Live growth performance, carcass grading characteristics, and harvest yields of beef steers supplemented zilpaterol hydrochloride and offered ad libitum or maintenance energy intake

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ABSTRACT: A trial was conducted to examine live growth efficiency, harvest yields, and carcass grading performance of steers fed at maintenance (M) or at ad libitum (A) level of intake during zilpaterol hydrochloride (Z) supplementation. Single-sired, beef steers (n = 56; start of trial BW 590 ± 36 kg) blocked (n = 2) by weight and terminal implant were sorted into pairs (n = 14 per block) by weight. Pairs of steers were initially assigned to 0, 28, or 56 d of feeding. Within 28 or 56 d, pairs were assigned to M or A intake. Steers within a pair assigned to 56 d of feeding were randomly assigned to either 20 d of Z supplementation (90 mg/d per steer) with a 4 d withdrawal period prior to slaughter or to no ZH supplementation (C). Steers were housed and fed in individual pens. Weights of all non-carcass and carcass components were recorded at slaughter; carcasses were graded 24-h postmortem. Data were analyzed via a mixed model; the fixed effect was treatment combination with random effects of block and pair. Live growth data used harvest day as the repeated measure and animal as the subject. Single df contrasts were constructed for day 0 vs. day 28, day 0 vs. day 56, day 28 vs. day 56, M vs. A, and C vs. Z. Treatment impacted ($P \leq 0.05$) live ADG; contrasts indicated A (1.33) was greater than M (0.14 kg), and Z (1.12) was greater than C (0.82 kg). Similarly, carcass ADG differences ($P < 0.01$) indicated A (1.04) was greater than M (0.36 kg), and Z (1.35) was greater than C (0.71 kg). Intake level altered BW and empty body weight (**EBW**); M cattle had reduced BW and EBW ($P < 0.01$, 585 and 540 kg) than A cattle (647 and 597 kg). Cattle fed at M had less carcass and internal cavity mass ($P < 0.01$, 359 and 79.4 kg) than A cattle (394 and 93.5 kg). Liver mass was reduced by M feeding ($P < 0.01$; M-5.03, A-6.69 kg) and Z treatment ($P < 0.01$; Z-5.64, C-6.06 kg). Moreover, mass of total splanchnic tissue was less ($P < 0.01$) for M cattle than A cattle (59.8 vs. 72.5 kg). Dressed carcass yield was greater ($P < 0.01$) for Z than C cattle (63.5 vs. 61.6%). Cattle fed at M had less 12th rib s.c. fat, lower numerical U.S. yield grades ($P < 0.01$; M-1.71 cm and 3.3, A-2.46 cm and 4.3) and lower numerical Canadian yield grades ($P < 0.01$; 51.9 vs. 53.9% for M and A, respectively) than A cattle. Results indicate that energy intake level and Z supplementation influence live and carcass growth, carcass transfer, kill yields, and carcass characteristics across time.

Key words: carcass, comparative slaughter, growth, steers, yield, zilpaterol

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INTRODUCTION

Zilpaterol hydrochloride (Z) is a FDA licensed β_2-adrenergic agonist labeled for increased carcass leanness and rate of weight gain and improved feed efficiency for cattle (Merck Animal Health, 2006). Improved live BW, ADG, and G:F (Montgomery et al., 2009b; Elam et al., 2009) and increased hot carcass weight (**HCW**), longissimus muscle area, dressed carcass yield, and carcass cutability (Elam et al., 2009; Hilton et al., 2010) was observed in cattle fed Z. In addition, Z increased the rate of carcass gain thus improving carcass transfer (carcass ADG/live ADG) and maximizing economically important tissues at the end of the finishing period (Vasconcelos et al., 2008; Rathmann et al., 2012). Montgomery et al. (2009b) and Holland et al. (2010) hypothesized that non-carcass components might be catabolized in response to Z to provide a pool of nutrients while muscle fibers are stimulated for growth. Non-carcass yields were reduced, whereas carcass yields increased in Z supplemented serially harvested Holstein steers (McEvers et al., 2013).

Splanchnic tissues [gastrointestinal tract (**GIT**), liver, gall bladder, spleen, and pancreas] utilize a disproportionate amount of oxygen and dietary AA for their metabolism relative to splanchnic tissue weight as a percentage of EBW (Reynolds et al., 1991; Lobley, 2003; Baldwin et al., 2004). Furthermore, different energy dense diets resulted in changes to visceral mass (Carstens et al., 1991; Sainz and Bentley, 1997; McCurdy et al., 2010). To date, no research has investigated the impact of Z fed to cattle at differing planes of energy upon live performance, carcass and non-carcass tissue yields, and carcass grading characteristics. Therefore, the objectives of this trial were to quantify live growth performance, non-carcass and carcass harvest yields, and carcass grading attributes of cattle fed differing energy levels with and without Z.

MATERIALS AND METHODS

All experimental procedures involving live animals were approved by the Animal Care and Use Committee at West Texas A&M University (#02-06-14) and adhered to the regulations in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies, 2010, Savoy, IL).

Live Cattle Procedures

Single-sired steers (n = 60; Hereford sire via artificial insemination and first parity Angus × Hereford dams) were sourced from 1 owner (2 separate ranches). Calves were born during a 21 d period and were weaned at 203 to 268 d of age. At weaning, all calves were transported (160 or 205 km) from the 2 ranches to Grandview, ID. Upon arrival, calves were vaccinated against bovine rhinotracheitis virus, bovine viral diarrhea virus type 1 and 2, bovine parainfluenza-3 virus, and bovine respiratory syncytial virus (Pyramid 5, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), *Clostridiums' chauvoei*, *septicum*, *hemolyticum*, *novyi*, *sordellii*, and *perfringens* Types C&D (Vision 8, Merck Animal Health, Summit, NJ), treated for internal and external parasites with an injectable anthelmintic (Dectomax, Zoetis, Florham Park, NJ), administered a metaphylaxis treatment (Oxytetracycline, Durvet Inc., Blue Springs, MO) and growth promoting implant (Revalor G, Merck Animal Health). Steers were backgrounded on a high-forage diet with a target rate of gain of 0.8 kg/d for 42 to 86 d. At the end of the backgrounding phase, steers were weighed, administered a second growth promoting implant (Revalor IS, Merck Animal Health), and adapted to a finishing diet over 14 d. Steers were administered a third growth promoting implant [either Revalor IS or Revalor XS (Merck Animal Health) depending upon estimated days to market] 90 d after the start of finishing diet adaptation. At third implant, DNA samples were collected from individual steers to ensure all candidate steers were of the same sire.

Once the sire was confirmed, candidate steers were selected and purchased for the study. Steers that had previously received 2 Revalor IS implants were reimplanted with a Revalor S (Merck Animal Health) 24 d after the Revalor IS implant to ensure that hormonal concentration would be similar between steers harvested for the current study and to ensure that days on feed would not exceed implant pay-out period. At time of purchase, all 60 steers were placed into a single pen and fed an intermediate energy dense diet for 55 d to control rate of weight gain to 1.2 kg/d prior to study start date. Steers were weighed (n = 60; BW 574 ± 36 kg) the afternoon prior to shipping and loaded onto 2 livestock haulers prior to being transported 1,944 km (23 h) to a private research facility in Canyon, TX. Upon arrival, cattle were weighed immediately off the truck (n = 60; BW 522 ± 33 kg) and on the consecutive day prior to morning feeding (n = 60; BW 542 ± 34 kg).

Immediately after unloading and weighing, steers were allowed access to feed and water. Steers were blocked in 2 pens (n = 30 each) by terminal implant (Revalor XS or Revalor S). Steers were placed on an intermediate energy diet (27% forage) for 3 d prior to being fed a finishing diet (Table 1).

While both blocks started on finisher diet at the same time, block 2 started the trial 28 calendar

Table 1. Timeline of events for control (CONT) and zilpaterol (ZH) steers fed 0, 28, or 56 d after ad libitum or maintenance intake level

Block	Block 1	Block 2	Block 1	Block 2	Block 1	Block 2
Harvest day	Day 0	Day 0	Day 28	Day 28	Day 56	Day 56
n	4	4	8	8	16	16
Pre-allocation period, d						
Weighed at commercial feedyard	1	1	1	1	1	1
Transported to research site[a]	2	2	2	2	2	2
Weighed at research site	3–4	3–4	3–4	3–4	3–4	3–4
Penned as block	3	3	3	3	3	3
Pretreatment feeding, d						
Intermediate energy ration	3–5	3–5	3–5	3–5	3–5	3–5
High energy finishing ration	6–24	6–52	6–24	6–52	6–24	6–52
Allocation period, d						
Weigh days[b]	23–24	51–52	23–24	51–52	23–24	51–52
Assigned to pairs, randomized to treatment, and penned individually	25	53	25	53	25	53
Treatment period, d						
Start of maintenance or continuation of ad libitum intake			29	57	29	57
Harvest	29	57	57	85	85	113
Fabrication	30	58	58	86	86	114
Zilpaterol hydrochloride supplementation or control					61–80	89–108
Treatment weigh days, d[b]						
Day −1 and day 0	28	56	28–29	56–57	28–29	56–57
Day 11			39	67	39	67
Day 21			49	77	49	77
Day 27 and 28			56	84	56–57	84–85
Day 55					112	112

[a]Transportation duration of 23 h.

[b]All weights taken off feed and water for 9 h.

days after block 1. Sort weights were recorded on day −5 and −6 prior to each respective block start date with 28 steers selected per block (block 1, initial BW = 589 ± 25 kg; block 2, initial BW = 614 ± 39 kg). Steers were sorted into individual pens on day −4; block 2 remained penned as a group for an additional 28 d with parallel sorting and weighing protocols to block 1. Within each block, 2 steers with weights furthest from the mean (heaviest and lightest steer in block 1 and 2 lightest steers in block 2) were penned in individual pens as alternates for the duration of the trial.

Experimental Design

The trial was constructed (Table 1) as a multifactorial treatment design with 3 harvest dates, 2 dietary energy levels, and 2 Z supplementation levels (0 or 90 mg/d per steer). Cattle were blocked by terminal implant status and randomized to pairs on the sort days (day −5 and day −6) by weight. Pairs were randomized to harvest day (0, 28, or 56 d) and for pairs randomized to day 28 or 56 maintenance (M) or ad libitum (A) dietary energy level within harvest date. Within day 56 harvest date, 1 animal within each pair for both M and A level of feeding was randomly assigned to Z (90 mg/d per steer for 20 d; Merck Animal Health) or control (no Z).

Maintenance adjustments were based on the NRC (1996) [((BW × 0.891)$^{0.75}$ × 0.077)/diet NE$_m$), BW day −1 and 1] with a positive 6.3% initial DM intake adjustment based on prior research observations in steers fed the same diet (Walter et al., 2016). Steers were weighed individually (day −1, 1, 11, 21, 27, 28, 55, 56) after a 9-h water and feed withdrawal with no additional shrink applied. All cattle weights were recorded individually using 4 load cells mounted under a chute (Trojan Livestock Equipment, Weatherford, TX) and a GSE 350 digital weight indicator (Avery Weigh-Tronix Group, Fairmont, MN) with ± 0.45 kg accuracy; the scale was validated with 738 kg of weights before each use and checked with 270 kg of weights after weighing every 20 animals. Biometric measurements were collected (resolution of 2.5 mm) on each animal according to the procedures previously reported by Reed et al. (2017).

Diets and Feeding

Dry matter intake adjustments were made for M steers using BW changes on day 11, 21, 27, and 28 with additional as-fed intakes for M steers adjusted on day 1, 12, 22, 28, 40, and 50 based on daily feed DM 5 d averages (DM from day 5 to 9 for adjustment starting on day 12; DM from day 15 to 19 for adjustments starting on day 22; DM from day 22 to 25 for adjustments starting on day 28; DM from day 33 to 37 for adjustments starting on day 40; and DM from day 43 to 47 for adjustments starting on day 50). Steers fed A dietary energy were adjusted daily depending upon feed refusal and morning bunk calls at 0600 h. Orts were weighed and sampled on day 0, 27, 28, 55, and 56 and anytime feed refusal was visually estimated to be greater than 5% of the previous days offering.

Diets were mixed in 900 kg batches for 3 min (340 Oswalt auger mixer, J-star, Fort Atkinson, WI); accuracy for ingredient loading was 4.5 kg. Feed samples were collected daily and subsampled for daily DM determination to a constant weight at 55 °C, in a forced-air convection oven (LBB 2-12, Despatch Industries, Minneapolis, MN). Daily subsamples were composited (as-is) by week for further determination of nutrients (Table 2). Cattle were hand fed once daily at 0800 h; feed for each steer was weighed on a scale with ± 0.045 kg accuracy, validated daily. Orts were dried at 55 °C for 48 h and analyzed for nutrient composition. Tylosin and monensin sodium (Tylan and Rumensin; Elanco Animal Health, Greenfield, IN) were fed continuously in the diet at 9.9 and 33.1 mg/kg (DM basis) and added to the diet with an automated micro-ingredient machine (MicroBeef Technology, Amarillo, TX). Vitamins and minerals were added to the diet in the form of a pelleted supplement (Table 2). Zilpaterol was preweighed as 1.875 g of Zilmax (4.8% zilpaterol hydrochloride) into a 50 mL tared centrifuge tube. When Z was fed, 45 mL of water was added to the centrifuge tube and top-dressed directly onto the feed. The tube was then flushed with an additional 50 mL of water and added to the feed.

Table 2. Dietary ingredients (% DM basis), and nutrient basis (DM basis) of finishing diets fed to steers

Ingredients, % DM basis	
Steam flaked corn	72.32
Corn gluten feed	9.38
Wheat hay	9.59
Molasses blend	1.20
Fat	2.35
Supplement[a]	5.26
Nutrient analysis (±SD)	
DM, %	79.92 ± 0.011
CP, % DM	13.28 ± 0.659
Starch	51.25 ± 2.153
NDF, % DM	16.38 ± 0.774
ADF, % DM	7.63 ± 0.405
Ether extract, % DM	5.72 ± 0.298
Calcium, % DM	0.52 ± 0.042
Phosphorus, % DM	0.34 ± 0.016

[a]Supplement: 49.01% cottonseed meal, 10.00% rice mill by-product, 3.20% ammonium sulfate, 3.70% sodium chloride, 10.20% urea (288% CP), 20.55% calcium carbonate (38% Ca), 1.95% potassium chloride (52% K), 0.33% vitamin A (44,092 IU/kg), 0.053% vitamin E (275,578 IU/kg), 0.001% vitamin D (176,370 IU/kg), and 1.00% trace mineral.

Harvest and Carcass Grading

Prior to harvest, steers were held in a separate pen without feed and water for 9 h. All steers were transported 52 km and harvested at a commercial beef processor (Est. ID 675; Hereford, TX). At harvest, weights of all harvest components (non-carcass and carcass) were recorded; samples of blood and hide (100 cm^2) were retained for further analysis. Internal offal was collected in 208-liter capacity drums, drum weights were tared and gross internal cavity component weights were captured at the processor (± 0.45 kg) prior to transportation to the WTAMU meat lab (Canyon, TX) for further processing. At the WTAMU meat lab, viscera was weighed ± 0.01 kg (ABM-60, Universal Weight Enterprise Company, Xindian City, Taiwan) individually [pancreas, liver, kidneys, gall bladder, thymus, kidney-pelvic-heart fat (**KPH**), trachea, heart, lungs and pluck trim]. Omental fat was trimmed from the stomach compartments and weighed; GITs were cleaned, flushed of contents with pressurized tap water, drained by hand, and weighed empty.

Left carcass sides were ribbed between the 12th and 13th ribs following a 24-h chill period. A detailed carcass evaluation was conducted which included marbling score, lean and skeletal maturity, 12th rib s.c. fat depth (cm), and LM area (cm^2). A final quality grade and calculated yield grade were determined (USDA, 1997). In addition, Canadian grading factors were calculated for muscle score (maximum length and width) and grade fat (fat class) to calculate Canadian yield grade measurement (Canadian Beef Grading Agency, 2001). A final quality grade and calculated yield grade were determined for each carcass (n = 55), except 1 carcass due to excessive trimming which resulted in unattainable yield grade measurements and was therefore excluded from grading measurements.

Sample Analysis

Dried diet and orts were ground through a 1-mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ). A commercial laboratory (Servitech Labs, Amarillo, TX) analyzed dried and ground feed and ort samples for DM (AOAC #934.01), nitrogen (AOAC #990.03), starch (Xiong et al., 1990), ADF (Ankom Technology Method 5), NDF (Ankom Technology Method 6), and ether extract (AOAC #2003.06); feed samples were also analyzed for Ca and P (AOAC #968.08).

Statistical Analysis

The mixed procedure of SAS (SAS Institute, Inc. Cary, NC) was used for model analysis; fixed effects were treatment combinations with random effects of block and pair. Differences among treatment means were determined using nonorthogonal single df contrasts. Contrasts included: day 0 vs. day 28, day 0 vs. day 56, day 28 vs. day 56, M vs. A, and C vs. Z to examine differences between harvest day, dietary energy intake, and Z supplementation. The KENWARDROGER option was used to generate new denominator df. A LSMEANS statement generated means and a PDIFF statement was used to assess differences ($\alpha = 0.05$) and trends ($\alpha = 0.10$) due to harvest day or Z supplementation.

Performance data were analyzed as a repeated measures design with day as the repeated measure and individual animal as the experimental unit. Several variance–covariance structures were evaluated for each variable analyzed. Variance–covariance structures were chosen depending upon Akaike information criterion and Bayesian information criterion being closest to zero. All live and carcass performance data and biometric data (DMI, ADG, G:F, BW gain, carcass gain, carcass ADG, carcass G:F, carcass transfer, and hip and shoulder height gain) used compound symmetry as a variance–covariance structure. Repeated measures data measured the gain or loss difference over time; differences among treatment means were determined using nonorthogonal single df contrasts. Contrasts included: harvest day, M vs. A, and C vs. Z to examine differences between harvest day, dietary energy intake, and Z supplementation. The KENWARDROGER option was used to generate new denominator df. A LSMEANS statement generated means and a PDIFF statement was used to assess differences ($\alpha = 0.05$) and trends ($\alpha = 0.10$) due to harvest day or Z supplementation.

RESULTS

Performance

Live growth performance differed across harvest day, dietary energy level, and Z supplementation ($P < 0.05$; Table 3). Start of trial BW did not differ across treatments ($P = 0.99$) but end of trial BW was 10.6% greater in A than M cattle ($P < 0.001$; 647 vs. 585 kg). Additionally, cattle harvested on day 56 had a greater ($P = 0.04$) BW (628 kg) than cattle harvested on day 28 (593 kg) and tended to have a greater BW ($P = 0.07$) than cattle harvested on day 0 (586 kg). Biometric growth of steers was impacted by treatment ($P < 0.05$). Starting hip height tended ($P = 0.09$) to be less in day 0 steers than day 56, whereas end of trial hip height was shorter in day 0 steers vs. all other treatments ($P < 0.05$). Additionally, M fed steers had shorter hip height than A steers ($P = 0.01$; 131 vs. 134 cm, respectively). Start of trial shoulder height did not differ ($P = 0.33$) across treatments, whereas end of trial shoulder height tended to be impacted by treatment ($P = 0.06$). Day 56 steers were taller

Table 3. Live weights and biometric data of steers fed to 0, 28, or 56 d on feed (0, 28, and 56) and given maintenance (M) or ad libitum (A) intake and control (C) or zilpaterol hydrochloride (Z) treatment

Item	0	28 A	28 M	56 AZ	56 AC	56 MZ	56 MC	SEM	*P*-value	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
n	8	8	8	8	8	8	8							
Start of trial BW[a], kg	586	586	582	597	589	595	594	16.1	0.99					
End of trial BW[a], kg	586[b]	617[ab]	569[b]	667[a]	658[a]	595[b]	591[b]	17.5	<0.01	0.80	0.07	0.04	<0.01	0.68
Biometric data														
Start hip height, cm	127	132	128	131	132	130	133	1.2	0.09	0.16	0.02	0.21	0.26	0.13
End hip height, cm	127[c]	133[ab]	130[bc]	133[ab]	136[a]	131[b]	133[ab]	1.4	<0.01	0.01	<0.01	0.10	0.01	0.07
Start shoulder height, cm	121	125	121	124	125	123	127	1.7	0.33					
End shoulder height, cm	121	124	126	128	129	127	127	1.7	0.06	0.11	<0.01	0.06	0.65	0.61

[a–c]Least squares means within a row with differing superscripts differ ($P \leq 0.05$).

[a]BW is unshrunk because animals were not allowed feed and water for 9 h.

at the shoulders than day 0 steers (128 vs. 121 cm, respectively) and tended to be taller at the shoulders than day 28 steers (125 mm).

Dry matter intake differed ($P < 0.01$) between diets as designed; A fed cattle consumed 55% more feed than M from day 1 to 28 and 53% more feed from day 29 to 56 (Table 4). Cattle on A intake consumed 1.46% of midpoint BW in the first 28 d. This is less than initially anticipated, likely due to stress resulting from steers being penned individually as well as time off feed for weigh days. Body weight gain was affected by harvest day, diet, and Z supplementation ($P < 0.01$). Gain was greater ($P < 0.01$) during day 29 to 56 vs. day 1 to 28 and was 218% greater in A vs. M fed cattle. Additionally, Z cattle had a 38.2% increase in BW gain ($P = 0.05$) vs. control when analyzed as repeated measures, even though end of trial and start of trial BW was not different ($P = 0.68$) between ZH treatments. There was a weight difference at the beginning of day 29 to 56 period in which AC cattle had a BW of 625 kg, whereas AZ cattle had a BW of 612 kg. Cattle fed Z on A diets gained more ($P < 0.05$) BW (47.4 kg) during day 29 to 56 than AC cattle (35.2 kg) resulting in no difference to final BW. Maintenance cattle from day 29 to 56 exhibited positive gains ($P < 0.01$) vs. weight loss expressed by M cattle day 1 to 28; this outcome is primarily due to weight loss in maintenance cattle during the first 28 d and a likely subsequent improvement in energetic efficiency due to shrinking GIT and liver mass, which is in agreement with Ledger and Sayers (1977).

Average daily gain increased ($P < 0.01$) over time from 0.27 kg/d for day 1 to 28 to 0.97 kg/d during day 29 to 56 across all treatments and as expected was greater ($P < 0.01$) for A fed cattle (1.33 kg/d) vs. M fed cattle (0.14 kg/d) over the length of the trial. Average daily gain was also impacted by Z treatment ($P = 0.05$); day 29 to 56 AZ and AC cattle had the greatest ($P < 0.01$) ADG (1.69 and 1.26 kg/d for AZ and AC, respectively) although AC cattle were not different than A cattle during day 1 to 28. Maintenance cattle initially (day 1 to 28) had a negative ADG (−0.50 kg) but conversely a positive ADG during day 29 to 56 with MZ cattle exhibiting 0.55 kg/d weight gain and MC exhibiting 0.37 kg/d ADG. Gain to feed efficiency (G:F) values were influenced ($P < 0.01$) by harvest day and dietary intake level. Day 1 to 28 M cattle exhibited the poorest ($P = 0.05$) G:F (−0.125). In contrast, day 29 to 56 AZ cattle had the highest G:F (0.182) but were not different from day 29 to 56 AC (0.153) or day 29 to 56 MZ (0.126) treatments. The G:F of day 29 to 56 MZ cattle (0.126) did not differ ($P \geq 0.11$) from any A fed cattle, whereas day 29 to 56 MC cattle had reduced ($P < 0.05$) G:F as compared to day 29 to 56 AC or AZ steers.

Carcass performance was also impacted by treatment ($P < 0.01$). Carcass gain increased

Table 4. Live performance and biometric gain of steers fed for 0–28, or 28–56 d and given maintenance (M) or ad libitum (A) intake and control (C) or zilpaterol hydrochloride (Z) treatment

	Treatments								Contrast *P*-values		
Item	1–28 A	1–28 M	29–56 AZ	29–56 AC	29–56 MZ	29–56 MC	SEM	*P*-value	Day[a]	M vs. A	C vs. Z
n	24	24	8	8	8	8					
Live performance											
DMI, kg	8.85^{a}	4.01^{b}	8.96^{a}	8.83^{a}	4.22^{b}	4.13b	0.227	<0.01	0.28	<0.01	0.57
BW gain, kg	28.9^{b}	−14.1^{d}	47.4^{a}	35.^{2b}	15.5^{c}	10.3c	3.56	<0.01	<0.01	<0.01	0.05
ADG, kg	1.03^{b}	−0.50^{d}	1.69^{a}	1.26^{ab}	0.55^{c}	0.37c	0.128	<0.01	<0.01	<0.01	0.05
G:F	0.113^{bc}	−0.125^{d}	0.182^{a}	0.153^{ab}	0.126^{abc}	0.092c	0.021	<0.01	<0.01	<0.01	0.19
Carcass performance[b]											
Carcass gain, kg	21.2^{b}	−6.79^{d}	34.9^{a}	15.9^{bc}	21.0^{b}	9.2c	2.65	<0.01	<0.01	<0.01	<0.01
Carcass ADG, kg	0.76^{b}	−0.24^{d}	1.25^{a}	0.57^{bc}	0.75^{b}	0.33^{c}	0.110	<0.01	<0.01	<0.01	<0.01
Carcass G:F	0.08^{c}	−0.06^{d}	0.14^{ab}	0.07^{c}	0.17^{a}	0.09^{bc}	0.017	<0.01	<0.01	0.02	<0.01
Carcass transfer[c], %	85.6^{b}	44.4^{d}	74.6^{bc}	44.9^{cd}	136.6^{a}	57.1^{bcd}	11.06	<0.01	0.08	0.22	<0.01
Biometric data											
Hip height gain (mm/d)	0.48	0.11	0.33	0.59	0.22	0.18	0.205	0.20			
Shoulder height gain (mm/d)	0.13^{b}	0.46^{ab}	1.13^{a}	1.13^{a}	0.33^{ab}	−0.13^{b}	0.306	0.05	0.28	<0.01	0.38

[a–d]Least squares mean s within a row with differing superscripts differ ($P \leq 0.05$).

[a]Day = harvest day.

[b]Carcass performance calculated using dressing percentage for harvested steers to calculate HCW of nonharvested steers.

[c]Carcass transfer = (HCW ADG/live ADG) * 100.

($P < 0.001$) over time (7.2 kg for day 1 to 28 vs. 20.3 kg, for day 29 to 56), with increased dietary energy intake (7.8 kg for M vs. 24.0 kg for A) and with Z treatment (29.5 kg for Z vs. 12.6 kg for C, respectively). Carcass ADG followed in a similar fashion to carcass gain with greatest carcass ADG observed in day 29 to 56 AZ cattle (1.25 kg/d; $P < 0.05$) followed by day 1 to 28 A (0.76 kg/d) and day 29 to 56 MZ cattle (0.75 kg/d). In addition, day 29 to 56 MC and day 29 to 56 AC cattle had similar carcass ADG of 0.33 and 0.57 kg/d, respectively. The lowest carcass ADG was evidenced in day 1 to 28 M cattle (−0.24 kg/d). Carcass G:F was also affected by time, dietary intake level, and ZH treatment ($P < 0.01$). Carcass G:F of day 29 to 56 MZ (0.17) cattle was greater than all other treatments ($P < 0.05$) except day 29 to 56 AZ (0.14). Carcass transfer was greater ($P < 0.05$) in day 29 to 56 MZ steers (136.6%) than all other treatments; Z steers had greater carcass transfer than C steers (105.6 vs. 51%, respectively).

Although, end of trial hip height differed between treatments, hip height gain did not differ by treatment ($P = 0.20$) ranging from 0.11 (day 1 to 28 M) to 0.59 (day 29 to 56 AC) mm/d. Shoulder height gain was greater ($P < 0.01$) for A (0.8 mm/d) than M (0.2 mm/d) steers.

Empty Body Weight and Tissue Component Yields

Final BW, empty body weight (**EBW**), and tissue component yields were impacted by treatment ($P < 0.05$; Table 5). Final BW increased ($P = 0.05$) from day 28 to day 56 (593 to 627 kg), whereas EBW tended ($P = 0.09$) to increase during the same time period (551 to 577 kg). Differences in final BW and EBW also occurred between M and A fed cattle ($P < 0.01$); as expected, A fed cattle had heavier final BW and EBW (62 and 56 kg difference, respectively) than M steers. In addition, day 56 AZ cattle had the heaviest final BW and EBW (666 and 615 kg, respectively), but were not different ($P > 0.05$) from the BW and EBW of day 56 AC cattle (658 and 602 kg, respectively). Day 56 AC cattle did not differ ($P > 0.05$) from day 28 A (573 kg), with respect to EBW, but were different from all other treatments ($P < 0.05$). The ratio of EBW/BW tended ($P = 0.08$) to differ across treatments; day 28 was 0.86% greater ($P = 0.05$; 92.1 vs. 93.0%, respectively) than day 56, and Z was 1.2% greater ($P = 0.01$; 92.7 vs. 91.5%, respectively) than C. Conversely, fill followed the opposite trend and ranged from 7.0% to 8.5% of BW.

Tissue component yields of HCW and non-carcass differed across treatments ($P < 0.01$). Hot carcass weight increased ($P = 0.03$) between day 0 and 56 by 30 kg (354 vs. 384 kg, respectively) and between day 28 and 56 by 23 kg (361 and 384, respectively). In addition, A fed cattle exhibited a 35 kg heavier carcass than M cattle ($P < 0.01$; 394 vs. 359 kg, respectively) and cattle supplemented with Z had a tendency ($P = 0.07$) for a heavier HCW (17 kg) vs. C cattle (393 vs. 376 kg, respectively). The 56 d AZ cattle exhibited heavier ($P < 0.05$) HCW compared to both 56 d MZ and 56 d MC, whereas the 56 d AC cattle did not have heavier ($P > 0.05$) HCW vs. the 56 d MZ cattle and the 28 d A cattle. Zilpaterol hydrochloride supplementation resulted in increased carcass tissue yield ($P < 0.01$) vs. C cattle (673 vs. 658 g/kg EBW). Day 56 AZ and day 56 MZ cattle had greater ($P < 0.05$) HCW (670 and 677 g/kg EBW, respectively) than all other treatments except 56 d MC (661 g/kg EBW). Additionally, day 56 cattle had greater ($P < 0.001$) carcass yield vs. day 0 (665 vs. 651 g/kg EBW, respectively) and day 28 (665 vs. 655 g/kg EBW, respectively). Mass of blood and hide did not differ across treatments ($P \geq 0.16$). In contrast, mass of non-carcass bone (hooves, metacarpals, metatarsals, and oxtail) was impacted ($P = 0.02$) and head mass tended to be impacted ($P = 0.06$) by harvest day; day 56 cattle had heavier head and non-carcass bone than day 0 or day 28 cattle ($P \leq 0.05$). When non-carcass bone and head weights were expressed as g/kg EBW both variables were decreased by increased dietary intake level ($P < 0.01$). Furthermore, Z supplementation decreased ($P = 0.02$) non-carcass bone weight (g/kg EBW) as compared to C cattle. Harvest trim included cod fat, additional fat trim from carcass (adjacent to hide pattern entry points), spinal cord, and penis, and was impacted by intake level. Cattle fed at M intake had reduced ($P < 0.01$) trim relative to A fed cattle (13.1 vs. 15.1 kg, respectively). More specifically, M cattle at day 56 had reduced ($P < 0.05$) trim compared to A fed cattle at day 56 irrespective of Z supplementation (12.84 vs. 15.44, respectively), likely due to a decrease in cod fat.

Internal cavity as a whole weight was impacted ($P < 0.01$) by dietary intake level; M cattle exhibited less ($P < 0.01$) internal cavity mass than A fed cattle (79.4 vs. 93.5 kg). Internal cavity mass as a fraction of EBW was impacted by dietary intake level ($P < 0.01$; M-147, A-155 g/kg EBW) and Z supplementation ($P < 0.01$; C-152, Z-145 g/kg EBW). Moreover, at day 56, cattle had less internal cavity g/kg EBW when compared to day 28 ($P = 0.02$; 149.48 vs. 156.43). Total non-carcass

Table 5. Empty body and tissue yields of steers fed for 0–28, or 28–56 d and given maintenance (M) or ad libitum (A) intake and control (C) or zilpaterol hydrochloride (Z) treatment

Item	0	28 A	28 M	56 AZ	56 AC	56 MZ	56 MC	SEM	*P*-value	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
n	8	8	8	8	8	8	8							
Final BW, kg[a]	586[b]	615[ab]	570[b]	666[a]	658[a]	593[b]	591[b]	18.8	<0.001	0.80	0.08	0.05	<0.001	0.74
Empty BW, kg	543[b]	573[ab]	529[b]	615[a]	602[a]	552[b]	540[b]	15.89	<0.01	0.74	0.10	0.09	<0.001	0.36
EBW/final BW, %	92.7	93.2	92.8	92.5	91.5	93.0	91.5	0.48	0.08	0.68	0.26	0.05	0.89	0.01
Fill, %	7.3	6.8	7.2	7.5	8.5	7.0	8.5	0.46	0.08	0.68	0.26	0.05	0.89	0.01
Hot carcass[b]														
kg	354[c]	376[bc]	346[c]	412[a]	394[ab]	373[bc]	357[c]	10.8	<0.001	0.65	0.03	0.03	<0.001	0.07
g/kg of EBW	651[d]	656[cd]	655[cd]	670[ab]	654[cd]	677[a]	661[bc]	4.3	<0.001	0.26	<0.001	<0.001	0.09	<0.001
g/kg of BW	604[c]	611[bc]	607[bc]	619[ab]	599[c]	629[a]	605[c]	5.7	<0.001	0.34	0.07	0.33	0.26	<0.001
Blood														
kg	14.65	14.64	14.18	14.75	16.28	13.74	14.21	0.809	0.30					
g/kg of EBW	27.0	25.7	26.8	24.1	27.1	24.9	26.4	1.49	0.62					
Hide[c]														
kg	53.18	52.42	50.54	56.12	54.43	50.23	51.64	1.935	0.26					
g/kg of EBW	97.9	91.7	95.7	91.1	90.3	91.2	95.6	2.16	0.16					
Non-carcass bone excluding head[d]														
kg	10.77[c]	11.37[abc]	10.91[c]	11.74[ab]	11.72[ab]	11.08[bc]	11.84[a]	0.265	0.02	0.27	<0.01	0.05	0.13	0.17
g/kg of EBW	19.8[bc]	19.9[bc]	20.7[ab]	19.1[c]	19.5[bc]	20.2[bc]	21.9[a]	0.46	<0.01	0.43	0.51	0.79	<0.001	0.02
Head[e]														
kg	12.40	12.83	12.45	13.36	12.98	13.12	12.82	0.224	0.06	0.45	0.02	0.05	0.16	0.10
g/kg of EBW	22.8[ab]	22.5[ab]	23.6[a]	21.8[b]	21.6[b]	23.9[a]	23.8[a]	0.59	<0.01	0.81	0.92	0.61	<0.001	0.79
Trim from harvest[f]														
kg	13.56[bc]	14.38[abc]	13.46[bc]	15.28[ab]	15.61[a]	12.79[c]	12.90[c]	0.710	0.02	0.69	0.47	0.72	<0.001	0.74
g/kg of EBW	25.0	25.1	23.3	25.0	25.9	23.2	24.0	1.00	0.54					
Internal cavity[g]														
kg	85.17[bc]	91.67[ab]	81.10[c]	91.91[ab]	96.78[a]	77.56[c]	79.47[c]	4.834	<0.001	0.78	0.74	0.99	<0.001	0.24
g/kg of EBW	156.6[ab]	159.6[a]	153.3[ab]	149.6[b]	156.9[a]	140.1[c]	147.2[bc]	5.68	<0.001	0.96	0.06	0.02	<0.001	<0.01
Total non-carcass														
kg	189.73[bcd]	197.32[abc]	182.64[cd]	203.16[ab]	207.8[a]	178.52[d]	182.88[cd]	6.470	<0.001	0.97	0.61	0.53	<0.001	0.32
g/kg of EBW	349.1[a]	344.4[ab]	345.4[ab]	330.5[cd]	345.6[ab]	323.4[d]	338.8[bc]	4.34	<0.001	0.26	<0.001	<0.001	0.09	<0.001
g/kg of BW	323.7[a]	320.8[a]	320.5[a]	305.6[cd]	316.1[ab]	300.8[d]	310.0[bc]	3.90	<0.001	0.41	<0.001	<0.001	0.13	<0.01

[a–d]Least squares means within a row with differing superscripts differ ($P \leq 0.05$).

[a]Final BW is the last chute weight prior to harvest.

[b]Carcass weight does not include kidney-pelvic-heart fat.

[c]Muzzle, ears, and tail included with hide weight.

[d]Includes front and hind hooves, metacarpals, metatarsals, and oxtail.

[e]Skinned head, tongue and tongue trim removed prior to weighing.

[f]Includes cod fat, fat trim from carcass, spinal cord, and penis.

[g]Includes all internal viscera and offal as well as tongue and tongue trim and kidney-pelvic-heart fat weights.

weight was impacted by treatment ($P < 0.001$) when expressed as an absolute mass, g/kg of EBW, or g/kg of BW. On an absolute weight basis, M level of intake reduced ($P < 0.01$) total non-carcass components compared to A feeding (181.35 vs. 202.76 kg, respectively). In addition 28 and 56 d M cattle had reduced ($P < 0.05$) non-carcass components relative to 56 d A intake cattle. When expressed on a relative basis to EBW and BW, non-carcass component weight was decreased over harvest day from day 0 to day 56 ($P < 0.01$) and day 28 to day 56 ($P < 0.01$); Z supplementation also decreased non-carcass weights expressed as g/kg of EBW and BW ($P < 0.01$).

Individual Harvest Yields

Harvest yields of kidneys, stomach (reticulorumen, omasum, and abomasum), intestines (small and large intestines), spleen, liver, pancreas, omental fat, and kidney-pelvic-heart fat (KPH) as well as total GIT (sum of stomach and intestines) and total splanchnic tissue (**TST**; sum of GIT, liver, spleen, gall bladder, and pancreas) with and without KPH and omental fat were impacted by treatment on an absolute basis (TST and TST_{FAT}) ($P < 0.05$; Table 6). Kidney weight was impacted by dietary intake level ($P < 0.01$) because A cattle had larger kidneys than M fed cattle (1.11 vs. 0.97 kg,

respectively). Stomach, intestines, and GIT were also increased ($P < 0.01$) in A relative to M fed cattle (A-43.87, M-37.49 kg). Additionally, day 56 cattle tended ($P = 0.07$) to have less total GIT vs. day 28 cattle (39.74 vs. 42.57 kg, respectively). Spleen weights were impacted by treatment; day 28 and day 56 cattle had heavier ($P < 0.05$) spleens than day 0 cattle. In addition, M cattle tended ($P = 0.08$) to have a lighter spleen than A fed cattle. The liver was greatly impacted by treatment; day 28 and day 56 cattle had lighter ($P < 0.01$) livers than day 0 cattle; primarily driven by the large decrease in liver weight of cattle fed M intake levels ($P < 0.001$; M-5.03, A-6.69). Liver weight was also impacted by Z supplementation ($P = 0.04$) with Z supplemented cattle having reduced liver weight to C cattle (5.64 vs. 6.05 kg, respectively). Pancreas weight was impacted by harvest day with day 28 and day 56 cattle having an increased pancreas weight vs. day 0 cattle ($P < 0.01$). Moreover, Z supplementation tended ($P = 0.10$) to decrease pancreas weight; AZ cattle had reduced ($P < 0.05$; 0.45 vs. 0.57 kg) pancreas weight compared to AC cattle. As a result, TST weight (not including fat) was decreased ($P < 0.001$) by dietary intake level with M fed cattle having decreased TST weight compared to A fed cattle (44.35 vs. 52.66 kg, respectively). Omental and KPH weights were affected ($P < 0.01$) by dietary intake level; A fed cattle had greater internal fat than M fed cattle (19.87 vs. 15.46 kg, respectively). Weight of KPH also tended to be decreased by Z supplementation ($P = 0.08$); Z supplemented cattle had less KPH than C cattle (7.72 vs. 8.73 kg, respectively). Total splanchnic tissue including omental fat was decreased ($P < 0.001$) in M as compared to A fed cattle (M-52.69, A-63.73 kg).

Comparing individual viscera and offal yields on a g/kg of EBW basis yielded similar trends to the absolute weight for most components. Trachea and heart were impacted ($P < 0.05$) by treatment on a g/kg EBW basis, whereas actual weights were not different between treatments. Neither spleen nor KPH exhibited differences ($P \geq 0.11$) when expressed as g/kg EBW. Trachea weight per unit of EBW was not impacted by a specific treatment but was less ($P = 0.05$) in 56 d A cattle vs. 28 d M and 56 d MZ cattle. Heart weight was affected by treatment ($P < 0.01$) with M cattle expressing greater weight as g/kg EBW compared to A fed cattle ($P < 0.01$; 4.6 vs. 4.2 g/kg EBW, respectively). Kidney was impacted by harvest day, when expressed as g/kg EBW ($P < 0.05$); day 56 cattle exhibited reduced kidney weight on an EBW basis vs. day 28 and day 0 cattle. Additionally, M and Z cattle had smaller kidney weights as g/kg EBW compared to A and C cattle, respectively ($P < 0.05$). Stomach, intestines, and total GIT as g/kg of EBW was affected ($P < 0.01$) by treatment; stomach weight was reduced in day 0 cattle and day 56 cattle compared to day 28 cattle. Similarly, M cattle had less stomach per unit of EBW than A cattle ($P = 0.02$) and Z supplemented cattle had less than C cattle ($P = 0.03$). Intestinal weight was reduced in a similar fashion to the stomach; day 56 cattle exhibited reduced intestinal weight as g/kg EBW vs. day 0 and day 28 cattle and Z supplemented cattle had decreased ($P = 0.04$) intestinal weight compared to C cattle. A tendency ($P = 0.09$) was detected between M and A cattle for reduced intestinal mass as g/kg EBW. Total GIT weight as g/kg EBW was impacted by dietary intake level ($P = 0.01$) and Z supplementation ($P = 0.01$); M and Z supplemented cattle had reduced GIT mass as g/kg EBW. Additionally, total GIT weight was reduced in day 56 cattle compared to day 0 and day 28 cattle ($P < 0.01$). Liver was decreased ($P < 0.01$) by increasing harvest day ($P < 0.01$) as well as by M dietary intake level ($P < 0.01$) and Z supplementation ($P < 0.01$). Pancreas weight was reduced in day 0 compared to day 28 and day 56 cattle ($P < 0.05$) and tended ($P = 0.06$) to be reduced in Z supplemented vs. C cattle. Omental fat and total omental + KPH fat was reduced ($P < 0.01$) in M vs. A fed cattle. Total splanchnic tissue with and without omental fat was impacted by treatment ($P < 0.001$) when expressed on g/kg EBW basis with day 56 cattle having a reduced TST mass compared to day 0 and day 28 ($P < 0.05$) as well as M intake and Z supplementation causing decreased TST ($P < 0.01$).

Carcass Traits

Carcass traits utilizing both U.S. and Canadian grading factors were impacted by treatment ($P < 0.05$; Table 7). Hot carcass weight was affected ($P < 0.05$) by harvest day, dietary energy level, and zilpaterol hydrochloride in a parallel fashion as HCW without KPH (Table 4). Dressed carcass yield was also impacted by treatment ($P < 0.01$); carcass yield tended to increase from day 0 to day 56 ($P = 0.08$; 61.7 vs. 62.6%, respectively). Zilpaterol supplementation also increased carcass yield as compared to C cattle ($P < 0.01$, 63.7 vs. 61.6, respectively). Carcass yield when calculated with a 4% pencil shrink (BW × 0.96) applied across live BW concurrent with industry standards resulted in

Table 6. Internal cavity yields of steers fed for 0–28, or 28–56 d and given maintenance (M) or ad libitum (A) intake and control (C) or zilpaterol hydrochloride (Z) treatment

Item	0	28 A	28 M	56 AZ	56 AC	56 MZ	56 MC	SEM	*P*-value	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
n	8	8	8	8	8	8	8							
Internal viscera and offal yields														
Tongue and tongue trim														
kg	5.51	5.27	5.12	5.66	5.43	5.29	5.04	0.175	0.12					
g/kg of EBW	10.2	9.2	9.7	9.2	9.1	9.6	9.4	0.42	0.28					
Bladder														
kg	0.74	0.46	0.58	0.67	0.77	0.55	0.80	0.171	0.59					
g/kg of EBW	1.4	0.8	1.1	1.1	1.3	1.0	1.5	0.29	0.55					
Thymus														
kg	1.69	1.83	1.94	2.16	2.36	2.01	1.83	0.186	0.24					
g/kg of EBW	3.1	3.2	3.6	3.5	3.9	3.7	3.4	0.29	0.56					
Trachea														
kg	0.96	0.98	1.00	1.00	0.99	1.02	0.95	0.996	0.86					
g/kg of EBW	1.8^{ab}	1.7^{ab}	1.9^{a}	1.6^{b}	1.7^{b}	1.9^{a}	1.8^{ab}	0.09	0.05	0.92	0.84	0.91	0.67	0.16
Heart														
kg	2.42	2.50	2.45	2.53	2.46	2.45	2.50	0.080	0.97					
g/kg of EBW	4.5^{ab}	4.4^{ab}	4.6^{a}	4.1^{b}	4.1^{b}	4.5^{ab}	4.6^{a}	0.17	0.03	0.79	0.39	0.14	<0.01	0.55
Lungs														
kg	2.62	2.68	2.78	2.88	2.86	2.79	2.91	0.170	0.70					
g/kg of EBW	4.8	4.7	5.3	4.7	4.8	5.1	5.4	0.28	0.17					
Pluck trim														
kg	2.63	2.38	2.25	2.40	2.76	2.23	2.18	0.334	0.48					
g/kg of EBW	4.8	4.1	4.2	3.9	4.6	4.0	4.0	0.52	0.50					
Esophagus														
kg	0.36	0.37	0.34	0.41	0.36	0.38	0.39	0.178	0.09	0.91	0.16	0.05	0.43	0.21
g/kg of EBW	0.7	0.6	0.6	0.7	0.6	0.7	0.7	0.03	0.09	0.69	0.60	0.22	0.06	0.47
Kidneys														
kg	1.06^{ab}	1.11^{a}	1.06^{ab}	1.06^{ab}	1.15^{ab}	0.90^{c}	0.96^{bc}	0.050	0.02	0.64	0.52	0.13	<0.01	0.12
g/kg of EBW	1.9^{ab}	2.0^{ab}	2.0^{a}	1.7^{cd}	1.9^{abc}	1.6^{d}	1.8^{bcd}	0.07	<0.01	0.73	0.02	<0.01	0.35	0.02
Kidney-pelvic-heart fat														
kg	7.80^{b}	7.92^{b}	6.94^{b}	8.29^{b}	10.17^{a}	7.15^{b}	7.28^{b}	0.895	0.01	0.64	0.55	0.15	<0.01	0.08
g/kg of EBW	14.34	13.80	13.09	13.56	16.92	12.88	13.49	1.389	0.11					
Stomach[a]														
kg	19.18^{bcd}	22.87^{a}	19.42^{bcd}	21.02^{abc}	21.35^{ab}	16.98^{d}	18.72^{cd}	0.989	<0.01	0.12	0.75	0.06	<0.001	0.23
g/kg of EBW	35.3^{b}	39.8^{a}	36.7^{ab}	34.2^{b}	35.4^{b}	30.7^{c}	34.8^{b}	1.23	<0.001	0.05	0.28	<0.001	0.02	0.03
Intestines[b]														
kg	21.26^{ab}	22.56^{a}	20.29^{ab}	20.83^{ab}	22.99^{a}	18.55^{b}	18.50^{b}	1.145	<0.01	0.90	0.39	0.19	<0.001	0.25
g/kg of EBW	39.1^{a}	39.3^{a}	38.4^{a}	33.8^{b}	38.2^{a}	33.5^{b}	34.2^{b}	1.38	<0.01	0.87	<0.01	<0.01	0.09	0.04
Total GIT[c]														
kg	40.44^{abc}	45.43^{a}	39.71^{bcd}	41.86^{ab}	44.34^{ab}	35.53^{d}	37.22^{cd}	1.998	<0.001	0.35	0.72	0.07	<0.001	0.17
g/kg of EBW	74.4^{b}	79.1^{a}	75.1^{ab}	68.0^{cd}	73.7^{b}	64.2^{d}	69.0^{c}	2.04	<0.01	0.22	<0.01	<0.01	0.01	0.01
Spleen														
kg	0.98^{c}	1.24^{a}	1.09^{abc}	1.27^{a}	1.20^{ab}	1.03^{bc}	1.26^{a}	0.071	0.02	0.04	<0.01	0.71	0.08	0.27
g/kg of EBW	1.8	2.2	2.1	2.1	2.0	1.9	2.3	0.14	0.17					
Liver														
kg	6.62^{a}	6.65^{a}	5.12^{b}	6.56^{a}	6.86^{a}	4.72^{b}	5.25^{b}	0.218	<0.001	0.02	<0.01	0.85	<0.001	0.04
g/kg of EBW	12.2^{a}	11.6^{ab}	9.7^{d}	10.7^{c}	11.4^{b}	8.6^{e}	9.7^{d}	0.26	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001
Gall bladder														
kg	0.29	0.33	0.26	0.39	0.34	0.28	0.27	0.429	0.40					
g/kg of EBW	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.07	0.89					
Pancreas														
kg	0.37^{c}	0.57^{a}	0.48^{abc}	0.45^{bc}	0.57^{a}	0.49^{ab}	0.49^{ab}	0.512	0.01	<0.01	<0.01	0.62	0.14	0.10

Table 6. Continued

Item	0	28 A	28 M	56 AZ	56 AC	56 MZ	56 MC	SEM	*P*-value	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
g/kg of EBW	0.7^{c}	1.0^{a}	0.9^{abc}	0.7^{bc}	1.0^{a}	0.9^{abc}	0.9^{ab}	0.59	0.04	0.01	0.03	0.30	0.92	0.06
TST[d], no omental, or kidney-pelvic-heart fat														
kg	48.65^{abc}	54.20^{a}	46.51^{bcd}	50.47^{ab}	53.30^{a}	42.05^{d}	44.49^{cd}	1.999	<0.001	0.49	0.62	0.10	<0.001	0.12
g/kg of EBW	89.5^{ab}	94.4^{a}	88.0^{bc}	82.0^{d}	88.6^{b}	76.0^{e}	82.5^{cd}	2.16	<0.001	0.48	<0.01	<0.001	<0.001	<0.01
Omental fat														
kg	9.38^{ab}	10.01^{ab}	8.34^{b}	11.45^{a}	11.77^{a}	8.49^{b}	8.19^{b}	1.392	0.01	0.85	0.54	0.28	<0.001	0.99
g/kg of EBW	17.2	17.3	15.8	18.7	19.6	15.2	15.1	2.18	0.10	0.67	0.96	0.58	<0.01	0.76
Omental and kindney-pelvic-heart fat														
kg	17.18^{bc}	17.93^{bc}	15.27^{c}	19.75^{ab}	21.94^{a}	15.64^{c}	15.47^{c}	2.285	<0.01	0.76	0.53	0.20	<0.001	0.40
g/kg of EBW	31.6	31.1	28.9	32.2	36.5	28.1	28.6	3.55	0.07	0.58	0.94	0.47	<0.001	0.22
TST[d], including omental fat														
kg	58.03^{bc}	64.21^{ab}	54.85^{cd}	61.92^{ab}	65.07^{a}	50.54^{d}	52.68^{cd}	3.256	<0.001	0.63	0.86	0.35	<0.001	0.23
g/kg of EBW	106.7^{abc}	111.7^{a}	103.7^{bcd}	100.7^{cd}	108.2^{ab}	91.2^{e}	97.6^{de}	3.90	<0.001	0.75	0.02	<0.001	<0.001	0.01

[a–e]Least squares means within a row with differing superscripts differ ($P \leq 0.05$).

[a]Stomachs includes reticulorumen, omasum, and abomasum.

[b]Intestines includes small intestine, large intestine, and cecum.

[c]Total gastrointestinal tract (GIT) includes reticulorumen, omasum, abomasum, small intestine, large intestine, and cecum.

[d]Total splanchnic tissue mass (TST) includes reticulorumen, omasum, abomasum, small intestine, large intestine, and cecum, spleen, liver, gall bladder, and pancreas.

64.3, 65.0, 64.5, 65.8, 64.0, 66.8, and 64.3% for day 0, day 28 A, day 28 M, day 56 AZ, day 56 AC, day 56 MZ, and day 56 MC cattle, respectively.

Individual carcass traits (adjusted 12th rib s.c. fat thickness, USDA calculated yield grade, Canadian fat class, and Canadian calculated yield grade) differed across treatments ($P < 0.05$) while KPH % tended ($P < 0.10$) to differ across treatments. Adjusted 12th rib s.c. fat thickness was reduced ($P < 0.05$) in M compared to A steers (1.7 vs. 2.5 cm, respectively) and between day 0 vs. day 56 (1.6 vs. 2.2 cm, respectively), whereas LM area was not impacted by treatment ($P = 0.53$). The percentage of KPH was decreased ($P = 0.02$) in Z supplemented cattle (1.93%) compared to C cattle (2.26%) and was less ($P = 0.05$) for M than A fed cattle (1.94 vs. 2.19%, respectively). As a result, calculated USDA yield grade was increased from day 0 to day 56 ($P = 0.05$; 3.3 vs. 3.9, respectively) and by increased dietary intake ($P < 0.01$; 3.3 vs. 4.2 for M and A fed steers, respectively), similar to 12th rib s.c. fat thickness.

With respect to individual Canadian grading traits, fat class and yield grade were affected by treatment ($P < 0.01$). Canadian fat class was impacted in a similar fashion as adjusted 12th rib fat thickness as cattle fed M had reduced fat class vs. A fed steers (7.0 vs. 8.6, respectively) while day 0 steers also had reduced fat class vs. day 56 (5.9 vs. 8.0, respectively). Canadian calculated lean yield was impacted by treatment ($P = 0.03$) with A steers having reduced lean yield vs. M ($P < 0.01$; 51.9 vs. 53.9%, respectively). Marbling scores, skeletal maturity, and color scores were not impacted by treatment ($P \geq 0.38$).

DISCUSSION

Dry matter intake in this trial across A intake level averaged 8.88 kg, 216% of M cattle (4.12 kg). Intakes for A cattle were 1.46, 1.40, and 1.38% of midpoint BW (unshrunk) for day 1 to 28, day 29 to 56 ZH, and day 29 to 56 control, respectively. Previous research conducted on long-term feeding trials in Angus steers fed ad libitum (70% concentrate diets) resulted in 1.28% of midpoint BW from 615 to 734 kg BW (Bond et al., 1982). Vasconcelos et al. (2008) reported a similar DMI in steers of 1.48 (8.60 kg) and 1.47% (9.03 kg), respectively, of midpoint BW during the last 43 d of a 177 and 198 d finishing period and Montgomery et al. (2009b) reported an average DMI of 8.76 kg across both Z and C cattle during the last 35 d. Intakes of M fed steers were increased (in addition to the positive 6.3% initial adjustment) during the first 28 d by 4.76% ± 3.25 for block 1 and 2.74% ± 2.73 for block 2 from the initial calculated value based on BW loss. Maintenance steers were fed 45% of A intake during day 1 to 28 and 47% of A intake during day 29 to 56. With respect to performance, A cattle gained 1.03 kg/d during day 1 to 28 and 1.48 kg/d during day 29 to 56, whereas M fed cattle lost 0.50 kg in the first 28 d after which M steers incurred a slightly positive BW during day 29 to 56. Vasconcelos et al. (2008) in extended feeding of steers for 177 and 198 to a final BW of 610 and 644 d reported an ADG

of 1.31 and 1.40 for the last 43 harvest day, similar to the results of this trial during day 29 to 56. The reduced ADG of 1.03 kg/d during day 1 to 28 is likely due to a loss of fill at the start of trial combined with multiple weigh days off feed and water.

With respect to Z supplementation effects on live performance, results from this trial are similar to previous research for improvements in live BW and ADG. Zilpaterol supplemented steers fed A intakes had 13 kg greater end BW ($P \leq 0.05$), and while not significant ($P > 0.05$), a 34% improvement in ADG and a 19.0% improvement in G:F, compared to AC fed steers. Additionally, steers fed M and supplemented Z had a numerical improvement ($P < 0.05$) in BW gain (5.2 kg), ADG and G:F (48 and 37.0% improvement for ADG and G:F, respectively) than MC steers. Overall G:F was not different for Z vs. C ($P > 0.10$) possibly due to limited animal numbers ($n = 8$ per treatment) and the impact of diet within Z supplementation in the current study. Previous studies reported similar improvements to final BW of 8 kg and 10.6 kg when Z was fed for 20 d (Vasconcelos et al., 2008; Elam et al., 2009). Previous studies reported similar improvements of 33 and 26% to ADG and G:F when Z was fed at 6 mg/kg for 40 d (Plascencia et al., 2008) and 44 and 47% improvement in ADG and G:F, respectively, when Z was fed at 8.3 mg/kg for 20 d (Montgomery et al., 2009a). When Z was fed for 20 d, Vasconcelos et al. (2008) and Elam et al. (2009) reported improvements of 11 and 16% for ADG and 10 and 16% for G:F, respectively. The lesser response in the latter 2 trials (Vasconcelos et al., 2008; Elam et al., 2009) may be due to performance data including the last 43 and 50 d of feeding performance, respectively, thus diluting the 20 d Z period improvement with additional time.

Carcass performance in the current study reflected changes to carcass ADG and G:F over harvest day, dietary plane of intake, and Z supplementation. Carcass ADG and carcass G:F was increased ($P \leq 0.01$) in cattle supplemented Z, regardless of plane of intake. Cattle fed A intake levels and supplemented Z had a 119 and 50% improvement ($P \leq 0.05$) in carcass ADG and G:F, respectively, vs. AC steers, whereas M fed steers supplemented with Z exhibited a 127 and 89% improvement ($P \leq 0.05$) in carcass ADG and G:F, respectively, vs. MC steers. Therefore, Z exerted a large impetus for increased skeletal muscle accretion regardless of plane of intake, perhaps due to catabolism of non-carcass tissue in favor of nutrients for carcass tissue (Holland et al., 2010; McEvers et al., 2013). Rathmann et al. (2012) reported improvements of carcass ADG and G:F due to Z in heifers of 34 and 36%, respectively, similar to A fed cattle during day 1 to 28 in the current study. Carcass transfer in the current study (carcass ADG/live ADG) was highest in day 29 to 56 MZ treated cattle (137%), whereas day 29 to 56 MC cattle had a carcass transfer of 57%; some of the increase in transfer was due to tissue weight loss during day 1 to 28 (day 1 to 28 M carcass transfer of 44%) and an increase in efficiency over time resulting in a positive energy balance during day 29 to 56 in M cattle. Carcass transfer of day 29 to 56 AZ cattle was 75%, whereas in day 29 to 56 AC cattle, carcass transfer was 45%. Similar to A fed cattle in the current study, Rathmann et al. (2012) reported a carcass transfer of 73% for control fed heifers and 89% for Z supplemented heifers during the treatment period. The low carcass transfer value of day 28 to 56 cattle may have been due to large variation in dressing percentage as day 1 to 28 A had a high carcass transfer of 86%.

Hip and shoulder height were impacted by time. Nkrumah et al. (2004) documented an average hip height of 127.5 cm in the last 70 d of feeding for cattle with a final body weight of 515 kg and reported no difference between hip heights or hip height gain in steers with different residual feed intake classifications. Bergen et al. (2006) reported weak correlations of hip height to HCW ($r = 0.16$) when measured in yearling bulls. The current study details changes between start and end of period hip height over harvest day, although hip height gain was not different, potentially as a result of large variation between steers in a limited (56 d) time span. Dietary intake level impacted shoulder height gain. This may be indicative of limited calories and negative feedback on continued frame growth. Bond et al. (1982) reported Angus steers fed A level of intake slaughtered at 18 mo had a shoulder height of 115.0, 3.2 cm greater than cattle fed M intake and slaughtered at the same age. The steers used in the current trial vs. those used by Bond et al. (1982) are likely to be of different genetic capacity for growth, even though both studies utilized British based breeds. Bond et al. (1982) recorded a BW at 18 mo of 305 kg and a shoulder height of 115.0 cm in steers fed a 70% concentrate diet at A intake levels. Cattle in the current study harvested at a similar age were 300 kg heavier and 10 cm taller at the shoulder than cattle utilized in the Bond et al. (1982) study 3 decades earlier. Regardless of treatment, both hip and shoulder height increased with longer harvest day, indicating the ability of the animal on high plane of nutrition diet to increase in frame size.

Table 7. Hot carcass weight and carcass characteristics of beef steers fed to 0, 28, or 56 d on feed and given maintenance or ad libitum intake and control or zilpaterol hydrochloride treatment

Item	0	28 A	28 M	56 AZ	56 AC	56 MZ	56 MC	SEM	P-value	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Hot carcass weight, kg[a]	361^{c}	383^{bc}	353^{c}	420^{a}	404^{ab}	380^{bc}	364^{c}	11.4	<0.01	0.67	0.03	0.03	<0.01	0.10
Dressed carcass yield[b], %	61.7^{c}	62.4^{bc}	62.0^{bc}	63.2^{ab}	61.4^{c}	64.1^{a}	61.7^{c}	0.52	<0.01	0.41	0.08	0.27	0.47	<0.01
Adj. 12th rib fab thickness, cm	1.63^{cd}	2.15^{bc}	1.68^{cd}	2.52^{ab}	2.72^{a}	1.92^{cd}	1.52^{d}	0.19	<0.01	0.22	0.01	0.12	<0.01	0.61
LM area, cm^2	85.81	89.03	85.97	93.55	89.11	87.82	88.39	0.45	0.53					
KPH, %	2.16	2.06	1.96	1.98	2.53	1.87	2.00	0.21	0.09	0.45	0.73	0.52	0.05	0.02
USDA calculated yield grade[c]	3.3^{cd}	3.8^{bc}	3.3^{cd}	4.3ab	4.7^{a}	3.6^{bcd}	3.1^{d}	0.27	<0.01	0.46	0.05	0.12	<0.01	0.81
Marbling score[d]	420	441	419	453	446	445	398	49.6	0.38					
Skeletal maturity[e]	138	145	140	145	146	145	160	10.4	0.79					
Color score[f]	5	5.4	5.1	5.0	4.9	5.1	5.4	0.5	0.90					
Canadian ribeye length[g]	1.38	1.75	2.00	2.13	1.88	1.75	1.75	0.25	0.49					
Canadian ribeye width[g]	2.13	2.25	2.00	1.88	2.00	1.50	1.75	0.24	0.43					
Canadian muscle score[g]	1.50	2.00	2.00	2.13	1.88	1.38	1.75	0.30	0.53					
Canadian fat class[g]	5.88^{cd}	8.13^{abc}	6.76^{cd}	8.63^{ab}	9.13^{a}	7.63^{bcd}	6.63^{d}	0.58	<0.01	0.36	0.05	0.20	<0.01	0.62
Canadian calculated lean yield[h]	53.9^{ab}	52.6^{abc}	54.6^{a}	51.9^{bc}	51.1^{c}	52.6^{abc}	54.6^{a}	0.92	0.03	0.81	0.17	0.16	<0.01	0.47

[a]Hot carcass weight includes kidney-pelvic-heart fat.

[b]BW used was unshrunk because steers were not allowed feed and water for 9 h.

[c]USDA calculated yield grade = 2.5 + (2.5 × FT) + (0.2 × KPH) + (0.0038 × HCW) − (0.32 × REA), where FT = adjusted 12th rib fat depth in cm, KPH = percentage of kidney-pelvic-heart fat, HCW = hot carcass weight in kg, and REA = longissimus muscle area in cm^2.

[d]100 = practically devoid^{00}, 300 = slight^{00}, 500 = modest^{00}, 700 = slightly abundant^{00}, and 900 = abundant^{00}.

[e]100 = A^{00} and 500 = E^{100}.

[f]1 = light pink, 2 = pink, 3 = dark pink, 4 = light cherry red, 5 = cherry red, 6 = dark red, 7 = very dark red (1/3 dark cutter), 8 = maroon (2/3 dark cutter), and 9 = dark maroon (full dark cutter).

[g]Canadian ribeye length and width, muscle score, and fat class calculated using Yield Ruler developed by Lacombe Research Station (CBGA, 2001).

[h]Canadian calculated yield grade calculated as estimated lean % = 63.65 + (1.05 × muscle score) − (0.76 × fat class) where estimated lean yield of 59% or ≥ YG1, 54–58% = YG2, and 53% or ≤ YG3.

In the current study, as harvest day increased, carcass weight increased as a fraction of EBW and subsequently, non-carcass weight decreased as a fraction of EBW. Carcass weight increased as a fraction of EBW with Z supplementation and exhibited a tendency to increase with reduced dietary intake. Holland et al. (2010) did not report an impact of Z supplementation on carcass weight as a fraction of EBW nor an effect on total non-carcass components. Discrepancy between studies might be due to the reduced head count used by Holland et al. (2010) with 3 steers per pen and pen used as the experimental unit. Other research has reported that growth of internal cavity and non-carcass components becomes nonlinear with age and carcass components steadily increase as a proportion of EBW (Carstens et al., 1991). In the current study, tissue component weights of hide and blood remained constant over days, diet, and Z supplementation, conversely non-carcass bone increased over days, indicative of a growing animal. Internal cavity also increased as a fraction of EBW over days, whereas M intake level and Z supplementation reduced internal cavity weight as a fraction of EBW. Similar to the current study, Hutcheson et al. (1997) reported total organ mass as a percentage of EBW decreased in estrogen and combination implanted steers compared to nonimplanted steers.

Total non-carcass weights were not changed by increasing days, but carcass weights were reduced by M intake level. When represented as a fraction of EBW, total non-carcass decreased over days and also due to reduced dietary intake level and Z supplementation. During the first 28 d, A cattle produced an additional 22 kg of carcass but only an additional 7.59 kg of non-carcass weight. Total non-carcass components remained similar to C cattle harvested at the start of the trial. Control, A cattle had heavier total non-carcass components than day 0 cattle but as a fraction of EBW, no difference was detected. Thus, A cattle not supplemented with Z appear to remain constant in depositing the same fraction of carcass and non-carcass components during the 56 d study period, whereas cattle supplemented with Z and placed on M plane of intake had reduced non-carcass components and increased carcass components as a fraction of EBW over time.

Visceral organ tissues changed with treatment when represented as weight per kg of EBW. In the current study, a reduction of dietary energy intake to M level resulted in changes to stomach, intestines, total GIT, liver, omental fat, KPH fat, and TST with and without fat as well as tendencies for reduction in spleen weight. Reynolds et al. (1991) and Lobley (2003) stated visceral organ mass, largely the splanchnic tissues, consume a disproportionately large amount of energy in the animal. Metabolic inefficiencies result from large GIT mass, poorly digested diets, and items of more complexity including individual AA and VFA uptake by tissues for their own energy needs (Reynolds et al., 1991; Lobley, 2003). Furthermore, the splanchnic tissues have proven to be incredibly dynamic, adapting to level of DMI and plane of nutrition with changes in cell size and number, weight, and efficiency over time (Reynolds et al., 1991; Sainz and Bentley, 1997). Total splanchnic tissue mass, without omental fat, was different in A vs. M steers after 28 d ($P < 0.05$), with A steers weighing an additional 7.69 kg vs. M steers. During the following 28 d period, TST without fat in M fed steers was different than A with MZ steers a total of 6.6 kg less weight than day 0 steers ($P < 0.05$). When TST included omental fat (TST_{fat}), M plane of intake reduced TST_{fat} vs. A intake at 28 d by 9.36 kg ($P < 0.05$). During day 28 to 56, TST_{fat} was decreased in MC and MZ steers vs. AC and AZ ($P < 0.05$). Maintenance plane of intake resulted in significant reductions to TST with and without omental fat, likely indicative of using adipose tissue as a source of fuel during periods of low energy intake (Drouillard et al., 1991). While Z supplementation resulted in numerical reductions of TST mass with and without omental fat at both A and M intakes, differences were not significant between AC and AZ nor MC and MZ steers. Therefore, the repartitioning impact of Z may not extend past the impact on the liver or the current study may not be sufficiently powered to quantify the treatment differences.

As a result of dietary intake reductions and Z supplementation, differences in visceral tissues on a g/kg EBW basis occurred over harvest day with day 56 cattle having reduced kidney, stomach, intestines, GIT, liver, and TST g/g EBW vs. day 28 and with day 56 cattle having reduced kidney, intestines, GIT, liver, pancreas, and TST g/kg EBW vs. day 0 cattle. Prior research analyzing non-carcass components due to different repartitioning effects has reported a reduction in internal fat in lambs fed cimaterol (Hanrahan et al., 1987). Hutcheson et al. (1997) reported decreased GIT mass as a percentage of EBW resulting from estrogen or combination estrogen/trenbolone acetate implants. Conversely, Hutcheson et al. (1997) reported increased liver percentage for implanted vs. unimplanted steers. Differences in liver weights with implants may potentially be a result of estrogenic implants stimulating IGF which acts upon the liver (Hannon et al., 1991) vs. beta-adrenergic agonists used in the current study which has a direct, cell-mediated effect (Johnson et al., 2014).

The impact of Z on visceral tissue mass appears to be in addition to the impact of M plane of intake on reducing visceral tissue mass. Restricted dietary energy level has resulted in reduced liver mass (Sainz and Bentley, 1997; Sharman et al., 2013) and improved total tract DM digestibility due to decreased GIT passage time (Hicks et al., 1990) and ruminal liquid dilution rates (Murphy et al., 1994). The additional decrease in visceral tissue mass with Z was not due to a reduction in DMI because that was not experienced in the current study nor is it due to an improvement in total tract digestibility at A or M levels (Brake et al., 2011; Walter et al., 2016). It is plausible that Z exerts a direct stimulus on TST resulting in improvements to protein turnover and efficiency and therefore a reduced mass necessary to support the tissues own needs as well as the need to metabolize nutrients and support additional maintenance and gain functions. It is also plausible that since the liver and intestines respond dynamically to available nutrient supply (Sainz and Bentley, 1997); increased protein synthesis and nitrogen retention (Brake et al., 2011; Walter et al., 2016) due to zilpaterol hydrochloride supplementation could reduce urea entry rate (Brake et al., 2011) and thus further reduce the level of nutrients available to the TST. The ability of Z to stimulate similar improvements in HCW and dressed carcass yield with concurrent reductions in visceral tissue mass at M level of intake is likely indicative of adjustments to cattle maintenance and gain requirements.

Carcass traits of HCW (with KPH), dressed carcass yield, adjusted 12th rib s.c. fat thickness, and USDA yield grade increased over time on feed. Hot carcass weight and dressed carcass yield increased over time with 56 d AZ cattle exhibiting the heaviest HCW (420 kg) and 56 d MZ treatment resulting in the highest dressed carcass yield (64.1%). Previous research using Z (20 d) in steers resulted in an average improvement of 15.7 kg and a 1.45% to HCW and dressed carcass yield, respectively (Vasconcelos et al., 2008; Elam et al., 2009; Montgomery et al., 2009a; Parr et al., 2011). While only a tendency existed for Z to increase HCW in the current study (16 kg, regardless of dietary intake level), results are very similar to prior research. Dressed carcass

yield in the current study improved 1.8 and 2.4% with Z supplementation between 56 d A or M fed cattle, respectively. The additional HCW in the 56 d M cattle is indicative of energy being repartitioned from other sources or a reduction in maintenance energy requirements due to Z supplementation.

With respect to rib fat thickness, AC cattle accreted 0.52 and 0.57 cm of 12th rib s.c. fat (adjusted) from day 1 to 28 and day 29 to 56, respectively. Cattle fed A intake level and supplemented with Z accrued 0.37 cm of 12th rib s.c. fat (adjusted) during the last 28 harvest day. While no difference was detected for adjusted 12th rib s.c. fat thickness in cattle supplemented with Z, dietary intake level was significant with M cattle at 28 or 56 d not different from day 0 cattle. Canadian fat class was impacted in a similar fashion as adjusted 12th rib s.c. fat thickness with A cattle having increased Canadian fat class vs. M cattle. Both 12th rib s.c. fat thickness and Canadian fat class are measures of 12th rib s.c. fat depth. Subcutaneous fat deposition likely dissipated in M fed cattle because fat deposition requires a positive energy balance. Neither Canadian ribeye length and width factors nor LM area were impacted by treatments, regardless USDA and Canadian calculated lean yield were greater in A vs. M cattle primarily due to the increased backfat thickness in A cattle. Marbling score did not differ in M fed cattle regardless of harvest day or Z supplementation. Ultimately, cattle fed M did not appear to accrue nor catabolize s.c. or i.m. fat depots as an energy source even though HCW increased in M cattle fed Z.

Results of the current study illustrate prominent effects of dietary energy intake level to live and carcass performance and kill yields. The effect of Z on carcass performance and numerical reduction in TST mass occurred irrespective of dietary energy intake. The effect of Z on non-carcass and carcass tissues at both energy intake levels may be indicative of shifting maintenance or gain energy requirements. Further research is needed to elucidate the efficiency of maintenance and gain in cattle supplemented with Z. Additionally, further research needs to delve into the prediction of empty body and carcass physical and chemical composition utilizing live and carcass grading factors.

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