The influence of supplemental zinc and dietary fiber concentration on mineral retention of beef steers[1]

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ABSTRACT: The objective was to determine if zinc (Zn) retention improved with supplemental Zn above recommended concentrations with increasing dietary fiber concentration. Angus steers (n = 32; 309 ± 4.2 kg body weight [BW]) with GeneMax gain scores of 3, 4, or 5 were utilized in a 2 × 2 factorial arrangement (8 steers per treatment). Steers were stagger started (four blocks of eight steers) and stratified by BW within growing diets to one of two Zn strategies (ZNTRT), no supplemental Zn (analyzed 36 mg Zn/kg dry matter [DM]; CON) or supranutritional Zn (CON + 60 mg Zn/kg DM as $ZnSO_4$ + 60 mg Zn/kg DM as Zn–amino acid complex; SUPZN). Dietary fiber strategies (FIBER) were formulated to target two fiber supplementation rates representing high fiber (HF; ~35% neutral detergent fiber [NDF]) or low fiber (LF; ~25% NDF). Within block, steers received HF for 60 d; then pens were randomly assigned to LF or HF for finishing. Steers fed LF were transitioned for 15 d; on day 75, steers were moved to metabolism crates and adapted for 10 d, followed by 5 d of total fecal and urine collection. Retention of Zn, Mn, Fe, Cu, and N were calculated. The model for analysis of metabolism data included the fixed effects of ZNTRT, FIBER, block, and the interaction of ZNTRT × FIBER, with the three-way interaction of ZNTRT × FIBER × block as random. Steer was the experimental unit (n = 8 per treatment combination). Zinc did not affect initial 60-d performance ($P \geq 0.62$). DM and organic matter digestibility were lesser ($P = 0.02$) and N digestibility tended to be lesser ($P = 0.07$) in CON vs. SUPZN. Intake and digestibility of NDF and acid detergent fiber were greater ($P \leq 0.01$) in HF vs. LF. Digestibility and retention of N as a percentage of intake were greater ($P \leq 0.04$) whereas N retention as grams per day tended to be greater in HF vs. LF ($P = 0.06$). Apparent absorption of Zn tended to be greater ($P = 0.06$) in CON vs. SUPZN. A ZNTRT × FIBER effect was identified for Zn retention (milligrams per day; $P = 0.01$) where within SUPZN Zn retention was greater in HF vs. LF ($P < 0.01$). Apparent absorption and retention of Zn were greater (% of intake; $P \leq 0.02$) in HF vs. LF. Apparent absorption of Cu, Fe, and Mn was unaffected by ZNTRT or FIBER ($P \geq 0.24$). Increasing dietary Zn increased Zn retained regardless of changes in coefficient of absorption. In addition, dietary fiber content may impact trace mineral and N metabolism by steers, potentially due to increased release of these nutrients from feed as fiber digestibility increases. It appears dietary Zn concentrations and diet composition influence trace mineral absorption in beef steers.

Key words: beef cattle, fiber, nitrogen, trace mineral, zinc

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INTRODUCTION

Zinc (Zn), a trace mineral found throughout almost all metabolic systems in mammals (Cousins et al., 2006), is a critical component in many growth pathways in the body including DNA and protein synthesis. Current recommendations for Zn (30 mg Zn/kg dry matter [DM]) were established more than 50 years ago to prevent deficiency in healthy animals and support growth (NRC, 2000). Previous research has shown that the combination of Zn–amino acid (Zn–AA) complex and $ZnSO_4$ increased cattle performance when receiving a relatively low-fiber finishing diet (~20% neutral detergent fiber [NDF]) and ractopamine hydrochloride (Genther-Schroeder et al., 2016a). In addition, Carmichael et al. (2018) found that increasing supplemental Zn concentrations positively impacted N retention in finishing beef steers that receive a low-fiber diet (~19% NDF). Recently, some have determined that feeding supplemental trace minerals may influence fiber digestibility (Faulkner et al., 2017; Faulkner and Weiss, 2017; VanValin et al., 2018). Regardless, few studies have been conducted evaluating the relationship of fiber and Zn supplementation exceeding current recommendations (NASEM, 2016). Arelovich et al. (2000) evaluated excessive concentrations of dietary Zn to control ammonia toxicity, which decreased nutrient digestibility (Arelovich et al., 2000); however, this concentration of dietary Zn (450 mg Zn/kg DM) approached the maximum tolerable level recommended for beef cattle (NASEM, 2016). To the best of our knowledge, no studies have been conducted in ruminants evaluating the relationship between fiber content and supplemental Zn concentrations exceeding current recommendations for beef cattle, yet below pharmacological rates. The objective was to evaluate fiber digestibility and Zn retention in beef steers that fed low- or high-fiber (HF) finishing diets when supplemental Zn concentrations are similar to rates supplemented in the feedlot industry (Samuelson et al., 2016). The hypothesis was that increasing dietary fiber and supplemental Zn concentrations would decrease Zn absorption and fiber digestibility.

MATERIALS AND METHODS

All procedures and protocols were approved by the Iowa State University Institutional Animal Care and Use Committee (8-15-8073-B).

Experimental Design

The study was conducted as a 2 × 2 factorial, with Zn (ZNTRT) supplementation strategies of no supplemental Zn (CON) or supranutritional Zn (CON + 60 mg Zn/kg DM from $ZnSO_4$ + 60 mg Zn/kg DM from Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; SUPZN) beginning on day 0, and differing dietary fiber strategies (FIBER) were formulated to target two fiber supplementation rates representing high fiber (HF; ~35% NDF) or low fiber (LF; ~25% NDF). The HF treatment was obtained by replacing 20% cracked corn in the LF diet with 14% corn silage and 6% grass hay (DM basis). One month prior to initiation of ZNTRT strategy, high-percentage Angus cattle were acquired from two producer sources and gentled with repeated human exposure. Steers (n = 32; 309 ± 4.2 kg) with GeneMax gain scores of 3, 4, or 5 (Zoetis, Parsippany, NJ), which indicate a predicted genetic value belonging in the top 60% for growth potential of tested Angus cattle (Certified Angus Beef LLC, 2012), were utilized in this study. Steers were separated into four blocks (n = 8 steers per block; 2 per treatment combination) and stagger-started on diets because of space limitations in the metabolism facility (treatment initiation interval between blocks was averaged to 30 d; blocks were sorted by body weight [BW]). On day 0 for each block, steers were stratified by BW and GeneMax score to receive ZNTRT diets for 60 d in pens equipped with GrowSafe bunks (GrowSafe Systems Ltd., Airdrie, Alberta, Canada). During the initial 60-d feeding period, three pens per ZNTRT were utilized, so that pen density did not exceed six steers and feed competition was limited. On day 60, within ZNTRT, steers were stratified by weight and GeneMax gain score, and half of them were selected to begin transition to the LF diet for 15 d. DM intakes during days 60 to 75 for all blocks were not included for any analyses because steers transitioning to LF were fed in concrete bunks where individual intake was unavailable and steers in each treatment and block were fed in a single pen. During this transition period, steers transitioning to LF were fed 80% (DM) of previous intake on HF for 3 d in concrete bunks, with daily increases for the remaining 11 d of transition at 0.227 kg DM per steer. Following return from the metabolism facility (days 90 to 95), two pens per treatment combination

Table 1. Diet ingredient composition and nutrient content during metabolism period (% DM basis)

	HF[1]		LF[1]	
Ingredient	CON[2]	SUPZN[2]	CON[2]	SUPZN[2]
Dry matter	41	41	47	47
Cracked corn	22	22	42	42
Modified distillers grains	22	22	22	22
Corn silage	40	40	26	26
Dried distillers grains[3]	5	5	5	5
Hay	6	6	-	—
Micronutrients and carrier[4]	5	5	5	5
Calculated composition				
NEm, Mcal/kg	1.79	1.79	1.92	1.92
NEg, Mcal/kg	1.28	1.28	1.39	1.39
Analyzed components[5]				
Crude protein	15.3	15.3	15.1	15.1
NDF	35.3	36.2	24.7	22.4
ADF	17.0	18.6	10.5	9.2
Cu, mg/kg DM	17	18	17	16
Fe, mg/kg DM	168	164	129	127
Mn, mg/kg DM	36	40	33	32
Zn, mg/kg DM	36	165	36	142

[1]HF (~35% NDF of DM); LF (~25% NDF of DM).

[2]Control (CON) received no supplemental Zn (36 mg Zn/kg DM); Supranutritional Zn (SUPZN) diet received formulated Zn inclusion of 120 mg Zn/kg DM (CON + 60 mg Zn/kg DM as $ZnSO_4$ and 60 mg Zn/kg DM as Availa-Zn [Zinpro Corporation, Eden Prairie, MN]).

[3]Dried distillers grains alone or as carrier for SUPZN premix.

[4]Basal includes dried distillers grains with solubles as carrier and micronutrients to provide to total diet (DM basis); limestone (1.4%), Rumensin (0.0135%), urea (0.3%), and salt (0.31%). Trace minerals and vitamins provided per kilogram of total diet DM: 0.15 mg Co (cobalt carbonate), 10 mg Cu (copper sulfate), 20 mg Mn (manganese sulfate). 0.1 mg Se (sodium selenite), 0.5 mg I (calcium iodate), vitamin A 2,200 IU (Rovimix A 1000 [1,000 kIU/g], DSM, Parsippany, NJ), and vitamin E 25 IU (Rovimix E50 [50 kIU/g], DSM, Parsippany, NJ).

[5]Sulfur was calculated as 0.25% of the diet with inclusion of modified distillers grains and dried distillers grains; S analysis on feedstuffs conducted by Dairyland Laboratories (Arcadia, WI).

were utilized where pen stocking rate did not exceed six steers. Diet composition and analysis are shown in Table 1. On day 28 of the study, steers were implanted with Component TE-IS with Tylan (80 mg trenbolone acetate, 16 mg estradiol USP, and 29 mg tylosin tartrate; Elanco Animal Health, Greenfield, IN). Steers were weighed prior to feeding on days 1 and 0, and 59 and 60 to determine initial and final BW of the initial feedlot period, respectively. Pre-feeding weights were recorded on days 74 and 75 for an initial metabolism weight. After weighing at the farm on day 75, steers were transported 6.3 km to the metabolism facility in Kildee Hall (Iowa State University, Ames, IA). Steers continued to receive their respective ZNTRT and FIBER treatments in the metabolism facility from days 75 to 90 (days 1 to 15 of metabolism period). A 4% pencil shrink was applied to all BW measurements, including calculations for average daily gain (ADG) and gain-to-feed ratio (G:F).

Metabolism Period

From day 75 to 90 (days 1 to 10 adaptation, days 11 to 15 collection), steers (437 ± 9.2 kg BW) were housed in individual stainless-steel crates (213.4 cm [length] × 182.9 cm [height] × 91.4 cm [width]), which were fitted with rubber fatigue mats. Each morning, steers were offered the appropriate total mixed ration (TMR) at 0700 h. As-fed feed delivery was 105% of the previous day's as-fed intake. All were offered TMR and refused feed for each steer was recorded daily and daily as-fed TMR intake amount was determined by subtracting refused feed from offered TMR. During the acclimation period, cattle were adjusted to crates and were allowed space to lie down. On the morning of day 10 (day 85 of the study) of the metabolism period cattle were removed from crates and crates were thoroughly cleaned. Preparation of metabolism crates prior to return of the steers, as well as daily fecal and urine collection procedures were as described by Carmichael et al. (2018). Feed delivery rate during collection was 105% of the previous day's as-fed intake. Water intake was recorded individually throughout metabolism period (DLJ single jet water meter; Daniel L. Jerman Co., Hackensack, NJ).

During the collection period (days 11 to 15; days 85 to 90 of the study), refused feed was removed and weighed, and aliquots were collected (~300 g or greater). TMR samples from CON-HF, SUPZN-HF, CON-LF, and SUPZN-LF were sampled daily. All TMR and refused feed samples were dried in a convection oven at 70 °C for 48 h. Fecal and urine aliquots were collected and determination of fecal DM was achieved according to procedures described by Pogge et al. (2014a). Dried fecal, TMR, and refused feed samples were ground through a 2-mm screen (Wiley Mill; Thomas Scientific, Swedesboro, NJ; Retsch Zm100 grinder; Glen Mills Inc., Clifton, NJ) and stored in sealed plastic bags until compositing and nutrient analysis.

On day 15 of the metabolism period (day 90 of the study), steers were removed from metabolism crates and transported 6.3 km back to the Iowa State Beef Nutrition Farm. Prior to fecal collection and subsampling on day 90, crates were hand-scraped with acid-washed plastic paint scrapers and deionized water to collect all remaining feces excreted during the collection period.

Upon return to the farm, steers were given 5 d to rest and were maintained on their respective diets until liver biopsies were collected on day 95 with methods established by Engle and Spears (2000).

Analytical Procedures

TMR samples of each diet were collected weekly during the feedlot period (days 0 to 75). Weekly TMR samples were dried for 48 h at 70 °C and the resulting DM value was multiplied by as-fed feed intake for each steer to determine dry matter intake (DMI) during the feedlot period. DM and organic matter of TMR, refused feed, and fecal matter during the collection period were determined according to Association of Official Analytical Chemists (1990) procedures. Nitrogen content of TMR, refused feed, fecal matter, and urine was determined using the combustion method (TruMac N, LECO Corporation, Saint Joseph, MI; Lundy et al., 2015). Nitrogen digestibility was calculated as described by Lundy et al. (2015). Digestibility of DM and OM was calculated by dividing fecal DM by DM intake, subtracting from 1 and multiplying by 100. Thirty-hour in vitro digestibility was conducted according to Goering and Van Soest (1970; Dairyland Laboratories, Arcadia, WI).

Inductively coupled plasma optical emission spectrometry (ICP; Optima 7000 DV, Perkin Elmer, Waltham, MA) was used to conduct mineral analysis of TMR, refused feed, urine, and fecal matter. Dried, ground, and composited TMR; refused feed; and fecal samples were acid digested prior to mineral analysis according to the methods described by Richter et al. (2012) and Pogge et al. (2014a). Liver samples were digested according to Pogge and Hansen (2013). Urine samples were prepared for the ICP with methods described by Carmichael et al. (2018). No additional dilutions were necessary for mineral analysis of TMR, refused feeds, or fecal matter for Cu, Fe, Mn, and Zn. A bovine liver standard from the National Institute of Standards and Technology (Gaithersburg, MA) was utilized to verify instrument accuracy and yttrium (PerkinElmer, Waltham, MA) as an internal standard to account for any variation in sample introduction within individual runs.

Calculations to determine TMR, refused feed, urine, and fecal mineral content and intake were described by Carmichael et al. (2018). Daily mineral intake, fecal mineral output, and urine mineral output were determined by dividing total mineral content of each by 5 (number of collection days). Apparent absorption, retention, and retention as a percentage of intake was calculated by methods described by Carmichael et al. (2018). NDF and acid detergent fiber (ADF) analysis was conducted on TMR, feces, and all feed refusals in duplicate with methods established by Van Soest et al. (1991) using an ANKOM 200 fiber analyzer (Ankom Technology, Macedon, NY). Alpha-amylase was used during the NDF analysis. Consistency was verified using a standard brome grass hay sample (inter-assay CV of 2.4% and 3.0% for NDF and ADF analysis, respectively).

Statistical Analysis

All data were analyzed as a randomized complete block design. Performance and intake data for the initial 60-d period prior to transition (steer as experimental unit; $n = 16$ per ZNTRT) were analyzed using the Mixed procedures of SAS (SAS Institute Inc., Cary, NC). The model included the fixed effects of ZNTRT, and block and initial BW values (day 0 of study) were used as a covariate. DM intake data were analyzed as repeated measures with week as the repeated effect and compound symmetry variance structure was selected to achieve the lowest Akaike information criterion value. Data collected following day 75 were analyzed as a 2 × 2 factorial arrangement utilizing the Mixed procedure of SAS. Pearson correlation analyses (PROC CORR) was used to identify and establish the relationship between Zn retention and N retention. The model for the analysis of the metabolism period and liver mineral included the fixed effects of ZNTRT, FIBER, block, and the interaction of ZNTRT × FIBER, with the three-way interaction of ZNTRT × FIBER × block as random. Data for urine excretion (milligrams per day [mg/d] and % of intake) were normally distributed after log transformation, and treatment means and SEM were reverse transformed for reported results. Steer was the experimental unit ($n = 8$ per treatment combination) for all analyses. Determination of outliers was accomplished using Cook's D statistic and removed if Cook's D ≥ 0.5. Due to negative retention values for Cu, Fe, Mn, and Zn during the collection period, data from one steer from CON-LF were removed from analysis. Significance was declared at $P \leq 0.05$ and tendencies were identified at $P = 0.06$ to 0.10. Values reported are least square means and SEM. Tabular values reported reflect the least square means and the PDIFF statement in SAS was utilized to determine pairwise differences.

RESULTS

Pre-metabolism Performance Period

During the first 60 d of Zn supplementation, when all steers received the HF diet, there was no week × ZNTRT effect on steer DMI (P = 0.55; Table 2). Zinc supplementation did not influence DMI, ADG, G:F, or final BW during the 60-d period preceding the metabolism period ($P \geq 0.62$; Table 2).

Table 2. Dietary Zn influence on 60-d performance preceding metabolism period in beef steers

	ZNTRT[1]			
Item	CON[2]	SUPZN[2]	SEM	*P*-value
Steers (*n*)	16	15		
DMI[3], kg/d	8.8	8.8	0.12	0.96
Initial BW[4], kg	310	307	6.0	0.65
Day 60 BW[4], kg	410	412	10.3	0.62
ADG[4], kg	1.69	1.73	0.171	0.62
G:F[4]	0.194	0.198	0.0119	0.66

[1]ZNTRT (mineral supplementation strategy). All steers received the HF diet (~35% NDF) during 60 d preceding metabolism period.

[2]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex; Availa-Zn; Zinpro, Eden Prairie, MN).

[3]Daily DMI based on repeated measures analysis (no week × ZNTRT effect; P = 0.55).

[4]A 4% pencil shrink was applied to all BWs, including ADG and G:F calculations.

Metabolism Period

Effects of ZNTRT and FIBER on nutrient intake, output, and digestibility assessments are shown in Tables 3 and 4. No ZNTRT × FIBER effects were identified for water intake, urine excretion, or intake, output, retention, and digestibility of DM, OM, NDF, ADF, and N ($P \geq 0.16$). No effects of ZNTRT were noted on nutrient intake, urine output, and fecal output parameters; NDF and ADF digestibility; or N retention ($P \geq 0.27$). Water intake was greater (P = 0.03) in CON vs. SUPZN and lesser (P = 0.01) in HF vs. LF. A positive correlation was detected between daily DMI (kg/d) and water intake (liters per day [L/d]; r = 0.48, P = 0.007) as well as urine output and water intake (L/d; r = 0.42, P = 0.02). DM and OM digestibility were lesser (P = 0.02) while N digestibility tended to be lesser (P = 0.07) in CON vs. SUPZN. No differences were detected due to FIBER for DMI, OM intake, N intake, or fecal output of DM, OM, and NDF ($P \geq 0.13$). Intake and digestibility of NDF and ADF were greater (P = 0.01) in HF vs. LF.

Table 3. Influence of dietary Zn and fiber concentration on daily nutrient intake and urine and fecal output in beef steers during 5-d collection period[1]

	ZNTRT[2]			FIBER[2]			
Item	CON[3]	SUPZN[3]	ZNTRT *P*-value[5]	HF[4]	LF[4]	FIBER *P*-value[5]	SEM
Steers (*n*)	15	16		16	15		
Intake							
DM, kg/d	8.24	8.15	0.88	7.85	8.54	0.25	0.391
OM, kg/d	7.69	7.81	0.85	7.27	8.24	0.13	0.418
NDF, kg/d	2.48	2.34	0.55	2.80	2.02	0.01	0.154
ADF, kg/d	1.15	1.09	0.55	1.41	0.84	0.01	0.067
N, g/d	200.8	199.7	0.92	193.5	207.0	0.26	8.06
Water, L/d	24.5	19.6	0.03	17.8	26.3	0.01	1.47
Urine output							
L/d	8.82	7.83	0.54	6.82	9.83	0.08	1.087
N, g/d	88.7	90.2	0.86	81.1	97.8	0.07	6.17
Fecal output							
DM, kg/d	2.36	2.16	0.30	2.13	2.39	0.21	0.132
OM, kg/d	2.01	1.82	0.29	1.79	2.04	0.18	0.116
NDF, kg/d	1.00	0.92	0.32	0.98	0.94	0.58	0.057
ADF, kg/d	0.43	0.39	0.42	0.45	0.37	0.07	0.028
N, g/d	67.4	62.0	0.30	59.4	70.0	0.06	3.43

[1]Steers were adapted to metabolism crates for 10 d (days 75 to 85 of the study) followed by 5 d of collection (days 85 to 90 of the study).

[2]ZNTRT (mineral supplementation strategy); FIBER (dietary fiber strategy).

[3]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; HF analyzed 165 mg Zn/kg DM; LF analyzed 142 mg Zn/kg DM).

[4]HF (~35% NDF of DM); LF (~25% NDF of DM).

[5]No ZNTRT × FIBER effect ($P \geq 0.17$).

Table 4. Influence of dietary Zn and fiber concentration on nutrient digestibility and N metabolism in beef steers[1]

	ZNTRT[2]			FIBER[2]			
Item	CON[3]	SUPZN[3]	ZNTRT *P*-value[5]	HF[4]	LF[4]	FIBER *P*-value[5]	SEM
Steers (*n*)	15	16		16	15		
DMD, %	71.5	73.6	0.02	72.9	72.2	0.37	0.53
OMD, %	73.9	76.7	0.02	75.4	75.2	0.86	0.73
NDFD, %	58.2	59.8	0.27	64.9	53.1	0.01	0.97
ADFD, %	61.3	62.2	0.56	68.0	55.5	0.01	1.12
N digestibility, %	66.3	68.9	0.07	69.2	66.0	0.04	0.92
N retention, g/d	45.0	47.5	0.69	52.9	39.6	0.06	4.71
N retention[6], %	22.1	23.9	0.60	27.3	18.7	0.03	2.43

DMD = dry matter digestibility, OMD = organic matter digestibility, NDFD = neutral detergent fiber digestibility, ADFD = acid detergent fiber digestibility.

[1]Steers were adapted to metabolism crates for 10 d (days 75 to 85 of the study) followed by 5 d of collection (days 85 to 90 of the study).

[2]ZNTRT (mineral supplementation strategy); FIBER (dietary fiber strategy).

[3]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; HF analyzed 165 mg Zn/kg DM; LF analyzed 142 mg Zn/kg DM).

[4] HF (~35% NDF of DM); LF (~25% NDF of DM).

[5]No ZNTRT × FIBER effect ($P \geq 0.23$).

[6]Reported as percentage of N intake.

Table 5. Influence of dietary Zn and fiber concentration on daily micro-mineral intake, fecal and urine excretion, and mineral retention in milligrams per day of beef steers during 5-d collection period[1]

	ZNTRT[2]		ZNTRT	FIBER[2]		FIBER	
Item	CON[3]	SUPZN[3]	*P*-value[5]	HF[4]	LF[4]	*P*-value[5]	SEM
Steers (*n*)	15	16		16	15		
Mineral intake							
Cu, mg/d	142	139	0.82	140	141	0.95	8.7
Fe, mg/d	1232	1185	0.78	1322	1095	0.20	115.4
Mn, mg/d	288	293	0.82	302	279	0.36	16.7
Zn, mg/d[6]	299	1255	0.01	766	788	0.69	36.5
Fecal excretion							
Cu, mg/d	131	132	0.89	128	135	0.43	6.2
Fe, mg/d	1132	1044	0.32	1175	1001	0.07	59.5
Mn, mg/d	236	233	0.87	245	224	0.18	10.2
Zn, mg/d	238	1070	0.01	606	701	0.03	26.2
Urinary excretion							
Cu, mg/d	0.29	0.20	0.11	0.25	0.23	0.66	0.026
Fe, mg/d	5.26	4.84	0.68	5.37	4.73	0.54	0.702
Mn, mg/d	0.71	0.51	0.21	0.63	0.57	0.72	0.109
Zn, mg/d	2.66	3.33	0.27	2.71	3.27	0.35	0.388
Mineral retention							
Cu, mg/d	11	7	0.54	12	6	0.27	4.1
Fe, mg/d	89	136	0.67	141	84	0.61	74.4
Mn, mg/d	51	59	0.61	56	54	0.88	11.9
Zn, mg/d[6]	57	181	0.01	157	82	0.01	14.4

[1]Steers were adapted to metabolism crates for 10 d (days 75 to 85 of the study) followed by 5 d of collection (days 85 to 90 of study).

[2]ZNTRT (mineral supplementation strategy); FIBER (dietary fiber strategy).

[3]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; HF analyzed 165 mg Zn/kg DM; LF analyzed 142 mg Zn/kg DM).

[4]HF (~35% NDF of DM); LF (~25% NDF of DM).

[5]No ZNTRT × FIBER effect for Cu, Fe, or Mn ($P \geq 0.11$).

[6]For fecal Zn excretion, there was a ZNTRT × FIBER effect ($P = 0.04$) where within SUPZN, Zn fecal excretion was lesser in HF vs. LF (979 vs. 1161 mg/d; $P < 0.01$), whereas CONHF (233 mg/d) was similar to CONLF (242 mg/d; $P = 0.88$). For Zn retention, there was a ZNTRT × FIBER effect ($P = 0.01$) where within SUPZN, Zn retention was increased in HF vs. LF (250 vs. 113 mg/d; $P < 0.01$), whereas CONHF (64 mg/d) was similar to CONLF (51 mg/d; $P = 0.65$).

Urine daily output, urinary N, and fecal N tended to be lesser in HF ($P \leq 0.08$) vs. LF. Nitrogen digestibility and N retention as a percent of intake were greater ($P \leq 0.04$) and N retention expressed as grams per day tended to be greater in HF vs. LF ($P = 0.06$).

Influence of ZNTRT and FIBER on trace mineral intake, excretion, apparent absorption, and retention as mg/d and percentage of intake are reported in Tables 5 and 6, respectively. No ZNTRT × FIBER effects were noted for Cu, Fe, or Mn intake; excretion; apparent absorption; and retention, or for Zn intake, fecal excretion (% of intake), urinary excretion, apparent absorption, and retention (% of intake; $P \geq 0.13$). Expressed as mg/d or percentage of nutrient intake, Cu, Fe, and Mn intake; fecal excretion; apparent absorption; and retention were unaffected by ZNTRT strategy ($P \geq 0.32$). Urinary excretion of Fe and Mn was unaffected by ZNTRT (mg/d and % of intake; $P \geq 0.21$). Copper urinary excretion tended to increase when expressed as percentage of intake ($P = 0.08$) in CON vs. SUPZN. Intake of Zn was lesser in CON vs. SUPZN (mg/d; $P = 0.01$). When expressed as percentage of Zn intake, fecal excretion of Zn tended to be lesser ($P = 0.06$) whereas urinary excretion of Zn was greater ($P = 0.01$) and apparent absorption of Zn tended to be greater ($P = 0.06$) in CON vs. SUPZN. A ZNTRT × FIBER interaction was detected for fecal Zn excretion (mg/d; $P = 0.04$) where within SUPZN, excretion was lesser in HF vs. LF (979 vs. 1161; $P < 0.01$), whereas CON-HF (233) was similar to CON-LF (242; $P = 0.88$). In addition, a ZNTRT × FIBER effect was identified for Zn retention (mg/d; $P = 0.01$) where within SUPZN, Zn retention was greater in HF vs. LF (250 vs. 113; $P < 0.01$), whereas within CON, HF was not different from LF (64 vs. 51; $P = 0.65$).

Regardless of manner of expression (mg/d or % of intake), Cu and Mn intake, excretion, absorption, and retention were unaffected by FIBER ($P \geq 0.18$). Intake, urinary excretion, apparent absorption, and retention of Fe were not affected by FIBER (mg/d and % of intake; $P \geq 0.20$). Fecal excretion of Fe

Table 6. Influence of dietary Zn and fiber concentration on daily micro-mineral fecal and urine excretion, and mineral retention of beef steers as a percent of nutrient intake during 5-d collection period

	ZNTRT[1]			FIBER[1]			
Item	CON[2]	SUPZN[2]	ZNTRT *P*-value[4]	HF[3]	LF[3]	FIBER *P*-value[4]	SEM
Steers (*n*)	15	16		16	15		
Fecal excretion							
Cu, %	93.1	95.3	0.57	91.9	96.6	0.24	2.67
Fe, %	95.1	89.4	0.41	91.5	93.0	0.83	4.74
Mn, %	83.2	80.0	0.56	81.9	81.4	0.92	3.72
Zn, %	80.2	85.6	0.06	79.4	86.4	0.02	1.70
Urinary excretion							
Cu, %	0.21	0.14	0.08	0.18	0.17	0.69	0.023
Fe, %	0.44	0.42	0.78	0.42	0.44	0.84	0.069
Mn, %	0.25	0.18	0.20	0.21	0.21	0.93	0.040
Zn, %	0.91	0.27	0.01	0.45	0.54	0.44	0.078
Apparent absorption							
Cu, %	6.9	4.7	0.57	8.1	3.4	0.24	2.67
Fe, %	4.9	10.6	0.41	8.5	7.0	0.83	4.74
Mn, %	16.8	20.0	0.56	18.1	18.7	0.92	3.72
Zn, %	19.8	14.5	0.06	20.6	13.6	0.02	1.70
Mineral retention							
Cu, %	6.6	4.5	0.59	7.9	3.2	0.24	2.70
Fe, %	4.4	10.1	0.41	8.0	6.5	0.83	4.75
Mn, %	16.5	19.7	0.56	17.8	18.4	0.92	3.72
Zn, %	18.6	14.1	0.12	20.0	12.7	0.02	1.81

[1]ZNTRT (mineral supplementation strategy); FIBER (dietary fiber strategy).

[2]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; HF analyzed 165 mg Zn/kg DM; LF analyzed 142 mg Zn/kg DM).

[3]HF (~35% NDF of DM); LF (~25% NDF of DM).

[4]No ZNTRT × FIBER effect ($P \geq 0.13$).

Table 7. Dietary Zn and fiber concentration influence on liver mineral concentrations of beef steers

	ZNTRT[1]			FIBER[1]			
Item	CON[2]	SUPZN[2]	ZNTRT *P*-value[4]	HF[3]	LF[3]	FIBER *P*-value[4]	SEM
Steers (*n*)	16	15		15	16		
Liver mineral, mg/kg DM[5]							
Cu	390	291	0.01	364	317	0.08	16.5
Fe	173	180	0.61	178	176	0.88	9.2
Mn	8.3	8.5	0.62	8.3	8.5	0.61	0.30
Zn	150	153	0.79	153	151	0.86	8.5

[1]ZNTRT (mineral supplementation strategy); FIBER (dietary fiber strategy).

[2]CON (no supplemental Zn; analyzed 36 mg Zn/kg DM); SUPZN (CON + 60 mg Zn/kg as $ZnSO_4$ + 60 mg Zn/kg as Zn–AA complex [Availa-Zn; Zinpro, Eden Prairie, MN]; HF analyzed 165 mg Zn/kg DM; LF analyzed 142 mg Zn/kg DM).

[3]HF (~35% NDF of DM); LF (~25% NDF of DM).

[4]No ZNTRT × FIBER effect ($P \geq 0.16$).

[5]Liver biopsies were taken on day 95 following metabolism period. No ZNTRT × FIBER effect ($P \geq 0.33$).

presented as mg/d tended to be greater ($P = 0.07$) in HF vs. LF. Zinc fecal excretion was lesser (% of intake; $P = 0.03$), whereas apparent absorption (% of intake) and retention (mg/d or % of intake) were greater ($P \leq 0.02$) in HF vs. LF.

No ZNTRT × FIBER effects were detected for day 95 liver mineral concentration data ($P \geq 0.33$; Table 7). Liver Cu concentrations were greater ($P = 0.01$) in CON vs. SUPZN and tended to be greater ($P = 0.08$) in HF vs. LF. Liver Fe, Mn, and Zn concentrations were unaffected by ZNTRT ($P \geq 0.61$) or FIBER ($P \geq 0.61$).

DISCUSSION

A combination of Zn–AA complex and Zn sulfate supplementation fed at rates near the industry reported average for Zn supplementation of 100 mg Zn/kg DM (Samuelson et al., 2016) positively affects cattle growth. Genther-Schroeder et al. (2016a) found that increasing supplemental Zn concentrations increased final BW and ADG during ractopamine hydrochloride supplementation in finishing steers. Utilizing the same Zn supplementation method, Carmichael et al. (2018) noted increased N retention regardless of ractopamine hydrochloride inclusion. These previous studies utilized relatively low-fiber finishing diets (~20% NDF) and recently supplemental mineral inclusion has been shown to impact fiber digestibility (Faulkner et al., 2017; Faulkner and Weiss, 2017; VanValin et al., 2018). Faulkner et al. (2017) noted differential impacts of fiber from by-products vs. forages such as corn silage on trace mineral absorption by dairy cows, and a large amount of by-product (modified distillers grains) were fed in previous studies examining the combination of Zn–AA complex and Zn sulfate (Genther-Schroeder et al., 2016a; Carmichael et al., 2018). Therefore, the objective of this study was to evaluate the impact of low- or high-fiber finishing diets on nutrient digestibility and Zn retention when Zn supplementation is similar to industry rates (Samuelson et al., 2016).

Fiber digestion was greater in HF vs. LF in this study. Negative associative effects occur when grains decrease voluntary intake or digestion of forages in the rumen (Dixon and Stockdale, 1999). Thirty-hour in vitro NDF digestibility of the silage fed during the metabolism period (62.6%) suggests that it was of high feeding value; however, ruminal fermentation of grains can be detrimental to fiber digestibility. Rapid fermentation of carbohydrates in the rumen results in production of volatile fatty acids (VFAs) and can rapidly decrease rumen pH when production exceeds absorption. Low ruminal pH can diminish ruminal fiber digestibility as fibrolytic microorganisms demand a narrow range in pH (6.6 to 7.0) to sustain function (Terry et al., 1969; Stewart, 1977; Mould and Ørskov, 1983). The greater NDF digestibility in HF vs. LF could be partially explained by negative associative effects occurring in LF steers because of the greater inclusion of dry rolled corn in the LF diet. However, Beckman and Weiss (2005), comparing diets with similar corn silage concentrations as this study with varying NDF:starch ratios, observed a change in ruminal VFA profile while ruminal pH was not affected. Possible negative associative effects affiliated with feedstuffs decreasing pH may have lessened NDF digestibility in LF, but ruminal pH and ruminal fiber digestibility were not measured in this study. Both LF and HF diets contained 32% (DM basis) of a combination of modified and dried distillers grains, and Loy et al. (2007) noted that supplementing distillers grains to heifers allowed ad libitum access to chopped grass

hay decreased ruminal pH and NDF disappearance. However, the inclusion of distillers grains for both diets in this study could have impacted rumen environment similarly. It is expected that steers fed the HF diet had increased rumination and should therefore have had greater buffering capacity due to saliva influx into the rumen as well as more stable rumen mat consistency, allowing for greater fiber digestion.

As aforementioned, high concentrate diets can decrease ruminal pH, often resulting in increased solubility of minerals within the rumen (Waghorn et al., 1990). Solubilized minerals are potentially susceptible to binding to phytate or undegraded fiber, which negatively impacts mineral absorption (Torre et al., 1991). Fortunately, ruminant microbes possess phytase activity, diminishing the inhibitory action of phytate on mineral absorption (Suttle, 2010). However, phytate may be an important consideration in the study because decreases in passage rate from greater amounts of forage in the diet can increase phytate degradation, whereas diets higher in concentrates may allow the opposite (Balch, 1950).

The effect within SUPZN for increased fecal excretion could be indicative of a supplemental vs. inherent dietary Zn concentration interaction with undegraded fiber. Minerals such as Zn and Cu are associated with the cell wall of plants, which consists of the NDF fraction of feedstuffs, and the increased NDF digestibility of HF may also explain the differences seen in Zn retention between HF and LF. Supplemental Zn in this study was provided as $ZnSO_4$ and as Zn–AA complex, both of which have been shown to be soluble in the rumen (Spears and Kegley, 2002; Spears et al., 2004). It is possible that supplemental Zn could be more susceptible to binding by undegraded fiber, because supplemental Zn solubilization may coincide with fiber digestion, allowing solubilized supplemental Zn to bind fiber not yet digested. Therefore, the increase in the amount of undegraded fiber noted in LF, coupled with potentially increased solubilized supplemental Zn, may have resulted in greater fecal Zn excretion for the SUPZN-LF steers. Decreased NDF digestibility in LF could negatively impact Zn absorption if ruminally solubilized Zn binds to undegraded fiber, whereas increased NDF digestibility in HF may have allowed for more solubilization and absorption with less undegraded fiber available to bind Zn. Collectively, possible depression of phytate degradation and NDF digestibility in higher concentrate diets could partially explain the interaction observed within SUPZN to increase Zn fecal excretion and decrease retention in LF (mg/d), as well as the decrease in Zn apparent absorption in steers consuming the LF diet.

This study utilized both inorganic and AA complexed Zn sources in the SUPZN treatment. Recent work suggests that ruminally soluble sources of Zn may negatively affect fiber digestion (Garg et al., 2008; Faulkner et al., 2017; VanValin et al., 2018); however, fiber digestion was unaffected by SUPZN in this study. As mentioned previously, fiber provided by the FIBER diets was highly digestible, which may not have been the case in previous studies displaying depressed fiber digestibility with the addition of Zn, potentially resulting in greater undegraded fiber available to bind ruminally solubilized Zn. Supranutritional Zn increased DM and OM digestibility relative to CON; this is in contrast to the results of Carmichael et al. (2018), where no differences in DM or OM digestibility were noted due to SUPZN in finishing cattle.

Diet differences exist between the two experiments (Carmichael et al., 2018), with greater corn inclusion in the diet of the comparison study and greater fiber in this study. In previous work, ruminal fluid Zn concentrations of 50 μg/mL decreased cellulose digestion when compared to control (Eryavuz and Dehority, 2009); however, the authors conceded this concentration was approximately 2000 mg Zn/kg DM, four times the maximum tolerable level suggested for beef cattle (NASEM, 2016). Consequently, supplying SUPZN, dietary Zn concentrations well below those previously shown to inhibit cellulose degradation, could result in a positive impact on fiber digestion by supplying adequate Zn concentrations for microbial function. However, this was not examined in this study and is beyond the scope of this article. Zn and fiber have a complex relationship within the rumen and more research should be conducted on the effect of supplemental Zn concentration and source on diet digestibility in ruminants. It is necessary to achieve a thorough understanding of this interaction while aspiring toward optimal supplemental Zn concentrations.

Apparent absorption of Zn tended to be decreased due to Zn supplementation in this study, and closely follows previous reports where increasing dietary Zn concentration decreases Zn apparent absorption (Weigand and Kirchgessner, 1979; Mohanna and Nys, 1999; VanValin et al., 2018). These results are in contrast to more recent research with heavy-weight finishing steers (570 ±

5.6 kg; Carmichael et al., 2018), where increasing Zn concentrations exerted no effects on Zn coefficient of absorption. Steers receiving SUPZN in this study had greater Zn retention (mg/d) in accordance with previous studies (Weigand and Kirchgessner, 1979; Carmichael et al., 2018), and supports that increasing dietary Zn concentrations will increase Zn retained. Coefficients of Zn absorption in this study (averaging 17.2% across all treatments) were similar to those previously reported in growing steers (16.0%, Pogge et al., 2014a; 9.9%, Pogge et al., 2014b; 10.0% [$ZnSO_4$], Shaeffer et al., 2017).

Previous studies have shown a positive relationship between Zn and N retention (Oberleas and Prasad, 1969; Greeley et al., 1980; Carmichael et al., 2018). In contrast to previous work in heavy-weight finishing steers (Carmichael et al., 2018), N digestibility tended to increase but N retention did not increase in SUPZN. The late-stage finishing steers utilized by Carmichael et al. (2018) retained a dramatically larger proportion of ingested N (42.2%) compared with the growing steers in this study (23.0%), reflecting an increased N need to support heavier BW. The influence of Zn supplementation on N retention in feedlot cattle across varying stages of growth remains to be fully elucidated.

Dietary fiber effects on N metabolism were also noted in this study and portray a positive effect of the HF diet. Lesser N degradation can result from concentrate addition (Lapierre and Lobley, 2001), and similar to this study, increased dietary concentrate inclusion has been shown to increase urinary N excretion decreasing available N for recycling to the rumen (Huntington et al., 1996). Increased N digestibility due to HF in this study is in contrast to previous research, where increased roughage decreased protein degradation in dairy cows (Balch, 1950). In addition, Faulkner and Weiss (2017) saw lesser N retention in a diet with a similar amount of corn silage (44%) when compared to a by-product diet. However, previous research established a decrease of N lost to the environment when corn silage was fed to dairy cattle (Dhiman and Satter, 1997; Kume et al., 2004, 2008a, 2008b), suggesting a more efficient utilization of dietary crude protein. Work conducted by Beckman and Weiss (2005) in lactating dairy cattle resulted in a linear increase in N retention with increasing NDF:starch ratio whereas in situ techniques evaluating differing forage-to-concentrate ratios saw decreasing protein degradation with lesser forage-to-concentrate ratios (Devant et al., 2001). In addition, as pH decreases protein degradation decreases, and collectively protein degradation decreases when substrate is provided by concentrate rather than forage (Bach et al., 1984). Further research should be conducted to increase understanding of N utilization in beef steers fed corn silage-based diets.

Moisture content of HF vs. LF may explain the lesser water intake by HF during the collection period (41.0 vs. 47.0% DM, respectively). Nevertheless, a positive correlation was detected between daily DMI (kg/d) and water intake (L/d; $r = 0.48$, $P = 0.007$). Water intake in this study was also positively correlated to urine excretion (L/d; $r = 0.42$, $P = 0.02$). Urinary water and N excretion have previously been shown to possess a positive relationship in dairy cattle (Murphy, 1992; Kojima et al., 2005) and similarly this study exhibited a tendency for reduced urine output coupled with decreased urinary N excretion in HF. Total tract absorption of N has been hypothesized to cause reductions in urinary N through increasing hindgut fermentation in dairy cattle by increasing ammonia absorption in the colon (Faulkner and Weiss, 2017). Further work is needed to establish the impact of higher roughage diets on urinary N excretion in beef steers. Unexpectedly, water intake was greater in CON vs. SUPZN. To the best of our knowledge, this is the first study to report lesser water intake with increased supplemental Zn concentrations in beef cattle and further investigation to define mechanisms involved will be required.

A complex interrelationship among dietary minerals exists. Copper absorption remained unchanged due to SUPZN, similar to previous work in finishing cattle (Carmichael et al., 2018); however, contrary to the study in finishing cattle, liver Cu was lesser in SUPZN. Increasing dietary Zn (90 to 180 mg Zn/kg DM) in cattle fed for 86 d numerically decreased liver Cu (Genther-Schroeder et al., 2016b). Lesser liver Cu along with greater amounts of Cu bound to metallothionein has observed in sheep due to high concentrations of dietary Zn (Bremner et al., 1976). High dietary concentrations of Zn can increase metallothionein in tissues, which may bind Cu and render it unavailable for utilization in the body (Oestreicher and Cousins, 1985). Regardless of numerical decreases in Cu absorption and retention, liver Cu status was highly adequate (Kincaid, 2000) in both CON and SUPZN steers. Awareness of the Cu and Zn antagonism remains important as trace mineral requirements of beef steers continue to be refined.

Opportunity remains to further improve Zn requirement recommendations in beef steers. Dietary fiber content and fiber digestibility may influence trace mineral and N metabolism by beef steers

and warrants further investigation of diet type and trace mineral supplementation strategy. Increasing dietary concentrations of Zn increases the amount of retained Zn, regardless of changes in coefficient of absorption. In addition, the recognition of antagonistic dietary constituents and the resulting impact on trace mineral availability in the rumen will be important to understand optimal utilization of trace minerals by beef cattle.

Conflict of interest statement. None declared.

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