Effect of zinc source and concentration and chromium supplementation on performance and carcass characteristics in feedlot steers^{1,2,3}

Ashley M. Budde,^{*} Karen Sellins,^{*} Karen E. Lloyd,[†] John J. Wagner,^{*} Jeff S. Heldt,[‡] Jerry W. Spears,[†] and Terry E. Engle^{*,4}

^{*}Department of Animal Sciences, Colorado State University, Fort Collins, CO 80523; [†]North Carolina State University, Raleigh, NC 27695; and [‡]Micronutrients USA LLC, Indianapolis, IN 46231

ABSTRACT: Four hundred crossbred steers were used in a randomized complete block design to investigate the effects of supplemental Zn source and concentration, and dietary Cr on performance and carcass characteristics of feedlot steers fed a steam-flaked corn-based finishing diet. Steers were blocked by initial BW within cattle source (3 sources) and randomly assigned within block to 1 of 5 treatments. Before the initiation of the experiment, trace mineral supplement sources were analyzed for Zn and Cr. Zinc and Cr concentrations of the Zn sources were used to balance all dietary treatments to obtain correct Zn and Cr experimental doses. Treatments were the addition of: 1) 90 mg Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from Cr propionate (90ZS+Cr); 2) 30 mg Zn/kg DM from Zn hydroxychloride and 0.25 mg Cr/kg DM from Cr propionate (30ZH+Cr); 3) 90 mg Zn/kg DM from Zn hydroxychloride and 0.25 mg Cr/kg DM from Cr propionate (90ZH+Cr); 4) 60 mg Zn/kg DM from ZnSO₄ and 30 mg Zn/kg DM from Zn methionine (90ZSM); and 5) 90 mg Zn/kg DM from Zn hydroxychloride (90ZH). Steers were individually weighed on d-2 and on 2 consecutive days at the end of the experiment. Initial liver biopsies were obtained from all steers at

processing. Equal numbers of pen replicates per treatment were slaughtered at a commercial abattoir on day 162, 176, and 211; individual carcass data and final liver samples were collected. Total finishing dietary Zn and Cr concentrations were 118.4, 58.2, 114.2, 123.0, and 108.2 mg Zn/kg DM and 0.740, 0.668, 0.763, 0.767, and 0.461 mg Cr/kg DM, for treatments 1 to 5, respectively. Data were analyzed statistically using preplanned single degree of freedom contrasts. Steers receiving 90ZH+Cr had greater final BW ($P < 0.04$) and ADG ($P < 0.03$) when compared with steers receiving 90ZH. Additionally, hot carcass weight was 8.5 kg greater ($P < 0.03$) for 90ZH+Cr compared with 90ZH supplemented steers. Steers receiving 90ZH+Cr had greater longissimus muscle area when compared with steers receiving 90ZSM. Dry matter intake, G:F, morbidity and mortality, and all other carcass measurements were similar across treatments. These data indicate that under the conditions of this experiment, Zn source and concentration had no impact on live performance, liver Zn and Cu concentrations, and carcass characteristics. Supplemental Cr in diets containing 90 mg of supplemental Zn/kg DM from ZH improved final BW, ADG, and hot carcass weights.

Key words: beef cattle, chromium, feedlot, zinc

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J. Anim. Sci. 2019.97:1286–1295
doi: 10.1093/jas/skz016

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³This research was supported in part by the Colorado State Univ. Agric. Exp. Stn. and by Micronutrients USA LLC, Indianapolis, IN.

⁴Corresponding author: terry.engle@colostate.edu.

Received October 15, 2018.

Accepted January 7, 2019.

INTRODUCTION

The National Academy of Science, Engineering and Medicine (NASEM) recommended concentration of Zn in beef cattle diets is 30 mg of Zn/kg DM (NASEM, 2016). However, the most recent survey of consulting feedlot nutritionists (Samuelson et al., 2016) reported the average Zn formulation for feedlot diets to be approximately 3 times the NASEM (2016) recommendation. Additionally, consultants also reported using a combination of organic and inorganic Zn sources to meet a targeted Zn concentration (Samuelson et al., 2016). The discrepancy between recommendations by NASEM (2016) and consulting nutritionists may be due to reports indicating that source and/or level of dietary Zn may affect carcass characteristics and immune function (Greene et al., 1988; Spears and Kegley, 2002). Bioavailability of Zn from different sources can vary, and this may affect responses to Zn supplementation in cattle (Malcolm-Callis et al., 2000; Nunnery et al., 2007).

Chromium potentiates the action of insulin in insulin-sensitive tissues. In cattle, Cr supplementation has increased insulin sensitivity (Spears et al., 2012), altered immune responses, and reduced morbidity in stressed calves (Spears, 2000; Bernhard et al., 2012). Finishing cattle responses to Cr supplementation have yielded variable results (Kneeskern et al., 2016; Baggerman et al., 2016). The Food and Drug Administration Center for Veterinary Medicine issued a regulatory discretion letter in 2009, which permitted the use of Cr propionate as a source of supplemental Cr in cattle diets in the U.S. Chromium propionate is the only Cr source currently permitted for addition to cattle diets, and it can be added at levels up to 0.5 mg Cr/kg DM.

Because of the possible improvement on carcass characteristic due to Zn supplementation and the positive impact of Cr supplementation on glucose metabolism, we hypothesized that Zn dose and source and Cr supplementation would affect animal performance and carcass characteristics in finishing steers. Therefore, the objective of this experiment was to examine the influence of Zn source and concentration and dietary Cr on performance and carcass characteristics in feedlot steers.

MATERIALS AND METHODS

Before the initiation of this experiment, all animal care, handling, and procedures described herein were approved by the Colorado State University Animal Care and Use Committee (Approval # 15-6110A).

Cattle Processing

Four hundred and fifty crossbred steers (initial BW 287.0 ± 13.89 kg) were obtained from 3 separate Angus-based cow herds. Each group was transported to the Colorado State University Agriculture, Research, Development, and Education Center (ARDEC) in Fort Collins, CO. Within 24 h of arrival, steers were individually weighed, identified with a unique ear tag, and breed type was assigned to each steer based on hair color and phenotype (red, black, or black–white face). Two groups from 2 of 3 cattle sources were processed on November 6, 2015 and 1 group of cattle from the remaining cattle source was processed on November 12, 2015. Processing of the steers in this experiment were similar to that described by Caldera et al. 2016. Each steer was vaccinated with the following: Presponse (Pasteurella Multocida Bacterial Extract-Mannheimia Haemolytica Toxoid, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), Pyramid 2 plus Type II BVD (Bovine Rhinotracheitis and Bovine Viral Diarrhea, Types I and II, Boehringer Ingelheim Vetmedica, Inc.), given Promectin (Ivermectin, Vedco, Inc., St. Joseph, MO) and drenched with Synanthic (Oxfendazole, Boehringer Ingelheim Vetmedica, Inc.) for parasite control, and implanted with Revalor – XS (120 mg Trenbolone Acetate and 24 mg Estradiol, Merck Animal Health, DeSoto, KS). Liver biopsies were obtained from each animal, using the technique described by Engle and Spears (2000). Following initial weighing and processing, steers were provided ad libitum access to long-stem grass hay and water and were housed (10 animals per pen) overnight.

Randomization of steers in this experiment was similar to that described by (Caldera et al., 2016). Briefly, steers were stratified by BW within cattle source and individuals whose weight was ± 2 SD from the mean BW were eliminated from further consideration for the experiment. Steers exhibiting red coat color or those found to be bulls, heifers, or displaying symptoms of illness or lameness were not enrolled in the experiment. The remaining steers were blocked by BW and assigned a random number from 1 to 1,000 within block using the random number function in Excel 2007 (Microsoft Corporation, Redmond, WA). Steers with the lowest random numbers were eliminated from the experiment reducing the number of remaining steers to 400. The 400 eligible steers were ranked by weight within cattle source and divided into 8 weight block replicates. Within each weight block

replicate, steers were ranked by weight and randomly assigned to 1 of 5 pens representing all 5 treatments. By following this randomization schedule, the 3 cattle sources were represented across all 8 weight block replicates, each replicate including all 5 treatments resulting in 80 steers per treatment. On day 2, steers were individually weighed before being fed, assigned individual ear tags that were inserted into the right ear of each steer, and steers were then placed into their respective treatment pens. On day -1 it was noted that certain cattle were misidentified. This error was corrected on day -1. Therefore, a second weight on all experiment animals was not obtained. The experiment was initiated on day 0 (December 10, 2015).

Pens were checked daily to ensure that the cattle were in the correct pen assigned, and that all cattle had ad libitum access to feed and water. In addition, all cattle were monitored daily for illness and lameness. Steers exhibiting symptoms of distress were removed from the pen and rectal body temperatures were recorded. Steers with rectal body temperatures greater than 39.4 °C were treated utilizing the appropriate ARDEC medical treatment protocols for the observed illness and immediately returned to their home pen. If illness or lameness persisted in a specific steer, the steer was removed from the experiment. If a steer was removed from the experiment, the steer was weighed, the feed in the feed bunk was weighed and placed back into the feed bunk, a feed sample was obtained for DM determination, and the feed delivery was adjusted accordingly for that pen the next day.

Diets

Steers were fed a steam-flaked corn-based finishing diet (Table 1). Steers were fed a series of step-up diets to adjust to the finishing diet. Diet changes during the step-up program were simultaneous across all treatments, and cattle reached the finishing diet by day 36 of the experiment. Finishing diets were formulated to meet or exceed NRC (2000) requirements for growing and finishing beef cattle. Nutrient composition of the basal dietary ingredients is shown in Table 2. Finishing diets were formulated to contain approximately 13.5% crude protein, 3.5% crude protein equivalent from nonprotein nitrogen, 3.5% added fat, 0.70% calcium, 0.36% phosphorus, 0.70% potassium, 0.25% magnesium, 35.0 mg of monensin/kg DM (Rumensin 90, Elanco Animal Health, Greenfield, IN), and 10.6 mg tylosin phosphate/kg DM (Tylan 100, Elanco Animal Health). Vitamins A and E were

included in the diets at 2,200 IU/kg of DM and 40 IU/kg of DM, respectively. The above-mentioned ingredients were added to the ration in a liquid supplement. Ractopamine hydrochloride (RH; Optaflexx 45, Elanco Animal Health) was fed at a feeding rate of 400 mg · steer⁻¹ · d⁻¹ for 28 d to replicate 1, 30 d to replicates 2, 4, and 6, and 40 d to replicates 3, 5, 7, and 8. The duration of RH feeding differed among replicates because cattle were fed to a visual degree of external finish. Diets were delivered once daily in the morning (0900 h) in amounts to allow cattle ad libitum access to feed for a 24-h period.

To manage ad libitum access to feed over a 24-h period, feed bunk observations were conducted daily by facility staff at 0700 h. Briefly, the amount of feed remaining in the feed bunk was visually estimated and recorded. Adjustments to daily feed deliveries were made to ensure ad libitum access to feed for the next 24 h period. During inclement weather or when excessive amounts of feed remained in the feed bunk, feed was removed from the feed bunks, weighed and subsampled. Subsamples were analyzed for DM and used to calculate the DM weight of theorts for a given period. This value was then subtracted from the total DM delivered to a given pen of cattle to calculate DMI for a given period. Weekly samples of each treatment diet were obtained and stored at -20 °C. At the end of each month, weekly treatment samples were subsampled and composited into monthly composites for use in diet analysis.

Dietary treatments were the addition of: 1) 90 mg Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from Cr propionate (KemTRACE Cr, Kemin Industries Inc., Des Moines, IA) (90ZS+Cr), 2) 30 mg Zn/kg DM from Zn hydroxychloride (IntelliBond Z, Micronutrients USA LLC, Indianapolis, IN) and 0.25 mg Cr/kg DM from Cr propionate (30ZH+Cr), 3) 90 mg Zn/kg DM from Zn hydroxychloride and 0.25 mg Cr/kg DM from Cr propionate (90ZH+Cr), 4) 60 mg Zn/kg DM from ZnSO₄ and 30 mg Zn/kg DM from Zn methionine (ZinMet, Global Animal Products, Amarillo, TX) (90ZSM), and 5) 90 mg Zn/kg DM from Zn hydroxychloride (90ZH). All Zn sources were analyzed for heavy metals before the initiation of the experiment. Metal concentrations in the Zn sources are shown in Table 3. The ZinMet source stood out from the other Zn sources in regard to Cr, analyzing 760 mg/kg. Other heavy metals were in the expected range for all Zn sources. Supplementation with ZinMet to provide 30 mg Zn/kg DM supplied approximately 0.25 mg Cr/kg diet. Chromium propionate was

Table 1. Dry matter ingredient composition of the finishing diet

Ingredient	90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZSM ^d	90ZH ^e
Percentage of Dry Matter					
Corn silage	13.9	13.9	13.9	13.9	13.9
Steam-flaked corn	77.1	77.1	77.1	77.1	77.1
Liquid Supplement ^f	4.2	4.2	4.2	4.2	4.2
Pellet Supplement ^g	4.8	4.8	4.8	4.8	4.8
<i>Chemical Analysis</i>					
DM, %	72.5	72.8	71.9	72.3	72.5
CP, %	13.12	13.10	13.04	13.14	13.18
NPN, %	3.22	3.22	3.22	3.22	3.22
ADF, %	6.21	6.17	6.24	6.22	6.18
NDF, %	12.41	12.74	12.24	12.32	12.29
Ether extract, %	3.80	3.62	3.71	3.64	3.68
NEg, Mcal/kg	1.44	1.40	1.42	1.41	1.41
NEm, Mcal/kg	2.0	1.98	2.0	1.98	1.99
Calcium, %	0.68	0.67	0.63	0.66	0.67
Phosphorus, %	0.30	0.30	0.33	0.30	0.32
Sulfur, %	0.20	0.19	0.21	0.22	0.20
Chromium, mg/kg	0.740	0.668	0.763	0.767	0.461
Copper, mg/kg	15.0	14.5	14.9	15.4	14.7
Manganese, mg/kg	37.9	38.3	38.6	40.0	38.3
Zinc, mg/kg	118.4	58.2	114.2	123.0	108.2

^aTreatment 1: 90 mg of Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from chromium propionate.

^bTreatment 2: 30 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^cTreatment 3: 90 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^dTreatment 4: 60 mg of Zn/kg DM from ZnSO₄ and 30 mg of Zn/kg DM from Zn Methionine.

^eTreatment 5: 90 mg of Zn/kg DM from IntelliBond Z.

^fLiquid supplement provided in a molasses suspension: 3.72% NPN (Urea), 0.61% Ca (CaCO₃), 0.26% Salt (NaCl), 0.05% K (KCl), 2,343 IU/kg Vitamin A, 9.4 IU/kg Vitamin E, 35 g/metric ton of monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN), 10.6 g/metric ton of tylosin (Tylan 100, Elanco Animal Health, Greenfield, IN)

^gPellet supplement provided in a wheat midds-soybean hull carrier per kg diet DM: 10 mg Cu (Cu hydroxychloride), 15 mg Mn (Mn SO₄), 5 mg Mn (Mn hydroxychloride), 0.20 mg Se (NaSeO₃), 0.10 mg Co (CoCO₃), and 0.70 I (EDDI), Zinc and Cr treatments were also delivered in the pellet supplement.

Table 2. Chemical analysis of basal feed ingredients (DM basis)

Ingredient	Corn Silage	Steam-flaked corn	Liquid supplement	Pellet supplement
DM, %	32.9	80.58	70.10	88.80
CP, %	9.63	9.07	95.58	16.87
NPN, %	---	---	86.96	---
ADF, %	29.29	3.89	2.18	16.17
NDF, %	46.00	7.25	2.38	37.17
Ether extract, %	2.02	3.12	0.94	2.85
NEg, Mcal/kg	0.97	1.50	2.29	1.06
NEm, Mcal/kg	1.69	2.22	2.99	1.78
Calcium, %	0.26	0.01	14.07	0.48
Phosphorus, %	0.24	0.22	0.11	0.82
Potassium, %	1.33	0.34	1.81	1.09
Magnesium, %	0.24	0.09	0.24	0.40
Sodium, %	0.01	< 0.01	2.98	0.05
Sulfur, %	0.16	0.11	0.29	0.33
Cobalt, mg/kg	<0.20	< 0.20	0.63	3.16
Copper, mg/kg	5.05	1.49	43.79	---
Iron, mg/kg	127.00	28.00	406.56	155.00
Manganese, mg/kg	36.10	4.91	118.26	---
Molybdenum, mg/kg	0.84	< 0.30	---	0.87
Zinc, mg/kg	34.50	16.10	145.51	---

added to Treatments 1, 2, and 3 to provide a similar concentration of supplemental Cr. To our knowledge, the source and bioavailability of Cr in Zn methionine used in this experiment are unknown. Treatment 5 served as a negative control to evaluate the effect of Cr supplementation on performance of steers receiving 90 mg Zn/kg DM from Zn hydroxychloride. Trace mineral test articles appropriate for each treatment were formulated and pelleted separately. The analyzed Cr and Zn concentrations for the total mixed rations for each finishing diet are shown in [Table 1](#). Water samples were obtained at the main water supply line to the ARDEC feedlot facility and sent to an established laboratory (SDK Labs, Hutchinson, KS) for routine water quality analysis (pH = 7.37 ± 0.16 ; total hardness = 771.3 ± 51.3 mg/L; electrical conductivity = $1,611 \pm 97.3$ μ S/cm; sulfate = 391.0 ± 27.6 mg/L; sodium = 62.1 ± 8.7 mg/L; chloride = 27.2 ± 3.7 mg/L; total dissolved solids = 981.0 ± 62.8 mg/L).

Weighing and Carcass Data Collection

Steers were weighed individually on day -2 and 2 consecutive days before slaughter, and all BW measurements were shrunk by 4% to achieve an empty BW. Interim weights were taken at day 70 and day 119 to track weight gain progress (data not shown). Equal numbers of pen replicates per treatment were transported to a commercial abattoir on day 162, 176, and 211 for slaughter. Carcass data were collected by Diamond T Livestock Services Inc., Yuma, CO and liver samples were collected by Center for Meat Safety & Quality personnel at Colorado State University. Hot carcass weights (HCW) were determined at the time of slaughter

and carcasses were chilled for approximately 36 h before carcass data were obtained. Carcass data collected included dressing percentage (DP), HCW, longissimus muscle (LM) area, adjusted subcutaneous adipose tissue thickness ([USDA, 1989](#)), KPH, marbling score, quality grade, and calculated USDA yield grade (YG). Liver samples were collected (approximately 200 g wet weight) on the day of slaughter from the left lobe of each liver after being inspected by USDA personnel. Each sample was placed into numbered Whirl Pak bags corresponding to carcass order, placed on ice, and transported to the Colorado State University Nutrition Laboratory and stored at -20 °C until analyzed for trace mineral concentrations.

Analytical Procedures

Samples of Zn sources and total mixed ration monthly composite samples were analyzed for Cr by electrothermal atomic absorption spectrophotometry (GFA-6500, Shimadzu, Kyoto, Japan). Handling and analysis procedures for Cr are outlined in [Lloyd et al. \(2010\)](#). Zinc sources were analyzed for other heavy metals at a commercial laboratory (LSAI Laboratories, Indianapolis, IN) by inductively coupled plasma optical emission spectroscopy. Total mixed ration monthly composite samples were sent to SDK Laboratories (Hutchinson, KS), for Zn analysis. Samples of corn silage, steam-flaked corn, liquid supplement, and pellet supplement were also sent to SDK Laboratories (Hutchinson, KS) for chemical analysis. Liver tissue samples for Cu, Mn, and Zn analysis were allowed to thaw at room temperature. Subsamples were obtained from the innermost portion of the liver sample and placed

Table 3. Heavy metal analysis of Zn sources

Metal	IntelliBond Z	Zinc Methionine	ZnSO ₄
Aluminum, mg/kg	28.9	94.7	51.6
Arsenic, mg/kg	<1.00	<1.00	<1.00
Barium, mg/kg	1.82	10.8	<1.00
Cadmium, mg/kg	0.75	1.12	4.61
Chromium, mg/kg	0.14	760.00	0.27
Cobalt	<1.00	<1.00	<1.00
Copper, mg/kg	<10.0	<10.0	<10.0
Iron, mg/kg	18.5	1780	3050
Mercury, mg/kg	<0.10	<0.10	<0.10
Manganese, mg/kg	412	251	514
Molybdenum, mg/kg	<10.0	<10.0	<10.0
Nickel, mg/kg	<0.50	<0.50	0.98
Lead, mg/kg	9.47	<1.00	<1.00
Selenium, mg/kg	<5.0	<5.0	<5.0
Vanadium, mg/kg	<1.00	<1.00	<1.00

in preweighed acid washed crucibles to be dried at 60 °C for 24 h. After drying, samples were weighed and ashed at 600 °C for 12 h. The ashed liver samples were resuspended in 5 mL of 1.2N HCl and analyzed for Cu, Mn, and Zn concentrations using an inductively coupled plasma-atomic emission spectrometer (NexION 2000B, Perkin Elmer, Waltham, MA). Samples were diluted in distilled H₂O to fit within a linear range of a standard curve generated by linear regression of known TM concentrations. Multielement analysis was then carried out by simultaneous/sequential ICP-AES analysis with cross flow nebulization (Caldera et al., 2016).

Statistical Analysis

Feedlot performance, liver trace mineral concentrations, and continuous carcass data were analyzed on a pen mean basis as a randomized block design using PROC MIXED of SAS (SAS Institute Inc., Cary, NC). Health data were evaluated on a pen mean basis using PROC GLIMMIX of SAS and assuming a binomial distribution. Treatment and replicate were included in the model as class variables. Replicate was included in the model as a random variable. Treatment was included in the model as a fixed classification effect, and weight block pen replicate was included in the model as a random effect. Covariates of pen initial BW, number of animals used in the pen average, source of cattle, and days on feed were used in the analysis of all performance and carcass response variables. Final liver mineral concentrations were analyzed using initial mineral concentration as a covariate. There were 2 missing pen observations for liver mineral analysis. Outlier tests were performed on all data, and no outliers were removed from the data set. A type 3 ANOVA table was constructed using the Kenward–Roger method of computing denominator degrees of freedom. Backwards elimination with AIC criteria was used to remove nonsignificant ($P \geq 0.10$) covariates from the model. The effect of treatment was determined significant at $P \leq 0.05$ and tendencies were noted at $P \leq 0.15$. Preplanned single degree of freedom contrasts was used to separate treatment means. Contrasts were: 1) 90ZS+Cr vs. 90ZH+Cr; 2) 30ZH+Cr vs. 90ZH+Cr; 3) 90ZH+Cr vs. 90ZSM; and 4) 90ZH+Cr vs. 90ZH.

RESULTS

Effects of Zn source and dose and Cr supplementation on feedlot cattle performance, morbidity, and mortality are presented in Table 4. Chromium

supplemented steers (90ZH+Cr) had greater final BW ($P < 0.04$), overall ADG ($P < 0.03$) and tended ($P < 0.13$) to have greater DMI compared to steers receiving 90ZH without supplemental Cr. Neither Zn dose (30ZH+Cr vs. 90ZH+Cr) nor Zn source (90ZS+Cr vs. 90ZH+Cr or 90ZH+Cr vs. 90ZSM) affected ($P \geq 0.18$) final BW, ADG, or G:F. However, Zn source tended to impact DMI. Steers receiving 90ZH+Cr tended ($P < 0.12$) to have greater DMI when compared to steers receiving 90ZSM. Incidence of morbidity and mortality was not affected ($P \geq 0.18$) by treatment (Table 4). Final liver Mn concentration tended ($P < 0.14$) to be different across treatments. Steers receiving 90ZH tended ($P < 0.13$) to have lower final liver Mn concentrations when compared to steers receiving 90ZH+Cr. Final liver Zn concentrations tended ($P < 0.09$) to be greater in steers receiving 90ZS+Cr compared with steers receiving 90ZH+Cr. Final liver Cu concentrations were similar across treatments (Table 5). The reason for the tendencies in treatment differences for liver Mn and Zn concentration is unknown. However, all liver concentrations noted for Zn, Cu, and Mn were above levels considered to be deficient in beef cattle (Mills, 1987; Puls, 1994).

Dressing percentage, YG, marbling score, and subcutaneous adipose tissue depth were not affected ($P \geq 0.58$) by Zn dose, Zn source, or Cr supplementation (Table 6). Steers supplemented with 90 mg Zn/kg DM from ZH and Cr propionate at 0.25 mg Cr/kg DM had a greater HCW ($P < 0.03$) compared with steers who received 90 mg Zn/kg DM from ZH, resulting in an additional 8.5 kg of carcass weight. Longissimus muscle area was greater ($P < 0.01$) in steers fed 90ZH + Cr compared with those in the 90ZSM treatment. Steers fed 90ZH + Cr also tended ($P < 0.08$) to have greater LM area than those fed 90 ZS + Cr. Increasing Zn supplementation from 30ZH + Cr to 90ZH + Cr tended to increase HCW ($P < 0.12$) and LM area ($P < 0.15$).

DISCUSSION

Increasing supplemental Zn from 30 (30ZH+Cr) to 90 mg/kg DM (90ZH+Cr) from Zn hydroxychloride did not affect performance over the entire feeding period. Other than a tendency for lighter hot carcass weights and smaller LM area values in steers fed 30ZH+Cr, carcass characteristics did not differ among steers supplemented with 30 vs. 90 mg Zn/kg DM. The 30ZH+Cr diet analyzed 58 mg Zn/kg DM, which is greater than the 30 mg Zn/kg DM recommended by NASEM (2016). However, the

Table 4. Effects of zinc source and dose and chromium supplementation on performance of feedlot steers

Item	Treatment							Contrasts, <i>P</i> <			
								90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZH+Cr ^c
	90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZSM ^d	90ZH ^e	SEM	<i>P</i> <	vs. 90ZH+Cr ^c	vs. 90ZH+Cr ^c	vs. 90ZSM ^d	vs. 90ZH ^e
Initial number of animals	80	80	80	80	80	---	---	---	---	---	---
Final number of animals	76	74	75	77	70	---	---	---	---	---	---
Initial BW, kg	278.7	273.3	275.1	275.3	274.6	9.19	0.99	0.78	0.89	0.99	0.97
Final BW, kg	583.2	581.2	588.4	580.7	575.3	4.25	0.30	0.41	0.23	0.20	0.04
ADG, kg/d	1.61	1.60	1.64	1.60	1.57	0.02	0.26	0.32	0.20	0.18	0.03
DM intake, kg/d	9.17	9.09	9.19	8.90	8.90	0.13	0.35	0.93	0.57	0.12	0.13
Gain:Feed	0.176	0.177	0.180	0.180	0.177	0.003	0.80	0.39	0.52	0.89	0.57
Morbidity, %	11.25	21.25	16.25	23.75	13.75	5.14	0.18	0.39	0.39	0.20	0.67
Mortality, % ^g	1.25	3.75	3.75	2.50	5.00	2.45	0.71	0.36	0.99	0.65	0.65

^aTreatment 1: 90 mg of Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from chromium propionate.

^bTreatment 2: 30 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^cTreatment 3: 90 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^dTreatment 4: 60 mg of Zn/kg DM from ZnSO₄ and 30 mg of Zn/kg DM from Zn Methionine.

^eTreatment 5: 90 mg of Zn/kg DM from IntelliBond Z.

^fMorbidity data = animals pulled, treated, and returned immediately to home pen for bovine respiratory disease, lameness, foot rot, ear infection, abscesses, and/or bloat.

^gTotal number of animals that were euthanized or died during the experiment for each dietary treatment.

level of Zn supplemented in the present experiment over the combined growing and finishing phases.

Table 5. Effects of zinc source and dose and chromium supplementation on liver mineral status

Item	Treatment							Contrasts, <i>P</i> <			
								90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZH+Cr ^c
	90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZSM ^d	90ZH ^e	SEM	<i>P</i> <	vs. 90ZH+Cr ^c	vs. 90ZH+Cr ^c	vs. 90ZSM ^d	vs. 90ZH ^e
Final Zn, mg/kg DM ^f	165.3	131.9	134.9	143.3	128.6	12.20	0.27	0.09	0.86	0.61	0.74
Final Cu, mg/kg DM ^f	318.0	346.0	306.4	339.6	334.7	23.75	0.72	0.72	0.21	0.35	0.44
Final Mn, mg/kg DM ^f	11.9	10.6	11.1	10.2	9.6	0.62	0.14	0.36	0.59	0.28	0.13

^aTreatment 1: 90 mg of Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from chromium propionate.

^bTreatment 2: 30 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^cTreatment 3: 90 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^dTreatment 4: 60 mg of Zn/kg DM from ZnSO₄ and 30 mg of Zn/kg DM from Zn Methionine.

^eTreatment 5: 90 mg of Zn/kg DM from IntelliBond Z.

^fInitial respective Zn, Cu, or, Mn concentration were used as a covariate for statistical analysis.

was considerably less than the mean supplemental concentration of 87.3 mg Zn/kg DM reported by feedlot consulting nutritionists in a recent survey (Samuelson et al., 2016). Responses to increasing dietary Zn in finishing cattle diets have been variable in previous studies. In a growing and finishing experiment, Zn supplementation (25 mg/kg DM) to the growing diet (analyzed 33 mg Zn/kg) improved ADG during an 84-d period (Spears and Kegley, 2002). Zinc supplementation did not affect performance during the subsequent 84- to 112-d finishing phase (control diet analyzed 26 mg Zn/kg) or

Steers supplemented with Zn had greater marbling scores and tended to have greater backfat thickness than controls (Spears and Kegley, 2002). The addition of 10 mg Zn/kg DM, from inorganic or organic sources, to a diet containing 35 mg Zn/kg DM did not affect performance or carcass characteristics in bulls during a 284-d feeding period (Kessler et al., 2003). Increasing supplemental Zn from 20 to 40 mg/kg DM (basal diet contained 31 mg Zn/kg) did not affect growth performance or carcass characteristics in calf-fed Holstein steers (Montano et al., 2018). Supplementation of 60, 90,

Table 6. Effects of zinc source and dose and chromium supplementation on carcass characteristics of feedlot steers

Item	Treatment						Contrasts, <i>P</i> <				
	90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZSM ^d	90ZH ^e	SEM	<i>P</i> <	90ZS+Cr ^a	30ZH+Cr ^b	90ZH+Cr ^c	90ZS+Cr ^a
								vs. 90ZH+Cr ^c	vs. 90ZH+Cr ^c	vs. 90ZSM ^d	vs. 90ZH ^e
Initial number of animals	80	80	80	80	80	---	---	---	---	---	---
Final number of animals ⁱ	76	74	75	77	70	---	---	---	---	---	---
Hot Carcass Weight, kg	362.5	361.8	367.8	362.5	359.3	2.67	0.25	0.19	0.12	0.16	0.03
Dressing Percentage, % ^f	62.1	62.2	62.5	62.2	62.4	0.22	0.69	0.22	0.30	0.37	0.74
Marbling Score ^g	397.1	395.4	399.7	407.5	383.2	10.69	0.61	0.87	0.77	0.59	0.27
Subcutaneous adipose tissue thickness, cm	1.39	1.34	1.38	1.41	1.31	0.05	0.60	0.80	0.59	0.59	0.31
Longissimus muscle area, cm ²	80.4	80.8	82.1	79.8	81.0	0.64	0.15	0.08	0.15	0.01	0.22
Yield grade, %	2.83	2.80	2.82	2.87	2.69	0.08	0.58	0.98	0.86	0.63	0.24

^aTreatment 1: 90 mg of Zn/kg DM from ZnSO₄ and 0.25 mg Cr/kg DM from chromium propionate.

^bTreatment 2: 30 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^cTreatment 3: 90 mg of Zn/kg DM from IntelliBond Z and 0.25 mg Cr/kg DM from chromium propionate.

^dTreatment 4: 60 mg of Zn/kg DM from ZnSO₄ and 30 mg of Zn/kg DM from Zn Methionine.

^eTreatment 5: 90 mg of Zn/kg DM from IntelliBond Z.

^fDressing Percentage calculated from shrunk final BW.

^gMarbling score; 300 = Slight⁰, 400 = Small⁰, 500 = Modest⁰.

^hUSDA (1989) numerical yield grade 1, 2, 3, 4, or 5 calculated as percentage of the pen, adjusted to 100%.

ⁱThirteen mortalities occurred during the experiment and 16 cattle were removed from the experiment for persisting illness, lameness, failure to meet slaughter withdrawal requirements, and condemnation at the time of slaughter.

or 120 mg Zn/kg DM to a control diet containing 30 mg Zn/kg DM did not affect performance but appeared to reduce marbling scores in finishing steers (Genther-Schroeder et al., 2018). However, Zn supplementation (75 mg/kg DM) to a control diet that analyzed 50.5 mg Zn/kg DM tended to increase ADG ($P = 0.11$) and gain/feed ($P = 0.06$) in finishing heifers, but did not affect carcass characteristics (Nunnery et al., 2007). The reason for the discrepancies between studies is unknown. Numerous factors may impact an animal's response to Zn supplementation such as: animal health status, dietary antagonists, protein content of the diet, and diet type (Suttle, 2010).

Growth performance in steers receiving 90ZS + Cr, 90ZH + Cr or 90ZSM was not affected by Zn source. In agreement with the present experiment, Wagner et al. (2008) reported that steers supplemented with 100 mg Zn/kg DM performed similarly when Zn was supplied from ZnSO₄ or a combination of ZnSO₄ (60%) and ZnMet (40%) over the entire finishing period. Other studies also have shown similar performance of finishing cattle

fed inorganic (ZnSO₄ or ZnO) and various organic sources (Galyean et al., 1995; Malcolm-Callis et al., 2000; Spears and Kegley, 2002).

Longissimus muscle area was lower in steers fed 90ZSM and tended to be lesser in steers receiving 90ZS+Cr compared with those in the 90ZH+Cr treatment. The reason for the Zn source effect on longissimus muscle area is unclear. Other carcass measurements were not affected by Zn source. In agreement with the present results, steers supplemented with Zn proteinate had greater longissimus muscle area than steers supplemented with ZnO (Spears and Kegley, 2002). Some research has indicated that organic Zn sources may affect certain carcass characteristics differently from inorganic Zn sources (Greene et al., 1988; Malcolm-Callis et al., 2000). However, other studies have not detected differences in carcass characteristics among cattle supplemented with inorganic or organic Zn sources (Galyean et al., 1995; Nunnery et al., 2007; Wagner et al., 2008). Based on the findings from the current experiment and previously published experiments, coming to a definitive conclusion regarding the

impact of Zn dose and source on carcass characteristics is not possible.

Chromium propionate supplementation (0.25 mg Cr/kg) to finishing cattle diets, supplying 90 mg Zn/kg DM from ZH, for 162 to 211 d increased ADG by 0.07 kg and HCW by 8.5 kg, and tended to increase DMI in the present experiment. Other carcass characteristics were not affected by Cr supplementation. In previous studies, Cr supplementation increased ADG in receiving cattle (Chang and Mowat, 1992; Moonsie-Shageer and Mowat, 1993; Bernhard et al., 2012) and growing cattle (Kegley et al., 1997). However, responses to Cr supplementation in finishing cattle have been inconsistent. In agreement with the present experiment, Cr propionate supplementation at 0.30 or 0.45 mg/kg DM for 147 d increased ADG and HCW in continental crossbred steers (Baggerman et al., 2016). The implant program and RAC feeding in this experiment was similar to that used in the current experiment. In contrast, Kneeskern et al. (2016) reported that supplementation with Cr propionate to provide 3 mg Cr/d (average of 0.36 mg Cr/kg diet over the feeding period) for a 134 to 174 d finishing period did not affect performance or HCW of Angus-cross steers. The discrepancy between this experiment and the present experiment could be due to differences among studies in diet composition, implant program, or RAC feeding at the end of the finishing period. Diets used in the Kneeskern et al. (2016) experiment were lower in CP (12.0 vs. 13.1%) and higher in NDF (19.7 vs. 12.3%) than those used in the current experiment. Furthermore, steers in the Kneeskern et al. (2016) experiment were implanted with 25.7 mg estradiol but not trenbolone acetate, and they were not fed RAC. The greater dressing percentage in Cr-supplemented steers observed by Kneeskern et al. (2016) was not detected in the present experiment. Supplementing 3 mg Cr/d from Cr propionate to finishing steers for 35 d before and during a 28-d RAC feeding period did not affect performance or carcass characteristics (Edenburn et al., 2016). Lack of a response to Cr in the experiment conducted by Edenburn et al. (2016) may have been due to the shorter length of time Cr was supplemented or the relatively low CP (10.4%) content of the diet compared to the present experiment.

Chromium content of the basal diet is another factor that may affect animal responses to Cr supplementation. However, analytical determination of Cr is difficult because of the low Cr concentrations present and Cr contamination that can occur during preparation of samples for Cr analysis. A recent experiment indicated that most ruminant

feedstuffs contain less than 0.50 mg Cr/kg DM, and that much of the analyzed Cr in feedstuffs appeared to be due to Cr contamination during harvesting and processing of feeds (Spears et al., 2017). Many Cr supplementation studies in the past have either not included an analysis of experimental diets for Cr or have used flame atomic absorption spectroscopy to measure Cr (Edenburn et al., 2016; Kneeskern et al., 2016). Flame atomic absorption spectrometry is not sensitive enough to accurately detect the low concentrations of Cr present in most feedstuffs (NRC, 2005). The graphite furnace atomic absorption procedure used in the present experiment is highly sensitive for measuring low concentrations of Cr with a detection limit of 0.005 µg Cr/L when an appropriate background correction is used (NRC, 2005). The Cr analytical procedure used in this experiment has been validated according to CLSI guidelines for a variety of matrices and was reviewed and accepted by the FDA as part of a food additive petition (21CFR573.304). The negative control diet of the present experiment, containing no supplemental Cr, analyzed 0.461 mg Cr/kg DM (Table 1). This value no doubt represents a certain amount of contamination from soil and metal contact during harvesting and feed processing. The diets supplemented with 0.25 mg Cr/kg DM, from Cr propionate, analyzed similar in Cr to the ZnMet-ZnSO₄ diet that contained no supplemental Cr.

CONCLUSIONS

These data indicate that under the conditions of this experiment, Zn source did not affect growth performance in finishing steers. Increasing supplemental Zn, from Zn hydroxychloride, from 30 to 90 mg/kg DM tended to increase DMI but not final BW or ADG of finishing steers. Longissimus muscle area was less in steers fed 90 ZSM and tended to be less for 90 ZS+Cr supplemented steers compared to those in the 90 ZH+Cr treatment. Supplemental Cr in diets containing 90 mg of supplemental Zn/kg DM from Zn hydroxychloride improved final BW, ADG, and hot carcass weight and tended to improve DMI. Overall, these data indicate that zinc and chromium supplementation to feedlot cattle diets may improve growth performance and carcass characteristics of finishing steers. However, the mechanisms by which zinc and chromium influence growth requires further investigation.

Conflict of interest statement. None declared.

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