Determining the influence of chromium propionate and *Yucca schidigera* on growth performance and carcass composition of pigs housed in a commercial environment[1]

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ABSTRACT: Two experiments were conducted to determine the effects of feeding chromium propionate (Cr; Kemin Industries, Inc., Des Moines, IA) and a *Yucca schidigera*-based extract (YS; Distributors Processing, Inc., Porterville, CA) on growth performance of finishing pigs housed in commercial conditions. In experiment 1, a total of 1,188 pigs (PIC 337 × 1050; initially 27.3 ± 0.48 kg body weight [BW]) with 27 pigs per pen and 11 pens per treatment were split by sex upon arrival at the facility and were randomly allotted to groups of four pens blocked by BW. Diets were corn–soybean meal-dried distillers grains with solubles-based and were fed in five phases. Treatments were arranged as a 2 × 2 factorial with main effects of Cr (0 vs. 200 µg/kg) or YS (0 vs. 62.5 mg/kg YS-based feed grade concentrate). Overall, adding Cr alone increased (*P* = 0.049) average daily feed intake (ADFI), and inclusion of YS resulted in a marginally significant increase (*P* = 0.077) in ADFI. Backfat depth was increased (*P* = 0.043) and lean percentage was decreased (*P* = 0.011) with added Cr. In experiment 2, a total of 2,430 pigs (PIC 359 × 1050; initially 29.3 ± 0.43 kg BW) were placed in balanced mixed-sex pens with 27 pigs per pen, blocked by average pen BW, and randomly assigned to one of six dietary treatments with 14 pens per treatment. Diets were corn–soybean meal-based and were formulated in five dietary phases. Treatments were arranged in a 2 × 3 factorial with main effects of Cr (0 vs. 200 µg/kg added Cr), and YS extract (0, 62.5, or 125 mg/kg YS-based feed grade concentrate). Overall, a marginally significant (linear, *P* = 0.072) Cr × YS interaction was observed for average daily gain (ADG) where there was insufficient evidence of a difference with increasing YS in diets not including added Cr (*P* ≥ 0.109); however, ADG increased (quadratic, *P* = 0.026) with YS addition in treatments fed 200 µg/kg added Cr. For overall ADFI, a marginally significant (linear, *P* = 0.071) Cr × YS interaction was observed where YS increased ADFI with 200 µg/kg added Cr (linear, *P* = 0.031), however, did not when diets contained no added Cr (*P* = 0.700). A marginally significant reduction in gain:feed ratio was observed when 62.5 mg/kg YS was included (quadratic, *P* = 0.053), and final BW and hot carcass weight were lowest with 62.5 mg/kg YS (quadratic, *P* = 0.012). In summary, adding Cr propionate along with YS led to modest changes in performance with the greatest benefit observed with 200 µg/kg Cr and 125 mg/kg YS-based feed grade concentrate.

Key Words: chromium propionate, finishing pigs, Yucca schidigera

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INTRODUCTION

Chromium (Cr) supplementation in swine feeding programs has been evaluated with significant variability in observed responses. Cr plays a role in the metabolism of multiple molecules, including carbohydrates, lipids, proteins, and nucleic acids (NRC, 2012). Corn–soybean meal-based diets contain a significant amount of Cr ranging from 750 to 3,000 µg/kg, but much of that is thought to be unavailable to the animal (NRC, 2012). Such variability in composition in ingredients may be one of the factors leading to significant variability in the presence and magnitude of response in swine. A meta-analysis was conducted by Sales and Jancík (2011) and observed that dietary supplementation with Cr to be associated with improved carcass characteristics including reduced backfat and increased percentage lean along with improved growth performance. In addition, *Yucca schidigera* (YS) is believed to have a positive impact on gastrointestinal microflora (Katsunuma et al., 2000) through its saponin characteristics, thereby reducing gaseous emissions (Sun et al., 2017) and potentially improving growth performance. Supplementation of YS in finishing pig diets has shown improvements in finishing pig gain:feed ratio (G:F) (Mader and Brumm, 1987); however, several additional studies in both nursery and finishing pigs did not observe a benefit (Amon et al., 1995; Van den Berghel et al., 2000; Colina et al., 2001, Panetta et al., 2006). Research related to the impact of YS on blood metabolites in swine is currently limited; however, it has been shown to reduce cholesterol and triglyceride levels (Munoz et al., 2008) in swine. Currently, no evidence exists evaluating potential interactions between Cr and YS-based feed additives. Therefore, the objective of this series of experiments was to further determine the effects of Cr supplementation with and without a YS-based feed grade concentrate supplemented at multiple levels on growth performance and carcass composition of pigs housed in a commercial environment.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The studies were conducted at a commercial research-finishing site in southwest Minnesota using three identical barns. The barns were naturally ventilated and double-curtain-sided. Each pen (5.5 × 3.0 m) was equipped with a four-hole stainless-steel feeder and cup waterer for ad libitum access to feed and water and allowed approximately 0.61 m^2 per pig. Feed additions to each pen were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN).

Animals and Diets

In experiment 1, a total of 1,188 pigs (337 × 1050; PIC, Hendersonville, TN; initially 27.3 ± 0.48 kg body weight [BW]) with 27 pigs per pen and 11 pens per treatment were used. Pigs were split by sex upon arrival at the facility, with five blocks of each sex and a final mixed-sex block. Blocks were randomly allotted to groups of four pen locations within the barn and randomized to dietary treatment within block. Diets were corn–soybean meal-dried distillers grains with solubles-based and were fed in five phases. All diets were formulated to meet or exceed NRC (2012) requirement estimates (Table 1). Treatments were arranged in a 2 × 2 factorial with main effects of Cr (0 vs. 200 µg/kg; KemTRACE Chromium; Kemin Industries, Inc., Des Moines, IA) or YS (0 vs. 62.5 mg/kg; Micro-Aid; Distributors Processing, Inc., Porterville, CA) and were fed for the full duration of the experiment. Ractopamine HCl (Paylean 19.84 g/kg; Elanco, Greenfield, IN) was included in phase 5 diets and fed for 27 d. Experimental diets were manufactured at a commercial feed mill (New Horizon Feeds, Pipestone, MN). The pigs used in the current experiments did not experience significant health challenges.

In experiment 2, a total of 2,430 pigs (359 × 1050; PIC, Hendersonville, TN; initially 29.3 ± 0.43 kg BW) with 27 pigs per pen and 14 pens per treatment were used. Pigs were placed in two research barns on separate weaning dates, each filling independently. Pigs were placed in mixed-sex pens with equal numbers of barrows and gilts across pens, blocked by average pen BW within barn, and randomly assigned to treatment. Diets were corn–soybean meal-based and formulated in five dietary phases to meet or exceed NRC (2012) requirement estimates within phase. Dietary treatments were fed for the full duration of the study and arranged in a 2 × 3 factorial. Main effects included added Cr (0 vs. 200 µg/kg), and YS-based feed grade concentrate (0, 62.5, or 125 mg/kg). All diets were manufactured at a commercial feed mill (New Horizon Feeds; Table 2) and fed in meal form. No ractopamine HCl was used in experiment 2.

In both experiments, pens of pigs were weighed and feeder measurements were recorded a minimum

Table 1. Diet composition, experiment 1 (as-fed basis)[1]

	BW range, kg				
Item	27 to 45	45 to 61	61 to 77	77 to 104	104 to 127
Ingredient, %					
Corn	56.05	61.25	65.80	69.25	67.25
Soybean meal, 46.5% CP	21.60	16.50	11.95	8.55	20.65
DDGS[2]	20.00	20.00	20.00	20.00	10.00
Calcium carbonate	1.25	1.28	1.23	1.20	1.03
Monocalcium phosphate, 21% P	0.15	—	—	—	0.10
Salt	0.35	0.35	0.35	0.35	0.35
L-Lys HCl	0.36	0.37	0.39	0.39	0.28
DL-Met	0.01	—	—	—	0.04
L-Thr	0.05	0.04	0.05	0.06	0.07
L-Trp	—	0.01	0.02	0.02	—
Ractopamine HCl[3]	—	—	—	—	0.03
Phytase[4]	0.01	0.01	0.01	0.01	0.01
Trace mineral premix[5]	0.10	0.10	0.10	0.10	0.10
Vitamin premix[6]	0.08	0.08	0.08	0.08	0.08
Cr[7]	+/−	+/−	+/−	+/−	+/−
YS[8]	+/−	+/−	+/−	+/−	+/−
Total	100	100	100	100	100
Calculated analysis[9]					
Standardized ileal digestible (SID) amino acids, %					
Lys	1.02	0.91	0.82	0.74	0.90
Ile:Lys	63	62	60	59	64
Leu:Lys	152	159	164	171	150
Met:Lys	29	29	30	31	32
Met and Cys:Lys	55	56	57	59	59
Thr:Lys	61	61	61	63	65
Trp:Lys	18.4	18.4	18.4	18.4	19.0
Val:Lys	70	70	70	70	71
Total Lys, %	1.18	1.06	0.96	0.87	1.04
ME[10], kcal/lb	1,502	1,506	1,509	1,511	1,506
NE[11], kcal/lb	1,103	1,118	1,130	1,140	1,123
SID Lys:ME, g/Mcal	3.08	2.74	2.46	2.22	2.71
SID Lys:NE, g/Mcal	4.20	3.69	3.29	2.94	3.64
CP, %	20.0	18.1	16.4	15.0	17.6
Ca, %	0.61	0.57	0.54	0.52	0.50
P, %	0.45	0.40	0.38	0.36	0.40
STTD[12] P, %	0.33	0.29	0.28	0.27	0.29

[1]A total of 1,188 finisher pigs (337 × 1050; PIC, Hendersonville, TN; initial BW = 27.3 ± 0.48 kg) were used in a 117 d, five-phase finisher study with 27 pigs per pen and 11 replications per treatment.

[2]DDGS = dried distillers grains with solubles.

[3]Paylean 19.84 g/kg (Elanco, Greenfield, IN).

[4]OptiPhos 2000 (Huvepharma, Sofia, Bulgaria) provided an estimated release of 0.10% STTD P.

[5]Premix provided per kg of premix: 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 33 g Mn from manganese oxide; 17 g Cu from copper sulfate; 330 mg I from calcium iodate; and 300 mg Se from sodium selenite.

[6]Premix provided per kg of premix: 7,054,798 IU vitamin A; 1,102,312 IU vitamin D3; 35,242 IU vitamin E; 3,528 mg vitamin K; 26.5 mg vitamin B12; 39,683 mg niacin; 22,046 mg pantothenic acid; and 6,173 mg riboflavin.

[7]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA) was added at 0.5 kg/tonne (200 µg/kg Cr) at the expense of corn in the appropriate treatment diets.

[8]YS-based feed grade concentrate (Distributors Processing, Inc., Porterville, CA) was added at 1 kg/tonne in the appropriate treatment diets at the expense of corn to provide 62.5 mg/kg active ingredient in the completed diet.

[9]NRC (2012).

[10]ME = Metabolizable energy.

[11]NE = Net energy.

[12]STTD = Standardized total tract digestible.

Table 2. Diet composition, experiment 2 (as-fed basis)[1]

	BW range, kg				
Item	27 to 45	45 to 68	68 to 91	91 to 109	109 to 127
Ingredient, %					
Corn	55.04	63.03	68.13	71.29	79.82
Soybean meal, 46.5% CP	22.80	14.97	9.89	6.71	8.21
DDGS[2]	20.00	20.00	20.00	20.00	10.00
Calcium carbonate	0.95	0.98	0.90	0.93	0.85
Monocalcium phosphate, 21% P	0.25	0.08	0.10	0.08	0.20
Salt	0.35	0.35	0.35	0.35	0.35
L-Lys HCl	0.38	0.39	0.40	0.41	0.33
DL-Met	0.02	—	—	—	—
L-Thr	0.05	0.04	0.05	0.06	0.07
L-Trp	—	0.01	0.02	0.02	0.01
Phytase[3]	0.01	0.01	0.01	0.01	0.01
Vitamin/trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15
Cr[5]	+/−	+/−	+/−	+/−	+/−
YS[6]	+/−	+/−	+/−	+/−	+/−
Total	100	100	100	100	100
Calculated analysis[7]					
Standardized ileal digestible (SID) amino acids, %					
Lys	1.06	0.89	0.78	0.71	0.65
Ile:Lys	62	60	59	58	58
Leu:Lys	149	158	166	173	166
Met:Lys	30	29	30	31	30
Met and Cys:Lys	55	56	58	60	59
Thr:Lys	61	60	61	63	65
Trp:Lys	18.3	18.1	18.0	18.0	18.0
Val:Lys	69	69	69	69	69
Total Lys, %	1.23	1.04	0.92	0.84	0.76
ME[8], kcal/lb	1,505	1,511	1,514	1,516	1,514
NE[9], kcal/lb	1,102	1,125	1,139	1,148	1,158
SID Lys:ME, g/Mcal	3.19	2.67	2.34	2.12	1.95
SID Lys:NE, g/Mcal	4.36	3.59	3.11	2.81	2.55
CP, %	20.5	17.5	15.6	14.4	12.9
Ca, %	0.52	0.48	0.43	0.43	0.42
P, %	0.48	0.41	0.39	0.37	0.37
STTD[10] P, %	0.35	0.30	0.29	0.28	0.28

[1]A total of 2,430 finisher pigs (359 × 1050; PIC, Hendersonville, TN; initial BW = 29.3 ± 0.43 kg) were used in a five-phase finisher study with 27 pigs per pen and 14 replications per treatment.

[2]DDGS = dried distillers grains with solubles.

[3]OptiPhos 2000 (Huvepharma, Sofia, Bulgaria) provided an estimated release of 0.10% STTD P.

[4]Premix provided per kg of premix: 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 200 mg Se from sodium selenite, 3,527,399 IU vitamin A; 881,850 IU vitamin D3; 17,637 IU vitamin E; 1,766 mg vitamin K; 15 mg vitamin B12; 33,069 mg niacin; 11,023 mg pantothenic acid; and 3,307 mg riboflavin.

[5]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA) was added at 0 or 0.5 kg/tonne (200 µg/kg added Cr) at the expense of corn.

[6]YS-based feed grade concentrate (Distributors Processing, Inc., Porterville, CA) was added at 0, 1, or 2 kg/tonne at the expense of corn to provide 0, 62.5, and 125 mg/kg active ingredient in the completed diets, respectively.

[7]NRC (2012).

[8]ME = Metabolizable energy.

[9]NE = Net energy.

[10]STTD = Standardized total tract digestible.

of every 14 d and at dietary phase changes, first marketing, and conclusion of the trial to determine average daily gain (ADG), average daily feed intake (ADFI), and G:F. The three largest pigs per pen were selected using visual evaluation by trained personnel and marketed at an average barn weight (experiment 1: 111 kg on d 97; experiment 2: 118 kg on d 95 for barn 1, 113 kg on d 98 for barn 2) following the

Table 3. Chemical analysis of diets, experiment 1 (as-fed basis)[1]

Added Cr[2], µg/kg	0	200	0	200
YS[3], mg/kg	0	0	62.5	62.5
BW range, kg				
27 to 45				
DM, %	88.0	87.1	88.7	88.3
CP, %	19.9	17.8	20.0	18.5
Ether extract, %	3.7	3.2	3.6	3.5
Crude fiber, %	3.6	3.6	3.0	2.8
45 to 61				
DM, %	88.1	88.8	88.2	87.4
CP, %	16.8	18.2	21.4	19.2
Ether extract, %	4.3	3.6	3.7	3.3
Crude fiber, %	3.4	3.5	3.5	4.6
61 to 77				
DM, %	88.9	88.7	88.5	89.3
CP, %	16.7	16.2	16.9	15.5
Ether extract, %	3.8	3.8	3.8	3.7
Crude fiber, %	3.2	3.0	3.3	3.1
77 to 104				
DM, %	88.3	88.3	88.6	88.7
CP, %	15.1	15.2	15.4	14.9
Ether extract, %	3.7	3.6	3.8	3.6
Crude fiber, %	3.1	3.2	3.1	2.9
104 to 127				
DM, %	87.6	88.9	88.7	88.3
CP, %	17.6	17.8	17.5	19.5
Ether extract, %	3.0	3.2	3.1	3.0
Crude fiber, %	2.6	2.9	2.8	2.8

[1]A composite sample was collected from feeders within treatment and phase, subsampled, and submitted to Ward Laboratories (Kearney, NE) for proximate analysis.

[2]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA) was added at 0.5 kg/tonne (200 µg/kg Cr) at the expense of corn in the appropriate treatment diets.

[3]YS-based feed grade concentrate (Distributors Processing, Inc., Porterville, CA) was added at 1 kg/tonne (62.5 mg/kg active ingredient) at the expense of corn in the appropriate treatment diets.

routine farm protocol with no carcass data collected on this subset. At the conclusion of the trial (experiment 1, d 117; experiment 2, d 103 for barn 1, d 113 for barn 2), the remaining animals were given a tattoo corresponding to pen number and were transported to a commercial packing facility (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements taken at the plant included live pen weight, hot carcass weight (HCW), backfat, percentage carcass lean, and loin depth. Loin depth and backfat were measured using an optical probe inserted between the third and fourth ribs from the caudal aspect of the carcass at a distance approximately 7 cm from dorsal midline as described by Gebhardt et al. (2018). Percentage carcass lean was calculated using a proprietary formula using HCW, backfat depth, and loin depth. In addition, percentage yield was calculated by dividing pen average HCW by pen average live weight collected at the research facilities prior to transport to processing facility. On the morning of scheduled transport to the packing facility, the electronic feeding unit was shut off and no further feed was delivered to pens. Pigs were loaded in late afternoon, transported approximately 70 miles to the packing facility, and harvested beginning early the following day.

Chemical Analysis

For both experiments, complete diet samples were collected from multiple feeders within treatment, combined within phase when applicable, and subsampled for analysis. All feed samples were analyzed (Ward Laboratories, Kearney, NE) for dry matter (DM) (method 934.01; AOAC, 2006), crude protein (CP) (method 990.03; AOAC, 2006), ether extract (method 920.39 A; AOAC, 2006), crude fiber (method 978.10; AOAC, 2006) and control diets (no added Cr, no added YS) were submitted to Agriculture and Food Laboratory, University of Guelph (Guelph, ON) for analysis of baseline Cr (method 6020a; US EPA, 1998).

Statistical Analysis

Data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. For experiment 1, block was included in the model as a random effect and accounted for gender, location within barn, and initial BW at the time of allotment. For experiment 2, weight block was included in the model as a random effect, which also accounted for barn. Linear and quadratic interactive effects were evaluated in the statistical model, as well as the main effect of added Cr and linear and quadratic effects of increasing YS. Backfat, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

RESULTS

Chemical Analysis

Chemical analysis of diets fed in experiment 1 (Table 3) and experiment 2 (Table 4) resulted in no notable differences among treatments. Cr analysis yielded a significant amount of variability among control diets across dietary phase and experiment,

Table 4. Chemical analysis of diets, experiment 2 (as-fed basis)[1,2]

Added Cr[2], μg/kg	0	0	0	200	200	200
YS[3], mg/kg	0	62.5	125	0	62.5	125
BW range, kg						
27 to 45						
DM, %	89.8	89.4	89.7	89.9	89.7	89.6
CP, %	20.7	21.7	21.6	21.3	20.6	21.5
Ether extract, %	3.4	3.7	3.4	3.3	3.6	3.7
Crude fiber, %	2.1	2.4	2.5	2.0	2.1	2.6
45 to 68						
DM, %	89.7	89.9	90.0	89.7	90.3	89.7
CP, %	19.2	18.7	19.7	19.5	19.6	19.1
Ether extract, %	3.8	3.6	3.6	3.6	3.9	3.7
Crude fiber, %	2.1	2.1	2.9	2.8	3.4	2.8
68 to 91						
DM, %	89.6	89.4	89.3	89.0	88.9	89.7
CP, %	16.2	16.1	16.0	16.1	15.0	15.6
Ether extract, %	3.8	3.7	4.0	3.9	4.0	3.9
Crude fiber, %	2.5	2.7	2.9	2.6	2.6	2.4
91 to 109						
DM, %	89.4	90.0	89.8	89.0	89.6	89.6
CP, %	16.8	17.7	18.4	15.9	15.7	17.9
Ether extract, %	3.9	3.6	3.7	3.8	3.9	3.8
Crude fiber, %	2.5	3.3	3.3	3.2	2.1	2.5
109 to 127						
DM, %	88.8	90.4	89.0	89.9	89.2	88.9
CP, %	13.9	13.8	14.2	12.7	13.9	14.9
Ether extract, %	3.5	3.8	4.0	3.6	4.0	4.2
Crude fiber, %	2.4	1.9	2.4	1.8	2.6	2.4

[1]A composite sample was collected from feeders within treatment and phase, subsampled, and submitted to Ward Laboratories (Kearney, NE) for proximate analysis.

[2]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA) was added at 0 or 0.5 kg/tonne (200 μg/kg added Cr) at the expense of corn.

[3]YS-based feed grade concentrate (Distributors Processing, Inc., Porterville, CA) was added at 0, 1, or 2 kg/tonne at the expense of corn to provide 0, 62.5, and 125 mg/kg active ingredient, respectively.

ranging from 450 to 1,700 μg/kg. Analyzed Cr in control diets in experiment 1 averaged across dietary phases was 570 μg/kg, and for experiment 2 was 1,270 μg/kg.

Experiment 1

In experiment 1, there was no evidence of a Cr × YS interaction observed ($P \geq 0.149$) for any growth performance or carcass characteristics (Table 5). For the grower period, added Cr increased ($P \leq 0.028$) ADG and ADFI. Added YS in the grower period resulted in a reduction ($P = 0.050$) in G:F. During the finishing period, added Cr resulted in a marginally significant increase in ADFI ($P = 0.080$) and reduction in G:F ($P = 0.056$). Added YS in the finishing period resulted in a marginally significant increase ($P = 0.088$) in ADFI. Overall, ADG and G:F were not influenced by treatment ($P \geq 0.115$). Overall ADFI was increased ($P = 0.049$) with Cr supplementation, and added YS resulted in a marginally significant improvement ($P = 0.077$) in ADFI. Carcass characteristics including HCW, loin depth, and carcass yield were not influenced by treatment ($P \geq 0.136$). Backfat depth was increased ($P = 0.043$) and lean percentage decreased ($P = 0.011$) when Cr was added to diets.

Experiment 2

In experiment 2, increasing YS in the grower period resulted in a marginally significant (Table 6; quadratic, $P = 0.093$) decrease then increase in ADG, with the poorest gain observed in pigs fed diets with 62.5 mg/kg YS and the best gain observed in pigs fed 125 mg/kg. This resulted in a marginally significant Cr × YS interaction (linear, $P = 0.100$) for BW at the end of the grower period. BW at the end of the grower period was similar across YS treatments when Cr was not included in the diet ($P \geq 0.322$), but was increased in a marginally significant manner when YS increased from

Table 5. Impact of Cr and YS on finishing pig growth performance and carcass characteristics, experiment 1[1]

Added Cr[2], µg/kg	0	200	0	200		Probability, $P <$		
YS[3], mg/kg	0	0	62.5	62.5	SEM	YS × Cr	Cr	YS
BW, kg								
Initial	27.3	27.3	27.3	27.4	0.48	0.653	0.907	0.726
End grower	60.5	61.0	60.4	61.0	0.79	0.906	0.099	0.916
Final	129.2	129.7	129.5	130.4	1.30	0.893	0.472	0.609
Grower[4]								
ADG, kg	0.85	0.86	0.85	0.86	0.010	0.989	0.027	0.713
ADFI, kg	1.73	1.77	1.75	1.78	0.033	0.980	0.028	0.224
G:F	0.49	0.49	0.48	0.48	0.005	0.975	0.769	0.050
Finisher[5]								
ADG, kg	0.88	0.88	0.89	0.89	0.010	0.761	0.954	0.334
ADFI, kg	2.47	2.52	2.52	2.56	0.056	0.907	0.080	0.088
G:F	0.36	0.35	0.35	0.35	0.006	0.924	0.056	0.418
Overall								
ADG, kg	0.87	0.87	0.87	0.88	0.009	0.810	0.446	0.490
ADFI, kg	2.22	2.26	2.26	2.30	0.047	0.955	0.049	0.077
G:F	0.39	0.39	0.39	0.38	0.006	0.915	0.115	0.178
Carcass characteristics[6]								
HCW, kg	96.2	97.6	97.5	98.3	1.11	0.716	0.136	0.165
Backfat, mm	16.87	17.83	17.26	17.43	0.269	0.149	0.043	0.993
Lean, %	56.98	56.41	56.83	56.51	0.446	0.457	0.011	0.880
Loin depth, mm	70.22	70.03	70.71	69.56	0.668	0.312	0.163	0.987
Yield, %[7]	74.50	75.22	75.28	75.43	0.456	0.510	0.305	0.251

[1]A total of 1,188 finisher pigs (337 × 1050; PIC, Hendersonville, TN; initial BW = 27.3 ± 0.48 kg) were used in a 117 d, five-phase finisher study with 27 pigs per pen and 11 replications per treatment.

[2]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA).

[3]YS-based feed grade concentrate (Distributors Processing, Inc., Porterville, CA).

[4]Dietary phases 1 and 2 fed from d 0 to 39.

[5]Dietary phases 3 to 5 fed from d 39 to 117.

[6]The largest three pigs were marketed from each pen on d 97. All remaining pigs were marketed from each pen on d 117. Carcass characteristics other than yield were adjusted to a common HCW by inclusion of HCW as a covariate in the statistical model.

[7]Yield was calculated by dividing HCW by average pen live weight collected at the research barn prior to transport to processing facility.

62.5 to 125 mg/kg in diets containing 200 ppb added Cr (quadratic, $P = 0.053$). Inclusion of Cr or YS had no effect ($P \geq 0.105$) on ADFI or G:F during the grower period.

During the finishing phase, pigs fed 62.5 mg/kg YS had decreased (quadratic, $P = 0.018$) ADG compared to control and 125 mg/kg YS-fed pigs. There was no evidence of differences ($P \geq 0.162$) among pigs for ADFI observed within the finishing period. A marginally significant reduction (linear, $P = 0.051$) in G:F was observed in pigs fed increasing YS. Added Cr during the finishing period did not influence ADG, ADFI, or G:F ($P \geq 0.167$).

For the overall data, a marginally significant (linear, $P = 0.072$) Cr × YS interaction was observed for ADG. Sufficient evidence of a linear relationship with increasing YS supplementation within either Cr level was not present ($P \geq 0.193$), however, ADG increased (quadratic, $P = 0.026$) in treatments fed 200 µg/kg added Cr. A marginally significant Cr × YS interaction ($P = 0.071$) was observed for overall ADFI where YS inclusion resulted in an increase in ADFI when 200 µg/kg added Cr was fed (linear, $P = 0.031$), however, no evidence of a difference was observed in diets containing no added Cr ($P = 0.700$). YS supplementation had a marginally significant impact on overall G:F, with the lowest G:F observed in diets containing 62.5 mg/kg added YS (quadratic, $P = 0.053$). A marginally significant (linear, $P = 0.058$) Cr × YS interaction was observed for final BW. Sufficient evidence of a linear relationship with increasing YS supplementation within either Cr level was not present ($P \geq 0.159$), however, final BW increased (quadratic, $P = 0.041$) in treatments fed 200 µg/kg added Cr. The main effect of added YS on final BW (quadratic, $P = 0.012$) resulted in pigs fed diets with 62.5 mg/kg having the lowest final BW. Added Cr alone did not influence overall growth performance ($P \geq 0.299$). Carcass characteristics, including HCW, loin depth, backfat, percentage lean, and percentage yield, were not influenced by added Cr ($P \geq 0.278$). Inclusion of YS at

Table 6. Impact of Cr and YS inclusion on finishing pig growth performance and carcass characteristics, experiment 2[1]

								Probability, $P <$				
								YS × Cr			YS	
Added Cr[2], μg/kg	0	0	0	200	200	200						
YS[3], mg/kg	0	62.5	125	0	62.5	125	SEM	Linear	Quad	Cr	Linear	Quad
BW, kg												
Initial	29.3	29.3	29.3	29.3	29.3	29.3	0.43	0.902	0.679	0.991	0.965	0.885
End grower[4]	91.4	91.0	90.8	91.0	90.4	91.8	0.92	0.100	0.254	0.971	0.797	0.109
Final[5]	124.2	122.5	123.1	123.9	123.0	124.9	0.84	0.058	0.723	0.167	0.936	0.012
Grower[6]												
ADG, kg	0.90	0.89	0.89	0.89	0.88	0.90	0.009	0.166	0.265	0.945	0.682	0.093
ADFI, kg	2.19	2.19	2.18	2.17	2.18	2.21	0.023	0.105	0.656	0.936	0.448	0.734
G:F	0.41	0.41	0.41	0.41	0.41	0.41	0.006	0.540	0.578	0.958	0.652	0.138
Finisher[7]												
ADG, kg	0.89	0.86	0.87	0.88	0.87	0.89	0.022	0.237	0.576	0.167	0.509	0.018
ADFI, kg	2.97	2.92	2.96	2.93	2.96	2.99	0.037	0.162	0.326	0.601	0.232	0.252
G:F	0.30	0.29	0.29	0.30	0.29	0.30	0.005	0.887	0.762	0.236	0.051	0.092
Overall												
ADG, kg[8]	0.89	0.88	0.88	0.89	0.88	0.90	0.013	0.072	0.649	0.299	0.976	0.007
ADFI, kg[9]	2.46	2.44	2.45	2.43	2.45	2.48	0.019	0.071	0.783	0.686	0.202	0.377
G:F	0.36	0.36	0.36	0.37	0.36	0.36	0.006	0.673	0.444	0.516	0.119	0.053
Carcass characteristics[10]												
HCW, kg	93.3	91.9	92.8	92.9	92.5	93.7	1.05	0.183	0.668	0.315	0.774	0.012
Loin depth, mm	66.39	65.85	66.40	66.42	65.94	65.16	0.784	0.196	0.422	0.353	0.206	0.648
Backfat, mm	16.56	16.25	16.45	16.69	16.36	16.69	0.292	0.811	0.851	0.409	0.819	0.152
Lean, %	56.73	56.85	56.79	56.65	56.79	56.50	0.226	0.482	0.642	0.278	0.787	0.267
Yield, %[11]	75.2	75.0	75.4	75.0	75.2	75.0	0.74	0.472	0.155	0.426	0.568	0.542

[1]A total of 2,430 finisher pigs (359 × 1050; PIC, Hendersonville, TN; initial BW = 29.3 ± 0.43 kg) were used in a five-phase finisher study with 27 pigs per pen and 14 replications per treatment using two commercial grow-finish barns (hereafter described as barn 1 and barn 2).

[2]Cr (chromium propionate; Kemin Industries, Inc., Des Moines, IA) was added at 0 or 0.50 kg/tonne (200 μg/kg added Cr) at the expense of corn.

[3]YS-based feed grade concentrate (YS; Distributors Processing, Inc.) was added at 0, 1, or 2 kg/tonne at the expense of corn to provide 0, 62.5, and 125 mg/kg YS, respectively.

[4]Dose effect of YS when Cr not included in diet, linear, $P = 0.322$, quadratic, $P = 0.743$; dose effect of YS when Cr included in diet, linear, $P = 0.179$, quadratic, $P = 0.053$.

[5]Dose effect of YS when Cr not included in diet, linear, $P = 0.159$, quadratic, $P = 0.121$; dose effect of YS when Cr included in diet, linear, $P = 0.197$, quadratic, $P = 0.041$.

[6]Dietary phases 1 to 3 fed for d 0 to 69 for both barns.

[7]Dietary phases 4 and 5 fed for d 69 to 103 and d 69 to 113, barn 1, barn 2, respectively.

[8]Dose effect of YS when Cr not included in diet, linear, $P = 0.193$, quadratic, $P = 0.109$; dose effect of YS when Cr included in diet, linear, $P = 0.209$, quadratic, $P = 0.026$.

[9]Dose effect of YS when Cr not included in diet, linear, $P = 0.700$, quadratic, $P = 0.414$; dose effect of YS when Cr included in diet, linear, $P = 0.031$, quadratic, $P = 0.667$.

[10]The largest three pigs were marketed from each pen on d 95 for barn 1, and d 98 for barn 2. All remaining pigs were marketed from each pen on d 103 and d 113, respectively. Carcass characteristics other than yield were adjusted to a common HCW by inclusion of HCW as a covariate in the statistical model.

[11]Yield was calculated by dividing HCW by average pen live weight collected at the research barn prior to transport to processing facility.

62.5 mg/kg resulted in the lowest HCW (quadratic, $P = 0.012$), but did not influence loin depth, backfat, percentage lean, or percentage yield ($P \geq 0.152$).

DISCUSSION

Cr interacts in many metabolic pathways as summarized by NRC (2012). Cr supplementation in swine feeding programs has shown a significant variability in observed response in scientific literature, as briefly summarized by Gebhardt et al. (2018). A number of factors are likely involved with the variability in growth performance benefits, including dietary composition, Cr source, environmental, and management factors (Lindemann, 2007). Cr is present in natural feedstuffs at relatively low levels ranging from 750 to 3,000 μg/kg (NRC, 2012), with a high degree of variability. In addition, Cr originating from natural feedstuffs has a low bioavailability (NRC, 2012), and organic forms are believed to be much more bioavailable (Lindemann, 2007). For these reasons, evaluation of dietary Cr content can be an analytical challenge.

Sales and Jancík (2011) attempted to summarize and quantify the effect of dietary Cr supplementation on carcass characteristics and growth performance of finishing swine across 31 studies using meta-analysis. Multiple sources and levels of Cr were included in the analysis, including Cr methionine chelate, Cr nanocomposite, Cr nicotinate, Cr propionate, Cr tripicolinate, and Cr yeast. The analysis suggested that when Cr is included in swine finishing diets, the carcass would have a reduced backfat thickness, increased percentage lean, and increased loin muscle area compared to no Cr supplementation. In experiment 1, inclusion of Cr propionate resulted in greater backfat and reduced percentage lean, which is in contrast to what Sales and Jancík (2011) observed. Supplementation of Cr had no influence on carcass characteristics in experiment 2. An important distinction to make when evaluating Sales and Jancík (2011) is a number of Cr sources, supplementation doses ranging up to 800 µg/kg, and significant variation in the date of publication. Studies included in the meta-analysis varied from 1993 until 2009, and could represent significant differences in genetic lean growth potential compared to modern high-producing genetic potential. Nonetheless, the current series of experiments did not demonstrate a significant improvement in carcass characteristics with Cr supplementation as would be suggested by summary of previously published literature.

In addition to carcass characteristics, Sales and Jancík (2011) found Cr supplementation to be positively correlated with ADG and G:F. In experiment 1, Cr supplementation improved overall ADFI, however, had no influence on overall ADG or G:F. In experiment 2, marginally significant Cr × YS interactions were present for both ADG and ADFI, where YS supplementation increased performance when 200 µg/kg added Cr was included. In the current series of experiments, overall ADG and G:F were not improved by Cr supplementation with the exception of a marginally significant interaction for overall ADG in experiment 2. Supplementation of Cr increased ADG during the growing period of experiment 1; however, no additional impact was observed in finishing or overall ADG.

Research designed to directly evaluate the impact of YS supplementation on growth performance of finishing pigs and carcass characteristics is relatively scarce in recent years, and no previous research has evaluated the combination of YS and Cr propionate under commercial conditions. The saponin characteristics of YS are thought to convert ammonia to less volatile forms, such as ammonium nitrogen (Panetta et al., 2006), thereby reducing ammonia concentrations in swine production facilities (Cheeke, 2000; Colina et al., 2001), as well as more generally reduce odorants in poultry production (Matusiak et al., 2016). Many such studies evaluating gaseous emissions also report growth performance measurements (Amon et al., 1995; Colina et al., 2001; Panetta et al., 2006). Within these studies, there was no evidence of differences in growth performance between pigs fed YS extract and control. However, it is important to consider such studies were not designed with evaluation of growth performance as the primary objective.

In experiment 1, YS supplementation at 62.5 mg/kg resulted in the lowest G:F in the grower period; however, evidence was not sufficient for any influence on overall G:F. Similarly in experiment 2, a marginally significant quadratic relationship was observed for G:F as YS supplementation was increased, resulting in 62.5 mg/kg YS having the lowest G:F. Hong et al. (2001) observed a quadratic relationship for finishing pig ADG and ADFI with 0, 60, and 120 mg/kg added YS-based extract where pigs fed 60 mg/kg had the poorest performance. These results are in contrast to Mader and Brumm (1987), which observed an improvement in finishing pig G:F when sarsaponin was supplemented at 63 mg/kg, particularly in late finishing. Mader and Brumm (1987), however, also found no evidence of a difference in G:F in a separate experiment with sarsaponin supplementation when fed to pigs ranging from 19 to 52 kg. Van den Berghel et al. (2000) found no evidence of a difference in ADG or G:F with YS supplementation to finishing pigs; however, they noted evidence of improved respiratory health as quantified by a reduction in presence of respiratory pathology. A clear understanding of the reduced performance observed with supplementation of 62.5 mg/kg in the current series of experiments is unknown; however, it is in agreement with Hong et al. (2001).

Additional mechanisms by which YS could affect swine growth performance could include impact on cholesterol and triglyceride concentrations as shown by Munoz et al. (2008). Hong et al. (2001) found no evidence of a difference in serum total cholesterol, low-density lipoprotein, or high-density lipoprotein concentrations when 60 or 120 mg/kg YS-based extract was fed to finishing pigs compared to control. Kucukkurt et al. (2016) observed supplementation of YS extracts in mice influenced both blood biochemical status, including glucose and lipoproteins, and metabolic hormone status. A greater understanding of the impact of YS on lipid metabolism pathways in swine is warranted and necessary. Additional potential mechanisms that have been previously described by which YS may influence growth performance include modulation of gastrointestinal microbiota (Katsunuma et al., 2000) and anti-inflammatory properties via inhibition of NF-κB and subsequent oxygen free radical scavenging (Cheeke et al., 2006). The objective of the current series of experiments was to evaluate YS in a commercial environment, however, further evaluation is warranted on a basic level.

To date, no published literature has evaluated the combined effect of Cr and YS in swine. Previously described mechanisms for both Cr and YS appear to be independent; however, there is some evidence specific to YS mechanisms observed in poultry that may indicate potential for a synergistic effect. Rezaei et al. (2017) found improvement in gain and G:F of broilers under heat stress conditions; however, no impact was observed in thermoneutral conditions. The authors propose the mechanism leading to these observations was through YS-associated antagonism of glucocorticoids produced in stress events. The action of Cr on glucose metabolism is thought to be through increased tissue sensitivity to insulin (NRC, 2012) and subsequent cellular uptake of glucose. In humans, glucocorticoids have been shown to reduce glucose uptake by skeletal muscle cells (Kuo et al., 2015). Furthermore, Lopes et al. (2004) observed that pigs given dexamethasone had greater circulating levels of glucose and insulin. Although evidence in swine is currently lacking, potential may be present for a synergistic relationship leading to improved uptake of glucose, particularly under stressful events when glucocorticoids are elevated. The current series of experiments were designed to evaluate the combination of YS and Cr in commercial conditions; therefore, no substantial stressful conditions were induced and no additional evidence for this hypothesis can be currently derived. There was marginally significant evidence of a Cr × YS interaction for overall ADG and ADFI in experiment 2, where YS supplementation improved growth performance in the presence of 200 μg/kg added Cr and the impact was not observed when no Cr was added to the diets. Further understanding and evaluation is necessary prior to drawing conclusions regarding potential synergistic effects, and cannot be fully derived at this time due to a complete lack of literature evaluating such a combination.

In conclusion, limited synergistic effects were observed when feeding both Cr and YS to pigs housed in a commercial environment. Significant variability was observed in analysis of Cr content of manufactured control diets, reinforcing the challenges associated with very low inclusion rates and significant variability in ingredient Cr content. Both Cr and YS have potential to elicit slight improvements in growth performance when used in commercial conditions as evaluated in the current series of experiments, however, no evidence of improved carcass characteristics was observed.

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