11-18-2015

Effects of shade and feeding zilpaterol hydrochloride to finishing steers on performance, carcass quality, heat stress, mobility, and body temperature

Bradley M. Boyd
University of Nebraska-Lincoln, bboyd4@unl.edu

Steven D. Shackelford
USDA MARC, Clay Center, NE, steven.shackelford@ars.usda.gov

Kristin E. Hales
USDA-ARS, U.S. Meat Animal Research Center, kristin.hales@ars.usda.gov

Tami M. Brown-Brandl
USDA–ARS U.S. Meat Animal Research Center, Tami.BrownBrandl@ARS.USDA.GOV

Meredith L. Bremer
University of Nebraska, mbremer3@unl.edu

See next page for additional authors

Published December 18, 2015

Effects of shade and feeding zilpaterol hydrochloride to finishing steers on performance, carcass quality, heat stress, mobility, and body temperature[1]

B. M. Boyd,* S. D. Shackelford,† K. E. Hales,†[2] T. M. Brown-Brandl,† M. L. Bremer,* M. L. Spangler,* T. L. Wheeler,† D. A. King,† and G. E. Erickson*[2]

*Department of Animal Science, University of Nebraska-Lincoln, Lincoln 68583; and †USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE 68933

ABSTRACT: Steers (*n* = 480; 22% with black hides and 78% with red hides) were used to study the effects of shade and feeding zilpaterol hydrochloride (ZH) on performance, carcass quality, heat stress, mobility, and body temperature (BT). A randomized block design with a 2 × 2 factorial treatment arrangement was used with 4 replicates per treatment. Factors included housing type (open or shaded pens) and the feeding of ZH (0 or 8.33 mg/kg DM) the last 21 d on feed with a 3-d withdrawal. Cattle were blocked by BW into a heavy or light block and randomly assigned to pen within each block. Rumen boluses to record BT were inserted before ZH feeding. Respiration rate and panting scores were recorded daily during the ZH feeding period. Mobility scores were collected at various time points from before ZH feeding through harvest. Interactions between ZH and housing type were not significant ($P > 0.26$) for animal performance, carcass characteristics, and respiration or panting score. No differences ($P > 0.44$) were observed for DMI, ADG, or G:F on a live basis due to ZH; however, cattle fed in open pens tended ($P = 0.08$) to have a greater ADG than cattle in shaded pens. Cattle fed ZH had 14 kg heavier carcasses with larger LM area ($P < 0.01$) than control cattle. Respiration rates for cattle fed ZH were greater ($P = 0.05$) with no differences ($P = 0.88$) due to housing. Time affected ($P < 0.01$) mobility scores, with observations on the morning of harvest at the abattoir being the worst for all groups of cattle. An interaction ($P < 0.01$) was observed between ZH and housing type for BT. Cattle fed ZH, in both shaded and open pens, had lower ($P < 0.05$) average, maximum, and area under the curve BT than control cattle fed in the same housing type. However, the observed reduction in BT due to ZH was greater for cattle fed ZH in open pens than for cattle fed ZH in shaded pens. From these results, we conclude that ZH improved HCW with little impact on heat stress or mobility, suggesting that animal welfare was not affected by feeding ZH for 21 d at the end of the feeding period.

Key words: body temperature, mobility, respiration rate, shade, zilpaterol hydrochloride

 J. Anim. Sci. 2015.93:5801–5811
doi:10.2527/jas2015-9613

INTRODUCTION

Zilpaterol hydrochloride (**ZH**; Merck Animal Health, De Soto, KS) is a β-adrenergic agonist that was approved for feeding to beef cattle in the United States in 2006 (FDA, 2006). Zilpaterol hydrochloride was commonly used in the United States feedlot industry until August 2013. Recently, there have been concerns of animal welfare issues with the feeding of ZH, which resulted in it being removed from the market by the manufacturer. Beta-agonists work by binding to specific β-receptors on fat and muscle cell surfaces that modify biochemical processes of tissue growth by increasing lipolysis, decreasing

[1]A contribution of the University of Nebraska Agricultural Research Division, supported in part by funds provided through the Hatch Act. Research partially supported by a grant from the Nebraska Beef Council. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. The USDA is an equal opportunity provider and employer. The authors have no conflict of interest. The efforts of C. Engle, B. Johnson, L. McPhillips, C. Felber, D. Janssen, A. Menke, C. C. Row, J. Buntyn, R. Oglesbee, Z. Carlson, and the entire feedlot crew at U.S. MARC are greatly appreciated.

[2]Corresponding authors: Kristin.Hales@ars.usda.gov and gerickson4@unl.edu

Received July 28, 2015.
Accepted October 6, 2015.

lipogenesis, decreasing protein degradation, and increasing protein synthesis (Strydom et al., 2009).

Performance responses from feeding ZH during the end of the finishing phase are well characterized and clearly show beneficial responses in final BW, ADG, G:F, and HCW. A 15-kg increase in HCW along with increased dressing percentage and decreased USDA yield grade have been consistently observed when ZH was fed at the end of the feeding period (Vasconcelos et al., 2008; Lean et al., 2014; Hilscher et al., 2015). However, there are few studies evaluating the effect of ZH on animal welfare issues, such as heat stress and mobility of cattle.

Hales et al. (2014) reported an increase in the slope of the regression lines for both panting score and respiration rate as days on ZH increased. However, this increase was not significant, and it is unclear whether this increase was caused by the addition of the β-agonist in the diet or some other variable. Research evaluating animal welfare and heat stress when ZH is supplemented is unavailable; therefore, the objective of this study was to further investigate the impact of feeding ZH on heat stress, mobility, and body temperature in addition to performance and carcass characteristics for steers fed in open or shaded pens.

MATERIALS AND METHODS

This study was conducted in accordance with, and approved by, the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Cattle

Four hundred eighty crossbred beef steers were fed at the U.S. Meat Animal Research Center (**USMARC**) feedlot near Clay Center, NE. The steers were from the MARC II (one-fourth each Simmental, Gelbvieh, Hereford, and Angus) and MARC III (one-fourth each Pinzgauer, Red Poll, Hereford, and Angus) composite breed populations. The hide color distribution was 22% black and 78% red. The cattle with black hides were stratified equally across pens. Cattle were started on the experimental diet on January 2, 2014. The diet consisted of 57.35% dry-rolled corn, 30% wet distillers' grains with solubles, 8% alfalfa hay, 4.25% supplement, and 0.40% urea for all pens and treatments. When cattle were to receive ZH, enough type B supplement was added directly to the feed truck to feed all pens on a common treatment. The ZH was fed according to the label at 8.33 mg/kg DM (Merck Animal Health) and the inclusion rate was confirmed by laboratory testing by Merck Animal Health. During the ZH feeding period, samples of the diet were collected each day. The samples were analyzed 2 times during the ZH feeding period and each time the samples were between 90 and 110% of the 8.33 mg/kg DM feeding recommendation.

Feed bunks were visually evaluated each day of the experiment at approximately 0630 h to determine the amount of diet each pen would receive. Feed bunks were managed so that less than 0.10 kg of DM per steer was remaining in the feed bunk at the time of evaluation. Separate trucks were used to feed the cattle to receive ZH and those on the control diet to prevent cross-contamination.

Cattle were implanted with Revalor XS (200 mg trenbolone acetate and 40 mg estradiol 17β; Merck Animal Health) and BW was measured on January 28, 2014, using a single-animal scale at the start of the study. At this time, cattle were divided into 2 BW blocks. The blocks were based on differences in BW and were labeled heavy (block 1) or light (block 2); the weight difference between blocks was 53 kg unshrunk BW. Other factors such as sire line, dam line, preweaning ADG, and hide color were stratified across pens at this time. Then, cattle were assigned to 16 soil-surfaced pens of 30 steers each. The pens were approximately 15.4 by 61 m with 15.1 m of bunk space and a concrete apron extending 4.7 m from the bunk. This provided the cattle with 31.3 m^2 of pen space and 0.5 m of bunk space per steer. Shade was provided in 8 of the 16 pens along both side fence lines and shared between adjacent pens. The artificial shade used during the study (Fig. 1) comprised poles 10 m tall by 15.4 m long (Eigenberg et al., 2013). The north/south structures were equipped with four 15.4 lengths of high-density polyethylene snow fence and provided an effective 50% shade coverage (Eigenberg et al., 2013). The shade structures tracked the sun during the day and offered 3 m^2 of shade per animal. The other 8 pens were unshaded and unprotected from environmental conditions. All pens were located in the center of the alley so that pens had cattle on either adjacent side and all shaded pens were shaded along both side fence lines.

Cattle in block 1 were fed ZH (21 d) beginning June 19, 2014, and ending July 10, 2014. After a 4-d withdrawal, block 1 cattle were transported to the abattoir on July 14, 2014, and they were harvested the following morning. Steers in block 2 were fed ZH for 21 d beginning July 18, 2014, and ending on August 8, 2014. After a 3-d withdrawal, cattle were transported to the abattoir on August 11, 2014, and they were harvested the following morning. For both blocks, before the initiation of the ZH feeding period, cattle were individually weighed and pen mobility scores were collected as steers exited their pens to be moved to the processing facility. For pen mobility measurements, an individual would watch a pen of cattle move down the alley and use tick marks to denote the number of animals with a score of 1, 2, 3, or 4. Then, the number of steers with

Figure 1. Photograph of the shade structures used during the experiment. The shades were incorporated into the fence line of each pen and the pens were north–south oriented. Each pen contained 2 shade structures, 1 on the west fence line and 1 on the east fence line.

a score of 0 was calculated by difference. These measurements were collected the morning that steers were transported to the abattoir. On the day the cattle were weighed and samples were collected, personnel on horseback moved cattle from pens as a group; cattle were individually weighed, held as a group in a pen, and returned to their respective home pens as a group. Throughout the experiment, cattle were allowed ad libitum access to water through automatic waters located in the fence line and shared between 2 adjacent pens.

Sample Collection

On the final sampling day, cattle were removed from the pen and brought to the working facility. After sample collection, they were placed in different pens, but pen treatments were maintained. The new pens were near the cattle shipment facility where the cattle would be loaded onto trucks to curtail any additional stress that may have occurred by returning them to their home pen and then removing them later that day to be loaded onto trucks. The average distance between the home pens and the working facility was 835 m. In these temporary pens, cattle had ad libitum access to water and were fed 75% of the feed call on the previous day. Later that day, cattle were loaded onto trucks at approximately 1730 h and held overnight at the abattoir for harvest the next morning. Antemortem inspection started at 0600 h and the cattle were harvested soon after. All cattle presented for antemortem inspection at the abattoir were cleared for harvest by a USDA veterinarian.

Experimental Design

The experiment was designed as a randomized block with 2 × 2 factorial arrangement of treatments. Factors consisted of housing type (shaded or open pens) and the inclusion of ZH at 0 or 8.33 mg/kg DM daily for the last 21 d of the finishing period with a 4- (block 1) and 3-d (block 2) withdrawal before harvest. Cattle were blocked by initial BW and the other factors previously mentioned and randomly assigned to pen, and pen was then randomly assigned to treatment. Dietary treatments were applied at the end of the finishing period for both blocks and staggered so that cattle could be harvested in what was predicted to be the warmest weeks of summer (mid July and early August). Four replications per treatment were used with a total of 16 pens. After block 1 cattle were harvested, block 2 cattle were then shifted into the 8 pens where block 1 cattle had been housed so the receivers for the rumen bolus system did not have to be relocated into new pens.

Heat Stress Measurements

Both blocks of cattle received a SmartStock (SmartStock, LLC, Pawnee, OK) temperature monitoring rumen bolus 5 d before the initiation of feeding ZH. The rumen boluses were set to record rumen temperature in 10-min intervals. The rumen temperatures were then transmitted from the boluses to a computer via a receiver located in the steer's home pen; therefore, temperature recording stopped when steers left their home pens. Body temperature (**BT**) data were edited such that missing time points and drinking events were imputed using individual animal regressions between the nearest 2 time points on both sides of the missing BT or drinking event. This created a continuous set of data with individual BT in 10-min intervals for the duration of the observation period.

After an adaptation period to humans being near and in the pens before initiating ZH feeding, panting scores (0 = no panting; 1 = slight panting, mouth closed, and no drool; 2 = fast panting, drool present, and no open mouth; 3 = open mouth and excessive drooling, neck extended, and head held up; and 4 = open mouth with tongue fully extended for prolonged periods plus excessive drooling, neck extended, and head up) and respiration rates were collected daily by trained individuals during the ZH feeding phase of the study starting at 1300 h and ending by 1530 h. Respiration rates were recorded as the amount of time it took the steer to take 10 breaths, and these data were then used to calculate breaths per minute. Panting scores and respiration rates were collected between June 20, 2014, and July 13, 2014, for block 1 and between July 19, 2014, and August 10, 2014, for block 2. Before ZH feeding, one-half of the cattle in each pen were selected and identified with a uniquely colored ear tag. One-half of the steers in each pen were individually evaluated on a daily basis such that each one-half of the steers in each pen were evaluated every other day. Panting scores and respiration rates were collected by a team of 2 people, and the first pen observed was rotated daily to minimize time of day effects.

Mobility and Carcass Data

Mobility scores were evaluated 10 times throughout the ZH feeding period. These scores were based on the 0 to 4 Tyson mobility scoring system (Tyson Foods, Springdale, AR). In the mobility system, 0 = normal, 1 = mildly lame, 2 = moderately lame, 3 = severely lame and reluctant to move, and 4 = nonambulatory/severe distress. The mobility observations were made when cattle were leaving their home pens on weigh/data collection days, as they were loaded onto the truck leaving the feedlot, during unloading at the abattoir, and as they were moved into holding pens at the abattoir. On the day of harvest, mobility scores were evaluated during antemortem inspection, as cattle left the holding pen, and as cattle were moved to the restrainer.

On the day of harvest, HCW and harvest order were recorded. After a 48-h chill, LM area, 12th rib fat thickness, and marbling score were determined by USMARC personnel using the VBG2000 beef grading camera (Shackelford et al., 2003). Yield grade was calculated [2.5 + (6.35 × 12th rib fat) + (0.2 × 2.5[KPH]) + (0.0017 × HCW) – (2.06 × LM area)] for each individual steer and then averaged within pen (USDA, 1997). Dressing percent was calculated for each pen by dividing HCW by final live BW using a 4% shrink.

Statistical Analysis

Performance data (ADG, DMI, G:F, and initial and final live BW) and carcass characteristics (HCW, LM, 12th rib fat, marbling score, and USDA yield grade) were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included fixed effects of block, dietary treatment (ZH fed or not), housing type (open or shaded pen), and the interaction between dietary treatment and housing type.

Respiration rate was analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit. The model included fixed effects of block, dietary treatment (ZH fed or not), housing type (open or shaded pen), their interaction, and a random residual. Interactions involving time were not significant and therefore they were removed from the model. To account for the inherent covariance structure between sequential respiration rate measures, the residual was fitted with a covariance pattern within pen and a covariance of 0 across pens. Multiple covariance patterns were investigated and autoregressive 1 was chosen based on Akaike's information criteria.

Mobility scores were analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit. Covariance structure was assessed using the same methods as the model for respiration rate and the variance components covariance structure was determined to be the best fit. The model included fixed effects of dietary treatment (fed ZH or not), time point of observation, housing type (open or shaded pen), the interaction of dietary treatment and time, and the interaction of dietary treatment and housing type. Interactions for housing type and time were not significant and therefore were removed from the model. Mobility scores were collected from multiple steers within each pen during each time point. The number of steers within each pen with a given mobility score was tallied for each collection point and divided by the number of steers in each pen to create a percentage of the pen with each given mobility score. A percentage was used rather than the number of steers because of death loss (2/480) before initiation of ZH feeding. Four time points were then created: before ZH, after ZH, arrival at the abattoir, and time of harvest. One steer was scored as a 3 before initiation of ZH feeding, but subsequent scores for this steer improved and consequently this score was removed from the analysis for the earliest time point. We speculate that this steer had foot rot or some other condition that was not relevant to

Table 1. Adjusted temperature–humidity index (THI), temperature, and humidity during the zilpaterol hydrochloride (ZH) treatment phase of both blocks of cattle

	Block 1			Block 2		
Day[1]	Adjusted THI[2]	Temperature, °C	Humidity, %	Adjusted THI	Temperature, °C	Humidity, %
1	69.9	22.2	69.2	61.3	17.5	86.0
2	70.2	24.4	69.0	65.6	19.9	84.9
3	69.6	22.7	78.6	70.9	24.8	78.5
4[3]	71.4	22.4	79.1	77.8	29.4	67.4
5[3]	69.2	20.6	79.9	76.5	26.1	73.5
6[3]	69.1	19.9	86.1	71.3	22.0	75.8
7	71.9	22.0	78.6	68.2	23.4	75.5
8[3]	68.9	22.0	83.7	77.2	27.7	70.1
9[3]	65.2	21.7	90.9	78.9	26.6	83.4
10	67.0	20.8	84.3	70.1	22.5	68.9
11	72.1	23.8	85.6	66.7	18.9	75.7
12	70.9	23.5	79.2	68.6	19.8	74.8
13	62.7	19.0	70.9	69.1	20.2	68.7
14	60.4	16.5	71.0	68.4	21.0	70.2
15	63.0	18.6	73.5	68.4	20.7	75.6
16	63.9	21.6	71.0	70.3	21.8	75.3
17[4]	73.9	25.0	77.7	72.9	23.1	72.1
18[4]	78.0	26.2	75.4	74.0	23.6	79.8
19[4]	72.7	23.4	73.9	73.7	24.5	77.5
20	67.3	20.5	74.0	72.1	22.9	85.7
21	66.4	20.0	78.9	72.4	22.2	86.1
22	68.1	22.3	81.0	71.7	22.2	84.2
23[4]	73.5	24.5	80.1	68.4	20.9	88.4
24[4]	74.3	24.1	78.8	71.4	21.9	81.8
25	75.1	23.9	77.5	N/A[5]	N/A	N/A

[1]Day since cattle started on the ZH treatment. Day 21 to 25 is withdrawal period.

[2]Adjusted THI calculated as {0.8 × ambient temperature + [(% relative humidity/100) × (ambient temperature – 14.4)] +46.4} + [4.51 – (1.992 × wind speed) + (0.0068 × solar radiation)] in which >84 is emergency, 79 to 84 is danger, 74 to 79 is alert, and <74 is normal (Mader et al., 2006).

[3]Days used as hot period for block 2.

[4]Days used as hot period for both blocks.

[5]N/A = Not applicable.

ZH feeding and that dissipated by the end of the study. Consequently, frequencies reported are scores of 0, 1, and 2. This scale was used because no steers received a score greater than 2 with the exception of the single steer before initiation of the study.

Chute exit speeds were analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit. Covariance structure was assessed using the same methods as that of mobility scores and an unstructured covariance structure was determined to best fit the data. The model included the fixed effects of block, dietary treatment (fed ZH or not), time of observation, housing type (shaded or open), the interaction of dietary treatment and time, and the interaction of dietary treatment and housing type. Interactions for housing type and time were not significant and therefore were removed from the model. Before analysis, data from steers that stopped walking before crossing the second sensor (the sensors were 7.92 m apart) were removed (n = 75; 7.84%). The number of steers that stopped walking before crossing the second sensor ranged from 5 to 8 per weigh day and were evenly distributed across treatment.

Body temperature was analyzed using the GLIMMIX procedure of SAS with steer as the experimental unit. Covariance structure was assessed using the same methods as the model for respiration and mobility data and the variance components covariance structure was determined to be the best fit for the data. All interactions were analyzed and only those that were significant remained in the model. The model included the fixed effects of day, dietary treatment (fed ZH or not), housing type (open or shade), the interaction of housing type and time, and the interaction of dietary treatment and housing type and the random animal effect and residual. Body temperature measurements were characterized as 4 different phenotypes. The average, maximum, and area under the curve were evaluated. Average and maximum values

Table 2. Main-effect means of zilpaterol hydrochloride (ZH) feeding and housing type on performance and carcass characteristics of finishing beef steers

	Open		Shade		*P*-value			
Item	Control	ZH	Control	ZH	Diet[1]	Housing[2]	Diet × housing	SEM[3]
Performance								
Initial BW, kg	360	362	358	359	0.37	0.24	0.72	3.1
Final BW, kg	645	649	635	640	0.43	0.08	0.90	7.6
DMI, kg/d	9.9	9.6	9.6	9.7	0.61	0.55	0.26	0.21
ADG, kg	1.58	1.58	1.52	1.55	0.56	0.10	0.68	0.034
G:F, kg/kg	0.160	0.164	0.159	0.160	0.44	0.39	0.53	0.0020
Carcass characteristic								
HCW, kg	410	425	406	418	<0.01	0.17	0.61	8.1
Dressing %	63.5	65.6	63.9	65.3	<0.01	0.78	0.29	0.30
LM area, cm^2	89.0	96.12	88.3	93.9	<0.01	0.27	0.59	0.20
12th Rib Fat, cm	1.64	1.59	1.63	1.52	0.15	0.39	0.54	0.020
Marbling score[4]	473	470	478	466	0.50	0.92	0.67	10.0
USDA yield grade [5]	3.6	3.2	3.5	3.2	<0.01	0.89	0.68	0.09
Nonperformance characteristics								
Respiration, breaths/min	92.9	99.7	91.8	101.9	0.05	0.88	0.69	5.82
Panting score[6]	0.59	0.64	0.52	0.72	0.10	0.99	0.31	0.107

[1]Main effect of ZH inclusion.

[2]Main effect of housing type.

[3]Pooled standard error of simple effects means; $n = 4$ pens/mean.

[4]300 = slight; 400 = small; 500 = modest.

[5]Calculated as 2.5 + (6.35 × 12th rib fat) + (0.2 × 2.5[KPH]) + (0.0017 × HCW) – (2.06 × LM area) (USDA, 1997).

[6]Panting scores based on 0 to 4 scale with 0 = no panting and 4 = severe distress.

were calculated on a daily basis. Area under the curve was approximated each day for each individual steer by summing all the temperature points for each day.

Two periods from each block were determined to be relevant heat-stress periods using the adjusted temperature–humidity index (**THI**; Mader et al., 2006; Table 1). There was a 2-d and a 3-d period chosen for each block when the daily adjusted THI was the greatest. These 2 hot periods were analyzed separately using the same procedure described above. Period × ZH and period × housing interactions were not significant ($P > 0.40$) and therefore the effect of period was removed from the model. Data from steers that had lost a bolus and had incomplete data during the observation period were removed before analysis. Additionally, steers that died during the trial (2 steers: 1 open lot control steer and 1 shaded control steer) were removed before analysis.

RESULTS

Performance and carcass data are summarized in Table 2. There were no ZH × housing type interactions ($P > 0.26$) for performance or carcass characteristics (Table 2). Initial BW was not different between dietary treatments or between housing types ($P > 0.24$). Final live BW was not different between the control and ZH-fed cattle ($P = 0.43$); however, there was a tendency for cattle fed in open lot pens to have a greater final live BW than cattle fed in shaded pens ($P = 0.08$). Moreover, ADG did not differ between control-fed and ZH-fed cattle ($P = 0.56$), but cattle fed in open pens tended to have a greater ADG than cattle fed in shaded pens ($P = 0.10$). Dry matter intake and G:F were not affected by dietary treatment or housing type ($P > 0.39$).

Hot carcass weight, dressing percent, and LM area were greater for cattle fed ZH than for cattle fed the control diet ($P < 0.01$). Nevertheless, there was no difference in HCW, dressing percent, and LM area for cattle fed in shaded vs. open pens ($P > 0.17$). Twelfth rib fat thickness and marbling scores were not different between dietary treatments or housing types ($P > 0.15$). Control cattle had a greater USDA yield grade compared with cattle fed ZH

Table 3. Main effect of zilpaterol hydrochloride (ZH) on mobility score calculated as the proportion of animals in a treatment that received the score[1]

Item	Control	ZH	SEM[2]	*P*-value
0 score	90.49	90.63	0.808	0.91
0 and 1 score[3]	99.00	98.44	0.344	0.21
CES[4]	4.94	5.02	0.145	0.68

[1]Mobility scores are based on the Tyson mobility scoring system (Tyson Foods, Springdale, AR) in which 0 is no lameness and 4 is nonambulatory.

[2]Pooled standard error of main-effect means; $n = 8$ pens/mean.

[3]The percentage of animals receiving a score of 0 or 1 added together. The percentage of animals that scored a 2 can be calculated as 100% – the percent of 0 and 1 scores together.

[4]CES = chute exit speed (reported as seconds to travel 7.93 m).

Table 4. Zilpaterol hydrochloride (ZH) effect on percentage of animals in a treatment with a given mobility score at different time points[1]

	Control				ZH					*P*-value				
Score	Before ZH	After ZH	Unloading at plant	Up to restrainer	Before ZH	After ZH	Unloading at plant	Up to restrainer	SEM[2]	Before ZH[3]	After ZH[3]	Unloading at plant[3]	Up to restrainer[3]	Time × ZH[4]
0	93.3	91.1	89.4	87.3	96.3	90.5	87.4	83.6	1.88	0.07	0.79	0.39	0.16	0.14
0 and 1[5]	98.8	99.6	99.0	98.1	99.2	99.2	98.0	95.7	1.01	0.54	0.48	0.26	0.06	0.49
CES[6]	4.60	5.28	–	–	4.70	5.35	–	–	0.15	0.66	0.75	–	–	0.84

[1]Mobility scores are based on the Tyson mobility scoring system (Tyson Foods, Springdale, AR) in which 0 is no lameness and 4 is nonambulatory.

[2]Pooled standard error of the simple effect means; $n = 8$ pens/mean.

[3]Main effect of ZH.

[4]Time × ZH interaction.

[5]The number of animals receiving a mobility score of 0 or 1 added together. The percentage of animals that scored a 2 can be calculated as 100% – the percent of 0 and 1 scores together.

[6]CES = chute exit speed (reported as seconds to travel 7.93 m).

($P < 0.01$), but no differences in USDA yield grade were detected between housing types ($P = 0.89$).

No ZH × housing type interactions were detected ($P > 0.31$) for respiration rates or panting scores (Table 2). Cattle fed ZH had greater respiration rates than cattle fed the control diet ($P < 0.05$), yet respiration rates were not different between housing types ($P = 0.88$). There was a tendency for cattle fed ZH to have a greater panting score than the control cattle ($P = 0.10$), but panting scores were not different between housing types ($P = 0.99$).

There were no ZH × housing or ZH × time interactions observed for mobility score ($P > 0.14$). Consequently, only the main-effect means of dietary treatment and time for mobility are presented in Tables 3 and 4, respectively. There was no difference in mobility between the control cattle and ZH-fed cattle for the percentage of steers scoring 0 ($P = 0.91$) or 0 and 1 ($P = 0.21$; Table 3). No steers during the study received a mobility score of 4 or 5 at any time, and only the 1 steer previously discussed received a mobility score of 3. There were no ZH × housing or ZH × time interactions for chute exit speed ($P > 0.48$; data not shown), and cattle fed the control diet vs. cattle fed the diet containing ZH did not differ in chute exit speed ($P = 0.68$; Table 3).

The effect of time was significant ($P < 0.01$) on overall cattle mobility, in that cattle were more mobile early in the feeding period but mobility decreased over time until harvest (Table 4). Additionally, time affected chute exit velocities with cattle taking more time to travel 7.93 m at the end of the ZH feeding period than before ($P < 0.01$). Even though there was not a significant time × ZH interaction ($P > 0.14$), the effects of ZH feeding across time are presented in Table 4. At the beginning of the trial, cattle assigned to the ZH treatment had a tendency ($P = 0.07$) to have a greater proportion of steers that scored 0 (more mobile) than cattle in the control treatment. Likewise, there was a tendency ($P = 0.06$) for cattle fed ZH to have a lesser proportion of cattle that scored 0 and 1 (less mobile) than the cattle in the control group at the point where cattle were going to the restrainer. For the remainder of the time points, there were no differences between the ZH and control treatments ($P > 0.16$) in the number of steers scoring 0 or 0 and 1. Furthermore, housing did not have an effect on mobility ($P > 0.70$; data not presented).

Zilpaterol hydrochloride × housing type interactions were observed for BT (Table 5; $P < 0.01$). Feeding ZH in open and shaded pens decreased BT relative to the control group ($P < 0.01$). Cattle fed ZH in open pens had the lowest average BT followed by cattle fed ZH in shaded pens, control cattle in shaded pens, and control cattle in open pens ($P < 0.05$). Maximum BT followed this same pattern ($P < 0.05$). Area under the curve and the average magnitude of BT each day also followed the same pattern as average and maximum BT. A housing × time interaction was observed for all BT measures ($P < 0.03$; data not reported). There was no difference ($P > 0.05$) between housing type for maximum, average, and area under the curve for most days; however, there was a difference ($P < 0.05$) for a few days (4, 6, and 6 d, respectively) during the feeding period, where cattle fed in open pens had lower values than cattle fed in shaded pens leading to the interaction.

The hot periods were defined by the greatest adjusted THI for a period of 2 or 3 d (Table 1). During these hot periods, an interaction between ZH and housing type (Table 6; $P < 0.05$) was observed for average BT and area under the curve BT; cattle fed ZH in open pens had the lowest BT followed by cattle in shaded pens, both ZH and control, and control cattle in open pens had the greatest BT ($P < 0.05$). For maximum BT, cattle fed ZH in open pens and in shaded pens were not different ($P = 0.52$) and had the lowest maximum BT followed by control cattle fed in shaded pens and control cattle in open pens with the greatest values ($P < 0.05$).

Table 5. Simple-effect means for cattle body temperature (BT) observed during the presence of a zilpaterol hydrochloride (ZH) × housing interaction

	Open		Shade			*P*-value		
Measurement	Control	ZH	Control	ZH	SEM[1]	Diet[2]	Housing[3]	Diet × housing
Average BT, °C	39.13^{d}	38.98^{a}	39.10^{c}	39.08^{b}	0.011	<0.01	<0.01	<0.01
Maximum BT, °C	40.31^{d}	40.12^{a}	40.26^{c}	40.17^{b}	0.016	<0.01	0.99	<0.01
AUC BT[4]	14,752^{d}	14,711^{a}	14,743^{c}	14,738^{b}	1.6	<0.01	<0.01	<0.01

[a–d]Values within rows with unique superscripts differ ($P < 0.05$).

[1]Pooled SEM; $n = 4$ pens/mean.

[2]Main effect of ZH.

[3]Main effect of housing type.

[4]AUC = area under the curve.

DISCUSSION

The effect of ZH on performance and carcass characteristics has been well documented. Vasconcelos et al. (2008) observed no increase in final live BW between the control group and the average of the other 3 treatments fed ZH over varying lengths of time. Although final live BW was not affected by feeding ZH, HCW was increased, which is consistent with results from the present study. Furthermore, Hilscher et al. (2015) did not observe an increase in final live BW or ADG for cattle fed ZH vs. control. In contrast, Elam et al. (2009) reported an increase in final live BW in addition to increased HCW when cattle were fed ZH. In our study, cattle fed ZH had numerically greater final live BW, which was similar to other literature reports (Vasconcelos et al., 2008; Hilscher et al., 2015).

Montgomery et al. (2009) observed a 0.47 kg/d increase in ADG, a 0.056 kg/kg increase in G:F, and a tendency for decreased DMI for steers fed ZH for 20 d. Likewise, Hales et al. (2014) observed no reduction in DMI in response to ZH, but there was an increase of 0.80 kg/d of ADG and a 0.016 kg/kg increase in G:F over the entire feeding period when ZH was fed for 21 d. In the present study, no effects on DMI, ADG, or G:F were noted. Similarly, Hilscher et al. (2015) noted no differences in DMI or ADG for cattle fed ZH but did note increased G:F over the entire feeding period for cattle fed ZH. Furthermore, Baxa et al. (2010) reported no difference in DMI for cattle fed ZH. Conversely, in a meta-analysis conducted by Lean et al. (2014), a live BW increase of 8 kg was observed along with a reduction in DMI of 0.12 kg/d and an increase of 0.15 kg/d in ADG across numerous studies feeding ZH. However, responses in DMI, ADG, and final live BW have been variable in available literature.

The 14-kg increase in HCW noted in the present study is consistent with the findings of other literature. Elam et al. (2009) observed a 14-kg increase in HCW when cattle were supplemented with ZH for 20, 30, or 40 d. In addition, Montgomery et al. (2009) reported a 13-kg increase in HCW as well as a 1.3% increase in dressing percent and a 7.9-cm^2 increase in LM area. Additionally, Montgomery et al. (2009) reported a 0.38-unit decrease in USDA yield grade, which is consistent with the results from the present study. Hilton et al. (2009) observed an increase in LM area and decreased USDA yield grade when ZH was fed. This is further supported by findings of Hilscher et al. (2015) that reported a 13-kg increase in HCW along with a 7.3-cm^2 increase in LM area and a 0.67-unit decrease in USDA yield grade when ZH was fed. Additionally, a numerical decrease in marbling score and 12th rib fat was observed in the present study for ZH fed cattle, which is consistent with other research (Vasconcelos et al., 2008; Hilton et al., 2009; Montgomery et al., 2009). The HCW and dressing percentage results in the present study are consistent with those of Lean et al. (2014), which reported a 15-kg increase in HCW and 1.7% increase in dressing percentage across a minimum of 27 studies.

Summer conditions consisting of above-normal ambient temperature, relative humidity, and solar radiation can increase an animal's heat load resulting in decreased performance, decreased animal comfort, and eventually death of the animal (Mader et al., 2006). One of the objectives of the present study was to evaluate the effects of feeding ZH during summer heat-stress conditions and determine if the severity of heat stress worsened. Increased respiration rates were observed in the present study with a tendency for increased panting scores in cattle fed ZH compared with the control. These data are consistent with the ZH feed label (Merck Animal Health) that states that increased respiration rates may be observed in conjunction with ZH feeding. Hales et al. (2014) observed a positive slope in the regression line for panting score and respiration rates as days fed ZH increased, suggesting that both measures increased as days on ZH increased. Although not significant, Hales et al. (2014) reported that cattle fed ZH had numerically greater respiration rate and panting scores consistent with the findings in the present study. Whether or not this increase is due to a greater amount

Table 6. Simple-effect means for cattle body temperature (BT) in the presence of a zilpaterol hydrochloride (ZH) × housing type interaction for 2 selected hot periods[1]

	Open		Shade			*P*-value		
Measurement	Control	ZH	Control	ZH	SEM[2]	Diet	Housing	Diet × housing
Average BT, °C	39.17[c]	39.04[a]	39.12[b]	39.11[b]	0.035	<0.01	0.57	<0.01
Maximum BT, °C	40.50	40.32	40.44	40.33	0.050	<0.01	0.31	0.05
AUC BT[3]	14,760[c]	14,728[a]	14,749[b]	14,744[b]	5.1	<0.01	0.57	<0.01

[a–c]Values within rows with unique superscripts differ ($P < 0.05$).

[1]Hot periods were based on highest adjusted temperature–humidity index values. The hot periods are defined in Table 1.

[2]Pooled SEM; $n = 4$ pens/mean.

[3]AUC = area under the curve.

of heat load on the animal with the increased muscle mass or an unobserved biological effect of increased metabolism due to feeding ZH is not well understood.

Although respiration rates and panting scores were increased in cattle fed ZH, the average and maximum BT were lower for cattle fed ZH than for the control group, for both open and shaded housing, which contradicts the theory that feeding a β-agonist increases the heat load on the animal. For cattle not fed ZH, shaded cattle had lower average and maximum BT than cattle in open lots, which is consistent with data reported by Gaughan et al. (2010) suggesting that shade decreases BT. Conversely, in the present study when ZH was fed in open lots, cattle had lower average and maximum BT than cattle in shaded pens. Many studies have reported decreases in DMI associated with feeding ZH. Potentially, the decreased BT could be associated with the heat of fermentation in the rumen because BT was measured via rumen bolus. Even though no differences in DMI were observed with feeding ZH, DMI was numerically lower over the entire feeding period. However, there are very few studies evaluating the effect of β-agonists on heat stress potential of cattle, and the summer conditions during this trial were relatively mild. It is possible that different responses to ZH would be observed under conditions of harsher heat stress.

With the lower BT observed for cattle fed ZH vs. that of the control group, it can be speculated that the increase in respiratory rate is a side effect of feeding ZH rather than a response to increased heat load. Although data does not exist in the literature to directly support this, Finch (1986) suggested that 15% of heat loss in cattle under high heat loads is lost directly through the respiratory tract. The mechanism by which respiration rate is increased in cattle fed ZH is not well understood. However, the fact that lower BT were observed in cattle fed ZH would suggest that the observed increase in respiration rate is not a correlated biological response of cattle attempting to moderate BT. A review by Mersmann (1998) suggested that the addition of an orally administered β-adrenergic agonist could increase blood flow to skeletal muscle and adipose tissues. Finch (1986) noted that under conditions of high heat load, only about 15% of the animal's heat load is lost directly from the core of the animal through the respiratory tract. Therefore, the bulk of heat loss must be transferred to the skin and be lost through conduction, convection, or evaporation off the body surfaces through sweating (Finch, 1986). Blackshaw and Blackshaw. (1994) noted that transfer of heat from the body core depends on blood flow to the skin. If feeding a β-agonist increases blood flow to the skin, as observed by Mersmann (1998), it can be speculated that with more blood being transferred away from the core of the body to muscle and fat, this could aid in cooling the animal and lead to decreased BT through conductive heat loss, although there is no direct evidence of this in literature.

There is very little published data on cattle mobility as impacted by ZH feeding. However, Bernhard et al. (2014) noted that ZH had no effect on chute exit speed or mobility score, which is consistent with the findings of the present study. As time progressed from starting ZH to the day of harvest, when cattle were going up to the restrainer at the abattoir, mobility decreased across all groups of cattle. After arrival at the abattoir, the number of 0 mobility scores decreased by 2.6% when mobility was measured near the holding pens. Furthermore, between arrival at the abattoir and harvest the next morning, the number of animals with a mobility score of 0 decreased by an additional 3.2%. Combined, these data suggest that cattle mobility decreases as cattle gain weight and that transport and standing on concrete at the abattoir further exacerbates this issue. However, further research may help better explain the mechanism by which mobility is decreased. It is important to note that mobility score measurements are subjective and that scores taken at the feedlot were on soil surfaces whereas at the packing plant, these scores were taken on concrete, which can affect the way an animal appears to walk. Also, all cattle passed antemortem inspection by a USDA veterinarian; no welfare or health concerns were noted for any of the cattle.

The effects of heat stress on BT, panting score, respiration rate, and animal performance of cattle has been well documented in literature. Mader et al. (1999)

suggested an effective means of helping animals maintain temperature regulation in hot environments is to reduce incoming thermal radiation by providing shade. Gaughan et al. (2010) evaluated the effects of shade on BT and reported that during a severe heat event, shade decreased cattle BT by 2.3%. In the present study, for cattle not fed ZH, there was a slight decrease in average and maximum BT for shaded cattle when compared with the open lot cattle but only by approximately 0.1%. This could be due, in part, to the mild summer conditions experienced during this study with the majority of day adjusted THI (Mader et al., 2006) falling within or below the alert category of 75 to 78 (Table 1). Gaughan et al. (2010) reported no difference in BT for shaded and unshaded cattle for the first period before the heat wave, which suggests that BT is well regulated and shade is beneficial in reducing BT only during severe heat episodes. Panting scores and respiration rates were not different for shaded and unshaded cattle in the present study, further suggesting that shade used was not effective at mitigating heat stress in the absence of a heat wave. Mitlöhner et al. (2001) observed a 29% decrease in respiration rates for shaded cattle over that of unshaded cattle, which is consistent with other research (Gaughan et al., 2004; Brown-Brandl et al., 2005).

The shades used in the present study were made of layered snow fence. A study conducted by Eigenberg et al. (2010) concluded that using snow fence as a shade material may not be the most effective means of providing shade, but it is one of the most cost effective shade materials and does reduce respiration rates compared with cattle in open pens without shade. In the present study, minimal production response to shade was observed. Mader et al. (1997) suggested that if shade structures are not adequate, then any positive production response of shade will be lost. Although the type of shade used has been shown by Eigenberg et al. (2010) to reduce respiration rates when compared with unshaded cattle, the snow fence shade material was the least effective of all the materials observed, potentially resulting in the lack of shade response noted in the present study.

The effect of shade on animal performance has been well documented. Gaughan et al. (2010) observed an increase in final live BW, ADG, DMI, and G:F for cattle fed in shade vs. cattle fed in an open lot system. In the present study, there were no differences observed for any animal performance or carcass characteristics between shaded and unshaded cattle, further suggesting that the shade provided was inadequate or heat stress was insufficient to hinder performance. However, Pusillo et al. (1991) suggested that DMI for cattle in the latter stages of the feeding period exposed to midwestern climatic conditions are relatively unaffected by presence or absence of overhead shelter. Similarly, Bond and Laster (1975) reported that cattle ADG and G:F during midwestern summers are unaffected by having access to shade or not. This could suggest that the cattle were simply not heat stressed enough to benefit from having access to shaded pens. Additionally, as G:F and DMI for the present study was calculated for the entire feeding period starting in January, the effect of heat stress and shade may have been masked by the winter and spring months. As no increase in performance was observed in the present study, this could suggest that with mild environmental conditions the shade constructed of snow fence that was used in the present study may have little effect on cattle performance.

In the present study, the use of ZH for 21 d at the end of the feeding period increased HCW, dressing percent, and LM area and improved yield grade with little effect on live animal performance. Shade used in the present study had little effect on cattle performance or carcass characteristics. Although respiration rates and panting scores were or had a tendency to be greater for cattle fed ZH, average and maximum BT for cattle fed ZH were lower than those of the control. This suggests that the inclusion of ZH had little impact on the heat load experienced by the animal. Overall, no impact was observed for feeding ZH on cattle mobility; however, with time, mobility decreased for all cattle up until harvest. Based on the observations in this study, it can be concluded that the use of ZH improved carcass characteristics with little impact on heat stress or mobility, suggesting that animal welfare was not affected by feeding ZH during the last 21 d of the feeding period.

LITERATURE CITED

Baxa, T. J., J. P. Hutchenson, M. F. Miller, J. C. Brooks, W. T. Nichols, M. N. Streeter, D. A. Yates, and B. J. Johnson. 2010. Additive effects of a steroidal implant and zilpaterol hydrochloride on feedlot performance, carcass characteristics, and skeletal muscle messenger ribonucleic acid abundance in finishing steers. J. Anim. Sci. 88:330–337. doi:10.2527/jas.2009−1797.

Bernhard, B. C., C. L. Maxwell, C. F. O'Neill, B. K. Wilson, C. G. Hixon, C. L. Haviland, A. N. Grimes, M. S. Calvo-Lorenzo, C. J. Richards, D. L. Step, B. P. Holland, and C. R. Krehbiel. 2014. The effects of technology use in feedlot production systems on the performance, behavior and welfare of steers finishing during late summer. In: Proceedings of the Plains Nutrition Council Spring Conference, San Antonio, TX. p. 142−169.

Blackshaw, J. K., and A. W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behavior: A review. Aust. J. Exp. Agric. 34:285–295. doi:10.1071/EA9940285.

Bond, T. E., and D. B. Laster. 1975. Influence of shading on production of Midwest feedlot cattle. Trans. ASAE 18:957–959. doi:10.13031/2013.36717.

Brown-Brandl, T. M., R. A. Eigenberg, J. A. Nienaber, and G. L. Hahn. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 1: Analyses of indicators. Biosyst. Eng. 90:451–462. doi:10.1016/j.biosystemseng.2004.12.006.

Eigenberg, R. A., T. M. Brown-Brandl, and M. D. Hayes. 2013. Shade structure design and evaluation. ASABE Meeting Presentation no. 131595866. Am. Soc. Agric. Biol. Eng. Kansas City, MO.

Eigenberg, R. A., T. M. Brown-Brandl, and J. A. Nienaber. 2010. Shade material evaluation using a cattle response model and meteorological instrumentation. Int. J. Biometeorol. 54:509−515. doi:10.1007/s00484-010-0343-z.

Elam, N. A., J. T. Vasconcelos, G. Hilton, D. L. VanOverbeke, T. E. Lawrence, D. A. Yates, and M. L. Galyean. 2009. Effect of zilpaterol hydrochloride duration of feeding on performance and carcass characteristics of feedlot cattle. J. Anim. Sci. 87:2133–2141. doi:10.2527/jas.2008−1563.

Finch, V. A. 1986. Body temperature in beef cattle: Its control and relevance to production in the tropics. J. Anim. Sci. 62:531–542.

Gaughan, J. B., S. Bonner, I. Loxton, T. L. Mader, A. Lisle, and R. Lawrence. 2010. Effect of shade on body temperature and performance of feedlot steers. J. Anim. Sci. 88:4056–4067. doi:10.2527/jas.2010-2987.

Gaughan, J. B., L. A. Tait, R. Eigenberg, and W. L. Bryden. 2004. Effect of shade on respiration rate and rectal temperature of Angus heifers. Anim. Prod. Aust. 25:69–72.

Hales, K. E., S. D. Shackelford, J. E. Wells, D. A. King, M. D. Hayes, T. M. Brown-Brandl, L. A. Kuehn, H. C. Freetly, and T. L. Wheeler. 2014. Effects of feeding dry-rolled corn-based diets with and without wet distillers grains with solubles and zilpaterol hydrochloride on performance, carcass characteristics and heat stress in finishing steers. J. Anim. Sci. 92:4023–4033. doi:10.2527/jas.2014−7638.

Hilscher, F. H., Jr., E. M. Hussey, B. L. Nuttelman, D. B. Burken, W. A. Griffin, K. J. Vander Pol, J. P. Hutcheson, and G. E. Erickson. 2015. Impact of sorting before feeding zilpaterol hydrochloride on feedlot performance and carcass characteristics of yearling steers. J. Anim. Sci. 93:2285–2296. doi:10.2527/jas.2014−8579.

Hilton, G. G., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutchenson, 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. doi:10.2527/jas.2008−1170.

Lean, J. I., J. M. Thompson, and F. R. Dunshea. 2014. A meta-analysis of zilpaterol and ractopamine effects on feedlot performance traits and shear strength of meat in cattle. PLoS ONE 9(12):e115904. doi:10.1371/journal.pone.0115904.

Mader, T. L., J. M. Dahlquist, and J. B. Gaughan. 1997. Wind protection effects and airflow patterns in outside feedlots. J. Anim. Sci. 75:26–36.

Mader, T. L., J. M. Dahlquist, G. L. Hahn, and J. B. Gaughan. 1999. Shade and wind barrier effects on summertime feedlot cattle performance. J. Anim. Sci. 77:2065−2072.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 84:712–719.

Mersmann, H. J. 1998. Overview of the effects of β-adrenergic receptor agonists on animal growth including mechanisms of action. J. Anim. Sci. 76:160−172.

Mitlöhner, F. M., J. L. Morrow, J. W. Dailey, S. C. Galyean. M. F. Miller, and J. J. McGlone. 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. J. Anim. Sci. 79:2327−2335.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutchenson, W. T. Nichols, M. N. Streeter, D. T. Bechtol, E. Johnson, T. TerHune, and T. H. Montgomery. 2009. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 87:1374–1383. doi:10.2527/jas.2008−1162.

Pusillo, G. M., M. P. Hoffman, and H. L. Self. 1991. Effects of placing cattle on feed at two-month intervals and housing on feedlot performance and carcass characteristics. J. Anim. Sci 69:443–450.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 2003. Online prediction of yield grade, longissimus muscle area, preliminary yield grade, adjusted preliminary yield grade, and marbling score using the MARC beef carcass image analysis system. J. Anim. Sci. 81:150−155.

Strydom, P. E., L. Frylinck, J. L. Montgomery, and M. F. Smith. 2009. The comparison of three β–agonists for growth performance, carcass characteristics and meat quality of feedlot cattle. Meat Sci. 81:557–564. doi:10.1016/j.meatsci.2008.10.011.

USDA. 1997. Official United States standards for grades of carcass. Beef. Agric. Marketing Serv., USDA, Washington, DC.

U.S. Food and Drug Administration (FDA). 2006. Freedom of information summary. Original new drug application NADA 141-258. Zilpaterol hydrochloride (ZILMAX). Type A medicated article for cattle fed in confinement for slaughter. http://www.fda.gov/downloads/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/FOIDrugSummaries/ucm051412.pdf. (Accessed 10 February 2015.)

Vasconcelos, J. T., T. J. Tathmann, R. R. Reuter, J. Leibovitch, J. P. McMeniman, K. E. Hales, T. L. Covey, M. F. Miller, W. T. Nichols, and M. L. Galyean. 2008. Effects of duration of zilpaterol hydrochloride feeding and days on the finishing diet on feedlot cattle performance and carcass traits. J. Anim. Sci. 86:2005–2015. doi:10.2527/jas.2008−1032.