Han, D., Yang, X., Sun, Q., Aleya, L., Abdel-Daim, M. M., & Yang, X. (2020). Effects of dietary inclusion of chromium propionate on growth performance, intestinal health, immune

response and nutrient transporter gene expression in broilers. *Science of The Total Environment, 705,* 135869. doi: 10.1016/j.scitotenv.2019.135869

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science, 49*(4), 447-457. doi: 10.1016/S0309-1740(98)00034-5

Huang, Y., Yang, J., Xiao, F., Lloyd, K., & Lin, X. (2016). Effects of supplemental chromium source and concentration on growth performance, carcass traits, and meat quality of broilers under heat stress conditions. *Biological Trace Element Research, 170*(1), 216-223. doi: 10.1007/s12011-015-0443-z

Kumari, R., Kumar, A., Monda, B., Sanjay, S., Rastogi, S., Palod, J., Rahal, A., Yadav, M., & Sharma, H. (2021). Effect of dietary inclusion of nano-chromium and phytase enzyme on growth performance and carcass quality of broiler chickens. *Journal of Entomology and Zoology Studies, 9*(2), 1178-1183.

Nakamura, M., & Katoh, K. (1981). *Influence of thawing methods on several properties of rabbit meat.* Bulletin of Ishikawa Prefecture College of Agriculture (Japan).

Neethling, N. E., Suman, S. P., Sigge, G. O., Hoffman, L. C., & Hunt, M. C. (2017). Exogenous and endogenous factors influencing color of fresh meat from ungulates. *Meat and Muscle Biology, 1*(1), 253-275. doi: 10.22175/mmb2017.06.0032

Olivo, R., Scares, A. L., Ida, E. I., & Shimokomaki, M. (2001). Dietary vitamin e inhibits poultry PSE and improves meat functional properties. *Journal of Food Biochemistry, 25*(4), 271-283. doi: 10.1111/j.1745-4514.2001.tb00740.x

Petracci, M., Mudalal, S., Soglia, F., & Cavani, C. (2015). Meat quality in fast-growing broiler chickens. *World's Poultry Science Journal, 71*(2), 363-374. doi: 10.1017/S0043933915000367

Piray, A., & Foroutanifar, S. (2022). Chromium supplementation on the growth performance, carcass traits, blood constituents, and immune competence of broiler chickens under heat stress: a systematic review and dose-response meta-analysis. *Biological Trace Element Research, 200*(6), 2876-2888. doi: 10.1007/s12011-021-02885-x

Rostagno, H. S., Albino, L. F. T., Melissa, I. H., Donzele, J. L., Sakomura, N. K., Perazzo, F. G., Saraiva, A., Teixeira, M. L., Rodrigues, P. B., Oliveira, R. F., Barreto, S. L. T., & Brito, C. O. (2017). *Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais* (4a ed.). UF, Departamento de Zootecnia.

Safwat, A. M., Elnaggar, A. S., Elghalid, O. A., & EL-Tahawy, W. S. (2020). Effects of different sources and levels of dietary chromium supplementation on performance of broiler chicks. *Animal Science Journal, 91*(1), e13448. doi: 10.1111/asj.13448

Soglia, F., Petracci, M., Davoli, R., & Zappaterra, M. (2021). A critical review of the mechanisms involved in the occurrence of growth-related abnormalities affecting broiler chicken breast muscles. *Poultry Science, 100*(6), 101180. doi: 10.1016/j.psj.2021.101180

Sorensen, G., & Jorgensen, S. S. (1996). A critical examination of some experimental variables in the 2-thiobarbituric acid (TBA) test for lipid oxidation in meat products. *Zeitschrift für Lebensmittel-Untersuchung und Forschung 202*(3), 205-210. doi: 10.1007/BF01263541

Souza, C., Eyng, C., Viott, A. M., Avila, A. S. de, Pacheco, W. J., Junior, N. R., Jr., Kohler, T. L., Tenorio, K. I., Cirilo, E. H., & Nunes, R. V. (2021). Effect of dietary guanidinoacetic acid or nucleotides supplementation on growth performances, carcass traits, meat quality and occurrence of myopathies in broilers. *Livestock Science, 251,* 104659. doi: 10.1016/j.livsci.2021.104659

Tian, Y.-Y., Zhang, L.-Y., Dong, B., Cao, J., Xue, J.-X., & Gong, L.-M. (2014). Effects of chromium methionine supplementation on growth performance, serum metabolites, endocrine parameters, antioxidant status, and immune traits in growing pigs. *Biological Trace Element Research, 162*(1-3), 134-141. doi: 10.1007/s12011-014-0147-9

Tijare, V. V., Yang, F. L., Kuttappan, V. A., Alvarado, C. Z., Coon, C. N., & Owens, C. M. (2016). Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. *Poultry Science, 95*(9), 2167-2173. doi: 10.3382/ps/pew129

Untea, A. E., Panaite, T. D., Dragomir, C., Ropota, M., Olteanu, M., & Varzaru, I. (2019). Effect of dietary chromium supplementation on meat nutritional quality and antioxidant status from broilers fed with Camelina-meal-supplemented diets. *Animal, 13*(12), 2939-2947. doi: 10.1017/S1751731119001162

Vyncke, W. (1975). Evaluation of the direct thiobarbituric acid extraction method for determining oxidative rancidity in mackerel (*Scomber scombrus* L.). *Fette, Seifen, Anstrichmittel, 77*(6), 239-240. doi: 10.1002/lipi.19750770610

Wold, J. P., Veiseth-Kent, E., Høst, V., & Løvland, A. (2017). Rapid on-line detection and grading of wooden breast myopathy in chicken fillets by near-infrared spectroscopy. *Plos One, 12*(3), e0173384. doi: 10.1371/journal.pone.0173384

Youssef, I. M. I., Abdo, I. M. I., Elsukkary, H. F. A., El-Kady, M. F., & Elsayed, M. (2022). Effects of dietary supplementation of chromium methionine chelate on growth performance, oxidative stress, hematological indices, and carcass traits of broiler chickens. *Tropical Animal Health and Production, 54*(5), 267. doi: 10.1007/s11250-022-03260-1

Zhang, L., & Barbut, S. (2005). Rheological characteristics of fresh and frozen PSE, normal and DFD chicken breast meat. *British Poultry Science, 46*(6), 687-693. doi: 10.1080/00071660500391516

Zheng, C., Huang, Y., Xiao, F., Lin, X., & Lloyd, K. (2016). Effects of supplemental chromium source and concentration on growth, carcass characteristics, and serum lipid parameters of broilers reared under normal conditions. *Biological Trace Element Research, 169*(2), 352-358. doi: 10.1007/s12011-015-0419-z