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Effects of Organic Chromium Yeast on Performance, Meat Quality, and Serum Parameters of Grow-Finish Pigs

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Abstract

Trivalent chromium (Cr) is an essential trace element for humans and animals. This study was conducted to investigate the effects of chromium(III) yeast (CrYst) on growth performance, carcass characteristics, meat traits, antioxidant status, immune traits, and serum biochemical parameters of grow-finish pigs. A total of 72 commercial hybrid barrows (Duroc × Landrace × Large White) of approximately 50 kg body weight were allocated into two dietary treatments randomly, which received a corn-soybean meal basal diet or a basal diet supplemented with 100 mg CrYst/kg. The trial duration was 11 weeks divided into three periods from body weights of 50–75 kg, 75–100 kg, and 100–110 kg, respectively. The results revealed that supplemental CrYst did not affect growth performance. Organic CrYst supplementation significantly decreased the backfat depth and increased the meat tenderness score and juiciness score values in pigs ($P < 0.05$), while other carcass traits and meat traits indexes were unaffected. CrYst addition significantly decreased serum malondialdehyde (MDA) content of pigs in the whole growth phase; significantly increased the serum levels of immunoglobulin G (IgG), total antioxidant capacity (T-AOC), glutathione peroxidase (GSH-Px), and reduced glutathione (GSH) in growing pigs; and also increased the serum IgG, IgM, and GSH concentrations in pigs during the finishing phase ($P < 0.05$). Additionally, diets supplemented with CrYst significantly decreased the serum high-density lipoprotein cholesterol (HDL-C) content in growing pigs and significantly increased the serum LDL-C level at the fattening period ($P < 0.05$), whereas no significant differences were observed for the other serum biochemical indexes compared to the control pigs. In conclusion, CrYst supplementation could reduce lipid peroxidation and backfat thickness and improve the meat tenderness and juiciness, immune traits, and antioxidant status of pigs.

Keywords Chromium yeast · Carcass characteristics · Meat traits · Immune traits · Grow-finish pigs

Introduction

Trivalent chromium (Cr) is an essential trace element for all living organisms and exerts numerous functions in animal physiological processes [1]. For instance, Cr activates certain enzymes, enhances insulin activity, stabilizes proteins and nucleic acids, and regulates the metabolisms of carbohydrates, lipid, and amino acids [1–3]. Dietary Cr deficiency can cause various types of diseases such as reproductive disorders, carbohydrate metabolism derangements, glucose tolerance impairment, immunity repression, and cAMP-dependent phosphodiesterase activity affliction in humans and animals [4, 5]. In the livestock and poultry industry, Cr supplementation has become a common practice used for improving growth performance, meat quality, and immune function in animals with the continuous in-depth discovery of its biochemical role [6]. Traditionally, Cr is supplemented into diets in the form of inorganic salts like chromium sulfate and chromium chloride, whereas organic compounds, such as chromium nicotinic acid (CrNic), chromium picolinate (CrPic), chromium propionate (CrPro), chromium yeast

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(CrYst), and chromium methionine (CrMet), are also used in recent years [7, 8]. Some researchers have elucidated that dietary CrPic supplementation at 200–400 μg/kg leads to improved growth performance, carcass characteristics, muscle mass, and decreased backfat thickness of pigs [9–11]. Furthermore, Cr supplementation can enhance the stress mechanism and immune response, and is beneficial in reducing immunologic stress, improve the immunity and survival rate of animals, thereby improving the efficiency of breeding [12]. Apple et al. (2000) stated that supplementation of Cr can increase the quantity of muscle tissues and redistribute nutrients through the influence of carbohydrate and lipid metabolism to reduce fat deposition in pork [13]. A study by Lien et al. (2001) on growing-finishing pigs demonstrated that Cr increased their insulin sensitivity and glucose clearance and improved the carcass yield and performance of the animals in consequence [9].

Previous studies have shown that chemical forms of mineral nourishment influence their bioavailability and consequently will affect both potential biological responses and the economics of mineral supply [6]. At present, many studies have shown that Cr in organic forms has greater absorption and higher immunoreactivity and bioavailability in animals as compared with inorganic forms, and additional of it results in more Cr deposited into animal tissues [14, 15]. Chromium-enriched yeast (*Saccharomyces cerevisiae*) is a yeast preparation with an enriched trivalent chromium content and no adverse reactions reported in a range of animal toxicological studies or human clinical efficacy trials [16, 17]. Pas et al. (2004) showed that trivalent Cr in the yeast cells first was incorporated on the cell wall surfaces and then was absorbed into the spheroplasts through a specific transporter and combined with the substances in the cell by the catalytic function of enzymes [18]. *S. cerevisiae* is a microorganism that does not produce endotoxins and, as a chromium-rich strain, can ensure its feed safety. In addition, *S. cerevisiae* fermentation is a very mature technology and has the advantages of a short production cycle, easy operation, and low production cost [7, 12]. Previous studies have described the benefits of CrYst in chicks, camels, cattle, and finishing pigs [1, 19–23]. Consider the multiple vital biological functions in animals of Cr, especially the regulation of carbohydrate and lipid metabolism. However, to our knowledge, little research has been performed to investigate the influence of CrYst on the production and health status of growing-finishing pigs. It hypothesized that the dietary addition of CrYst would positively affect the performance and meat quality of growing-finishing pigs.

The purpose of our research was to study the effects of CrYst on growth performance, carcass characteristics, meat traits, antioxidant status, immune traits, and serum biochemical parameters of pigs, thus, providing the scientific basis for applicating CrYst on pigs.

Materials and Methods

Experimental Design and Animal Husbandry

All animal care and use procedures were conducted in accordance with the Chinese Guidelines for Animal Welfare and the experimental procedures were approved by the Animal Care and Use Committee of Animal Nutrition Institute, Sichuan Agricultural University.

A total of 72 commercial hybrid barrows (Duroc × Landrace × Large White) of approximately 50 kg BW were used in this study and randomly allocated into two dietary treatments with 12 replicate pens (3 pigs/pen) per treatment. Dietary treatments were a corn-soybean meal basal diet as the control group and a basal diet supplemented with 100 mg/kg chromium yeast (provided by Angel yeast Co., Ltd., 600,298, China; with chromium content ≥ 2000 mg/kg) was called as CrYst group. The Cr in CrYst all are organic was analyzed by French National Centre for Scientific Research (CNRS). The CrYst was premixed with corn flour and then added to each experimental diet. The basal diet (for three phases based on the body weights from 50 ~ 75 kg (0–5 weeks), 75 ~ 100 kg (6–9 weeks), and 100 ~ 110 kg (10–11 weeks), respectively) were formulated to meet nutrient requirements suggested in the NRC (2012) (Table 1). The actual concentration of chromium in the final diet is shown in Table 2. All pigs were housed in the same room and had free access to feed and water. The pigs were fed three times daily (at 08:00, 15:00, and 20:00 h), and feed allowance and feed refusals were weighed daily to determine the average daily feed intake (ADFI). The animal house was disinfected regularly, and the room temperature (22–25℃) and ventilation were kept in commercial conditions. Pigs were examined daily to ensure the record and, if necessary, therapy of pigs suffering from diseases.

Feed and Blood Sample Collection

Feed samples (2 kg) were collected from each diet phase according to the quarter method to retain 200 g and then stored at – 20 °C until further analysis [24]. At the conclusion of each trial phase, pigs were fasted for 12 h prior to sampling with free access to water. Blood samples from each pig (approximately 10 ml/pig) were collected from the superior vena cava into non-heparinized tubes, and then kept on 4℃ refrigerator immediately after the collection until serum was separated within 30 min, and then the serum samples were separated by centrifugation of blood samples for 15 min at 1200 g at 4 °C, and stored in plastic vials at – 80 °C until analysis.

Table 1 Ingredient and nutrient composition of experimental diets (as-fed basis)

Item	Phase		
	Grower phase	Finisher phase	
	First period (50–75 kg)	Second period (75–100 kg)	Third period (100–110 kg)
Ingredients (%)			
Corn (CP, 7.8%)	69.117	69.985	73.325
Soybean meal (CP, 44.2%)	19	18	14
Wheat bran (CP, 15.7%)	7.3	8.6	10.4
Fish meal	2	1	0
Soy oil	0.7	0.7	0.6
L-Lsyine HCl (78.8%)	0.145	0.065	0.082
Threonine	0.004	0	0
Dicalcium phosphate	0.405	0.269	0.226
Limestone	0.799	0.851	0.837
Chloride choline	0.1	0.1	0.1
NaCl	0.3	0.3	0.3
Vitamin premix[1]	0.03	0.03	0.03
Mineral premix[2]	0.1	0.1	0.1
Total (%)	100.00	100.00	100.00
Nutrient levels[3]			
CP (%)	16.54	15.66	13.84
NE (Kcal kg^{-1})	2.478	2.476	2.478
Ca (%)	0.59	0.52	0.46
P (%)	0.52	0.47	0.43
ATTD-P (%)	0.23	0.21	0.18

[1]Provided the following per kilogram of diet: vitamin A 9000 IU, vitamin D_3 3000 IU, vitamin E 24 mg, vitamin K_3 5 mg, vitamin B_1 3 mg, vitamin B_2 7.5 mg, vitamin B_6 3.6 mg, vitamin B_{12} 36 μg, folic acid 1.5 mg, nicotinamide 30 mg, D-biotin 0.15 mg, D-pantothenic acid 15 mg

[2]Provided the following per kilogram of diet: Fe 50 mg (from $FeSO_4 \bullet H_2O$), Cu 3.5 mg (from $CuSO_4 \bullet 5H_2O$), Mn 2 mg (from $MnSO_4 \bullet H_2O$), Zn 80 mg (from $ZnSO_4 \bullet H_2O$), Se 0.30 mg (from Na_2SeO_3), I 0.14 mg (from KI)

[3]All nutrient levels were analyzed using values for feed ingredients from National Research Council (2012)

Table 2 Chromium content in experimental diets (μg/kg)

Treatment	Phase		
	Grower phase	Finisher phase	
	50–75 kg	75–100 kg	100–110 kg
CON group	390	330	280
CrYst group	550	570	540

Carcass and Meat Traits Measurement

At the conclusion of the third phase, pigs were transported to a meat factory (Ya'an, Sichuan, China). These animals were slaughtered by exsanguination after electrical stunning, immediately scalded, de-haired, eviscerated (retained leaf lard and kidneys), and split along the mid-line performed within 30 min according to standard commercial procedures. Then, warm carcass weights (the brain, hoof, and tail were also removed from the carcass) were assessed. Carcass length was determined on split carcasses by measuring from the first thoracic vertebra to the pelvic bone using a measuring tape. Average backfat depth was determined by averaging the backfat thickness at the last shoulder, mid-section between the sixth and seventh-last rib, last rib, and the midpoint of the hip semicircle, and thickness was determined with a vernier caliper. The loin muscle area was measured by tracing the loin muscle surface area at the 10th rib, and the area was measured using a compensating polar planimeter.

The marbling score (45 min, 24 h) and taste score was estimated with pork quality standards (NYT1333-2007) [25]. The water-holding capacity indicators of the psoas were evaluated by drip loss and cooking percentage. The meat color was determined with a Minolta Chromameter (CR 400, Konica Minolta Inc., Tokyo, Japan). The pH of the longissimus was measured with a pH meter (pH-start, Matthaus, Germany) 45 min after slaughter and then stored at 4℃, measured again after 24 h. The

shear force was measured using a Stable Micro Systems Texture Analyzer (TA-XT Plus, Stable Micro Systems, Surrey, UK).

Sample Treatment and Analysis

The feed samples were dried in a convection oven at 75 °C until a constant weight was achieved, and then dried samples were ground through a 0.45-mm screen and stored in desiccators. Feed samples were dissolved by microwave heating with nitric acid (HNO_3) and perchloric acid ($HClO_4$) mixture (4:1). The concentrations of Cr in feed samples were determined by flame atomic absorption spectrometry (FAAS). The instrument used was an AA7000 atomic absorption spectrophotometer with a graphite furnace (Shimadzu, Kyoto, Japan).

The serum contents of urea nitrogen, glucose (Glu), total triglycerides (TG), lactic acid (LAC), total cholesterol (TCHOL), high-density lipoprotein cholesterol (HDLC), and low-density lipoprotein cholesterol (LDLC) were analyzed using an automatic biochemical analyzer (RA-1000, Technicon Instruments Corporation, Tarrytown, NY, USA). Serum insulin (INS), immunoglobulin G (IgG), and immunoglobulin M (IgM) were analyzed using commercial enzyme-linked immunosorbent assay (ELISA) kits obtained from the Jiancheng Biochemical Reagent Co. (Nanjing, China). The serum levels of malondialdehyde (MDA), glutathione peroxidase (GSH-Px), total antioxidant capacity (T-AOC), and reduced glutathione (GSH) were determined by assay kits (Nanjing Jiancheng Biotechnology Institute, China) according to the manufacturer's instructions.

Statistical Analyses

All data were analyzed by one-way analysis of variance (ANOVA) using the GLM procedure of SAS software (Version 9.4, SAS Institute Inc., Cary, NC, USA) as a randomized complete block design. Each pen was considered the experimental unit for growth performance and the individual pig as the experimental unit for other indexes. The initial body weight of pigs was set as a covariate for growth performance data. For carcass, meat quality, and serum indexes, data using the same procedure considered the effects of sex and diets as main effects, as well as their interaction. The significant differences among the groups were compared using Duncan's multiple range test with the threshold of $P=0.05$ and presented as the mean ± standard error.

Results

Growth Performance, Carcass Characteristics, and Meat Traits

The effects of dietary supplementation with CrYst on growth performance and carcass traits of pigs are listed in Tables 3 and 4, respectively. The body weight, average daily gain, average daily feed intake, and feed convention ratio were not significantly affected by the dietary treatments in any period of growth or the overall data ($P>0.05$). At the conclusion of the third phase, the backfat depth value in pigs from CrYst group was significantly lower than the control group ($P<0.05$). However, no significant differences were observed in other carcass traits. As shown in Table 5, the meat tenderness score and juiciness score values of CrYst group were significantly higher than those of the control group ($P<0.05$). However, no significant differences were apparent in other meat traits.

Table 3 Effect of chromium yeast on growth performance of pigs

Item	CON group	CrYst group	*P*-value
Body weight (kg)			
Initial weight	43.29 ± 1.61	43.29 ± 1.58	1.000
First period	75.94 ± 2.50	76.52 ± 2.4	0.868
Second period	101.05 ± 2.79	101.29 ± 2.78	0.953
Third period	113.04 ± 2.75	113.67 ± 2.25	0.861
ADG (g/d)			
First period	931 ± 30	942 ± 31	0.800
Second period	891 ± 23	879 ± 23	0.704
Third period	922 ± 44	901 ± 44	0.736
Overall	911 ± 18	906 ± 19	0.835
ADFI (g/d)			
First period	2668 ± 98	2658 ± 99	0.945
Second period	3254 ± 101	3145 ± 113	0.479
Third period	3794 ± 99	3761 ± 114	0.827
Overall	3130 ± 86	3071 ± 83	0.621
F:G			
First period	2.86 ± 0.06	2.82 ± 0.05	0.543
Second period	3.66 ± 0.09	3.58 ± 0.08	0.522
Third period	4.23 ± 0.26	4.26 ± 0.21	0.915
Overall	3.43 ± 0.06	3.39 ± 0.05	0.580

ADG average daily gain, *ADFI* average daily feed intake, *F:G* feed:gain, *Overall* from trial initiation through harvest. values are expressed as means ± SE

Table 4 Effect of chromium yeast on carcass traits of finishing pigs

Item	CON group	CrYst group	*P*-value
Carcass weight (kg)	85.57 ± 0.76	84.70 ± 1.34	0.584
Dressing percentage (%)	75.29 ± 0.72	74.36 ± 0.38	0.279
Carcass length (cm)	91.17 ± 1.53	93.43 ± 1.54	0.321
Backfat depth (mm)	25.89 ± 0.98	21.32 ± 1.30	0.023
Loin muscle area (cm^2)	56.59 ± 2.76	58.65 ± 1.25	0.513

values are expressed as means ± SE

Serum Immunity and Antioxidant Indexes

The effects of dietary supplementation with CrYst on the immune indexes and antioxidant capacity of pigs are shown in Table 6. During the first period, pigs receiving CrYst had significantly higher serum content of IgG, as well as higher levels of T-AOC, GSH-Px, and GSH, and a lower MDA content than the pigs from the control group ($P < 0.05$), whereas there was no statistical differences observed in serum content of IgM. At the conclusion of the third phase, the CrYst supplement also significantly increased the serum concentrations of IgG, IgM, and GSH and reduced the serum MDA content than the control group ($P < 0.05$). However, there were no statistical differences in serum levels of T-AOC and GSH-Px.

Serum Biochemical Parameters

As shown in Table 7, diets supplemented with CrYst did not affect the serum contents of Glu, LAC, SUN, TG, TCHOL, LDL-C, and INS in the first phase, whereas serum HDL-C content was decreased significantly in pigs compared with the control group ($P < 0.05$). At the end of the third phase, compared with the control group, CrYst supplementation significantly increased the serum LDL-C level of pigs ($P < 0.05$), and there were no significant differences observed in other indexes of serum biochemistry.

Discussion

Chromium is an essential mineral for animals and plays an important role in body growth and development [26, 27]. A deficiency of chromium in animals results in severe metabolic disorder of protein and carbohydrates, reduced

Table 5 Effect of chromium yeast on meat traits of finishing pigs

Item	CON group	CrYst group	*P*-value
Marbling score	3.08 ± 0.11	2.89 ± 0.10	0.296
Drip loss (%)	1.19 ± 0.09	1.10 ± 0.14	0.556
Cooking percentage (%)	64.8 ± 1.42	62.7 ± 1.3	0.580
Lightness (*L**)	44.3 ± 0.78	43.6 ± 0.7	0.548
Redness (*a**)	9.36 ± 0.62	9.34 ± 0.44	0.978
Yellowness (*b**)	7.07 ± 0.24	7.04 ± 0.18	0.923
pH_{45min}	6.59 ± 0.09	6.57 ± 0.16	0.935
pH_{24h}	5.61 ± 0.08	5.80 ± 0.1	0.567
Shear force (kg)	2.99 ± 0.33	2.61 ± 0.34	0.441
Flavor score	3.12 ± 0.16	3.30 ± 0.26	0.560
Meat tenderness score	2.83 ± 0.28	3.60 ± 0.27	0.045
Juiciness score	2.80 ± 0.17	3.55 ± 0.26	0.039

values are expressed as means ± SE

Table 6 Effect of chromium yeast on serum immunity and antioxidant indexes in pigs

Item	CON group	CrYst group	*P*-value
First period			
IgG (g/L)	4.40 ± 0.09	4.63 ± 0.03	0.043
IgM (g/L)	0.59 ± 0.04	0.64 ± 0.02	0.258
T-AOC (U/mL)	1.42 ± 0.065	1.61 ± 0.043	0.023
GSH-Px (U/mL)	1101.99 ± 20.43	1272.03 ± 75.87	0.042
MDA (nmol/mL)	3.31 ± 0.282	1.66 ± 0.15	< 0.001
GSH (μmol/mL)	8.13 ± 0.66	11.01 ± 1.02	0.028
Second to third period			
IgG (g/L)	3.83 ± 0.20	4.29 ± 0.10	0.047
IgM (g/L)	0.55 ± 0.03	0.65 ± 0.01	0.004
T-AOC (U/mL)	1.32 ± 0.04	1.42 ± 0.06	0.193
GSH-Px (U/mL)	1173.56 ± 46.99	1142.39 ± 23.52	0.559
MDA (nmol/mL)	2.73 ± 0.13	1.81 ± 0.04	< 0.001
GSH (μmol/mL)	5.49 ± 0.51	20.22 ± 3.71	0.001

IgG immunoglobulin G, *IgM* immunoglobulin M, *T-AOC* total antioxidant capacity, *GSH-Px* glutathione peroxidase, *GSH* reduced glutathione, *MDA* malondialdehyde, *Second to third period* 75 ~ 110 kg period (finishing pigs). values are expressed as means ± SE

Table 7 Effect of chromium yeast on serum biochemistry in pigs

Item	CON group	CrYst group	*P*-value
First period			
Glu (mmol/L)	4.30 ± 0.12	4.27 ± 0.12	0.842
LAC (mmol/L)	4.49 ± 0.08	4.51 ± 0.16	0.937
SUN (mmol/L)	4.92 ± 0.15	4.95 ± 0.28	0.932
TG (mmol/L)	0.46 ± 0.03	0.45 ± 0.02	0.796
TCHOL (mmol/L)	2.21 ± 0.05	2.07 ± 0.11	0.259
HDL-C (mmol/L)	0.61 ± 0.02	0.51 ± 0.03	0.017
LDL-C (mmol/L)	1.04 ± 0.02	1.04 ± 0.55	0.988
Insulin (mIU/L)	9.35 ± 0.12	8.68 ± 0.18	0.260
Second to third period			
Glu (mmol/L)	0.95 ± 0.08	0.85 ± 0.05	0.302
LAC (mmol/L)	4.30 ± 0.17	4.05 ± 0.10	0.235
SUN (mmol/L)	4.49 ± 0.08	4.05 ± 0.10	0.272
TG (mmol/L)	0.45 ± 0.02	0.44 ± 0.02	0.790
TCHOL (mmol/L)	2.97 ± 0.09	3.20 ± 0.09	0.096
HDL-C (mmol/L)	1.68 ± 0.13	1.60 ± 0.09	0.626
LDL-C (mmol/L)	0.95 ± 0.02	1.05 ± 0.02	0.003

Glu glucose, *LAC* lactic acid, *SUN* serum urea nitrogen, *TG* total triglycerides, *TCHOL* total cholesterol, *HDLC* high-density lipoprotein cholesterol, *LDLC* low-density lipoprotein cholesterol, *INS* insulin, *Second to third period* 75 ~ 110 kg period (finishing pigs). values are expressed as means ± SE

insulin sensitivity in peripheral tissues, and a negative influence on the growth rate [28, 29]. However, many additional studies have been conducted with mixed results on the impact of Cr supplementation on growth performance and carcass characteristics. Lien et al. (2001) and Li et al. (2016) exhibited that dietary supplementation with organic Cr in the pig's ration improved their growth performance, average daily gain, and feed intake [3, 9]. A meta-analysis conducted by Sales et al. (2011) also clarified that dietary Cr supplementation could improve feed efficiency and average daily gain of swine [30]. In general, Cr exerts its effect on the improvement in animal performance owing to stimulating the secretion of digestive enzymes, which improves nutrient absorption and utilization [31]. Conversely, studies by Zhang et al. (2010) [32], who supplemented with 200 μg/kg Cr from CrYst in growing and finishing pigs, and Prak et al. (2009) [33], who used $CrCl_3$, CrMet, CrPic, and CrYst in finishing pigs, reported that dietary Cr supplementation did not affect the growth performance, which was in line with the current study. In addition, Mooney et al. (1995) and Mayorga et al. (2019) observed that dietary addition of 200 μg/kg Cr as CrPic or CrPro tended to improve the growth rate of pigs, but no effects of Cr on most production parameters [34, 35]. The various outcomes of those studies may be due to differences in the feeding stage, experimental conditions, basic diet composition, and Cr source and dose [3, 6].

Chromium is an active component in the glucose tolerance factor, which increases the sensitivity of cell receptors to insulin, resulting in increased glucose and amino acid uptake by muscle tissues [26, 31]. NRC (2012) indicated that supplementation of organic Cr for growing-finishing pigs could improve carcass leanness and pork quality [36]. Previous studies have also demonstrated that Cr supplementation can reduce fat accumulation by inhibiting fat production [9]. In the present investigation, the addition of CrYst significantly decreased the backfat depth in pigs, but no significant differences were observed in other carcass traits. Similarly, Hung et al. (2015) had shown that dietary supplementation with CrPic increased insulin sensitivity, carcass weight, and muscle depth of lean pig and decreased P_2 backfat depth [37]. Li et al. (2017) also found that dietary Cr supplementation could reduce backfat thickness and serum nonesterified fatty acids concentrations of pigs [3]. In the same way, Arvizu et al. (2011) suggested that Cr may affect the amount of fat deposition in monogastric animals by changing the lipogenic enzyme activity of organisms and promoting a redistribution of fatty tissue in carcass [38]. Wang et al. (2014) also stated that Cr could improve the insulin sensitivity of tissue, causing enhanced deposition of dietary protein and carbohydrate in the muscle cells, thereby improving the quality of carcass [39].

Previous studies have found that the addition of Cr had no significant effect on pH, drip loss, shear force, and flesh color at 24 h after slaughter [40, 41]. Shelton et al. (2003) reported that addition CrPic to diets significantly reduced the drip loss of frozen meat and fresh meat [42]. In the present study, adding 200 μg/kg Cr from CrYst to diets of growing-finishing pigs made no difference in marbling score, drip loss, cooked meat rate, L^*, a^*, b^*, pH_{45min}, pH_{24h}, and meat aroma score in pigs. Meat tenderness and juiciness scores are the main indicators to evaluate the eating quality of meat, and shear force is an indicator that can intuitively reflect the tenderness of pork [41]. In this study, dietary supplementation with organic Cr significantly enhanced the tenderness and juiciness score, but it does not affect the shearing force of pork. Similarly, Kuhn et al. (1997) found that growing and finishing pigs dietary supplemented 400 μg/kg CrYst increased meat tenderness and intermuscular fat content in pork [43]. Guan et al. (2000) also pointed out that dietary 200 mg/kg nano-chromium supplementation increased intramuscular fat level, thus improving the tenderness and flavor of meat [44].

The antioxidant status of an organism is critical for maintaining animal health and can be affected by nutrients [45]. GSH-Px is a key antioxidant enzyme catalyzing the specific reduction of hydrogen peroxide and lipid peroxides to protect against oxidative tissue damage [46, 47]. T-AOC represents the radical scavenging capacity of antioxidants contained in animal samples and indicates the oxidative status of the whole organization [48, 49]. MDA is the major product of irreversible lipid peroxidation between oxygen free radicals and polyunsaturated fatty acids on biofilm, and the amount of oxygen free radicals and the degree of lipid peroxidation positively correlated with the MDA content in the organism [48–51]. Thus, the content of MDA detection can reflect the level of oxygen free radicals and the degree of lipid peroxidation [48–51]. Some studies have demonstrated that supplementing Cr to mammals and poultry effectively improved antioxidant capacities and prevented lipid peroxidation [1, 52]. In the current study, the levels of T-AOC, GSH-Px, and GSH in the serum increased, and MDA concentration reduced, indicating that CrYst supplementation improved the antioxidant capacity of pigs. Similar results were also observed by Tian et al. (2014), who used CrMet in growing pigs [6], and Bucko et al. (2015), who used CrNic in growing-finishing pigs [41]. In addition, Shan et al. (2020) demonstrated that supplementation with CrYst improved the antioxidant and immune function to alleviate heat stress in mid-lactation dairy cows [17].

Immunoglobulin G (IgG) is the most abundant immunoglobulin found in the blood and extracellular fluid. It occupies a major position in the antibody-mediated defense mechanism and has various activities, such as anti-bacterial, anti-viral, and anti-exotoxin [52–54]. Immunoglobulin

A (IgA) divided into serotype and secretion. The serotype IgA is produced primarily by plasma cells in the mesenteric lymphoid tissue and exists in the serum [53]. FcαRI can specifically bind to serotype and secretory IgA and mediate a series of immune responses through the γ chain [53, 54]. Previous studies have found that CrNic can increase the titer of red blood cell antibodies [55], and CrPic can enhance the lymphocyte transformation rate of weaned piglets, improve the function of pseudorabies virus antibodies, and participate in stimulating lymphocyte proliferation [56]. Studies by Mayorga et al. (2019) and Wang et al. (2007) reported that diets supplemented with CrPro and nano-chromium significantly increased the serum lgG and lgM levels and improved the immune performance of pigs [35, 57]. Tian et al. (2014) pointed out that the concentrations of IgA, IgG, and IgM in serum were increased linearly with increased Cr dosage, and pigs fed 400 μg/kg Cr had greater serum IgM contents [6]. Similarly, CrYst supplementation to diets for growing pigs in our trial significantly improved the serum IgG and IgM concentrations.

Cholesterol is the most abundant sterol in animals and is the raw material for the synthesis of vitamin D, sterol hormones, and bile acid. Serum cholesterol includes free cholesterol and cholesterol lipids, and its serum content is in a state of dynamic equilibrium with liver cholesterol [48, 58]. Insulin could induce the synthesis of HMGCoA reductase and increase cholesterol synthesis [59]. Trivalent Cr has been demonstrated to strengthen the function of insulin and promote the utilization of glucose, thus changing the lipid metabolism direction and reducing fat deposition [6, 15]. In addition, the elevation of insulin activity also promotes the conversion of glucose into glycogen and TG in tissues like muscle, liver, and fat cells, thereby furthering the absorption of plasma TG by fat tissue by promoting the activity of LPL [9, 42]. Serum TG content is a lipid metabolism indicator, and its decreased level indicates that lipolysis is more active [42, 50]. HDL could strengthen the serum decomposition of chylomicrons and vLDL and promote the transfer of cholesterol from extrahepatic tissues to the liver, where it is excreted from the body through metabolism or bile secretion [15, 58]. HDL has an inhibitory effect on the binding of LDL to cell receptors in extrahepatic tissues, and the absorption of cholesterol by peripheral tissues would be reduced in this case [9, 15]. Thus, this shows that Cr plays an important role in maintaining the balance of serum cholesterol. Early studies with supplemental organic Cr by Lien et al. (2001) and Wang et al. (2017) at levels of 200 μg/kg to growing and finishing pigs demonstrated some enhancement in serum HDL-C and lipase levels and reduction in serum concentrations of LDL-C, TG, TCHOL, and urea [9, 57]. While dietary supplementation of 200 μg/kg CrYst did not affect the serum contents of TG, TCHOL, LDL-C, and HDL-C in the DLY piglets and growing pigs reported by Li et al. (2017), Tian et al. (2014), and Mayorga et al. (2019) [3, 6, 35]. The current study indicated that additional CrYst to the diet reduced the serum HDL-C concentration of growing pigs and increased the serum LDL-C concentration of finishing pigs but not affect the other indexes. That different result may be due to the differences in animal growth stage and diets total Cr levels. Inconsistent with the results of the present study, some studies in rats have also found that the addition of chromium (III) glycinate (CrGly) to the diet significantly decreased serum cholesterol and HDL-C contents [60]. In addition, Lemme et al. (2000) found that diets supplemented with 200 μg/kg CrYst did not affect the serum contents of glucose and insulin in pigs, which was in agreement with the current study [61]. However, in contrast to the results presented herein, Huang et al. (2002) addition of 500 μg/kg Cr as CrYst to diets of 23–90 kg pigs indicated reduction in serum glucose content and increased serum insulin content, whereas the Cr concentration in the control group of that study was far lower than that of our research and only 0.42 μg/kg [62].

Conclusions

The present data demonstrated that dietary supplemental Cr at 200 μg/kg from chromium yeast significantly decreased the backfat depth value and increased the meat tenderness score and juiciness score values in pigs, but did no influence on growth performance and other carcass traits and meat traits indexes. In addition, chromium yeast supplementation improved antioxidant capacity and immune status in growing-finishing pigs.

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Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare potential conflict of interest, given that ZP Chen is an employee of Angel Yeast Co., Ltd., one of financial supporters of the present study.

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