The effects of zilpaterol hydrochloride on carcass cutability and tenderness of calf-fed Holstein steers[1]

A. J. Garmyn,* J. N. Shook,*[2] D. L. VanOverbeke,* J. L. Beckett,† R. J. Delmore,‡ D. A. Yates,§ D. M. Allen,§ and G. G. Hilton*[3]

*Department of Animal Science, Oklahoma State University, Stillwater 74078; †Beckett Consulting Service, Atascadero, CA 93422; ‡Department of Animal Science, California Polytechnic State University, San Luis Obispo 93407; and §Intervet Schering Plough, DeSoto, KS 66018

ABSTRACT: To evaluate the impact of zilpaterol hydrochloride (ZH) on carcass cutability and tenderness of calf-fed Holstein steers, calf-fed Holstein carcasses (n = 102) were selected from a pool of 2,300 steers that were fed 0 or 8.3 mg/kg (DM basis) of ZH. Zilpaterol hydrochloride was supplemented the last 20 d of the finishing period and withdrawn for 3 d before slaughter. Carcasses were selected based on carcass weight as well as predetermined USDA Yield grade categories. For tenderness evaluation, steaks from the strip loin, bottom round, and top round (n = 54 per subprimal) were aged for 14 or 21 d postmortem. Carcasses from ZH-fed steers had more ($P < 0.01$) saleable yield than carcasses from control-fed steers. Additionally, ZH-fed steers had greater ($P \leq 0.01$) subprimal yield from the shoulder clod, strip loin, peeled tenderloin, top sirloin butt, bottom sirloin tri-tip, peeled knuckle, inside round, bottom round flat, eye of round, heel, and shank. Furthermore, ZH decreased ($P < 0.01$) the total amount and percentage of bone and fat trim from the carcass. Moisture loss was not affected by ZH in LM or inside round steaks ($P > 0.05$); however, ZH increased thawing loss ($P = 0.05$) but reduced cooking loss ($P = 0.05$) in bottom round steaks. Shear force values of LM and inside round steaks increased with ZH inclusion ($P < 0.01$), but there was no difference in bottom round steaks ($P > 0.05$). Steaks aged for 21 d had smaller ($P < 0.01$) Warner-Bratzler shear force (WBS) values than 14-d steaks from all 3 subprimals. Trained sensory panelists did not detect any differences ($P > 0.05$) in sensory juiciness, tenderness, or flavor variables of LM or inside round steaks, except ZH steaks from the LM received smaller scores for sustained juiciness ($P = 0.01$) and overall tenderness ($P = 0.04$) than control steaks. Although LM steaks from ZH cattle were tougher than control steaks, the ZH-treated steaks had an average WBS value of 4.10 kg, which would be classified as intermediate in tenderness, with trained panelists rating ZH steaks slightly to moderately tender. Feeding ZH improved carcass cutability of calf-fed Holstein steers; however, tenderness was reduced in LM and inside round steaks. The interaction of postmortem tenderization techniques should be investigated to evaluate their impact on palatability in cattle supplemented with β-agonists to allow the beef industry to take full advantage of the enhancement in performance and carcass yield.

Key words: beef, cutability, Holstein, tenderness, zilpaterol hydrochloride

J. Anim. Sci. 2010. 88:2476–2485
doi:10.2527/jas.2009-2635

INTRODUCTION

Zilpaterol hydrochloride (**ZH**), commercially available as Zilmax (Intervet Schering Plough, DeSoto, KS), is a β-adrenergic agonist (**β-AA**) recently approved for use in the United States in beef finishing diets. Zilpaterol hydrochloride is similar in nature to the catecholamines and acts as a repartitioning agent similar to other β-AA. Zilpaterol hydrochloride is marketed as a compound that can increase lean deposition and decrease fat accretion as well as improve animal growth performance characteristics much like the β-AA clenbuterol and cimaterol (Ricks et al., 1984; Moloney et al., 1990; Chikhou et al., 1993).

As reported by Shook et al. (2009), ZH can increase the amount of wholesale lean recovered from the carcass; however, a reduction in tenderness in strip loin steaks resulting from ZH supplementation was also documented. Calf-fed Holstein steers comprise almost 9%

---

[1] Approved for publication by the director, Oklahoma Agric. Exp. Stn. (OAES, Stillwater). This project was supported, in part, under OAES Project H-1167.

[2] Present address: Smithfield Packing Company Inc., Tar Heel, NC 28392.

[3] Corresponding author: gretchen.hilton@okstate.edu

Received November 4, 2009.
Accepted March 19, 2010.

of the total beef slaughter in the United States (Smith et al., 2006) and typically produce a large percentage of USDA Choice or better carcasses. However, calf-fed Holstein steers typically have poor muscling, smaller dressing percentages, and reduced fabrication yields when compared with beef steers (Knapp et al., 1989). Therefore, supplementing calf-fed Holstein steers with ZH in the final finishing phase could potentially result in greater improvements in carcass yields than those seen by the incorporation of ZH in finishing diets of traditional beef steers. The objectives of this experiment were to determine the effect of ZH on carcass cutability from calf-fed Holstein steers, as well as assess the effect of ZH on palatability of steaks from the strip loin, inside round, and bottom round.

MATERIALS AND METHODS

The California Polytechnic State University Institutional Animal Care and Use Committee approved procedures relating to animal care and use.

Animals

The live portion of this experiment regarding blocking, penning, and animal selection is described in Beckett et al. (2009). Carcasses for this experiment were acquired from 4 different sources during 2 selection phases (2 sources/phase) at a large commercial feedlot in the desert Southwest United States from approximately 2,300 calf-fed Holstein steers. Steers were fed 8.3 mg/kg of ZH (DM basis) for 20 d and removed from the supplement 3 d before slaughter or were fed a control (no ZH) diet. Phase 1 cattle were slaughtered on 2 separate days, control animals were slaughtered on October 7, 2008, and ZH cattle were slaughtered on October 8, 2008. For phase 2, slaughter was again on 2 separate days with control animals slaughtered on October 21, 2008, and ZH steers slaughtered on October 22, 2008. After slaughter and chilling, carcasses were ribbed at the 12th rib. Fat thickness was measured to determine the preliminary yield and adjusted accordingly. Longissimus muscle area was measured. Marbling score and KPH were assigned by a trained evaluator, and yield grades were calculated (USDA, 1997). After grading, carcasses were selected giving priority to HCW and then USDA Yield grade (**YG**). Carcasses were selected that weighed ±1 SD (11.36 kg) from the mean HCW of the pen and to fit 1 of 6 predetermined USDA YG categories: YG $\leq$1.99, YG 2.00 to 2.49, YG 2.50 to 2.99, YG 3.00 to 3.49, YG 3.50 to 3.99, and YG $\geq$4.00 for ZH-supplemented and control cattle. Not all categories had equal representation due to the availability of carcasses filling certain YG categories; the obtained carcass distribution is presented in Table 1. This reduction from the desired number of carcasses resulted in a total of 102 carcasses for both phases combined. After selection, carcasses were transported 2,095 km via commercial refrigerated truck (0 to −2°C) to the Oklahoma State University Food and Agriculture Products Center, Stillwater, for further fabrication, where they arrived within 4 to 5 d postmortem.

Table 1. Number of carcasses selected per treatment within each phase[1] based on yield grade

	Phase 1		Phase 2	
	ZH,[2] mg/kg		ZH,[2] mg/kg	
Yield grade	0	8.3	0	8.3
<1.99	1	4	4	6
2.0 to 2.49	4	11	5	6
2.5 to 2.99	7	6	4	5
3.0 to 3.49	5	8	6	5
3.5 to 3.99	7	0	4	3
>4.0	1	0	0	0
Total	25	29	23	25

[1] Phase 1 = control group slaughtered on October 7, 2008; zilpaterol hydrochloride (ZH) group slaughtered on October 8, 2008. Phase 2 = control group slaughtered on October 21, 2008; ZH group slaughtered on October 22, 2008.

[2] Zilmax, Intervet Schering Plough, DeSoto, KS.

Carcass Fabrication

Once carcass sides arrived at Food and Agriculture Products Center, they were stored in holding coolers (2 ± 2°C) until fabrication. Cold side weights (**CSW**) were recorded before fabrication using a certified rail scale. Carcasses were then fabricated into subprimals according to the North American Meat Processors Association (**NAMP**) guidelines to include 109B rib blade meat (trimmed to blue), 112A ribeye roll, lip-on, 114C chuck shoulder clod (0.635-cm trim), 114F chuck shoulder tender, 115D pectoral meat (trimmed to blue), 116A chuck roll (0.635-cm trim), 116B chuck (mock) tender (trimmed to blue), 120 brisket whole (packer trim), 121 short plate, 121C outside skirt (denuded), 121D inside skirt (denuded), 124 rib back ribs, 130A boneless chuck short ribs, (trimmed to blue), 167A peeled knuckle, 168 top inside round (0.635-cm trim), 171B bottom round flat (0.635-cm trim), 171C eye of round (0.635-cm trim), 171F heel meat, 180 strip loin (0.635-cm trim), 184 top sirloin butt (0.635-cm trim), 185A bottom sirloin flap (denuded), 185B bottom sirloin ball tip (trimmed to blue), 185D bottom sirloin tri-tip (trimmed to blue), 189A peeled tenderloin, 193 flank steak (trimmed to blue), shank meat, and elephant ear (cutaneous trunci from the flank). Lean trimmings from all components were categorized into 3 categories: 90% lean/10% fat (90/10), 80% lean/20% fat (80/20), or 50% lean/50% fat (50/50) according to industry standard sorting techniques. Kidney knob fat, all trimmed fat, and all bones were also collected separately and weighed. After all weights from each side were recorded and entered, fabrication yield was calculated to ensure that 99 to 100.5% of CSW was recovered. Weights for all previously mentioned products of fabrication were also expressed as a percentage of CSW.

Muscle Selection

Upon completion of carcass fabrication, strip loins (NAMP 180; n = 54), top (inside) rounds (NAMP 168; n = 54), and bottom round flats (NAMP 171B; n = 54) from phase 1 were selected for subsequent fabrication for shear force and sensory analysis. Strip loins were fabricated by making a transverse cut through the center of the muscle, leaving 2 equal halves. Top inside rounds and bottom round flats were also fabricated by making a transverse cut across the muscle to yield 2 equal halves.

Steak Fabrication and Aging

For each subprimal half, two 2.54-cm steaks were cut from the medial face and randomly assigned to 1 of 2 aging times (14 or 21 d postmortem) for instrumental tenderness determination. Two additional 2.54-cm steaks were cut from top rounds and strip loins and assigned to 1 of 2 aging times (14 or 21 d postmortem) for sensory evaluation. After fabrication, all steaks were individually vacuum packaged and aged for their respective time under refrigeration at 2 ± 2°C. After steaks had completed their appropriate aging time, they were frozen in a blast freezer (−30° ± 10°C) for 24 h and then held in a subsequent freezer at −10 ± 2°C until further analysis.

Warner-Bratzler Shear Force

Warner-Bratzler shear force (**WBS**) was completed using the American Meat Science Association (**AMSA**) guidelines (1995), with modifications. Before thawing, frozen weights were recorded for all steaks while in the vacuum-packaged bag. For all samples, frozen steaks were allowed to temper at 2 ± 2°C for 24 h before cooking. Before cooking, steaks were blotted free of any purge and thawed weights were recorded. Thawing loss was calculated by determining the difference in thawed weight and frozen weight. Steaks were broiled on an impingement oven (XLT Impinger, model 3240-TS, BOFI Inc., Wichita, KS) at 200°C to an internal temperature of 68°C. An Atkins AccuTuff 340 thermometer (Atkins Temtec, Gainesville, FL) was used to measure the temperature of each steak as it exited the oven. If the steak had not yet reached 68°C, it was put back on the conveyor until it reached 68°C. All final internal temperatures were recorded, steaks were immediately weighed, and cooked weight was recorded. Cooking loss was determined by calculating the difference between thawed weight and cooked weight. After cooked weights were recorded, steaks were placed on trays and covered and then cooled at 2 ± 2°C for 18 to 24 h. Before coring for WBS, chilled weights were recorded and chilling loss was determined by calculating the difference between cooked weight and chilled weight. Thawing, cooking, and chilling loss were reported as a percentage of the loss determined by taking the loss and dividing it by the initial frozen steak weight. Six cores, 1.27 cm in diameter, were removed parallel to muscle fiber orientation and sheared once perpendicular to the muscle fibers, using a Warner-Bratzler head attached to an Instron Universal Testing Machine (model 4502, Instron Corporation, Canton, MS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/min. Peak load (kg) of each core was recorded by an IBM PS2 (model 55 SX) using software provided by the Instron Corporation. Peak load (kg) for all 6 cores was averaged, and mean peak load (kg) was analyzed for each sample.

Sensory Panel

Strip loin and top round steaks used for sensory evaluation were allowed to temper for 24 h before each session and were then cooked as described above for WBS analysis. After cooking, samples were uniformly cut into 2.54 × 1.27 × 1.27 cm cubes and placed in a cup with the corresponding randomized number. Cups were placed in a warmer (Food Warming Equipment, model PS-1220-15, Crystal Lake, IL) until being served to the panelists.

The sensory panel consisted of 8 trained Oklahoma State University personnel. Panelists were trained on tenderness, juiciness, and 3 specific flavor attributes (Cross et al., 1978). Sensory sessions were conducted twice a day, and each session contained 12 samples. Samples were evaluated using a standard ballot from the AMSA (1995). The ballot consisted of a numerical, 8-point scale for initial and sustained juiciness (8 = extremely juicy, 1 = extremely dry), initial and overall tenderness (8 = extremely tender, 1 = extremely tough), and connective tissue amount (8 = none, 1 = abundant). The flavor attributes of beef, painty/fishy, and livery/metallic were evaluated using a 3-point scale (1 = not detectable, 2 = slightly detectable, 3 = strongly detectable).

During sessions, panelists were randomly seated in individual booths in a temperature controlled room with red lights. The 12 samples were served in a randomized order according to panelist. The panelists were provided distilled, deionized water and unsalted crackers to cleanse their palate.

Statistical Analysis

Carcass Data and Cutout Characteristics. Data were analyzed using the MIXED model procedures (SAS Inst. Inc., Cary, NC). An ANOVA was performed for a completely randomized design, including the fixed main effect of ZH and random effect of individual carcass identification in the model. Carcass side was the experimental unit used for analysis. Least

Table 2. Effects of feeding zilpaterol hydrochloride[1] (ZH) for 20 d on carcass characteristics of calf-fed Holstein steers (n = 102)

	ZH, mg/kg			
Trait	0	8.3	*P*-value	SEM
HCW, kg	351.5	356.0	0.14	2.17
Marbling score[2]	426.0	440.4	0.32	10.1
Adjusted fat thickness, mm	8.87	8.71	0.76	0.363
LM area, cm^2	77.0	79.6	0.07	1.01
KPH, %	2.03	2.02	0.81	0.038
USDA calculated yield grade	2.90	2.79	0.31	0.076

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.

[2] Scores: 300 = slight; 400 = small; 500 = modest.

squares means were generated and separated using a pairwise *t*-test when the model displayed a treatment effect ($\alpha = 0.05$). All data for phase 1 and phase 2 were combined for analysis.

WBS and Moisture Loss. Warner-Bratzler shear force and moisture loss data were analyzed using the MIXED model procedures of SAS using a completely randomized design with the fixed effects of ZH, postmortem aging period, and ZH × aging interaction. Location (anterior vs. posterior) within carcass ID was included in the model as a random effect. When a treatment difference ($P < 0.05$) occurred in internal cooked temperature (in strip loins), internal cooked temperature was included in the model for WBS and moisture loss as a covariate. Least squares means were generated and separated using a pairwise *t*-test when the model displayed a treatment effect ($\alpha = 0.05$).

Trained Sensory Panel. Data collected from sensory panels were analyzed using the MIXED model procedures of SAS using a completely randomized design with fixed effects of ZH, postmortem aging period, and ZH × aging interaction. Location (anterior vs. posterior) within carcass ID was included in the model as random effects. Least squares means were generated and separated using a pairwise *t*-test when the model displayed a treatment effect ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Carcass Data

Carcass data are presented in Table 2. Hot carcass weight was similar ($P > 0.05$) between control and ZH-fed cattle. Although Beckett et al. (2009) reported cattle fed ZH for 20 d had significantly heavier carcasses, the sides utilized in this study were selected to equalize weight. Fat thickness, KPH, USDA calculated YG, as well as marbling score were not affected ($P > 0.05$) by ZH supplementation; however, LM area tended ($P = 0.07$) to be larger in ZH carcasses.

Carcass Cutout

Results of carcass cutout, trim, fat, and bone based on a percentage of CSW and weights are presented in Table 3. Whereas Beckett et al. (2009) reported that feeding ZH increased HCW compared with control groups in the population from which these carcasses were selected, the subsample of carcasses utilized in the current study was chosen to equalize weight; therefore, total side weight was not affected by ZH inclusion into the diet ($P = 0.27$). However, saleable yield (total side weight minus kidney knob fat, total fat trim, and total bone) was increased ($P < 0.01$) by almost 5 kg, and this increase resulted in a 2% increase in percent saleable yield when expressed on a carcass-weight basis. A significant reduction in total fat trim ($P < 0.01$) and total bone ($P < 0.01$) was also documented from carcasses of steers receiving ZH supplementation, resulting in a decrease in the percent fat trim ($P < 0.01$) and percent bone ($P < 0.01$) when expressed as a percentage of carcass weight. Moreover, there was no impact of ZH on any of the 3 lean trim levels measured. Finally, there was a tendency for ZH to decrease ($P = 0.07$) the amount of kidney knob fat; however, when expressed as a percentage of carcass weight, ZH supplementation decreased ($P = 0.03$) kidney knob fat. Whereas in this study, carcass weight was not influenced by ZH supplementation, the ratio in which lean, fat, and bone contributed to carcass weight was affected by ZH inclusion into the diet of calf-fed Holstein steers. The decrease in percent fat trim, bone, and kidney knob fat was counteracted by an increase in carcass lean, which resulted in similar carcass weights as compared with carcasses from control animals.

Results of carcass subprimals and other component parts from the forequarter based on a percentage of CSW and weight are presented in Table 4. When comparing the subprimal yields from the forequarter, few differences due to ZH supplementation were observed. Shoulder clod weights increased ($P < 0.01$) with ZH inclusion into the diet. Also, the total yield of rib blade meat ($P = 0.04$) and inside skirt ($P < 0.01$) increased with ZH inclusion into the diet. However, the yield from rib back ribs ($P = 0.04$) was reduced in ZH-fed steers. When expressed as a percentage of carcass weight, ZH increased the percentage of the shoulder clod ($P < 0.01$) and inside skirt ($P < 0.01$), but reduced the percent yield in rib back ribs ($P = 0.02$). Zilpaterol

Table 3. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet on the amount and percentage[2] of carcass cutout of calf-fed Holstein steers (n = 102)

	ZH, mg/kg			
Trait	0	8.3	*P*-value	SEM
Total side weight, kg	171.55	173.26	0.27	1.10
Saleable yield,[3] kg	115.38	120.32	<0.01	0.77
Saleable yield, %	67.21	69.38	<0.01	0.002
50/50 trim, kg	11.80	11.35	0.55	0.54
50/50 trim, %	6.87	6.53	0.41	0.14
80/20 trim, kg	3.02	3.42	0.18	0.22
80/20 trim, %	1.76	1.98	0.13	0.06
90/10 trim, kg	12.09	12.63	0.24	0.33
90/10 trim, %	7.04	7.30	0.32	0.09
Kidney knob fat, kg	6.48	6.04	0.07	0.17
Kidney knob fat, %	3.77	3.48	0.03	0.05
Total fat trim, kg	13.10	11.49	<0.01	0.35
Total fat trim, %	7.62	6.62	<0.01	0.09
Total bone, kg	36.70	35.53	<0.01	0.09
Total bone, %	21.40	20.52	<0.01	0.06

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.

[2] % listed as a percentage of cold side weight.

[3] Total side weight minus kidney knob fat, total fat trim, and total bone.

also tended to increase ($P = 0.07$) the percentage of rib blade meat.

Table 5 illustrates the results of carcass subprimals and other component parts from the hindquarter based on a percentage of CSW and weight. In the hindquarter, numerous subprimals and muscles responded to ZH inclusion into the diet as recorded weights significantly increased. Weights increased for the strip loin ($P <$

Table 4. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet before slaughter on the amount and percentage[2] of wholesale beef cuts from the forequarter of calf-fed Holstein steers (n = 102)

	ZH, mg/kg			
Item	0	8.3	*P*-value	SEM
Rib blade meat, kg	1.34	1.43	0.04	0.03
Rib blade meat, %	0.35	0.38	0.07	0.01
Ribeye roll, kg	5.19	5.24	0.57	0.06
Ribeye roll, %	1.37	1.37	0.98	0.01
Shoulder clod, trimmed, kg	8.70	9.30	<0.01	0.11
Shoulder clod trimmed, %	2.30	2.44	<0.01	0.02
Chuck shoulder tender, kg	0.42	0.44	0.26	0.01
Chuck shoulder tender, %	0.11	0.12	0.42	0.01
Pectoral meat, trimmed to blue, kg	0.62	0.66	0.13	0.02
Pectoral meat, trimmed to blue, %	0.16	0.17	0.33	0.01
Chuck roll, kg	8.06	8.12	0.70	0.12
Chuck roll, %	2.13	2.13	0.90	0.03
Chuck mock tender, kg	1.49	1.55	0.14	0.03
Chuck mock tender, %	0.39	0.40	0.22	0.01
Brisket whole, boneless packer trim, kg	4.48	4.67	0.14	0.09
Brisket whole, boneless packer trim, %	1.18	1.22	0.20	0.02
Short plate, kg	8.49	8.69	0.41	0.18
Short plate, %	2.24	2.27	0.59	0.04
Outside skirt, kg	0.68	0.68	0.74	0.02
Outside skirt, %	0.18	0.18	0.70	0.01
Inside skirt, kg	1.08	1.20	<0.01	0.02
Inside skirt, %	0.29	0.31	<0.01	0.01
Rib back ribs, kg	1.47	1.38	0.04	0.03
Rib back ribs, %	0.39	0.36	0.02	0.01
Chuck short ribs, boneless, kg	1.57	1.62	0.45	0.05
Chuck short ribs, boneless, %	0.41	0.42	0.53	0.01

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.

[2] % listed as a percentage of cold side weight.

Table 5. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet before slaughter on the amount and percentage[2] of wholesale beef cuts from the hindquarter of calf-fed Holstein steers (n = 102)

	ZH, mg/kg			
Item	0	8.3	*P*-value	SEM
Knuckle, peeled, kg	5.21	5.55	<0.01	0.06
Knuckle, peeled, %	1.38	1.45	<0.01	0.01
Top inside round, kg	9.28	9.99	<0.01	0.11
Top inside round, %	2.46	2.62	<0.01	0.03
Bottom round flat, kg	6.16	6.53	0.01	0.10
Bottom round flat, %	1.63	1.71	0.01	0.02
Eye of round, kg	2.15	2.39	<0.01	0.02
Eye of round, %	0.57	0.63	<0.01	0.01
Heel meat, kg	2.20	2.36	<0.01	0.02
Heel meat, %	0.58	0.62	<0.01	0.01
Strip loin, kg	4.09	4.50	<0.01	0.05
Strip loin, %	1.08	1.18	<0.01	0.01
Top sirloin butt, kg	5.49	5.77	0.01	0.07
Top sirloin butt, %	1.46	1.51	0.04	0.02
Bottom sirloin flap, denuded, kg	1.50	1.51	0.89	0.03
Bottom sirloin flap, denuded, %	0.40	0.39	0.82	0.01
Bottom sirloin ball-tip, denuded, kg	0.49	0.53	0.45	0.03
Bottom sirloin ball-tip, denuded, %	0.13	0.14	0.53	0.01
Bottom sirloin tri-tip, denuded, kg	0.86	0.95	<0.01	0.01
Bottom sirloin tri-tip, denuded, %	0.23	0.25	<0.01	0.01
Peeled tenderloin, side muscle on, kg	2.54	2.83	<0.01	0.03
Peeled tenderloin, side muscle on, %	0.68	0.74	<0.01	0.01
Flank steak, kg	0.90	0.92	0.41	0.02
Flank steak, %	0.24	0.24	0.58	0.01
Shank meat, kg	2.40	2.59	<0.01	0.03
Shank meat, %	0.64	0.68	<0.01	0.01
Elephant ear, kg	1.25	1.19	0.38	0.05
Elephant ear, %	0.33	0.31	0.28	0.01

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.

[2] % listed as a percentage of cold side weight.

0.01), peeled tender ($P < 0.01$), top sirloin butt ($P = 0.01$), bottom sirloin tri-tip ($P < 0.01$), peeled knuckle ($P < 0.01$), top inside round ($P < 0.01$), bottom round flat ($P < 0.01$), eye of round ($P < 0.01$), heel meat ($P < 0.01$), and shank meat ($P < 0.01$). Moreover, when expressed as a percentage of carcass weight, the percent yield increased for strip loin ($P < 0.01$), peeled tender ($P < 0.01$), top sirloin butt ($P = 0.04$), bottom sirloin tri-tip ($P < 0.01$), peeled knuckle ($P < 0.01$), top inside round ($P < 0.01$), bottom round flat ($P = 0.01$), eye of round ($P < 0.01$), heel meat ($P < 0.01$), and shank meat ($P < 0.01$) with ZH inclusion into the diet.

In the present study, an increase in saleable yield was documented and is similar to results reported by Hilton (2009) where calf-fed Holstein steers had a 1% increase in red meat yield when supplemented with ZH. As reported by Shook et al. (2009), there was no impact of ZH supplementation on total fat trim or percent fat trim, which contradicts the present study. Additionally, Shook et al. (2009) reported that ZH supplementation had no impact on 50/50, 80/20, or 90/10 trim levels, which is similar to the response seen in the current study with calf-fed Holstein steers.

Shook et al. (2009) found total bone as well as percent bone decreased in beef steers supplemented with ZH for 20 d, which supports the findings of the present study. Bone mass is maintained at a constant level by balancing bone-resorption and bone-formation phases. Beta-AA receptors are present in human osteoblasts and can regulate bone remodeling (Togari et al., 1997). Arai et al. (2003) first revealed that β-AA actually stimulate bone-resorption in mature human osteoclasts. Furthermore, it has been shown that clenbuterol can decrease bone mineral content (Kitaura et al., 2002), as well as decrease bone mineral density in rats (Bonnet et al., 2005). Because clenbuterol works similarly to ZH, the reduction in bone mass of cattle fed ZH may be explained by β-AA targeting osteoclasts in those cattle to stimulate bone-resorption.

Similar to results summarized by Hilton (2009), as well as Shook et al. (2009), subprimals from the forequarter showed less of a response to ZH supplementation compared with subprimals of the hindquarter. In the present study, only 1 subprimal of major significance in the forequarter responded to ZH as compared with 7 major subprimals that responded to ZH from the hindquarter. As previously reported by Smith et al. (1995), type II muscle fibers show a greater response to β-AA stimulation, and therefore, muscles with a greater amount of type II fibers will have a greater response to

Table 6. Effects of zilpaterol hydrochloride[1] (ZH) and postmortem aging on LM Warner-Bratzler shear force (WBS) values, moisture loss values, and trained panelist sensory scores (n = 108)

	ZH, mg/kg				Aging, d			
Item	0	8.3	SEM	*P*-value	14	21	SEM	*P*-value
Thawing loss,[2] %	7.22	7.23	0.216	0.96	6.91	7.53	0.181	<0.01
Cooking loss,[2] %	22.50	22.80	0.303	0.49	23.88	21.41	0.285	<0.01
Chilling loss,[2] %	1.71	1.53	0.090	0.17	1.53	1.70	0.090	0.18
WBS, kg	3.28	4.10	0.111	<0.01	3.84	3.55	0.096	<0.01
Initial juiciness[3]	4.84	4.62	0.089	0.09	4.76	4.70	0.089	0.59
Sustained juiciness[3]	4.57	4.24	0.090	0.01	4.45	4.36	0.090	0.51
Initial tenderness[4]	6.13	6.13	0.862	0.99	6.23	6.02	0.852	0.86
Overall tenderness[4]	5.46	5.22	0.079	0.04	5.31	5.37	0.078	0.56
Connective tissue[5]	5.64	5.41	0.093	0.09	5.47	5.58	0.088	0.35
Beef flavor[6]	2.64	2.57	0.036	0.19	2.63	2.58	0.034	0.20
Painty/fishy flavor[6]	1.11	1.07	0.016	0.09	1.07	1.11	0.016	0.14
Livery/metallic flavor[6]	1.10	1.10	0.017	0.87	1.09	1.11	0.017	0.42

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.
[2] Expressed as percentage of frozen steak weight.
[3] 1 = extremely dry; 8 = extremely juicy.
[4] 1 = extremely tough; 8 = extremely tender.
[5] 1 = abundant; 8 = none.
[6] 1 = not detectable; 3 = strong.

β-AA supplementation. Kirchofer et al. (2002) reported that the muscles from the chuck have a wide variety of muscle fiber types; moreover, they documented that the muscles from the round are mostly composed of type II (white) muscle fibers. With a greater amount of type II fibers present in the round, it may be suggested that β-AA would have a greater influence on the muscles of the rounds compared with the muscles of the chuck.

Moisture Loss, Shear Force, and Sensory Panel

Strip Loin. Results for ZH and postmortem aging on moisture loss, WBS, and trained sensory panel scores of strip loin steaks are presented in Table 6. No ZH × aging interactions ($P > 0.05$) existed for moisture loss, WBS, or sensory traits for strip loin steaks. Steaks aged for 14 d had significantly less thawing loss but greater cooking loss percentage when compared with steaks aged for 21 d ($P < 0.01$). Zilmax supplementation did not affect moisture loss in strip loin steaks ($P > 0.05$). Control steaks had significantly smaller ($P < 0.01$) WBS values compared with ZH strip steaks, and aging reduced WBS values ($P < 0.01$). Although there was only a tendency ($P = 0.09$) for ZH steaks to have reduced initial juiciness scores, sustained juiciness scores were decreased with ZH supplementation ($P = 0.01$). Panelists initially rated tenderness of control steaks similar to ZH steaks ($P > 0.05$); however, the tendency ($P = 0.09$) to detect a greater amount of connective tissue in ZH steaks appeared to contribute to smaller ($P = 0.04$) overall tenderness scores of ZH steaks compared with control strip steaks. None of the flavor attributes were affected by ZH supplementation or aging period of strip steaks ($P > 0.05$).

Inside Round. Table 7 demonstrates the effects of ZH and postmortem aging on inside round WBS values, moisture loss, and trained sensory panel results. No ZH × aging interactions ($P > 0.05$) existed for moisture loss, WBS, or sensory traits for inside round steaks. Similarly to strip loins, ZH had no effect ($P > 0.05$) on moisture loss percentage; however, aging significantly altered thawing loss and chilling loss, whereas there was a tendency for aging to influence cooking loss percentage ($P = 0.09$). Inside round steaks aged 14 d exhibited greater thawing loss ($P < 0.01$), but less chilling loss ($P = 0.01$) than 21-d-aged steaks. Both aging and ZH supplementation significantly influenced WBS values of inside round steaks ($P < 0.01$). Control animals produced steaks with smaller WBS values than ZH steaks, whereas aging improved tenderness as 21 d steaks exhibited smaller WBS values compared with 14-d-aged steaks. Panelists rated initial and sustained juiciness and initial tenderness similar regardless of ZH supplementation or aging period ($P > 0.05$). Panelists tended ($P = 0.07$) to assign greater overall tenderness scores to control steaks, yet they found no difference ($P > 0.5$) in connective tissue amount between control and ZH steaks. Although panelists initially failed to detect differences ($P > 0.05$) in tenderness of inside round steaks aged 14 and 21 d, they felt 21-d steaks had less connective tissue ($P < 0.01$), resulting in greater overall tenderness scores for 21-d-aged steaks compared with 14-d inside round steaks. None of the flavor attributes were influenced by ZH inclusion or aging period ($P > 0.05$).

Bottom Round. Results for ZH and postmortem aging on moisture loss and WBS values of bottom round steaks are presented in Table 8. No ZH × aging interactions ($P > 0.05$) existed for moisture loss or WBS values for bottom round steaks. Thawing loss was

Table 7. Effects of zilpaterol hydrochloride[1] (ZH) and postmortem aging on inside round Warner-Bratzler shear force (WBS) values, moisture loss values, and trained panelist sensory scores (n = 108)

	ZH, mg/kg				Aging, d			
Item	0	8.3	SEM	*P*-value	14	21	SEM	*P*-value
Thawing loss,[2] %	9.65	10.41	0.358	0.13	10.92	9.14	0.358	<0.01
Cooking loss,[2] %	26.33	25.96	0.310	0.40	25.77	26.52	0.310	0.09
Chilling loss,[2] %	1.42	1.70	0.185	0.29	1.24	1.89	0.180	0.01
WBS, kg	4.97	5.80	0.139	<0.01	5.65	5.11	0.138	<0.01
Initial juiciness[3]	4.64	4.37	0.114	0.10	4.52	4.50	0.102	0.91
Sustained juiciness[3]	4.42	4.17	0.108	0.11	4.29	4.30	0.098	0.90
Initial tenderness[4]	4.49	4.73	0.412	0.69	4.17	5.05	0.407	0.13
Overall tenderness[4]	4.46	4.16	0.116	0.07	4.16	4.46	0.104	0.02
Connective tissue[5]	4.46	4.32	0.123	0.42	4.20	4.58	0.109	<0.01
Beef flavor[6]	2.77	2.70	0.034	0.18	2.76	2.72	0.034	0.40
Painty/fishy flavor[6]	1.07	1.09	0.016	0.41	1.07	1.09	0.015	0.40
Livery/metallic flavor[6]	1.06	1.06	0.013	0.94	1.06	1.06	0.013	0.93

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.
[2] Expressed as percentage of frozen steak weight.
[3] 1 = extremely dry; 8 = extremely juicy.
[4] 1 = extremely tough; 8 = extremely tender.
[5] 1 = abundant; 8 = none.
[6] 1 = not detectable; 3 = strong.

less in control steaks ($P = 0.03$), whereas cooking loss was greater in control steaks ($P = 0.05$), and there was no difference in chilling loss ($P > 0.05$) when compared with ZH bottom round steaks. Aging appeared to exude more influence on moisture loss in bottom round steaks compared with ZH inclusion as thawing, cooking, and chilling loss percentages were all influenced by aging period. Steaks aged 14 d had less thawing loss ($P < 0.01$), yet greater cooking loss ($P < 0.01$) and chilling loss ($P = 0.02$) compared with steaks aged 21 d. Finally, aging steaks 21 d reduced ($P < 0.01$) WBS values compared with 14 d aged steaks; however, ZH did not affect WBS values of bottom round steaks ($P > 0.05$).

In the present study thawing, chilling, and cooking loss were not affected by ZH in LM or inside round steaks; however, ZH increased thawing loss but reduced cooking loss in bottom round steaks. Previous studies (Hilton et al., 2009; Kellermeier et al., 2009; Leheska et al., 2009) of ZH effects on LM tenderness did not report differences in LM cooking loss. In the present study LM and inside round WBS values were increased in ZH steaks, whereas there was no difference in bottom round steaks; however, 7 d of additional aging reduced WBS values of 21 d steaks from all 3 subprimals. Previous reports (Strydom et al., 1998; Hilton et al., 2009; Kellermeier et al., 2009; Shook et al., 2009) of ZH effects on LM WBS values were similar to the results of the current study, although semitendinosus WBS values were not affected by ZH inclusion. Zilpaterol is known to cause muscle hypertrophy, which correlates to an increase in the diameter of muscle fibers (Mills, 2002). This increase in muscle fiber diameter can lead to a subsequent decrease in objective and subjective measures of tenderness. Moreover, Mills (2002) indicated that β-AA alter muscle metabolism to favor a greater proportion of fast-twitch muscle due to altered protein metabolism and increased blood flow to skeletal muscles. This increase in fast-twitch muscle fibers could also lead to a decrease in tenderness as Seideman and Theer (1986) documented a positive correlation between the percentage of white fiber number and area with sensory tenderness ratings. Although there were differences in WBS values of LM and inside round steaks, panelists failed to detect a difference in initial tenderness between ZH and control steaks. However, panelists rated

Table 8. Effects of zilpaterol hydrochloride[1] (ZH) and postmortem aging on bottom round Warner-Bratzler shear force (WBS) and moisture loss values (n = 108)

	ZH, mg/kg				Aging, d			
Item	0	8.3	SEM	*P*-value	14	21	SEM	*P*-value
Thawing loss,[2] %	7.49	8.04	0.173	0.03	7.03	8.50	0.163	<0.01
Cooking loss,[2] %	22.95	22.21	0.442	0.05	24.78	22.38	0.427	<0.01
Chilling loss,[2] %	1.86	1.83	0.150	0.91	2.05	1.64	0.135	0.02
WBS, kg	7.02	7.71	0.333	0.15	7.68	7.06	0.262	<0.01

[1] Zilmax, Intervet Schering Plough, DeSoto, KS.
[2] Expressed as percentage of frozen steak weight.

LM overall tenderness less in ZH steaks. In the present study, all LM sensory juiciness and flavor variables were unaffected except a reduction in sustained juiciness of ZH steaks. Inside round sensory variables of tenderness, juiciness, and flavor were not altered by ZH. Hilton et al. (2009) reported decreased scores for LM sensory juiciness, tenderness, and beef flavor, but felt those differences may be attributed to the decreased marbling of ZH carcasses, which did not exist in the current study. However, Leheska et al. (2009) also reported a decrease in scores for trained sensory traits of tenderness, juiciness, and flavor of cattle fed ZH, attributing these differences to modifications in protein structure or function caused by ZH.

Shackelford et al. (1997) determined LM steaks aged 14 d were intermediate in tenderness when steaks had WBS values less than 4.8 kg. Although LM steaks from ZH cattle were tougher than control steaks, steaks from ZH steers had an average WBS value of 4.10 kg with trained panelists rating ZH steaks slightly to moderately tender. According to results of Hilton et al. (2009), although consumers detected differences in tenderness scores, consumer tenderness and overall acceptability were not affected by ZH treatment. Shackelford et al. (1991) reported a WBS value of 4.6 kg was 88.6% accurate at predicting consumer acceptance of beef tenderness, whereas Miller et al. (2001) reported WBS tenderness values of <3.0, 3.4, 4.0, 4.3, and 4.9 kg resulting in 100, 99, 94, 86, and 25% consumer satisfaction for beef tenderness. Based on these studies and the results from the LM trained sensory panels in the present study, although ZH reduced tenderness in LM and inside round steaks, consumer acceptance should not be adversely affected by the tenderness of beef from cattle supplemented with ZH.

In conclusion, ZH, when fed for the last 20 d of the finishing phase at 8.3 mg/kg (DM basis), had a positive impact on carcass cutability in calf-fed Holstein steers, especially noting the significant increase in lean muscle accretion in the hindquarter of the animal. However, ZH supplementation during the final portion of the finishing phase had a negative impact on tenderness in LM and inside round steaks. Fortunately, this tenderness difference does not adversely affect the classification (tender or tough) given to each steak; however, future studies should focus on the interaction of postmortem tenderization techniques to evaluate their effects on improving beef tenderness in cattle supplemented with β-AA. Learning how to counteract the negative impacts of β-AA on tenderness will allow the beef industry to take full advantage of the improvements in performance and carcass cutability from using these products in the finishing diets of beef cattle.

LITERATURE CITED

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. Natl. Livest. Meat Board, Chicago, IL.

Arai, M., T. Nagasawa, Y. Koshihara, S. Yamamoto, and A. Togari. 2003. Effects of β-adrenergic agonists on bone-resorbing activity in human osteoclast-like cells. Biochim. Biophys. Acta 1640:137–142.

Beckett, J. L., R. J. Delmore, G. C. Duff, D. A. Yates, D. M. Allen, T. E. Lawrence, and N. Elam. 2009. Effects of zilpaterol hydrochloride on growth rates, feed conversion, and carcass traits in calf-fed Holstein steers. J. Anim. Sci. 87:4092–4100.

Bonnet, N., C. L. Benhamou, B. Brunet-Imbault, A. Arlettaz, M. N. Horcajada, O. Richard, L. Vico, K. Collomp, and D. Courteix. 2005. Severe bone alterations under β2 agonist treatments: Bone mass, microarchitecture and strength analyses in female rats. Bone 37:622–633.

Chikhou, F. H., A. P. Moloney, P. Allen, R. L. Joseph, P. V. Tarrant, J. F. Quirke, F. H. Austin, and J. F. Roche. 1993. Long-term effects of cimaterol in Friesian steers: II. Carcass composition and meat quality. J. Anim. Sci. 71:914–922.

Cross, H. R., R. Moen, and M. Stanfield. 1978. Training and testing judges for sensory analysis of meat quality. Food Technol. 32: 48–54.

Hilton, G. G. 2009. Effect of zilpaterol hydrochloride on fabrication yields of beef and calf-fed Holstein steer. Application of zilpaterol hydrochloride in the beef industry: Technical Symposium. Proc. 62nd Reciprocal Meats Conf., Rogers, AR.

Hilton, G. G., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, J. R. Blanton Jr., and M. F. Miller. 2009. Effects of feeding zilpaterol hydrochloride with and without monensin and tylosin on carcass cutability and meat palatability of beef steers. J. Anim. Sci. 87:1394–1406.

Kellermeier, J. D., A. W. Tittor, J. C. Brooks, M. L. Galyean, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, B. J. Johnson, and M. F. Miller. 2009. Effects of zilpaterol hydrochloride with or without and estrogen-trenbolone acetate terminal implant on carcass traits, retail cutout, tenderness, and muscle fiber diameter in finishing steers. J. Anim. Sci. 87:3702–3711.

Kirchofer, K. S., C. R. Calkins, and B. L. Gwartney. 2002. Fiber-type composition of muscles of the beef chuck and round. J. Anim. Sci. 80:2872–2878.

Kitaura, T., N. Tsunekawa, and W. J. Kraemer. 2002. Inhibited longitudinal growth of bones in young male rats by clenbuterol. Med. Sci. Sports Exerc. 34:267–273.

Knapp, R. H., C. A. Terry, J. W. Savell, H. R. Cross, W. L. Mies, and J. W. Edwards. 1989. Characterization of cattle types to meet specific beef targets. J. Anim. Sci. 76:2294–2308.

Leheska, J. M., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. Streeter, J. R. Blanton, and M. F. Miller. 2009. Dietary zilpaterol hydrochloride. II. Carcass composition and meat palatability of beef cattle. J. Anim. Sci. 87:1384–1393.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062–3068.

Mills, S. E. 2002. Biological basis of the ractopamine response. J. Anim. Sci. 80(E. Suppl. 2): E28–E32.

Moloney, A. P., P. Allen, D. B. Ross, G. Olson, and E. M. Convey. 1990. Growth, feed efficiency and carcass composition of finishing Friesian steers fed the β-adrenergic agonist L-$_{644,969}$. J. Anim. Sci. 68:1269–1277.

Ricks, C. A., R. H. Dalrymple, P. K. Baker, and D. L. Ingle. 1984. Use of a β-agonist to alter fat and muscle deposition in steers. J. Anim. Sci. 59:1247–1255.

Seideman, S. C., and L. K. Theer. 1986. Relationships of instrumental textural properties and muscle fiber types to the sensory properties of beef. J. Food Qual. 9:251–261.

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289–296.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1997. Tenderness classification of beef: I. Evaluation of beef longissimus shear force at 1 or 2 days postmortem as a predictor of aged beef tenderness. J. Anim. Sci. 75:2417–2422.

Shook, J. N., D. L. VanOverbeke, L. A. Kinman, C. R. Krehbiel, B. P. Holland, M. N. Streeter, D. A. Yates, and G. G. Hilton. 2009. Effects of zilpaterol hydrochloride and zilpaterol hydrochloride withdrawal time on beef carcass cutability, composition, and tenderness. J. Anim. Sci. 87:3677–3685.

Smith, G. C., J. W. Savell, J. B. Morgan, and T. E. Lawrence. 2006. Report of the June – September, 2005 National Beef Quality Audit: A benchmark for the U.S. Beef Industry. Pages 6–11 in Proc. 38th Beef Improvement Federation, Choctaw, MS. Mississippi State Univ., Mississippi State.

Smith, S. B., S. K. Davis, J. J. Wilson, R. T. Stone, F. Y. Wu, D. K. Garcia, D. K. Lunt, and A. M. Schiavetta. 1995. Bovine fast-twitch myosin light chain 1: Cloning and mRNA amount in muscle of cattle treated with clenbuterol. Am. J. Physiol. 268:E858–E865.

Strydom, P. E., E. H. Osler, E. Nel, and K. J. Leeuw. 1998. The effect of supplementation period of a beta-agonist (zilpaterol) on growth performance, carcass yield, and meat quality characteristics. Pages 894–895 in Proc. 44th Int. Congr. Meat Sci. Technol., Barcelona, Spain.

Togari, A., M. Arai, S. Mizutani, S. Mizutani, Y. Koshihara, and T. Nagatsu. 1997. Expression of mRNAs for neuropeptide receptors and beta-adrenergic receptors in human osteoblasts and human osteogenic sarcoma cells. Neurosci. Lett. 233:2–3.

USDA. 1997. Official United States Standards for Grades of Carcass Beef. Agric. Mark. Serv., USDA, Washington, DC.