Byproduct yields of serially harvested calf-fed Holstein steers fed zilpaterol hydrochloride[1]

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ABSTRACT: A 2 × 11 factorial treatment structure was applied in a completely randomized experimental design to investigate differences in noncarcass tissue among serially harvested Holstein steers. Steers (n = 110) were randomly assigned to 1 of 2 dietary treatments: a ration supplemented with zilpaterol hydrochloride (ZH) fed at a rate of 8.3 mg/kg DM for 20 d followed by a 3-d withdrawal or a control ration with no ZH included in the diet. Within treatment, steers were assigned to harvest groups of 254, 282, 310, 338, 366, 394, 422, 450, 478, 506, or 534 d on feed (DOF) prior to initiation of the trial. Cattle fed ZH realized an empty BW (EBW) increase ($P \leq 0.03$) of 2.8% (644.2 vs. 626.4 kg [SEM 5.4]) and a HCW increase of 5.0% (429.1 vs. 408.4 kg [SEM 4.0]) with a concomitant 12% reduction (45.1 vs. 51.2 kg [SEM 3.1]) in gastrointestinal contents and 2.1 percentage unit increase in dressed carcass yield (62.1 vs. 60.0% [SEM 0.01]). Additionally, ZH supplementation decreased (P ≤ 0.03) the absolute weight of the liver and kidneys by 0.3 and 0.1 kg, respectively. When noncarcass components were expressed on an empty body basis (g/kg EBW), reductions ($P \leq 0.01$) in the limbs (18.8 vs. 19.5 g/kg EBW [SEM 0.1]), hide (81.1 vs. 78.1 g/kg EBW [SEM 0.7]), liver (14.2 vs. 13.2 g/kg EBW [SEM 0.2]), kidneys (2.6 vs. 2.3 g/kg EBW [SEM 0.04]), small and large intestines (74.9 vs. 69.6 g/kg EBW [SEM 1.2]), and gastrointestinal tract (119.8 vs. 113.4 g/kg EBW [SEM 1.3]) were observed with ZH supplementation. Additionally, there was a tendency ($P = 0.07$) for the proportion of total offal to be reduced (253.2 vs. 247.4 g/kg EBW [SEM 2.5]) with ZH supplementation. Empty BW and HCW linearly increased ($P < 0.01$) by 1.16 and 0.758 kg/d ($P < 0.01$), respectively, with additional DOF. The weight of the liver and intestines linearly increased ($P < 0.01$) by 0.007 and 0.133 kg/d ($P < 0.01$), respectively, with additional DOF. These data indicate the magnitude of change in noncarcass tissues that can be expected when calf-fed Holstein steers are supplemented with ZH.

Key words: beef, byproduct, Holstein, yield, zilpaterol

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INTRODUCTION

Visceral organs represent metabolically active tissues vital to carcass growth and development (Hutcheson et al., 1997). In beef cattle, maintenance requirements have been estimated to account for 70 to 75% of total energy expenditures (Ferrell, 1988), which constitutes a major portion of feed energy. Garrett (1971) indicated Holstein steers were 20% less efficient in converting feed energy into soft tissues compared with Hereford steers, with Holsteins requiring 5% more feed to maintain BW. Results indicated Holstein steers accrued protein at rates similar to Hereford steers and accrued lipids at a reduced rate while consuming a diet containing ample energy for maintenance requirements.

Metabolic modifiers such as growth-promoting implants and β-adrenergic agonists have been used by producers to improve feeding performance and carcass growth (Dikeman, 2007). Zilpaterol hydrochloride (**ZH**), a beta-2 adrenergic agonist, alters deposition of body tissue through increased protein accretion and decreased fat accretion in the carcass (Leheska et al., 2009) during times when the impetus for fat deposition is increased (Owens et al., 1995). Furthermore, ZH has consistently demonstrated the ability to increase the

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dressed carcass yield (**DY**) of beef steers and heifers (Elam et al., 2009; Montgomery et al., 2009a; Rathmann et al., 2012), cull cows (Neill et al., 2009; Lawrence et al., 2011), and dairy steers (Beckett et al., 2009). Effects on DY in previous experiments have indicated that HCW gains are greater than live BW gains when fed ZH (Montgomery et al., 2009a,b). Therefore, Montgomery et al. (2009b) hypothesized that increased HCW and DY observed in cattle fed ZH may be due to changes in the mass of noncarcass to carcass tissues. Few trials have investigated differences in visceral organ weight across a wide range of days on feed (**DOF**). The objective of this investigation was to determine differences in noncarcass tissues of calf-fed Holstein steers fed ZH for 0 or 20 d throughout a 280-d serial harvest period.

MATERIALS AND METHODS

Cattle included in this investigation were fed at Agri-Research (Canyon, TX). The Animal Care and Use Committee at West Texas A&M University approved all experimental procedures involving live animals. Furthermore, this investigation adhered to the regulations included in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 2010).

Animal Harvest

Steers were harvested every 28 d over a 280-d period commencing at 254 DOF and concluding at 534 DOF for a total of 11 harvest points (254, 282, 310, 338, 366, 394, 422, 450, 478, 506, and 534 DOF). Ten steers were harvested on each day; 5 animals had received ZH (Merck Animal Health, Summit, NJ) at a rate of 8.3 mg/kg DM for the final 20 d prior to harvest followed by a 3-d withdrawal and 5 cattle had received no dietary ZH (control ration [**CON**]). Further details on experimental design, cattle selection, feeding procedures, and steer live performance are detailed in a companion paper (Walter et al., 2016). Cattle were humanely harvested using commercial methods from d 254 to 394 at the West Texas A&M University Meat Laboratory (Canyon, TX; Establishment number 7124) and subsequently at the Caviness Packing Company (Hereford, TX; Establishment number 675) from 422 to 534 d because animals reached a size that the facilities at West Texas A&M University could no longer handle.

Harvest Procedures

All animals were weighed the day prior to harvest to obtain a live weight and given ad libitum access to water only for the final 24 h before harvest. Upon harvest, all animals were immediately stunned with a captive bolt and exsanguinated; the weight of the blood from exsanguination was captured by placing a collection tub underneath the animal for 1 min. Following exsanguination, the head was removed between the occipital condyles and atlas joint and was further separated by removing the masseter muscle (cheek meat), salivary glands, and oxlips. The weight of the head, masseter muscles, salivary glands, and oxlips were summed and included in the weight of the head. The ears were removed from each animal and added to the weight of the hide. The tongue was removed from the head and the epiglottis was removed and trimmed to remove the hyoid bone. Hind shanks were removed at the tarsal bone joint separating the metatarsal and the tibia and foreshanks were removed from the animal three-quarters of the dorsal length of the metacarpal bones; hind shanks and foreshanks (**LIMBS**) were weighed and summed together for analysis. The hide was manually removed on a dehiding cradle at the West Texas A&M Meat Laboratory or by mechanical side and down pullers at the Caviness Packing Company. The penis was removed from all animals and weighed separately. Upon evisceration, the gastrointestinal tract (**GIT**; reticulorumen, omasum, abomasum, and small and large intestines) were removed and placed in an evisceration cart. The spleen and bladder were removed and weighed separately from the GIT. The reticulorumen, omasum, and abomasum were cut open and the contents were removed, rinsed, and weighed together as the whole stomach. The intestinal contents were removed by passing water through and gently squeezing and flushing out the contents. Following the removal of digestive contents from small and large intestines, both components were weighed and the sum defined as intestines. The liver was removed from the viscera by severing the posterior vena cava and the hepatic veins at the base of the liver and weighed; the gall bladder was removed at the cystic duct. The heart was separated by removing the pericardium and severing the superior vena cava, aorta, and pulmonary arteries at the base of the heart. The trachea was removed posterior to the epiglottis and separated from the lungs. The kidneys were removed by severing the ureter and the renal vein and artery at the base of the kidneys. The tail was removed at approximately the 12th coccygeal vertebra, and the oxtail was concomitantly removed from the carcass between the 2nd and 3rd coccygeal vertebrae. The thymus gland was removed by cutting along the side of the carotid artery near its attachment and weighed separately. The lungs, bladder, spinal cord, and carcass trim were also removed from each animal. The weights of the blood, thymus, penis, bladder, spinal cord, and carcass trim are not included in this report because they were observed to have neither treatment ($P > 0.10$) nor DOF ($P > 0.10$) effects. Prior to chilling, all KPH was removed and weighed. A HCW including the weight of KPH was obtained prior to carcass chilling.

Estimation of Empty Body and Calculations

The empty BW (**EBW**) was calculated as the sum of the HCW and the weight of all visceral organs, empty GIT, head, blood, tongue, ears, oxtail, hide, and LIMBS. Due to constraints within the Caviness Packing Company harvesting facility, a stun weight prior to exsanguination was unable to be obtained for all animals. The shrunk BW (**SBW**) was calculated by multiplying the gross BW by a 4% shrink and serves as the final weight. Gastrointestinal contents (**GIC**) were calculated as the difference between the full GIT and the empty GIT. Moreover, the difference between gross BW and EBW was calculated and fill was calculated as the difference between gross BW and EBW. Total viscera (**VISC**) was calculated as the sum of the heart, lungs, kidneys, liver, and spleen. The empty GIT was calculated as the sum of the empty stomach and empty intestine weights after rinsing to remove digestive components. The total splanchnic tissue (**TST**) was calculated as the sum of the GIT, liver, spleen, and pancreas. The total offal produced from each carcass was calculated as the sum of the head, tongue, LIMBS, ears, hide, oxtail, penis, bladder, liver, gallbladder, spleen, pancreas, kidneys, lungs, heart, and GIT.

Statistical Analysis

A 2 × 11 factorial treatment structure in a completely randomized experimental design was used. The MIXED procedure of SAS (SAS 9.3; SAS Inst. Inc., Cary, NC) was used. Individual calf-fed Holstein steers served as the experimental unit ($n = 110$). Fixed effects included ZH treatment, DOF, and ZH × DOF interaction. The harvest facility was included as a random effect in the model. Linear and quadratic relationships were calculated using the CONTRAST statement to evaluate differences across DOF for each item of interest. Results are discussed as significant if $P \leq 0.05$.

RESULTS

Body Weights, Dressed Carcass Yield, and Fill

No ZH × DOF interactions ($P \geq 0.15$) were detected for any of the body components measured (Table 1). Although ZH-fed steers were 11.7 kg heavier, SBW was not different ($P = 0.13$) between treatments. However, SBW linearly increased ($P < 0.01$) by 1.16 kg/d with increasing DOF. The weight of the empty body was increased ($P = 0.02$) by 17.8 kg with ZH supplementation and linearly increased ($P < 0.01$) by 1.16 kg/d with

Table 1. Body weights, gastrointestinal fill, and dressed carcass yield (DY) of calf-fed Holstein steers supplemented with zilpaterol hydrochloride (ZH)[1] for 0 or 20 d during the last 28 d of a 280-d serial harvest study

	Days on ZH[1]			Days on feed (DOF)												*P*-value				
Item	0	20	SEM	254	282	310	338	366	394	422	450	478	506	534	SEM	ZH	DOF	ZH × DOF	Linear	Quadratic
Cattle	55	55	–	10	10	10	10	10	10	10	10	10	10	10	–	–	–	–	–	–
Shrunk BW,[2] kg	677.7	689.4	5.4	508.9	525.3	560.7	606.8	634.9	689.3	723.0	764.8	822.6	849.5	833.6	12.8	0.13	<0.01	0.16	<0.01	0.37
Empty BW,[3] kg	626.4	644.2	5.2	461.2	495.3	510.1	558.8	584.3	636.3	660.9	725.2	768.2	803.0	785.0	12.3	0.02	<0.01	0.30	<0.01	0.85
HCW, kg	408.4	429.1	4.0	295.9	318.3	332.9	365.0	379.7	414.3	474.7	480.1	506.2	531.0	508.0	9.4	<0.01	<0.01	0.53	<0.01	0.04
Fill,[4] kg	79.6	73.0	3.3	68.9	51.9	74.0	73.3	77.1	81.7	92.3	71.4	88.7	81.9	83.7	6.6	0.06	<0.01	0.15	<0.01	0.38
GIC,[5] kg	51.2	45.1	3.1	47.7	30.0	50.6	48.0	49.1	51.5	60.7	38.1	55.9	48.0	50.0	6.0	0.03	<0.01	0.17	0.20	0.32
DY, %	60.0	62.1	0.01	58.2	60.6	59.4	60.2	59.7	60.1	61.0	63.5	62.4	63.5	64.4	0.1	<0.01	<0.01	0.92	<0.01	0.15

[1]Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at a rate of 8.3 mg/kg (DM basis) for 20 d followed by a 3-d withdrawal.

[2]Shrunk BW = BW × 0.96.

[3]Sum of HCW, visceral organs, empty gastrointestinal tract, head, hide, blood, tongue, metatarsals, and metacarpals.

[4]Difference between gross BW and empty BW (kg).

[5]GIC = gastrointestinal contents: the mass of removed digesta from the gastrointestinal tract.

increasing DOF. Hot carcass weight was increased by 20.7 kg following ZH supplementation ($P < 0.01$) and linearly increased ($P < 0.01$) by 0.76 kg/d with additional DOF. With regard to fill, a trend ($P = 0.06$) was detected between treatments; ZH-supplemented cattle had less (6.6 kg) than CON cattle and a linear increase ($P < 0.01$) in fill was observed with additional DOF. Moreover, ZH-fed cattle had less ($P = 0.03$; 6.1 kg) GIC than CON cattle. Although GIC differed ($P < 0.01$) by DOF, no linear ($P = 0.20$) or quadratic ($P = 0.32$) trends for GIC were observed with additional DOF in this study. Dressed carcass yield was increased ($P \leq 0.01$) by 2.1 percentage points with ZH supplementation. Additionally, DY linearly increased ($P < 0.01$) by 0.008 percentage points per day with increasing DOF.

Absolute Noncarcass Weights

Absolute noncarcass weights (Table 2) did not reveal any ZH × DOF interactions ($P \geq 0.10$); likewise, no dietary treatment or DOF ($P \geq 0.19$) differences were observed for the weight of the gallbladder, spleen, or lungs. Although no differences ($P = 0.47$) were observed for the weight of the head following ZH supplementation, the head weight linearly increased ($P < 0.01$) by 0.01 kg/d with increasing DOF. Similarly, the tongue weight was not altered ($P = 0.11$) by ZH supplementation but linearly increased ($P < 0.01$) by 0.007 kg/d with increasing DOF. The weight of the LIMBS was also not influenced ($P = 0.91$) by ZH supplementation but linearly increased ($P < 0.01$) by 0.007 kg/d with increasing DOF. The weight of the hide was not altered ($P = 0.45$) with ZH supplementation, yet the hide weight linearly increased ($P < 0.01$) by 0.06 kg/d with increasing DOF. Moreover, the weight of the oxtail also was not different ($P = 0.18$) with ZH supplementation but did linearly increase ($P < 0.01$) by 0.002 kg/d with increasing DOF. The liver weight was 3.4% less ($P = 0.03$; 0.3 kg) for ZH-supplemented cattle and linearly increased ($P < 0.01$) by 0.007 kg/d with increasing DOF. Additionally, the pancreas weight was not different ($P = 0.33$) for ZH-supplemented cattle but did increase ($P \leq 0.01$) by 0.003 kg/d with additional DOF. The kidney weight was 6.3% less ($P < 0.01$; 0.1 kg) for ZH-supplemented cattle and linearly increased ($P < 0.01$) by 0.0004 kg/d with additional DOF. No treatment effects were detected in the heart ($P = 0.60$) weight following ZH supplementation. However, the heart weight linearly increased ($P < 0.01$) by 0.005 kg/d throughout the feeding period. Cattle supplemented with ZH had no difference in stomach ($P = 0.99$) or intestine ($P = 0.25$) weight. However, the weight of the stomach and intestines linearly increased ($P < 0.01$) by 0.04 and 0.13 kg/d, respectively, with increasing DOF. The weight of KPH did not differ ($P = 0.99$) between ZH-fed and CON cattle but did linearly increase ($P < 0.01$) by 0.07 kg/d with increasing DOF. No difference was detected for VISC ($P = 0.13$) due to ZH supplementation. However, VISC linearly increased ($P < 0.01$) by 0.01 kg/d with increasing DOF. No treatment effect ($P = 0.34$) was detected for the weight of the empty GIT but it did linearly increase ($P < 0.01$) by 0.18 kg/d with additional DOF throughout the trial duration. Addition of ZH to the diet did not affect TST ($P = 0.24$) or total offal weight ($P = 0.36$). Nevertheless, both TST and total offal weight linearly increased ($P < 0.01$) by 0.19 and 0.31 kg/d, respectively, with additional DOF.

Weight of Noncarcass Components Expressed on an Empty Body Basis

Noncarcass weights of the empty body were also expressed as a proportion in grams per kilogram (g/kg) of EBW (Table 3). No interactions ($P \geq 0.07$) were observed for ZH × DOF when noncarcass components were expressed as a fraction of the empty body. No difference ($P = 0.12$) in the proportional head weight was detected for cattle supplemented with ZH. Nevertheless, the proportion of the head relative to the empty body linearly decreased ($P < 0.01$) by 0.02 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF. No treatment ($P = 0.64$) effect was detected for the tongue relative to the empty body. However, the proportion of the tongue linearly decreased ($P < 0.01$) by 0.003 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF. The proportion of the LIMBS relative to the empty body was less ($P < 0.01$; 0.7g/kg EBW) when ZH was included in the diet. Additionally, with increasing DOF, the proportion of the LIMBS linearly decreased ($P < 0.01$) by 0.025 $g \cdot kg^{-1} \cdot d^{-1}$. A 3 g/kg EBW reduction ($P < 0.01$) in the proportion of hide relative to the empty body was detected with dietary ZH inclusion; additionally, the proportion of hide relative to the empty body linearly decreased ($P < 0.01$) by 0.026 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF. The oxtail was not affected ($P = 0.69$) by dietary treatment but did differ across DOF in a quadratic ($P = 0.04$) manner; the proportion of oxtail to EBW reached a maximal point at 422 DOF and a minimal point at 506 DOF. This variability is likely due to the small sample size at each harvest end point and error related to removal of the oxtail upon harvest.

The proportion of the liver relative to the empty body was 1.0 g/kg less ($P < 0.01$) with ZH inclusion and linearly decreased ($P < 0.01$) by 0.015 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF. The proportions of the gallbladder, spleen, and pancreas relative to the empty body were not impacted ($P = 0.99$, $P = 0.56$, and $P = 0.30$, respectively) by ZH inclusion. However, the proportion of the gallbladder and spleen linearly decreased ($P < 0.01$) by 0.001 and 0.004 $g \cdot kg^{-1} \cdot d^{-1}$, respectively, with addition-

Table 2. Absolute weights (kg) of harvest byproducts from calf-fed Holstein steers supplemented with zilpaterol hydrochloride (ZH)[1] for 0 or 20 d during the last 28 d of a 280-d serial harvest study

	Days on ZH			Days on feed (DOF)												*P*-value				
Item	0	20	SEM	254	282	310	338	366	394	422	450	478	506	534	SEM	ZH[1]	DOF	ZH × DOF	Linear	Quadratic
Cattle	55	55	–	10	10	10	10	10	10	10	10	10	10	10	–	–	–	–	–	–
Head, kg	15.0	15.1	0.1	12.8	14.1	13.6	15.3	15.2	14.9	14.2	16.0	16.6	16.4	16.6	0.3	0.47	<0.01	0.82	<0.01	0.42
Tongue, kg	4.6	4.8	1.2	3.1	2.9	3.2	2.8	3.4	5.2	7.6	6.0	6.4	5.6	5.1	1.3	0.11	<0.01	0.86	<0.01	<0.01
Limbs,[2] kg	11.9	11.9	0.1	10.8	10.9	11.3	11.3	11.7	12.7	10.9	12.7	12.9	13.0	12.7	0.3	0.91	<0.01	0.52	<0.01	0.84
Hide, kg	50.7	50.2	0.5	37.6	42.1	41.0	46.7	46.7	50.9	53.3	59.4	58.0	61.2	57.9	1.2	0.45	<0.01	0.89	<0.01	0.01
Oxtail, kg	1.3	1.3	0.1	1.0	1.0	1.0	1.2	1.3	1.4	1.5	1.5	1.5	1.4	1.6	0.1	0.18	<0.01	0.45	<0.01	0.02
Liver, kg	8.7	8.4	0.1	7.6	7.5	7.8	8.3	7.9	8.4	8.7	9.4	9.6	9.6	9.5	0.3	0.03	<0.01	0.19	<0.01	0.79
Gallbladder, kg	0.3	0.4	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.2	0.5	0.5	0.5	0.4	0.2	0.22	0.43	0.36	0.24	0.74
Spleen, kg	1.5	1.5	0.1	1.5	1.4	1.6	1.4	1.3	1.5	1.5	1.5	1.5	1.6	1.6	0.1	0.84	0.63	0.63	0.16	0.23
Pancreas, kg	0.6	0.6	0.03	0.2	0.5	0.7	0.5	0.6	0.6	0.6	0.8	0.8	0.9	0.9	0.1	0.33	<0.01	0.37	<0.01	0.27
Kidneys, kg	1.6	1.5	0.03	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.6	0.1	<0.01	0.03	0.53	<0.01	0.33
Lungs, kg	4.0	4.1	0.1	4.0	3.8	3.9	4.1	3.9	4.2	4.1	4.2	4.1	4.1	4.3	0.1	0.20	0.19	0.73	<0.01	0.89
Heart, kg	3.1	3.1	0.1	2.4	2.6	2.6	2.9	2.8	3.0	3.3	3.4	3.6	3.7	3.7	0.1	0.60	<0.01	0.58	<0.01	0.91
Stomach, kg	27.0	27.0	3.9	20.8	23.8	19.5	21.3	21.2	26.0	33.7	31.7	31.3	33.4	32.4	4.5	0.99	<0.01	0.10	<0.01	0.77
Intestines, kg	49.5	48.0	5.4	29.8	31.8	35.0	40.7	48.0	51.8	43.4	54.7	63.8	70.3	67.0	6.5	0.25	<0.01	0.66	<0.01	0.60
KPH, kg	15.9	15.9	0.7	6.6	9.5	8.8	11.6	13.2	16.3	18.0	21.2	21.9	22.5	25.3	1.4	0.99	<0.01	0.19	<0.01	0.97
Viscera,[3] kg	18.9	18.5	0.2	16.9	16.7	17.3	18.1	17.3	18.7	19.1	20.1	20.5	20.7	20.7	0.4	0.13	<0.01	0.46	<0.01	0.53
GIT,[4] kg	76.1	74.6	1.1	49.8	54.7	53.6	61.1	68.3	77.1	76.3	87.3	96.0	104.6	100.3	2.4	0.34	<0.01	0.43	<0.01	0.21
TST,[5] kg	87.0	85.1	1.1	59.0	64.1	63.6	71.3	78.0	87.7	87.0	99.0	107.9	116.8	112.2	2.7	0.24	<0.01	0.36	<0.01	0.21
Total offal, kg	179.2	177.1	1.6	131.3	142.1	140.9	156.2	163.7	180.9	182.5	205.3	214.1	225.3	217.1	3.8	0.36	<0.01	0.41	<0.01	0.86

[1]Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at a rate of 8.3 mg/kg (DM basis) for 20 d followed by a 3-d withdrawal.

[2]Weight of metacarpals and metatarsals.

[3]Viscera = weight of heart, lungs, kidneys, liver, and spleen.

[4]GIT = gastrointestinal tract: the weight of the emptied stomach and intestines.

[5]TST = total splanchnic tissue: the weight of the gastrointestinal, pancreas, spleen, and liver.

al DOF. The proportional weight of the pancreas linearly increased ($P < 0.01$) by 0.003 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF. The proportion of kidneys relative to the empty body was 0.3 g/kg less ($P < 0.01$) for cattle supplemented with ZH and linearly decreased ($P < 0.01$) by 0.004 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF.

The proportion of the lungs relative to the empty body were not different ($P = 0.99$) for cattle supplemented with ZH but linearly decreased ($P < 0.01$) by 0.01 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF. No difference ($P = 0.11$) for the proportion of the heart relative to the empty body was detected between treatments. However, the proportion of the heart relative to the empty body linearly decreased ($P < 0.01$) by 0.001 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF.

The proportion of the stomach relative to the empty body was not different ($P = 0.34$) for cattle supplemented with ZH. However, the proportion of the stomach relative to the empty body linearly decreased ($P < 0.01$) by 0.05 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF. A 5.3 g/kg EBW reduction ($P < 0.01$) in the proportion of intestines relative to the empty body was detected with inclusion of ZH in the diet. With additional DOF, the relative proportion of the intestines to the empty body linearly increased ($P < 0.01$) by 0.12 $g \cdot kg^{-1} \cdot d^{-1}$. No treatment difference ($P = 0.20$) was detected in the proportion of KPH

Table 3. Absolute weights expressed as a proportion of the empty body (g/kg) of harvest byproducts from calf-fed Holstein steers supplemented with zilpaterol hydrochloride (ZH)[1] for 0 or 20 d during the last 28 d of a 280-d serial harvest study

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Cattle	55	55	–	10	10	10	10	10	10	10	10	10	10	10	–	–	–	–	–	–
Head	24.4	24.0	0.2	27.8	28.5	26.5	27.2	26.2	23.4	21.6	22.0	21.4	20.5	21.2	0.5	0.12	<0.01	0.77	<0.01	0.17
Tongue, g/kg	4.0	4.0	0.1	4.3	3.4	4.2	3.0	3.5	5.2	4.4	4.4	4.5	3.8	3.6	0.2	0.64	<0.01	0.43	<0.01	0.05
Limbs,[2] g/kg	19.5	18.8	0.1	23.4	21.8	22.2	20.5	19.5	20.3	16.4	17.5	16.5	16.2	16.3	0.3	<0.01	<0.01	0.07	<0.01	0.02
Hide, g/kg	81.1	78.1	0.7	81.6	84.6	80.7	83.4	79.2	78.3	81.1	80.8	76.1	76.0	74.2	1.6	<0.01	<0.01	0.75	<0.01	0.18
Oxtail, g/kg	2.0	2.0	0.04	2.1	2.1	1.9	2.1	2.1	2.0	2.2	2.1	1.9	1.8	2.0	0.1	0.69	0.02	0.71	0.10	0.04
Liver, g/kg	14.2	13.2	0.2	16.4	15.0	15.3	14.8	13.1	13.3	13.3	12.8	12.5	12.0	12.1	0.4	<0.01	<0.01	0.86	<0.01	0.02
Gallbladder, g/kg	0.6	0.6	0.04	0.7	0.7	0.6	0.8	0.8	0.8	0.5	0.5	0.5	0.4	0.4	0.1	0.99	<0.01	0.37	<0.01	0.02
Spleen, g/kg	2.4	2.4	0.1	3.2	2.8	2.6	3.0	2.2	2.4	2.2	2.1	1.9	2.0	2.0	0.2	0.56	<0.01	0.80	<0.01	0.17
Pancreas, g/kg	1.0	1.0	0.05	0.3	0.9	1.3	0.9	1.1	0.9	0.8	1.0	1.0	1.2	1.1	0.1	0.30	<0.01	0.24	<0.01	0.09
Kidneys, g/kg	2.6	2.3	0.04	3.2	2.9	2.8	2.5	2.4	2.4	2.3	2.2	2.1	2.1	2.1	0.1	<0.01	<0.01	0.55	<0.01	<0.01
Lungs, g/kg	6.6	6.6	0.1	8.7	7.6	7.6	7.5	6.6	6.5	6.4	5.9	5.4	5.1	5.6	0.2	0.99	<0.01	0.71	<0.01	0.03
Heart, g/kg	5.0	4.8	0.1	5.1	5.2	5.2	5.3	4.8	4.6	5.0	4.6	4.7	4.5	4.7	0.2	0.11	<0.01	0.32	<0.01	0.72
Stomach, g/kg	45.0	43.9	0.8	52.4	54.1	45.6	44.8	40.6	45.9	55.3	38.4	36.8	37.5	37.1	1.9	0.34	<0.01	0.48	<0.01	0.84
Intestines, g/kg	74.9	69.6	1.2	55.5	55.6	59.7	63.3	73.2	74.3	61.9	80.1	89.6	91.5	90.3	2.8	<0.01	<0.01	0.88	<0.01	0.23
KPH, g/kg	24.2	23.2	0.6	14.1	18.7	16.6	19.8	22.8	24.5	26.9	29.2	29.3	27.4	32.0	1.4	0.20	<0.01	0.50	<0.01	0.12
Viscera,[3] g/kg	30.8	29.3	0.3	36.6	33.5	33.5	33.1	29.1	29.3	29.3	27.6	26.6	25.8	26.5	0.7	<0.01	<0.01	0.99	<0.01	<0.01
GIT,[4] g/kg	119.9	113.5	1.3	107.9	109.7	105.3	108.2	113.8	120.2	117.2	118.5	126.4	129.0	127.4	3.0	<0.01	<0.01	0.92	<0.01	0.33
TST,[5] g/kg	137.5	130.0	1.3	127.8	128.4	124.5	126.9	130.1	136.9	133.5	134.5	141.9	144.3	142.6	3.0	<0.01	<0.01	0.91	<0.01	0.19
Total offal, g/kg	253.2	246.8	2.5	275.5	271.9	256.5	261.8	255.6	250.5	254.4	234.5	232.8	234.0	222.7	5.9	0.07	<0.01	0.43	<0.01	0.76

[1]Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at a rate of 8.3 mg/kg (DM basis) for 20 d followed by a 3-d withdrawal.

[2]Weight of metacarpals and metatarsals.

[3]Viscera = weight of heart, lungs, kidneys, liver, and spleen.

[4]GIT = gastrointestinal tract: weight of the emptied stomach and intestines.

[5]TST = total splanchnic tissue: the weight of the gastrointestinal, pancreas, spleen, and liver.

relative to the empty body when ZH was included in the diet. However, the proportion of KPH linearly increased ($P < 0.01$) by 0.06 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF. Viscera and TST relative to the empty body decreased ($P < 0.01$) by 1.5 and 7.5 g/kg EBW, respectively, with ZH supplementation. However, TST linearly increased ($P < 0.01$) by 0.05 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF, whereas VISC linearly decreased ($P < 0.01$) by 0.04 $g \cdot kg^{-1} \cdot d^{-1}$ with additional DOF. The GIT was 6.4 g/kg EBW less ($P < 0.01$) in cattle supplemented with ZH and linearly increased ($P < 0.01$) by 0.07 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF. The total proportion of offal tended ($P = 0.07$) to be 6.4 g/kg EBW less for ZH-treated cattle and linearly decreased ($P < 0.01$) by 0.19 $g \cdot kg^{-1} \cdot d^{-1}$ with increasing DOF.

DISCUSSION

Previous literature by Elam et al. (2009) summarized 4 trials using beef-type steers fed ZH for 0, 20, 30, or 40 d and reported an 8-kg increase in live BW in beef-type steers fed ZH for 20 d. Vasconcelos et al. (2008) summarized data from beef-type British- and British Continental–cross steers fed ZH for 0, 20, 30, and 40 d and reported a 10.6-kg increase in the live BW of beef-type steers supplemented with ZH for 20 d. Beckett et al. (2009) reported a 3.5-kg difference in live BW in calf-fed Holstein steers fed ZH for the final 20 d of the finishing period. In comparison, the lack of significance in the present trial is likely an artifact of the small sample size and the large variation in weight among animals over differing marketing end points. The increase in EBW of ZH-supplemented cattle in the current trial is in agreement with Holland et al. (2010), who reported a 17-kg numerical difference in the EBW of 32 British-cross steers supplemented with ZH for 20 d and paired to withdrawal periods of 3, 10, 17, and 24 d before harvest. The literature to date is limited in describing the effect of ZH supplementation on the empty body; these data help elucidate the differences in EBW for calf-fed Holstein steers when ZH is added to the diet.

The magnitude of HCW response of the current trial is greater than the 11.6-kg increase previously reported by Beckett et al. (2009) for calf-fed Holsteins. Additionally, the 5.0% increase in HCW is also larger than the 3.7 and 3.4% increase in HCW reported by Montgomery et al. (2009a) in beef-type steers and heifers, respectively, fed ZH for 20 d; the 2.9% increase in HCW reported by Montgomery et al. (2009b) in beef-type steers fed ZH for 30 d including tylosin phosphate and monensin; and the 4.5% increase in HCW reported by Vasconcelos et al. (2008) in beef-type steers fed ZH for 20 d. It should be noted that cattle in this study were harvested at time points ranging from 254 to 534 DOF, which is well before and after typical current marketing end points (360 ± 60 d) and may explain the magnitude of response in the current trial. Similar to that in previous literature, the HCW advantage was greater in magnitude than the SBW advantage in cattle supplemented with ZH (Vasconcelos et al., 2008; Elam et al., 2009; Baxa et al., 2010).

Previous literature reporting differences in GIC for cattle supplemented with ZH are scarce; however, differences in GIC may likely be correlated with a reduction in DMI that has been associated with ZH supplementation (Montgomery et al., 2009a,b; Holland et al., 2010). Walter et al. (2016) summarized the consumption and behavioral dynamics of the cattle in this current investigation. Results indicated DMI was not different during the 5-d period before ZH supplementation. Nonetheless, upon supplementation of ZH, DMI was reduced by 8.7 and 6.2% during the 20-d supplementation period and subsequent 3-d withdrawal period before harvest. The reduction of DMI described by Walter et al. (2016) may better explain the reduction in GIC measured during the harvest process.

Dressed carcass yield is typically less for Holstein steers in comparison with that of beef-breed steers (Buege, 1988). Reasons for reductions in DY include the increased proportion of the GIT (Nour et al., 1983; Taylor and Murray, 1991), a lower muscle-to-bone ratio (Kauffman et al., 1976; Duff and Anderson, 2007), and an increased liver size (Terry et al., 1990). Increased DY has previously been reported in Holstein steers when fed ZH (Beckett et al., 2009). Although the magnitude of difference in DY observed in the current study is larger than the 1.5% increase reported by Beckett et al. (2009) in calf-fed Holsteins, mean DY between studies reported for ZH-supplemented Holsteins is similar (62.9 vs. 62.4%). In agreement with the current trial, Winterholler et al. (2007) reported that as DOF increased, DY improved in yearling beef steers fed ractopamine hydrochloride for 28 d prior to harvest. Likewise, Vasconcelos et al. (2008) also observed linear increases in DY with increasing DOF. In summation, these data demonstrate that a metabolic modifier such as ZH could increase the HCW, DY, and EBW of dairy steers fed in commercial feeding operations.

Relative to noncarcass components, the magnitude of change between treatments for the head proportion is similar to that of Holland et al. (2010), who reported no difference in the weight of the head or the proportion of the head relative to the empty body in beef-type steers fed ZH. Interestingly, Avendaño-Reyes et al. (2011) reported a 0.41% decrease in head weight expressed as a percentage of final live BW for ewe lambs supplemented with ZH at a rate of 10 mg/ewe lamb for 32 d prior to a 2-d withdrawal. Relative to the proportional weight of the tongue, Terry et al. (1990) reported no difference in the percentage of the tongue for Holstein steers compared with beef breeds, which is in agreement with the current trial. In relation to the LIMBS, Holland et al. (2010) reported no difference in the weight or proportional weight of the feet and ears. Conversely, the current trial differs in that the proportional weight of LIMBS was less for cattle supplemented with ZH. Regarding growth of the LIMBS and the head, both decreased in proportional weight across DOF, which is a direct illustration of the change that occurs relative to the dilution of these components by other carcass and noncarcass tissues.

Holstein steer hides are typically valued at a premium due to less frequent hot-iron brands and thinner hides (Buege, 1988). Relative to hide weight, Holland et al. (2010) reported no difference between ZH-fed and control beef-type cattle relative to the weight of the hide, which is in agreement to the current trial. Additionally, Terry et al. (1990) and Taylor and Murray (1991) reported that hide as a fraction of live BW was 1.7% less for dairy breeds than for English beef breeds. Compared with previous literature, the proportion of hide to EBW in the current data set is 1.18% less than that of the crossbred steers used by Holland et al. (2010). The reduction in the hide proportion between ZH-supplemented and control cattle reported in this study may help explain some of the advantages in DY observed when cattle are supplemented with ZH. Although changes in the proportional hide weight would not represent an economic advantage to the processor, a reduction in the weight of the hide may improve DY and therefore improve the economics of marketing Holsteins sold on value-based grids when competing against a threshold or plant average DY.

Alterations in liver weight become metabolically important due to the estimated 22.5% of total energy expended as fasting heat in the ruminant animal (Ferrell, 1988). According to Elwyn (1970), the liver plays a critical role in waste management and N balance by removing AA absorbed in excess of requirements, thus producing urea and repackaging carbon skeletons. A reduction in liver weight may contribute to less overall energy expenditures by the animal and thus increase energy available to the animal for growth. Burrin et al. (1989) also suggested that blood flow to the liver, which is determined by the weight of the liver, is regulated to ensure a constant rate of delivery of nutrients and removal of end products. A decrease of 8 to 12.5% in liver weight has been reported in mice fed clenbuterol, a beta-2 agonist (Bates and Pell, 1991; Sharma et al., 1997). These findings may indicate that beta adrenergic agonists repartition nutrients away from the liver for use in anabolism of carcass tissues. Results of the current trial indicate that the liver as a proportion of EBW decreased with additional DOF. In agreement, López-Carlos et al. (2012) reported that the relative weight of the liver was reduced by 20.7% in lambs supplemented with ZH 30 d prior to slaughter at a rate of 6.0 mg/kg of diet on an as-fed basis. Decreased proportional liver weight concurrent with decreased DMI has previously been reported in sheep (Burrin et al., 1990) and beef steers (Sainz and Bentley, 1997). The liver proportion has been considered to be positively correlated with maintenance energy requirements and potentially positively correlated with lactation potential (Taylor and Murray, 1991). Holstein cattle have also been reported to have heavier liver weights in proportion to live weight versus traditional beef breeds, which may contribute to greater maintenance energy requirements (Terry et al., 1990).

In the current investigation, weights and proportional weight of the gallbladder, spleen, and pancreas did not differ. In a study by Holland et al. (2010), although data were not reported for the gallbladder, differences were not detected for the spleen or pancreas, which is similar to the current trial. Regarding the kidneys, compared with other organs, they receive more blood flow per unit weight than any other tissue in the ruminant (Hales, 1973). The increase in blood flow is largely attributable to their function in the excretion of waste products and the maintenance of fluid balance. The findings of the current trial are supported by data reported by Hansen et al. (1994), who indicated decreased kidney weights in salbutamol-fed swine. Additionally, in Holstein steers supplemented with the beta agonist $L_{644,969}$, Moloney et al. (1990) reported a 3.0% reduction in kidney weight. Yet the current data do not agree with that from Holland et al. (2010), who did not detect a difference in kidney weight or proportion among ZH treatments in crossbred beef-type steers.

Sharma et al. (1997) reported minimal increases in the weight of the heart for clenbuterol-treated mice. Moloney et al. (1990) reported that the weight of the heart linearly decreased with increasing concentration of L644,969 in Holstein steers when live weight was used as a covariate in the analysis. In a comparison of lung weight by breed type, Terry et al. (1990) reported that Holstein cattle had 0.25% heavier lungs relative to live weight than English or exotic-type beef steers. Compared with the present study, no treatment effects were detected for the heart or lungs either by weight or proportion of EBW. Similarly, Holland et al. (2010) reported no difference in the weights of the heart and lungs of crossbred beef steers.

Relative to the stomach, no differences were detected, which is in agreement with Holland et al. (2010), who reported that no differences were found for the weight of the reticulorumen, omasum, or abomasum of beef-type steers supplemented with ZH. Additionally, the proportion of the stomach relative to the empty body was not different but did linearly decrease with additional DOF. These findings agree with Avendaño-Reyes et al. (2011), who reported no difference in the weight of rumen, omasum, and abomasum as a percentage of final BW in crossbred ewe lambs treated with ZH. Holland et al. (2010) reported no difference in the weight of the small and large intestines between ZH-fed cattle and controls, which is a comparable outcome relative to intestine weight in the present trial. Additionally, Holland et al. (2010) reported a reduction in the proportion of small intestine for cattle fed ZH, which mirrored the results calculated for intestines on a grams per kilogram EBW basis in this data set.

Moloney et al. (1990) reported a 22.8% decrease in the weight of KPH when Holstein steers were supplemented with 1.0 mg/kg of $L_{644,969}$. In contrast, previous literature involving ZH has indicated that KPH was generally not affected by ZH supplementation (Plascencia and Zinn, 1999; Beckett et al., 2009; Montgomery et al., 2009a). However, percentages of KPH reported in these studies were visually estimated, whereas in the present study, KPH was determined by physical separation. In agreement with previous literature, the weight of KPH was not different between diet treatments. However, the weight of KPH did linearly increase, which is in contrast to May et al. (1992) and Van Koevering et al. (1995), who reported increases in KPH before reaching a plateau as frame size increased in British and Continental crossbred yearling steers and Angus × Hereford crosses, respectively. Additionally, Bruns et al. (2004) also reported quadratic increases in the percentage of KPH with additional DOF in Angus steers of known ages and genetic background.

In the present experiment, addition of ZH to the diet did not affect TST or total offal weight, which is in agreement with Holland et al. (2010), who reported no difference in the weight of TST or total offal in beef-type steers supplemented with ZH. However, when comparing the proportion of TST from the Holland et al. (2010) trial with the current data set, crossbred beef steers had 3.5% less than TST compared with the Holstein steers in the current trial. Increases in the TST proportion may indicate an overall increase in the maintenance energy requirement of steers during the finishing period (Huntington and Reynolds, 1987). This observation may indicate a lower maintenance energy requirement being plausible for ZH-supplemented steers, which could explain the differences observed in BW and HCW gain for ZH-fed cattle. Describing the GIT, no differences were reported by Holland et al. (2010), which is in contrast to the current trial, where less GIT was observed for ZH-supplemented steers on a grams per kilogram EBW basis. Although the GIT and liver represent only 8 to 14% of BW, heat produced by the GIT and liver accounts for approximately one-half of a ruminants' maintenance energy requirement (Seal and Reynolds, 1993). The potential for mobilization of nutrients from noncarcass tissue to carcass tissue may elucidate the magnitude of change observed between BW and HCW of cattle fed ZH.

Results from the present study provide further understanding of important changes in the absolute and proportional weight of noncarcass components when ZH is fed in the final days of the feeding period. Feeding ZH resulted in increased EBW, HCW, and DY. Concomitantly, reductions in GIC, liver, and kidney weights were also noted. In addition, relative to the empty body, reductions in metabolically active tissues such as the liver, kidney, intestines, TST, and VISC were observed with ZH supplementation. These observations help elucidate the relative growth of noncarcass tissues with and without β-adrenergic agonist supplementation.

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