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Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers

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ABSTRACT: Experiments were conducted at 3 US locations (CA, ID, and TX) to determine the effects of dietary zilpaterol hydrochloride (Zilmax, Intervet Inc., Millsboro, DE) and duration of zilpaterol feeding on performance and carcass merit of finishing steers and heifers. At each site, 160 steers and 160 heifers were stratified within sex by initial BW (study d −1) and assigned randomly within BW strata to 1 of 4 treatments in a randomized complete block design (4 blocks/treatment for each sex). The 4 treatments were arranged in a 2 (no zilpaterol vs. zilpaterol) × 2 (20 or 40 d duration of zilpaterol feeding) factorial arrangement of treatments. When included in the diet, zilpaterol was supplemented at 8.3 mg/kg of DM. Each pen consisted of 10 animals. Each animal was individually weighed unshrunk on d 1, 21 or 41, and 66 of the experiment. Following d 66, cattle were slaughtered and carcass data collected. Feeding zilpaterol increased ($P < 0.01$) final BW of steers and heifers by 11.6 and 6.7 kg, respectively. In addition, feeding zilpaterol hydrochloride increased ($P \leq 0.001$) ADG 36 and 18%, and increased ($P < 0.001$) G:F 28 and 21% for steers and heifers, respectively. For heifers, DMI was decreased ($P < 0.001$) 6.2% when zilpaterol was fed, whereas in steers DMI tended ($P = 0.09$) to be decreased 2%. For steers and heifers, feeding zilpaterol increased ($P < 0.001$) HCW 16.4 and 12.1 kg, dressing percentage 1.5 percentage units for each sex, and LM area 8.23 and 6.37 cm^2, respectively. Twelfth-rib fat ($P \geq 0.12$) and KPH ($P \geq 0.70$) were not affected by feeding zilpaterol to steers or heifers. Feeding zilpaterol decreased (i.e., improved; $P = 0.02$) calculated yield grade of steer and heifer carcasses. Marbling score ($P = 0.002$) and quality grade ($P = 0.002$) were decreased when zilpaterol hydrochloride was fed to steers, and the decrease in marbling score and quality grade tended to be greater when zilpaterol was fed for 40 compared with 20 d (zilpaterol × duration interaction, $P = 0.07$). For heifers, marbling score tended ($P = 0.07$) to be decreased and quality grade was decreased ($P = 0.05$) when zilpaterol hydrochloride was fed. In general, it appears from these data that zilpaterol hydrochloride fed for 20 to 40 d at the end of the finishing period enhances growth performance and carcass muscle deposition for steers and heifers.

Key words: beef cattle, β-adrenergic agonist, carcass characteristic, finishing performance, zilpaterol

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INTRODUCTION

The use of β-adrenergic agonists (**βAA**) to improve the efficiency of animal production has been of interest to researchers for over 20 yr. Zilpaterol hydrochloride is a new βAA pharmaceutical commercially available in Mexico, the Republic of South Africa, and the United States as Zilmax (Intervet Inc., Millsboro, DE). Although other βAA such as clenbuterol, L-$_{644,969}$, cimaterol, and ractopamine hydrochloride have been shown to increase ADG and G:F as well as to affect several carcass characteristics (Ricks et al., 1984; Moloney et al., 1990; Chikhou et al., 1993b), fewer data have been reported on zilpaterol hydrochloride. Casey et al. (1997) was the first to report that zilpaterol hydrochloride improved feed efficiency and increased feedlot steer ADG, dressing percent, HCW, and LM area. The authors showed that effects of zilpaterol hydrochloride on ADG were additive with implants (120 mg of trenbolone acetate and 24 mg of estradiol), whereas effects on HCW and LM area were synergistic with implants.

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Strydom et al. (1998), Plascencia et al. (1999), and Avendaño-Reyes et al. (2006) also reported that zilpaterol hydrochloride was effective in increasing G:F, dressing percent, and HCW, whereas marbling was not affected by feeding zilpaterol hydrochloride.

The objectives of these experiments were to determine the effects of zilpaterol hydrochloride on performance and carcass characteristics when fed to steers and heifers at the minimum and maximum (20 vs. 40 d) treatment durations, and to increase performance and carcass information available about zilpaterol hydrochloride in steers and heifers fed in the United States. Additional effects of zilpaterol hydrochloride on carcass muscle deposition and beef tenderness using samples obtained from cattle in the present experiment were reported by Leheska et al. (2009).

MATERIALS AND METHODS

Animals were handled in compliance with applicable local regulations and in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

Cattle

Experiments were conducted using 480 steers and 480 heifers at 3 study locations (Reedley, CA; Parma, ID; and Canyon, TX) selected to represent different cattle feeding areas in the United States. Cattle were medium to large frame and predominantly *Bos taurus*-English or *Bos taurus*-Continental crosses. Steers arrived on March 12, 2002 (arrival BW = 358 ± 30 kg), April 3 to 15, 2002 (arrival BW = 376 ± 34 kg), and June 18, 2002 (arrival BW = 395 ± 25 kg) at the TX, ID, and CA sites, respectively. Heifers arrived on March 11, 2002 (arrival BW = 297 ± 35 kg), April 17, 2002 (arrival BW = 364 ± 34 kg), and June 20, 2002 (arrival BW = 347 ± 30 kg) at the TX, ID, and CA sites, respectively. Cattle were received and processed according to routine management procedures used at each experiment site within 7 d of arrival. Cattle were given an individually numbered ear tag, vaccinated with Titanium 5 vaccine (AgriLabs Ltd., St. Joseph, MO) and Vision 7 vaccine with Spur adjuvant (Intervet), treated for internal parasites with Safe-Guard dewormer (Intervet), and individual BW were recorded (a single-animal scale was mounted on 4 load cells and calibrated with certified weights before use). All male animals were inspected for the presence of intact testicles, and bulls were excluded from use in the study. Heifers at the TX and ID site were pregnancy-tested and treated with an abortifacient drug (Prostamate, Phoenix Scientific Inc., St. Joseph, MO) if they were found to be pregnant. At the CA site all the heifers were treated with an abortifacient drug (Prostamate) as the heifers had been commingled with a bull before arrival at the feedlot site, and then they were confirmed nonpregnant after treatment with the abortifacient. Both ears of each animal were palpated and confirmed devoid of implants. No anabolic implants or the feed additive melengestrol acetate were used at any time during this experiment. Following processing, cattle were housed by sex in large soil-surfaced floor pens and fed a starter diet. During the adaptation period cattle initially received a forage-based receiving diet, were checked daily for disease, and were provided medical treatment as needed. During the adaptation cattle were stepped up to the final finishing diet (Table 1).

Following the adaptation/growth period (67 or 68 d before slaughter), 160 steers and 160 heifers were selected from a larger population of cattle at each experiment site. For all experiments, animals were stratified within sex by initial BW (study d −1) and assigned randomly within BW strata to 1 of the 4 treatments in a randomized complete block design (4 blocks/treatment for each sex). The 4 treatments were arranged in a 2 (no zilpaterol hydrochloride vs. zilpaterol hydrochloride; 8.3 mg/kg, DM basis) × 2 (20 or 40 d duration of zilpaterol hydrochloride feeding) factorial arrangement of treatments. Animals were sorted to a newly assigned dirt floor pen (d 1 of the experiment). The pens were of sufficient size to provide at least 11.5, 10.2, or 8.7 m^2 of space/animal at the CA, ID, and TX sites, respectively. Each pen consisted of 10 animals of the same sex. Each animal was individually weighed unshrunk on d 1, 21 or 41, and 66 of the study.

Diets

Ingredient and nutrient composition of the concentrate diet that was fed throughout the 66-d feeding study for each experiment site are shown in Table 1. Each of the diets were supplemented at 2.5% (as fed) with a premix consisting of zilpaterol hydrochloride and ground corn. The treatment premix was calculated to provide 8.3 mg/kg of DM of zilpaterol hydrochloride in the final finishing diet. For the control premix, the same amount of ground corn as the treatment premix was used and the zilpaterol hydrochloride was substituted with 814 Grit-O'Cobs (The Andersons, Maumee, OH). The premixes at the CA and ID sites were manufactured by mixing ground corn and zilpaterol hydrochloride or Grit-O'Cobs for 15 min at the CA site or 8 min at the ID site in a 1,815-kg model S-30 Davis mixer (H. C. Davis Sons Manufacturing Co. Inc., Bonner Springs, KS). At the TX site the premixes were manufactured in a model 280 Oswalt mixer (J-Star, Fort Atkinson, WI) by mixing for 3 min. At the CA site the premixes were bagged in double-lined Kraft paper bags; at the ID site the premixes were stored in 132.5-L plastic containers, and at the TX site the premixes were stored in 208.2-L metal drums.

At the CA site the treatment diets were mixed in a 45,635-kg capacity model NDE 600 mixer (New Direction Equipment Co., Sioux Falls, SD) for 15 min. After the treatment diets were mixed they were allotted to

Table 1. Composition of treatment finishing diets among the different study sites

	Experimental site		
Item	California	Idaho	Texas
Ingredient, as-fed basis, %			
Dry-rolled corn	38.2	—	—
Dry-rolled barley	38.2	—	—
Dry-rolled wheat	—	40.5	—
Steam-flaked corn	—	—	75.5
Earlage	—	42.0	—
Alfalfa hay	7.00	4.50	6.00
Corn silage	8.00	—	—
Cottonseed hulls	—	—	2.50
Cottonseed meal	—	—	2.50
Canola meal	—	2.30	–
Animal/vegetable fat	—	3.00	2.00
Molasses blend	—	–	4.00
Ground corn premix	2.50	2.50	2.50
Calcium carbonate	1.00	—	—
Trace mineralized salt[1]	0.20	—	—
Vitamin/trace mineral premix[2]	5.00	5.20	5.00
Nutrient composition, DM basis[3]			
DM, %	82.4	82.4	80.8
NE_m Mcal/kg	1.85	2.16	2.17
NE_g Mcal/kg	1.25	1.54	1.50
CP, %	13.4	13.8	13.5
CP from NPN, %	31.1	21.2	21.0
Crude fiber, %	6.3	6.3	5.7
NDF, %	17.3	19.7	17.3
ADF, %	9.0	9.6	7.6
Ether extract, %	1.9	6.2	5.9
Ca, %	0.70	0.88	0.73
P, %	0.35	0.37	0.35
Mg, %	0.17	0.18	0.18
Na, %	0.18	0.61	0.17
K, %	0.80	0.62	0.73
S, %	0.17	0.24	0.27
Mn, mg/kg	24.4	43.9	40.0
Co, mg/kg	0.34	0.40	1.47
Cu, mg/kg	6.7	15.2	19.4
Zn, mg/kg	29.8	85.5	105.5

[1]Contained: Salt, zinc oxide, ferrous carbonate, manganous oxide, magnesium oxide, copper sulfate, calcium iodate, cobalt carbonate, mineral oil, and red iron oxide for color. Calculated analysis provided by the manufacturer was as follows (DM basis): NaCl, 95.5%; Zn, 3,500 mg/kg; Fe, 2,000 mg/kg; Mn, 1,800 mg/kg; Cu, 280 mg/kg; I, 100 mg/kg; and Co, 60 mg/kg.

[2]California site contained: 64.88% soybean meal, 11.25% canola pellets, 10.00% ground almond shells, 3.75% limestone, 3.75% cane molasses, 2.50% wheat millrun, 1.50% salt, 1.25% dicalcium phosphate (21% P), 0.50% vitamin ADE, 0.375% calf trace mineral, and 0.25% vitamin B premix. Idaho site guaranteed analysis: 50% minimum CP (not more than 48.15% NPN), 8 to 9% NaCl, 10.5 to 11.5% Ca, 0.30% minimum P, vitamin A minimum 88,184 IU/kg, vitamin D_3 minimum 8,818 IU/kg, vitamin E minimum 110 IU/kg, and Se 2.6 mg/kg. Texas site contained: 53.36% wheat middlings, 3.20% ammonium sulfate, 1.20% rice mill by-product, 3.70% salt, 14.20% urea (288% CP), 2.45% potassium chloride (52% K), 20.70% calcium carbonate (38% Ca), 0.16% vitamin A (44,092,000 IU/kg), 0.026% vitamin E (275,575 IU/kg), 0.0005% vitamin D (176,368,000 IU/kg), and 1.00% trace mineral.

[3]Nutrient values are based on tabular values for individual feed ingredients (NRC, 1996) except for DM, CP, crude fiber, Ca, and P, which are laboratory results. Values of trace minerals (Mn, Co, Cu, and Zn) are calculated from individual feed ingredients and do not include the amount of each element supplied by trace mineral salt or mineral supplement.

the individual pens. At the ID site the treatment diet was mixed in a model V-19 Harsh paddle mixer (Harsh International Inc., Eaton, CO) for 5 min. After mixing was complete the treatment diets were loaded into 1 of 12 approximately 900-kg feed bins on a compartmentalized feed truck. The diet in each feed bin on the feed truck was then delivered via a metal conveyor belt to individual pens. At the TX site the total mixed ration (consisting of all the feed ingredients except the premix) was mixed in a model 340 Oswalt auger mixer (J-Star) for 3 min. After mixing the total mixed ration was unloaded. Next, for each treatment diet the total mixed ration and respective premix were combined and mixed in the model 340 Oswalt auger mixer (J-Star) for 3 min. After each of the treatment diets was mixed, it was allotted to the respective individual pens.

For each of the sites each feed bunk was evaluated visually at approximately 0600 to 0700 h daily. The quantity of feed remaining in each bunk was estimated, and the daily allotment of feed for each pen was recorded. This bunk-reading process was designed to allow for little or no accumulation of unconsumed feed (0 to 0.5 kg/pen). Feed bunks were cleaned, and unconsumed feed was weighed on d 11, 21, 31, 41, 51, 61, and 67. Orts were composited by treatment, and DM content of bunk orts samples was determined in a forced-air oven by drying overnight at 100°C. In addition, daily samples of the treatment diets were taken starting on study d 1. In 10-d increments the different treatment diets were combined, and DM determinations of the 10-d feed bunk samples were used to calculate DMI and G:F for each pen. Additionally, the 10-d composites were analyzed for ash, CP, ADF, Ca, and P (AOAC, 1990).

Experimental Treatments

Cattle were adapted to a basal final finishing diet for varying durations at the different sites. Once adapted, cattle were fed the basal final finishing diet for 37, 68, or 61 d before study d 1 at the CA, ID, and TX sites, respectively. The basal finishing diet was similar to the treatment diet shown in Table 1, except that the basal diet contained monensin (Rumensin; Elanco Animal Health, Indianapolis, IN) at approximately 360 mg/(animal·d) and tylosin (Tylan; Elanco Animal Health) at approximately 90 mg/(animal·d). In addition, instead of the 2.5% premix, the basal diets contained an additional 2.5% (as-fed basis) dry rolled corn/barley (50% each), dry rolled wheat, or steam flaked corn at the CA, ID, and TX sites, respectively. After sorting, weighing, and allotting cattle to their final pens on study d 1, all cattle were fed the basal final finishing diet for an additional 20 d (study d 1 through 20) before feeding the experimental treatment diets. Therefore, the basal finishing diet fed at each site was fed from 37 to 68 d following diet adaptation, and for an additional 20 d after cattle were sorted into their final pens. On study d 21, cattle from the 40-d treatment durations were weighed and returned to their treatment pens. Cattle in the 40-d treatment duration then were fed the control or zilpaterol hydrochloride treatment diets. Treatment diets for the 40-d duration group continued daily for the next 40 d. On study d 21, cattle from the 20-d treatment durations were not weighed and continued to receive the basal finishing diet, which included monensin and tylosin. On d 41 only cattle from the 20-d treatment durations were weighed and returned to their pens. Cattle in the 20-d treatment duration were then fed the control or zilpaterol hydrochloride treatment diets. Treatment diets for the 20-d duration group continued daily for the next 20 d. None of the treatment diets (control or zilpaterol hydrochloride) contained monensin or tylosin. On d 61, all cattle at each site were fed the control diet without monensin or tylosin as a withdrawal diet. Feeding of the withdrawal diet continued for 5 consecutive days to d 65. On d 66, all cattle were weighed before feeding. After being weighed cattle were returned to their respective pens and given access to the withdrawal (control) diet.

Slaughter and Carcass Evaluation

At the CA site cattle were loaded onto trucks on d 67 and transported approximately 1,603 km to the slaughter facility. Cattle were unloaded at approximately 0000 h on d 68 and then slaughtered at 0600 h. At the ID site cattle were loaded onto trucks on d 66 and transported approximately 410 km to the slaughter facility. Cattle were unloaded at approximately 0000 h on d 67 and slaughtered at 0600 h. At the TX site cattle were loaded on to trucks on d 67 and transported approximately 101 km to the slaughter facility. Cattle were unloaded at approximately 1300 h on d 67 and then slaughtered at 1500 h. For each site cattle were slaughtered using approved humane techniques. Hot carcass weight and liver abscess scores (liver abscesses vs. none) were collected at slaughter.

Carcasses were spray-chilled for approximately 24 h (1°C) for the CA and ID carcasses and for approximately 36 h (1°C) for the TX site carcasses. After chilling, carcasses were ribbed at the 12th rib, and USDA quality and yield grades and traits were recorded (USDA, 1997). Carcasses were evaluated for skeletal maturity, lean maturity, overall maturity, marbling score, lean color, fat thickness at the 12th rib, adjusted preliminary yield grade, LM area, percentage of KPH, and the incidence of dark cutting beef (USDA, 1997). Masculinity was evaluated according to Herschler et al. (1995) using a 9-point scale (1 = least masculine; 9 = most masculine). Dressing percentage and yield grades were calculated.

Calculations and Statistical Analyses

Initial BW was unshrunk BW measured on d 21 (40-d duration) or d 41 (20-d duration). Initial and final BW were pencil shrunk 4% for calculating ADG. Carcass-adjusted final BW was calculated as HCW divided by the average dressing percent of all animals within sex and treatment. Carcass-adjusted ADG and G:F were calculated from carcass-adjusted final BW and days on experimental treatment (25 or 45 d including the 5-d withdrawal). Feedlot performance and carcass trait data were analyzed using a 2 (no zilpaterol hydrochloride vs. zilpaterol hydrochloride) × 2 (20 or 40 d duration of zilpaterol hydrochloride feeding) factorial arrangement of treatments in a randomized complete block design, where a pen of 10 animals was the experimental unit. Data for steers and heifers were analyzed separately. For the pooled analysis, the ANOVA was performed using the MIXED procedure (SAS Inst. Inc., Cary, NC). Heterogeneity among experiment locations was tested using a residual and random component.

Table 2. Effects of zilpaterol hydrochloride (Zilmax, Intervet Inc., Millsboro, DE) and duration of zilpaterol hydrochloride feeding on feedlot performance of steers

	20 d		40 d			*P*-value		
Item	No Zilpaterol	Zilpaterol	No Zilpaterol	Zilpaterol	SEM	Duration (D)	Zilpaterol (Z)	D × Z
Initial BW, kg	537	535	512	510	13	<0.001	0.30	0.85
Final BW, kg	564	574	566	580	19	0.24	0.006	0.48
Carcass-adjusted final BW,[1] kg	564	571	566	583	19	0.06	0.009	0.14
Performance								
Total BW gain, kg	26.9	38.8	54.1	69.5	5.7	<0.001	<0.001	0.44
ADG, kg/d	1.08	1.55	1.20	1.54	0.16	0.26	<0.001	0.21
DMI, kg/d	8.95	8.78	9.23	8.99	0.41	0.05	0.09	0.77
G:F, kg/kg	0.120	0.176	0.129	0.171	0.012	0.65	<0.001	0.17
Carcass-adjusted performance[2]								
ADG, kg/d	1.07	1.42	1.21	1.62	0.17	0.01	<0.001	0.64
G:F, kg/kg	0.119	0.161	0.130	0.179	0.012	0.02	<0.001	0.63

[1]Carcass-adjusted final BW was calculated as HCW/average dressing percent of each treatment.

[2]Carcass-adjusted ADG and G:F were calculated from carcass-adjusted final BW and days on experimental treatment (25 or 45 d including the 5-d withdrawal).

Because no experiment heterogeneity was observed, an unweighted mixed model analysis was conducted for all response variables. The model included $y_{ijklm} = \mu + L_i + D_j + T_k + (DT)_{jk} + B_l(L_i) + (LD)_{ij} + (LT)_{ik} + (LDT)_{ijk} + e_{ijkl}$, where y is the observed value, μ is the total mean, L is the random effect of location, D is the fixed effect of treatment duration, T is the fixed effect of zilpaterol hydrochloride treatment, B(L) is the random effect of block within location, and e is the residual variation. Categorical data (USDA Quality and Yield grades, liver abscesses, and dark cutters) were analyzed using the CATMOD procedure of SAS.

RESULTS

At the CA site, a heifer in the 40-d duration zilpaterol hydrochloride treatment died due to a localized abscess in the diaphragm during the acclimation phase of the study before βAA treatment. At the ID site, a heifer in the 20-d duration zilpaterol hydrochloride treatment was removed from the study due to severe laminitis and lameness during the acclimation of the study before βAA treatment. Additionally, at the ID site, a steer in the 40-d zilpaterol hydrochloride treatment died due to acute tympanitis during the withdrawal feeding period after the βAA treatment. No animals died at the TX site.

Performance

Steers. There were no zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interactions ($P \geq 0.14$) for performance data in steers (Table 2). Feeding zilpaterol hydrochloride increased final (11.6 kg; $P = 0.006$) and carcass-adjusted final (11.5 kg; $P = 0.009$) BW of steers. In addition, ADG and G:F were increased ($P < 0.001$) 36 and 28%, respectively, for steers fed zilpaterol hydrochloride. Dry matter intake tended ($P = 0.09$) to be 2% less when zilpaterol hydrochloride was fed to steers. Feeding zilpaterol hydrochloride increased ($P < 0.001$) carcass-adjusted ADG and carcass-adjusted G:F of steers by 33 and 26%, respectively.

By design, initial BW and therefore total BW gain were greater ($P < 0.001$) for steers fed for the 40-d duration compared with steers fed for the 20-d duration (Table 2). However, duration of feeding did not affect final BW ($P = 0.24$), ADG ($P = 0.26$), or G:F ($P = 0.65$) in steers. Steers fed for the 40-d duration had greater ($P = 0.05$) DMI than steers fed for the 20-d duration.

Heifers. With the exception of total BW gain ($P = 0.02$), there were no zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interactions ($P \geq 0.38$) for performance data in heifers (Table 3). Feeding zilpaterol hydrochloride increased final (6.7 kg; $P = 0.009$) and carcass-adjusted final (6.8 kg; $P < 0.001$) BW of heifers. In addition, heifers fed zilpaterol hydrochloride for 40 d had greater total BW gain over controls (10.1 kg) than heifers fed zilpaterol hydrochloride for 20 d (5.3 kg; zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interaction, $P = 0.02$). For heifers, ADG was increased ($P = 0.001$) 18%, DMI was decreased ($P < 0.001$) 6%, and G:F was increased ($P < 0.001$) 21% when zilpaterol hydrochloride was fed. Feeding zilpaterol hydrochloride increased carcass-adjusted ADG ($P = 0.003$) and carcass-adjusted G:F ($P < 0.001$) of heifers by 20 and 21%, respectively.

By design, initial BW and therefore total BW gain were greater ($P < 0.001$) for heifers fed for the 40-d duration compared with heifers fed for the 20-d duration (Table 3). In addition, heifers on the 40-d treatment tended ($P = 0.08$) to have greater final BW and had greater ($P = 0.002$) carcass-adjusted final BW compared with heifers fed for 20 d. Duration of feeding did not affect ADG ($P = 0.55$) or G:F ($P = 0.23$). Similar to steers, heifers fed for the 40-d duration had greater ($P = 0.004$) DMI than heifers fed for the 20-d duration.

Table 3. Effects of zilpaterol hydrochloride (Zilmax, Intervet Inc., Millsboro, DE) and duration of zilpaterol hydrochloride feeding on feedlot performance of heifers

	20 d		40 d			*P*-value		
Item	No Zilpaterol	Zilpaterol	No Zilpaterol	Zilpaterol	SEM	Duration (D)	Zilpaterol (Z)	D × Z
Initial BW, kg	482	482	462	460	21	<0.001	0.49	0.43
Final BW, kg	510	516	513	521	24	0.08	0.009	0.50
Carcass-adjusted final BW,[1] kg	509	514	514	522	24	0.002	<0.001	0.38
Performance								
Total BW gain, kg	28.7	34.0	50.3	60.4	3.1	<0.001	<0.001	0.02
ADG, kg/d	1.15	1.36	1.12	1.34	0.10	0.55	0.001	0.85
DMI, kg/d	8.56	8.07	8.87	8.34	0.58	0.004	<0.001	0.83
G:F, kg/kg	0.134	0.168	0.126	0.162	0.005	0.23	<0.001	0.89
Carcass-adjusted performance[2]								
ADG, kg/d	1.10	1.31	1.14	1.38	0.10	0.30	0.003	0.72
G:F, kg/kg	0.129	0.160	0.129	0.165	0.006	0.67	<0.001	0.73

[1]Carcass-adjusted final BW was calculated as HCW/average dressing percent of each treatment.

[2]Carcass-adjusted ADG and G:F were calculated from carcass-adjusted final BW and days on experimental treatment (25 or 45 d including the 5-d withdrawal).

Carcass Merit

Steers. Hot carcass weight was increased ($P < 0.001$) 16.4 kg when zilpaterol hydrochloride was fed to steers (Table 4). Feeding zilpaterol hydrochloride resulted in a 1.5-percentage unit increase ($P < 0.001$) in dressing percentage, and a 8.23-cm^2 increase ($P < 0.001$) in LM area. Dressing percent tended to be greater when zilpaterol hydrochloride was fed for 40 d compared with when zilpaterol hydrochloride was fed for 20 d, whereas duration did not affect dressing percent for control steers (zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interaction, $P = 0.06$). Twelfth-rib fat ($P = 0.12$) and KPH ($P = 0.89$) were not affected by feeding zilpaterol hydrochloride. Marbling score ($P = 0.002$) and quality grade ($P = 0.002$) were decreased when zilpaterol hydrochloride was fed, and the decrease in marbling score and quality grade tended to be greater when zilpaterol hydrochloride was fed for 40 compared with 20 d (zilpaterol hydrochloride × duration of feeding interaction, $P = 0.07$). Zilpaterol hydrochloride decreased ($P < 0.001$) the percentage of USDA Premium Choice carcasses and increased ($P = 0.005$) the percentage of USDA Select carcasses. In contrast, calculated yield grade was decreased (i.e., improved; $P < 0.001$) by feeding zilpaterol hydrochloride. Feeding zilpaterol hydrochloride increased ($P = 0.04$) the percentage of USDA Yield grade 1 carcasses, tended ($P = 0.06$) to increase the percentage of USDA Yield grade 2.00 to 2.49 carcasses, and decreased ($P = 0.003$) the percentage of USDA Yield grade 3.50 to 3.99 carcasses. Masculinity was similar when control steers were fed for 20 or 40 d but was greater when zilpaterol hydrochloride was fed for 40 vs. 20 d (zilpaterol hydrochloride × duration of feeding interaction, $P = 0.01$). Skeletal, lean, and overall maturity and color and dark cutter score were not affected ($P \geq 0.12$) by feeding zilpaterol hydrochloride. In addition, feeding zilpaterol hydrochloride did not affect ($P = 0.31$) the percentage of condemned livers in steers.

Hot carcass weight (tendency, $P = 0.06$), dressing percent ($P = 0.04$), LM area ($P = 0.02$), and masculinity ($P = 0.008$) were greater for steers on the 40- vs. 20-d duration treatments (Table 4). With the exception of marbling score (tendency, $P = 0.09$) and quality grade (tendency, $P = 0.09$), no other carcass measures were affected ($P \geq 0.18$) by duration of feeding.

Heifers. With the exception of percent dark cutters ($P = 0.05$), there were no zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interactions ($P \geq 0.15$) for carcass traits in heifers (Table 5). Hot carcass weight (12.1 kg; $P < 0.001$), dressing percent (1.5 percentage units; $P < 0.001$), and LM area (6.37 cm^2; $P < 0.001$) were greater when zilpaterol hydrochloride was fed. Feeding zilpaterol hydrochloride did not affect 12th-rib fat ($P = 0.40$) or KPH ($P = 0.70$) in heifers. Marbling score tended ($P = 0.07$) to be decreased and quality grade was decreased ($P = 0.05$) when zilpaterol hydrochloride was fed. Feeding zilpaterol hydrochloride tended ($P = 0.08$) to decrease the percent of USDA No Roll carcasses; however, no other differences ($P \geq 0.23$) in USDA Quality grade distribution were observed. Feeding zilpaterol hydrochloride resulted in a 10% decrease (improvement; $P = 0.02$) in calculated yield grade. Feeding zilpaterol hydrochloride increased ($P = 0.03$) the percentage of USDA Yield grade 2.00 to 2.49 carcasses and decreased the percentage of USDA Yield grade 3.00 to 3.49 ($P = 0.01$) and 3.50 to 3.99 ($P = 0.02$) carcasses. Masculinity increased ($P = 0.008$) in heifers fed zilpaterol hydrochloride compared with control heifers. Color score was more ($P = 0.04$) favorable for heifers fed zilpaterol hydrochloride. Although percentage of dark cutters was not affected ($P = 0.20$) by zilpaterol hydrochloride, percentage of dark cutters was less when zilpaterol hydrochloride was fed for 20 d, but was greater when zilpaterol hydrochloride was fed for 40 d (zilpaterol hydrochloride × duration of feeding, $P = 0.05$). Skeletal and overall maturity were not affected ($P \geq 0.26$) by feeding zilpaterol hydrochloride; however, lean maturity was decreased ($P = 0.04$). Feed-

Table 4. Effects of zilpaterol hydrochloride (Zilmax, Intervet Inc., Millsboro, DE) and duration of zilpaterol hydrochloride feeding on carcass characteristics of steers

	20 d		40 d			*P*-value		
Item	No Zilpaterol	Zilpaterol	No Zilpaterol	Zilpaterol	SEM	Duration (D)	Zilpaterol (Z)	D × Z
HCW, kg	353.7	366.7	354.8	374.7	8.3	0.06	<0.001	0.13
Dressing %	62.7	64.0	62.8	64.6	1.2	0.04	<0.001	0.06
LM area, cm^2	84.0	91.9	85.5	94.1	1.7	0.02	<0.001	0.65
12th-rib fat, cm	1.31	1.20	1.26	1.20	0.11	0.59	0.12	0.61
KPH, %	3.03	2.08	2.04	2.00	0.09	0.48	0.89	0.38
Marbling score[1]	461	432	462	398	17	0.09	0.002	0.07
Quality grade[2]	4.60	4.31	4.62	3.94	0.17	0.09	0.002	0.07
Yield grade	2.99	2.61	2.87	2.55	0.13	0.18	<0.001	0.64
Masculinity[3]	5.04	5.33	5.05	5.59	0.05	0.008	<0.001	0.01
Color score[4]	5.08	5.20	5.06	5.31	0.14	0.70	0.12	0.54
Dark cutters,[5] %	0.00	1.67	0.00	1.68	—	—	0.37	—
Skeletal maturity	A^{70}	A^{71}	A^{68}	A^{72}	3.9	0.84	0.38	0.67
Lean maturity	A^{65}	A^{65}	A^{68}	A^{66}	3.1	0.61	0.77	0.69
Overall maturity	A^{70}	A^{71}	A^{71}	A^{72}	3.1	0.72	0.67	0.94
Condemned livers, %	26.7	22.5	29.2	25.2	4.2	0.51	0.31	0.98
USDA Quality grade, %								
Prime	0.8	1.7	1.7	0.0	—	—	0.55	—
Total Choice	71.7	62.5	65.6	49.6	4.6	0.03	0.004	0.44
Premium Choice	25.8	10.8	20.2	7.6	4.0	0.18	<0.001	0.72
Low Choice	45.8	51.7	45.4	42.0	4.6	0.27	0.79	0.31
Select	26.7	32.5	30.2	48.7	4.6	0.02	0.005	0.14
No Roll	0.8	3.3	2.5	1.7	1.6	0.99	0.53	0.20
USDA Yield grade, %								
1.00 to 1.99	7.5	15.0	9.2	13.5	3.3	0.98	0.04	0.58
2.00 to 2.49	19.2	28.3	20.0	25.2	4.1	0.77	0.06	0.61
2.50 to 2.99	28.3	35.0	35.0	31.1	4.4	0.75	0.75	0.22
3.00 to 3.49	21.7	15.0	24.2	21.9	3.9	0.20	0.22	0.56
3.50 to 3.99	13.3	4.2	8.3	3.4	3.1	0.22	0.003	0.37
4.00 to 4.99	10.0	2.5	3.3	5.0	2.7	0.31	0.15	0.02

[1]Marbling scores: 300 = $Slight^{00}$; 400 = $Small^{00}$; 500 = $Modest^{00}$.
[2]Quality grade: 3.00 = Select; 4.00 = low Choice, 5.00 = average Choice.
[3]Masculinity score: 1 to 9 scale; 1 = least masculine; 9 = most masculine.
[4]Color score scale: 8 = extremely bright cherry red; 1 = extremely dark red.
[5]Percentage of cattle that cut 34% or greater dark.

ing zilpaterol hydrochloride did not affect the percentage of condemned livers in heifers ($P = 0.68$).

Hot carcass weight ($P = 0.002$), dressing percent ($P = 0.05$), LM area ($P < 0.001$), and masculinity ($P = 0.03$) were greater when heifers were fed for the 40-d vs. the 20-d duration (Table 5). No other carcass measures were affected ($P \geq 0.13$) by duration of feeding.

DISCUSSION

The primary objective of these studies was to examine clinical effectiveness of zilpaterol hydrochloride in improving ADG and G:F to gain FDA approval of Zilmax in cattle fed in confinement (FDA, 2006). Previous to the present experiments, several studies had been conducted in the Republic of South Africa and Mexico. These development studies indicated that zilpaterol hydrochloride was effective at stimulating growth of feedlot cattle when fed for up to 50 d at a concentration of 8.3 mg/kg (DM basis). Thus, the present experiment was conducted feeding 8.3 mg/kg (DM basis) for 20 or 40 d, the minimum and maximum duration of feeding time approved for feeding zilpaterol hydrochloride to steers and heifers in the United States.

Previous experiments in which zilpaterol hydrochloride has been fed have been restricted to steers, and no data are available for heifers. In the present experiment, zilpaterol hydrochloride effects on ADG and G:F in steers were similar to improvements reported by Plascencia et al. (1999), whereas improvements in ADG were less in the studies of Casey et al. (1997), Strydom et al. (1998), and Montgomery et al. (2009). Montgomery et al. (2009) conducted an experiment in large commercial pens (average = 94 steers/pen) and showed that feeding zilpaterol hydrochloride for 30 d at the end of the finishing period resulted in a 14% increase in ADG and an 18% increase in G:F. In the present experiment, DMI was decreased by approximately 2% for steers and 6% for heifers when cattle were fed zilpaterol hydrochloride. Vasconcelos et al. (2008) found that as duration of zilpaterol hydrochloride feeding increased from 20 to 40 d, DMI decreased and G:F increased linearly in steers.

The effect of zilpaterol hydrochloride on ADG in the present experiment was greater (36% vs. 17 to

Table 5. Effects of zilpaterol hydrochloride (Zilmax, Intervet Inc., Millsboro, DE) and duration of zilpaterol hydrochloride feeding on carcass characteristics of heifers

	20 d		40 d			*P*-value		
Item	No Zilpaterol	Zilpaterol	No Zilpaterol	Zilpaterol	SEM	Duration (D)	Zilpaterol (Z)	D × Z
HCW, kg	320	331	323	336	14	0.002	<0.001	0.34
Dressing %	62.7	64.2	63.0	64.6	1.1	0.05	<0.001	0.78
LM area, cm^2	85.0	90.8	86.8	93.7	1.7	<0.001	<0.001	0.39
12th-rib fat, cm	1.39	1.30	1.35	1.35	0.09	0.96	0.40	0.33
KPH, %	2.05	2.04	2.04	2.09	0.07	0.67	0.70	0.55
Marbling score[1]	461	457	470	437	23	0.58	0.07	0.15
Quality grade[2]	4.59	4.48	4.68	4.34	0.25	0.83	0.05	0.28
Yield grade	2.74	2.46	2.63	2.42	0.14	0.35	0.02	0.65
Masculinity[3]	4.86	5.13	4.97	5.32	0.06	0.03	<0.001	0.50
Color score[4]	5.05	5.28	5.09	5.35	0.10	0.61	0.04	0.91
Dark cutters,[5] %	5.00	0.85	0.83	1.68	3.8	0.20	0.20	0.05
Skeletal maturity	A^{75}	A^{72}	A^{73}	A^{74}	2.5	0.85	0.74	0.46
Lean maturity	A^{71}	A^{65}	A^{68}	A^{63}	5.0	0.27	0.04	0.82
Overall maturity	A^{76}	A^{72}	A^{74}	A^{72}	2.5	0.61	0.26	0.56
Condemned livers, %	15.0	16.1	20.0	21.9	2.0	0.13	0.68	0.92
USDA Quality grade, %								
Prime	3.3	2.5	4.2	1.7	1.8	0.99	0.29	0.59
Total Choice	62.5	62.7	64.2	61.9	4.5	0.93	0.81	0.78
Premium Choice	20.8	22.9	22.5	22.0	3.9	0.91	0.84	0.74
Low Choice	41.7	39.8	41.7	39.8	4.5	1.00	0.68	1.00
Select	30.8	33.1	27.5	35.6	4.4	0.93	0.23	0.49
No Roll	3.3	1.7	4.2	0.8	1.8	0.99	0.08	0.56
USDA Yield grade, %								
1.00 to 1.99	16.7	21.2	20.8	26.9	4.1	0.19	0.16	0.84
2.00 to 2.49	20.8	32.2	19.2	24.4	4.3	0.22	0.03	0.43
2.50 to 2.99	25.0	27.1	27.5	26.9	4.1	0.78	0.85	0.74
3.00 to 3.49	21.7	13.6	22.5	13.4	3.8	0.92	0.01	0.89
3.50 to 3.99	12.5	4.2	9.2	5.9	3.0	0.73	0.02	0.31
4.00 to 4.99	3.3	1.7	0.8	2.5	1.6	0.52	0.99	0.20

[1]Marbling scores: 300 = $Slight^{00}$; 400 = $Small^{00}$; 500 = $Modest^{00}$.
[2]Quality grade: 3.00 = Select; 4.00 = low Choice, 5.00 = average Choice.
[3]Masculinity score: 1 to 9 scale; 1 = least masculine; 9 = most masculine.
[4]Color score scale: 8 = extremely bright cherry red; 1 = extremely dark red.
[5]Percentage of cattle that cut 34% or greater dark.

20% increase) for steers when compared with previous reports with ractopamine hydrochloride (Optaflexx brand, Elanco Animal Health; Anderson et al., 1989; Carroll et al., 1990; Schroeder et al., 2003a). However, effects of zilpaterol hydrochloride and ractopamine on ADG appear to be similar for heifers (18% vs. 17 to 20% increase; Schroeder et al., 2003b). Results from the present experiment suggest that improvements in G:F are greater for zilpaterol hydrochloride than ractopamine for both steers (28 vs. 13 to 20%) and heifers (21 vs. 7 to 17%; Schroeder et al., 2003a,b). Similar to zilpaterol hydrochloride, ADG and G:F have been shown to improve when other β_2-adrenergic agonists (**β_2-AA**) such as clenbuterol (Schiavetta et al., 1990), $L_{644,969}$ (Moloney et al., 1990; Wheeler and Koohmaraie, 1992; Chwalibog et al., 1996), and cimaterol (Quirke et al., 1988) have been fed. All of these latter experiments were conducted with steers. With the exception of ractopamine (Schroeder et al., 2003b), reports of other βAA on stimulating heifer growth are limited to a heifer study conducted with clenbuterol (Miller et al., 1988). Although effects of βAA on growth vary between studies and βAA, it seems that effects of β_2-AA are generally greater in comparison with β_1-AA. The greater effectiveness of β_2-AA in comparison with ractopamine hydrochloride might be attributable to the distribution of β-adrenergic receptor subtypes in muscle and adipose tissue (Winterholler et al., 2007). Bovine muscle almost exclusively has β_2-adrenergic receptors, whereas adipose tissue has predominantly a β_2-adrenergic receptor distribution (De Vente et al., 1980; Sillence and Matthews, 1994; Van Liefde et al., 1994). Treatment with a β_2-AA has been shown to downregulate and desensitize β-adrenergic receptors as well as decreased receptor concentrations (Lefkowitz, 1982; Re et al., 1997; Mills, 2002).

One of the objectives of the present experiments was to determine potential differences in feeding zilpaterol hydrochloride to steers and heifers for the minimum (20 d) or maximum (40 d) zilpaterol hydrochloride feeding durations. For heifers, there was only one zilpaterol hydrochloride × zilpaterol hydrochloride feeding duration interaction for total BW gain. In heifers, total BW gain was greater when heifers were fed zilpaterol hydrochloride for 40 d compared with 20 d. For steers, there were 4 zilpaterol hydrochloride × zilpaterol hydrochlo-

ride feeding duration interactions. Dressing percent (tendency) and masculinity were increased to a greater extent when steers were fed zilpaterol hydrochloride for 40 d compared with 20 d. In contrast, marbling score and quality grade tended to be decreased to a greater extent when zilpaterol hydrochloride was fed to steers for 40 d compared with 20 d. Therefore, it appears that some growth and muscling factors can be enhanced by feeding zilpaterol hydrochloride for a greater duration, whereas the impact on marbling and quality grade can be mediated and decreased by feeding zilpaterol hydrochloride for the shorter duration. However, in general it appears that advantages of feeding zilpaterol hydrochloride for more than 20 d are minimal, at least in the genotypes studied.

Feeding steers and heifers zilpaterol hydrochloride increased dressing percent approximately 2.3%, which is similar to previous reports in which zilpaterol hydrochloride has been fed (Casey et al., 1997; Strydom et al., 1998; Plascencia et al., 1999). In steers, dressing percent has been shown to increase linearly with increased duration of zilpaterol hydrochloride feeding, when fed for 20 to 40 d (Vasconcelos et al., 2008). Generally, treatment of cattle with β_2-AA has resulted in increased HCW and improved dressing percent as observed in the present experiment (Fabry and Sommer, 1990; Chikhou et al., 1993a; Fiems et al., 1993). Previous reports have indicated that feeding zilpaterol hydrochloride increased dressing percent, HCW, and LM area, whereas KPH and marbling were generally not affected (Casey et al., 1997; Plascencia et al., 1999). In contrast, clenbuterol has been shown to drastically decrease percent KPH (Williams et al., 1987; Miller et al., 1988; Schiavetta et al., 1990) as well as 12th-rib fat thickness (Ricks et al., 1984; Miller et al., 1988). In the present experiment, 12th-rib fat thickness and KPH were not affected by feeding zilpaterol hydrochloride to steers or heifers, similar to previous reports in steers (Casey et al., 1997; Plascencia et al., 1999). However, marbling score was decreased when zilpaterol hydrochloride was fed to steers, and the decrease in marbling score was approximately 2-fold greater when zilpaterol hydrochloride was fed for 40 (64 units) compared with 20 d (29 units). For heifers, a decrease in marbling score occurred when zilpaterol hydrochloride was fed for 40 d (33 units) but not at 20 d (4 units), although the zilpaterol hydrochloride × duration of zilpaterol hydrochloride feeding interaction was not significant ($P = 0.15$). Although a shift in USDA Quality grade from Choice to Select occurred for steers fed zilpaterol hydrochloride, a similar shift did not occur in heifers. In contrast to potentially less favorable quality grades, calculated yield grade was improved 14% for steers and 10% for heifers, and there was a general shift from USDA Yield grade 3.50 to 3.99 to USDA Yield grade 1 and 2.00 to 2.49 carcasses compared with controls. Similarly, previous studies with other β_2-AA in cattle have shown an improvement in yield grade when clenbuterol (Ricks et al., 1984; Miller et al., 1988; Schiavetta et al., 1990) or $L_{644,969}$ was administered (Moloney et al., 1990; Wheeler and Koohmaraie, 1992). These data suggest that similar to other β_2-AA, zilpaterol hydrochloride greatly improves carcass muscle deposition and yield.

In conclusion, feeding zilpaterol hydrochloride during the final 20 to 40 d of the finishing period increases ADG, G:F, final BW, and HCW for both steers and heifers. In addition, zilpaterol hydrochloride improves carcass muscling and yield grade. Although the frequency of USDA Choice carcasses decreased in steers, the decrease in quality grade when zilpaterol hydrochloride was fed was less for heifers. It appears from these data that zilpaterol hydrochloride fed for 20 to 40 d at the end of the finishing period enhances growth performance and red meat yield for both steers and heifers.

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