Zilpaterol Hydrochloride Effects on Red Meat Yield and Quality

J. C. Brooks,* A. W. Tittor,* J. D. Kellermeier,* E. Alsup,† J. P. Hutcheson,† J. L. Montgomery,† W. T. Nichols,† M. Streeter,† D. A. Yates,† and M. F. Miller*

*Texas Tech University, Department of Animal and Food Sciences, Lubbock, TX 79409
†Intervet/Schering-Plough Animal Health, Millsboro, DE 19966

Introduction

Zilpaterol hydrochloride is a β-adrenergic agonist, which belongs to a group of compounds known as catecholamines. β-Adrenergic agonists activate β-receptors in muscle and fat causing increased lipolysis, decreased lipogenesis or increased protein accretion (Mersmann, 1998), or both. β-Adrenergic agonists vary greatly in their effect on meat animals. Supplementation of diets with β-agonists can result in increased rate of weight gain, feed efficiency, leanness, and dressing percentage (Moody et al., 2000). Supplementation of β-agonists has also been shown to decrease marbling scores, increase Warner-Bratzler shear force, and adversely affect consumer sensory scores.

Zilpaterol hydrochloride was originally developed to treat pulmonary distress in humans through relaxation of the muscles associated with the airway (Verhoeckx et al., 2006). However, its ability to increase protein accretion in skeletal muscle and reduce body fat to improve red meat yield has resulted in further development in meat animal production. Zilpaterol hydrochloride was approved for use in South Africa and Mexico in 1998 and approved for use in the United States in 2006. Zilpaterol hydrochloride is marketed under the brand name Zilmax with the following label indications: "For increased weight gain, improved feed efficiency, and increased carcass leanness in cattle fed in confinement for slaughter during the last 20 to 40 days on feed." Zilmax pricing is determined monthly using USDA-AMS pricing for USDA Select beef carcasses and is published on the company's Web site (http://www.zilmax.com/customerpricing.aspx).

Increased weight gains and feed efficiency leading to carcass leanness and higher dressing percentage can offset high feed costs and increase profitability. However, these advantages might come at the expense of meat quality, heavy carcasses, and large subprimals. To better understand the role zilpaterol hydrochloride will play in the meat industry, it is important to characterize the effects it can have on economically important traits. This paper will review the literature in an effort to chronicle the effects of zilpaterol hydrochloride on beef carcass characteristics, cutability, carcass quality traits, shear force, and palatability characteristics, in an effort to better understand the compound and its potential use.

Carcass Characteristics

A summation of the literature suggests zilpaterol hydrochloride has a greater impact on longissimus muscle area and hot carcass weights than backfat thickness and internal fat measures. Plascencia et al. (1999) reported significant increases in longissimus muscle area in cattle treated with zilpaterol hydrochloride, whereas no differences were observed between treatments for backfat and internal fat measures. In steers fed in South Africa, Casey et al. (1997a,b) reported zilpaterol hydrochloride treatment increased longissimus area by approximately 23% and decreased subcutaneous fat by 5.8%. Among steers and heifers fed zilpaterol hydrochloride for 20 d, Montgomery et al. (2008a) reported that longissimus muscle area increased ($P < 0.01$) 1.23 and 0.9 in^2 for steers and heifers, respectively. However, backfat and percentage internal fat were not affected in either steer or heifer carcasses at 20- or 40-d feeding durations (Montgomery et al., 2008a; Table 1 and 2). Feeding zilpaterol hydrochloride in

J. C. Brooks
Texas Tech University, Department of Animal and Food Sciences, Lubbock, TX 79409

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Table 1. Effects of Zilmax and duration of Zilmax feeding on carcass characteristics of steers[a]

	20 d		40 d			Probability		
Item	Control	Zilmax	Control	Zilmax	SEM	Duration (D)	Zilmax (Z)	D × Z
HCW, lb	780	808	782	826	18	0.06	0.0001	0.13
Dressing %	62.7	64.0	62.8	64.6	1.23	0.04	<0.0001	0.06
LM area, in^2	13.02	14.25	13.26	14.59	0.26	0.02	<0.0001	0.65
12th-rib fat, in	0.52	0.47	0.50	0.47	0.04	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[b]	461	432	462	398	0.17	0.09	0.002	0.07
Quality grade[c]	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	0.0009	0.64
Masculinity	5.04	5.33	5.05	5.59	0.05	0.008	<0.0001	0.01
Color score[d]	5.08	5.20	5.06	5.31	0.14	0.70	0.12	0.54
Dark cutters,[e] %	0.00	1.67	0.00	1.68	—	—	—	—
Skeletal maturity	A^{70}	A^{71}	A^{68}	A^{72}	3.89	0.84	0.38	0.67
Lean maturity	A^{65}	A^{65}	A^{68}	A^{66}	3.13	0.61	0.77	0.69
Overall maturity	A^{70}	A^{71}	A^{71}	A^{72}	3.12	0.72	0.67	0.94
Condemned livers,[f] %	26.67	22.50	29.17	25.21	—	—	—	—

[a]Data source: Montgomery et al. (2008a).

[b]Marbling scores: 400 = Small^{00}; 500 = Modest^{00}.

[c]Quality grade: 4.00 = low Choice, 5.00 = average Choice.

[d]Color score scale: 8 = extremely bright cherry red; 1 = extremely dark red.

[e]Cochran-Mantel-Haenszel chi-square ($P = 0.37$).

[f]Cochran-Mantel-Haenszel chi-square ($P = 0.90$).

combination with monensin and tylosin (Montgomery et al., 2008b) for 30 d has been shown to decrease backfat thickness by 0.4 in, internal fat by 0.07%, and increase longissimus muscle area by 7.7% (+1.2 in^2). Montgomery and associates categorized longissimus muscle area for treated and control carcasses and demonstrated zilpaterol hydrochloride increased longissimus muscle area 1.3 to 1.5 in^2 (Figure 1).

Table 2. Effects of Zilmax and duration of Zilmax feeding on carcass characteristics of heifers[a]

	20 d		40 d			Probability		
Item	Control	Zilmax	Control	Zilmax	SEM	Duration (D)	Zilmax (Z)	D × Z
HCW, lb	705	730	711	741	31	0.002	<0.0001	0.34
Dressing %	62.7	64.2	63.0	64.6	1.07	0.05	<0.0001	0.78
LM area, in^2	13.17	14.07	13.45	14.52	0.26	0.0009	<0.0001	0.39
12th-rib fat, in	0.55	0.51	0.53	0.53	0.03	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[b]	461	457	470	437	0.23	0.58	0.07	0.15
Quality grade[c]	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	4.86	5.13	4.97	5.32	0.06	0.03	0.0008	0.50
Color score[d]	5.05	5.28	5.09	5.35	0.10	0.61	0.04	0.91
Dark cutters,[e] %	5.00	0.85	0.83	1.68	—	—	—	—
Skeletal maturity	A^{75}	A^{72}	A^{73}	A^{74}	2.46	0.85	0.74	0.46
Lean maturity	A^{71}	A^{65}	A^{68}	A^{63}	4.95	0.27	0.04	0.82
Overall maturity	A^{76}	A^{72}	A^{74}	A^{72}	2.50	0.61	0.26	0.56
Condemned livers,[f] %	15.0	16.1	20.0	21.9	—	—	—	—

[a]Data source: Montgomery et al. (2008a).

[b]Marbling scores: 400 = Small^{00}; 500 = Modest^{00}.

[c]Quality grade: 4.00 = low Choice, 5.00 = average Choice.

[d]Color score scale: 8 = extremely bright cherry red; 1 = extremely dark red.

[e]Cochran-Mantel-Haenszel chi-square ($P = 0.09$).

[f]Cochran-Mantel-Haenszel chi-square ($P = 0.12$).

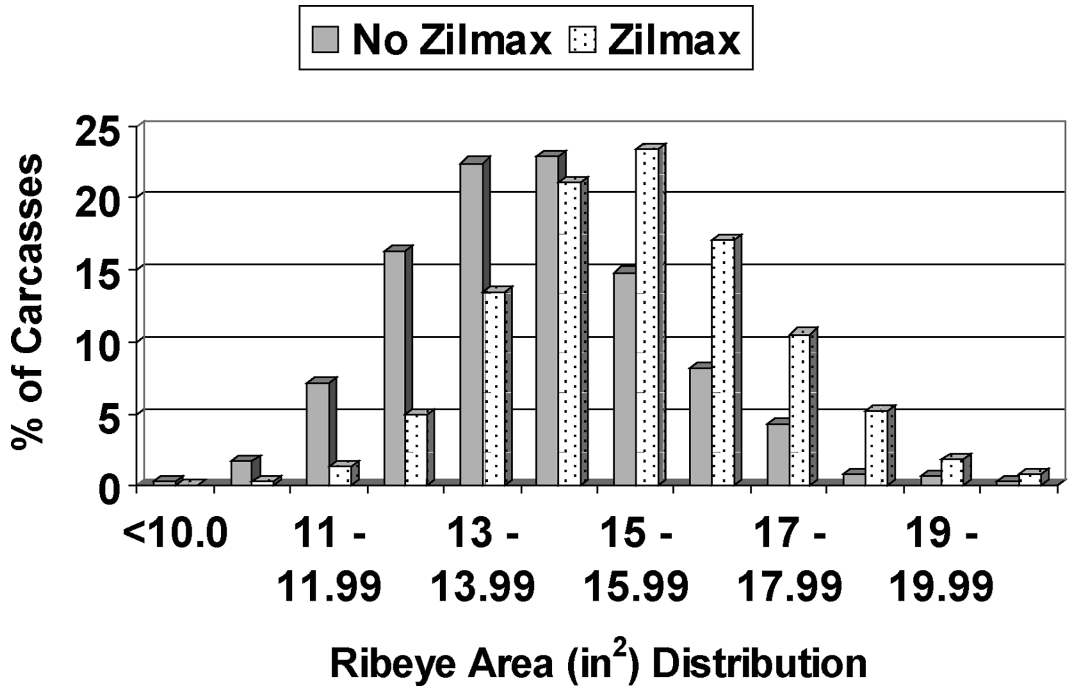

Figure 1. Effect of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d on ribeye area distribution. Source: Montgomery et al. (2008b).

Zilpaterol hydrochloride feeding has been shown to increase hot carcass weights by 3 to 5% (Strydom et al., 1998; Plascencia et al., 1999; Montgomery et al., 2008a,b), although Casey et al. (1997a) reported an 18% increase in hot carcass weight. Carcass weight gain among zilpaterol hydrochloride-treated animals appears to be greater in steer carcasses when compared with heifer carcasses, although both show significant increases when treated (Table 1 and 2). Dressing percentage of steers and heifers treated with zilpaterol hydrochloride increases 1 to 5% (Casey et al., 1997a,b; Strydom et al., 1998, 1999; Plascencia et al., 1999; Montgomery et al., 2008a,b), whereas most of the reports show a 1.5% increase in dressing percentage of treated animals. This increase in dressing percentage provides an advantage to producers who sell beef on a carcass weight or grid basis, as well as meat processors with live cattle ownership.

Increases in hot carcass weights and longissimus muscle area resulting from zilpaterol hydrochloride can be observed in beef yield grades. Montgomery et al. (2008a,b) reported an 8 to 15% improvement in beef yield grades (see Table 1, 2, and 3) attributed to zilpaterol hydrochloride. Categorical yield grade distribution among steer and heifer carcasses from cattle fed zilpaterol hydrochloride for 20 or 40 d indicated a decrease in USDA Yield grade 3 carcasses with a concomitant increase in USDA Yield grade 1 carcasses (Montgomery et al., 2008a; Figure 2 and 3). In addition, commercial trials comparing zilpaterol hydrochloride with or without monensin and tylosin increased the frequency of USDA Yield grade 1 carcasses and decreased the frequency of USDA Yield grade 3 and 4 carcasses compared with control (Figure 4).

Cutability (Red Meat Yield)

Cutability can be estimated with USDA Yield grades or measured with fabrication trials. The following data were generated from fabrication trials. Data reveals that feeding zilpaterol hydrochloride for 20 to 40 d significantly

Table 3. Effects of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d on carcass characteristics[a]

Item	Control	Zilmax	SEM	Pr > F[b]
HCW, lb	813	841	2.86	<0.0001
Dressing %	64.8	66.0	0.09	<0.0001
LM area, in^2	14.2	15.4	0.09	<0.0001
LM:100 lb HCW	1.75	1.83	0.01	<0.0001
12th-rib fat, in	0.46	0.42	0.01	0.0009
KPH, %	1.99	1.92	0.03	0.0004
Marbling[c]	421	397	4.37	<0.0001
Quality grade[d]	11.25	10.79	0.07	<0.0001
Preliminary YG	3.14	3.05	0.03	0.001
Calculated YG	2.59	2.19	0.04	<0.0001
USDA YG	2.59	2.21	0.04	<0.0001
Color score[e]	5.10	5.05	0.04	0.09
Total liver abscess rate, %	15.38	11.85	0.99	0.006

[a]Data source: Montgomery et al. (2008b).

[b]Standard error of the least squares mean.

[c]Marbling score: Slight^{00} = 300; Small^{00} = 400.

[d]Quality grade: 10.00 = low Choice, 11.00 = average Choice.

[e]Color score: (1 to 9 scale, 1 being the lightest and 9 the darkest) 1 = light pink; 2 = pink; 3 = dark pink; 4 = light cherry red; 5 = cherry red; 6 = dark red; 7 = very dark red (considered 1/3 dark cutter); 8 = maroon (considered 2/3 dark cutter); 9 = dark maroon (considered full dark cutter).

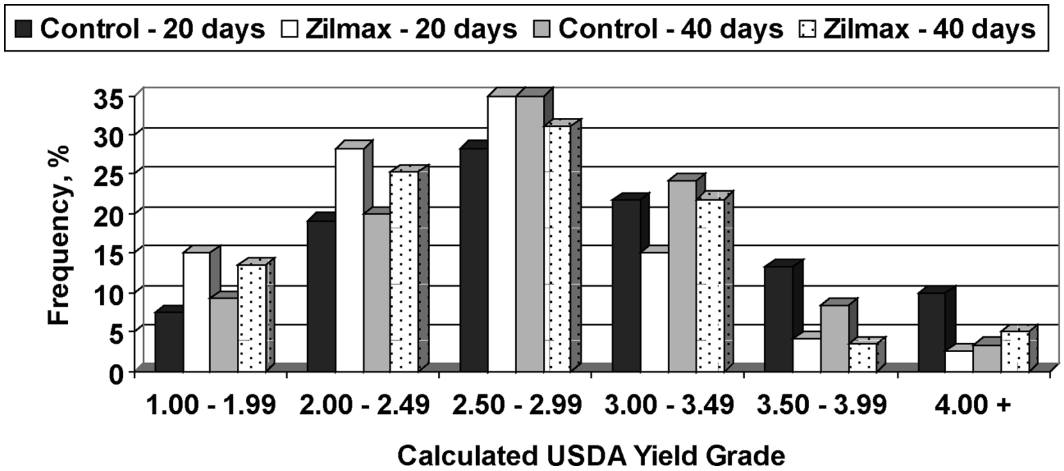

Figure 2. Effects of feeding Zilmax for 20 or 40 d on calculated USDA Yield grade distribution of steer carcasses. Source: Montgomery et al. (2008[a]).

Item	1.00 – 1.99	2.00 – 2.49	2.50 – 2.99	3.00 – 3.49	3.50 – 3.99	4.00+
Control – 20 d	7.50	19.17	28.33	21.67	13.33	10.00
Zilmax – 20 d	15.00	28.33	35.00	15.00	4.17	2.50
Control – 40 d	9.17	20.00	35.00	24.17	8.33	3.33
Zilmax – 40 d	13.45	25.21	31.09	21.85	3.36	5.04
χ^2 probability	0.35	0.57	0.66	0.56	0.02	0.12

improves red meat yield and profitability. Plascencia et al. (1999) reported significant increases in the percentage of knuckle, inside skirt, neck, inside round, and tri-tip in zilpaterol hydrochloride-treated steers, with an overall increase of 3.2% in subprimal yield (expressed as a percentage of carcass weight). Hilton et al. (2008) reported the following carcass subprimals (USDA Institutional Meat Purchase Specifications number, name) from zilpaterol hydrochloride-treated cattle had significantly ($P < 0.05$) heavier weights when compared with control carcasses: 109B blade meat; 114 shoulder cold; 116B chuck tender (m. supraspinatus); 167A knuckle, peeled; 169 inside round; 171B outside (flat) round; 171C eye of round; 180 strip loin, short-cut, boneless; 184 top sirloin butt; 189A

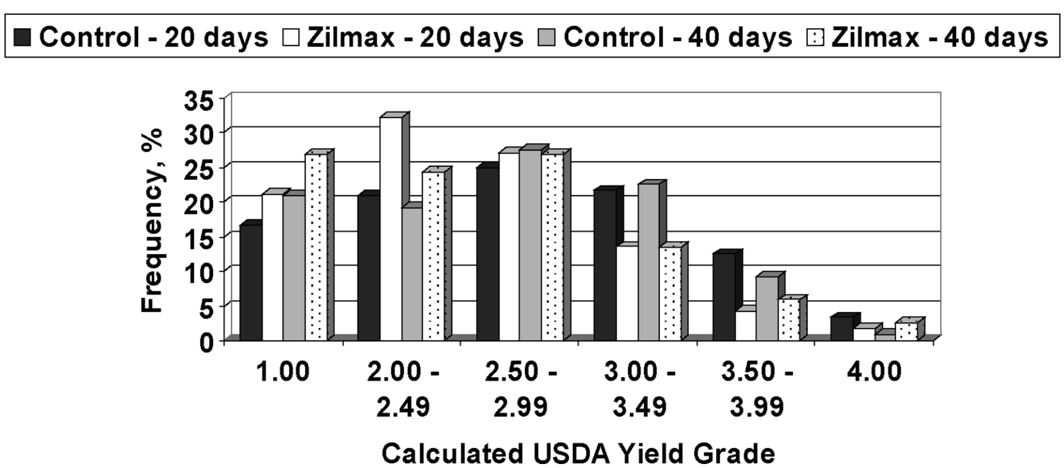

Figure 3. Effects of feeding Zilmax for 20 or 40 d on calculated USDA Yield grade distribution of heifer carcasses. Source: Montgomery et al. (2008a).

Item	1.00	2.00 – 2.49	2.50 – 2.99	3.00 – 3.49	3.50 – 3.99	4.00
Control – 20 d	16.67	20.83	25.00	21.67	12.50	3.33
Zilmax – 20 d	21.19	32.20	27.12	13.56	4.24	1.69
Control – 40 d	20.83	19.17	27.50	22.50	9.17	0.83
Zilmax – 40 d	26.89	24.37	26.89	13.45	5.88	2.52
χ^2 probability	0.07	0.90	0.74	0.31	0.18	0.57

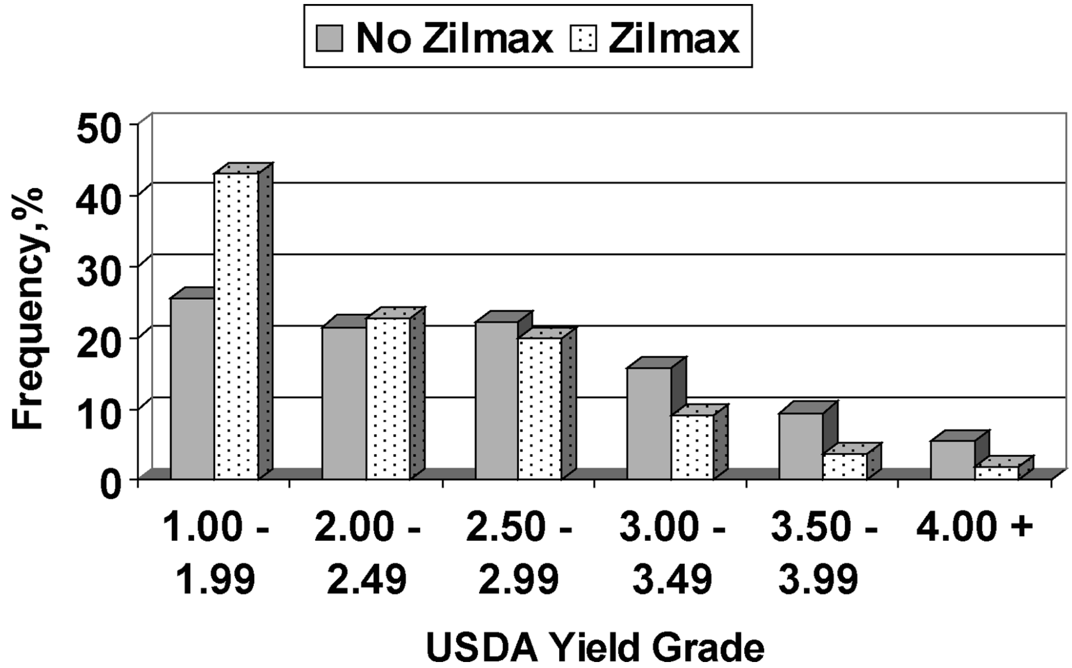

Figure 4. Effect of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d before slaughter on USDA Yield grade distribution. Source: Montgomery et al. (2008b).

Item	1.00 – 1.99	2.00 – 2.49	2.50 – 2.99	3.00 – 3.49	3.50 – 3.99	4.00+
No Zilmax	25.46	21.52	22.22	15.75	9.49	5.56
Zilmax	42.87	22.61	19.77	9.02	3.73	2.00
χ^2 probability	<0.0001	0.43	0.07	<0.0001	<0.0001	<0.0001

full tenderloin, trimmed; 193 flank steak, neck meat, and deep pectoral meat (Table 4 and 5). In addition, the percentage of 90% lean trimmings was increased with zilpaterol hydrochloride treatment, and the percentage of fat significantly decreased in zilpaterol hydrochloride-treated cattle (Hilton et al., 2008). Zilpaterol hydrochloride increased the yield of shoulder clod, beef round (inside, outside, and eye of round), strip loin, and tenderloin by 7, 8, 5, and 6%, respectively. These increases in carcass yield lead to larger subprimal weights for the clod, mock tender, ribeye roll, strip loin, tenderloin, top butt, flat, eye, inside, and knuckle from zilpaterol hydrochloride-treated carcass chosen to have carcass weights equal to control carcasses. This weight advantage increased the value of zilpaterol hydrochloride-treated carcasses by US$52.81 per carcass using prices as of November of 2005 (Hilton et al., 2008; Table 5). Thus, zilpaterol hydrochloride treatment significantly increased carcass weight, subprimal weight, and decreased carcass fat, resulting in increased red meat yield and value.

Carcass Quality Grade

Carcass quality is determined by intramuscular fat (marbling) in the longissimus muscle at the 12th-13th rib interface and carcass maturity. These factors combine to determine USDA Quality grade, which is an estimate of meat palatability. Casey et al. (1997a) indicated zilpaterol hydrochloride-treated steers in South Africa tended to have decreased marbling scores from (Select^{83} to Select^{40}) compared with controls, but the numerical difference was statistically significant. Plascencia et al. (1999) reported cattle fed in Mexico and supplemented with zilpaterol hydrochloride showed no difference in marbling scores compared with control cattle. Montgomery et al. (2008a) reported zilpaterol hydrochloride treatment for 20 d decreased marbling score by 4 and 29 degrees in steers and heifer, respectively, whereas treatment for 40 d resulted in 33- and 64-degree decreases compared with control carcasses. In addition, a 30-d treatment of zilpaterol hydrochloride decreased marbling score by 24 degrees compared with control carcasses (Montgomery et al., 2008b). The distribution of USDA Quality grades from cattle fed zilpaterol hydrochloride for 30 d is shown in Figure 5. Feeding zilpaterol hydrochloride decreased USDA premium (modest and moderate marbling) Choice carcasses by 3.4% and low (small marbling) Choice by 9.3% and increased Select and no-roll (USDA Standard) carcasses by 7.8 and 5.7% compared with cattle not fed zilpaterol hydrochloride (Montgomery et al., 2008b). Montgomery et al. (2008a) also reported that duration of feeding time had a moderating effect on marbling score and USDA Quality grade, especially in steers, suggesting marbling and

Table 4. Effects of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d on carcass cutability[a]

Item[b]	Control	Zilmax	SEM	Pr > F[c]
109B Blade meat	1.05	1.15	0.04	0.002
112A Ribeye roll	3.71	3.79	0.04	0.06
114 Shoulder clod	4.94	5.27	0.05	0.0001
116A Chuck roll	5.28	5.29	0.07	0.84
116B Chuck tender (supraspinatus)	0.91	0.96	0.01	0.005
120 Brisket, bnls, deckle off	2.84	2.76	0.07	0.17
121C Skirt steak (diaphragm), outer	0.63	0.66	0.07	0.19
121D Skirt steak, inner	0.68	0.70	0.05	0.15
121G Short plate, bnls, (short ribs removed)	3.33	3.19	0.08	0.14
123 Short ribs	1.47	1.51	0.02	0.13
124 Back ribs	0.81	0.91	0.08	0.40
130A Short ribs, bnls	0.66	0.65	0.02	0.81
167A Knuckle, peeled	2.26	2.36	0.04	0.008
169 Top (inside) round	5.34	5.80	0.09	0.0001
171B Outside (flat) round	4.62	5.02	0.04	0.0001
171C Eye of the round	1.51	1.64	0.02	0.0004
180 Strip loin, short-cut, bnls	3.05	3.20	0.05	0.003
184 Top sirloin butt	3.40	3.61	0.06	0.0009
185A Bottom sirloin butt, flap	0.98	1.02	0.02	0.09
185B Bottom sirloin butt, ball tip	0.80	0.96	0.04	0.0007
185C Bottom sirloin butt, tri-tip[d]	0.80	0.85	0.01	0.002
189A Full tenderloin, defatted	1.57	1.73	0.02	0.0001
193 Flank steak	0.48	0.54	0.01	0.0001
Neck meat	1.29	1.41	0.11	0.02
Deep pectoral meat	0.52	0.58	0.02	0.001
Hanging tender meat (diaphragm)	0.47	0.46	0.03	0.68
Rose meat (cutaneous omobrachialis)	0.52	0.54	0.02	0.22
90/10 trimmings	3.18	3.34	0.17	0.001
80/20 trimmings	6.88	7.18	0.33	0.09
50/50 trimmings	5.53	5.29	0.40	0.20
Fat	11.69	10.04	0.38	0.002
Bone	14.80	14.67	0.19	0.59

[a]Data source: Hilton et al. (2008).

[b]Institutional Meat Purchase Specifications (IMPS) number (USDA, 1996) followed by the common name of the subprimal. Values expressed as a percentage of chilled carcass weight.

[c]Probability of an effect of zilpaterol.

[d]For tri-tip percentage yield, there was a zilpaterol hydrochloride supplementation × monensin/tylosin supplementation interaction ($P = 0.02$). Tri-tip percentage yield from steers supplemented zilpaterol hydrochloride without monensin/tylosin supplementation was greater ($P = 0.03$) than all other treatment groups.

USDA Quality grade can be managed more effectively in cattle fed zilpaterol hydrochloride for 20 d. A comparison of β-adrenergic agonists in steers in South Africa revealed that clenbuterol reduced marbling scores over 30 degrees compared with controls, whereas zilpaterol hydrochloride and ractopamine marbling scores did not differ from control steers (Strydom et al., 2002). Data reporting the effect of zilpaterol hydrochloride on carcass maturity is not well documented. Nonetheless, Montgomery et al. (2008a) and Strydom et al. (2002) reported carcass lean and skeletal maturity scores were not affected by zilpaterol hydrochloride treatment in steers or heifers.

Montgomery et al. (2008a) reported carcass color scores measured in the longissimus muscle were improved in zilpaterol hydrochloride-treated heifers, and the percentage of dark, firm, and dry carcasses was not affected by zilpaterol hydrochloride treatment (Table 1 and 2). In another study by Montgomery et al. (2008b), zilpaterol hydrochloride treatment tended to decrease color scores, resulting in a more cherry red-colored longissimus muscle (Table 3). In the same study, zilpaterol hydrochloride treatment had no effect on the incidence of dark cutters (Montgomery et al., 2008b). Buys and Strydom (2000) showed that trained panelist's scores for ground beef from 30- and 50-d zilpaterol hydrochloride treatments were more acceptable than controls and produced an additional day of acceptability compared with controls. Hilton et al. (2008) and Strydom et al. (2002) observed an improvement in shelf-life, as well as lower levels of metmyoglobin in steaks from cattle treated with zilpaterol hydrochloride. In addition, Hilton et al. (2008) observed improved color

Table 5. Effects of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d on carcass cutability traits of the major cuts and estimated value

Subprimal[a,b]	Yield difference by feeding zilpaterol, %	Weight difference by feeding zilpaterol, lb	Value gain, $
Brisket	−0.06	−0.30	−0.36
Chuck roll	−0.07	−1.00	−1.78
Clod	0.28	3.85	6.09
Mock tender	0.03	0.52	0.86
Ribeye roll (2 × 2)	0.00	1.14	5.78
Strip (0X1)	0.07	1.53	6.01
Tenderloin	0.11	1.40	12.94
Top butt	0.14	2.15	4.51
Eye	0.08	1.10	2.49
Flat	0.28	3.70	6.84
Inside	0.32	4.26	7.30
Knuckle	0.05	1.15	2.13
Total	1.23	19.50	52.81

[a]Data source: Hilton et al. (2008). November 7, 2005 US boxed beef prices used in estimates.

[b]Note: carcasses of equal weight were selected for fabrication (Control = 808 and zilpaterol hydrochloride = 812 lb; P = 0.39).

scores over a 5-d period of display for m. longissimus (Figure 6) steaks from zilpaterol hydrochloride-treated steers. Buys and Strydom (2000) found that polyvinylchloride film over wrapped strip loin steaks from zilpaterol hydrochloride-treated cattle produced more desirable lean color scores compared with control cattle, especially during the first 5 d of display. In addition, the saturation values of the strip steaks did not differ significantly between treatments; indicating zilpaterol hydrochloride decreased the onset of lean color browning. Strydom (2000) and Strydom et al. (2002) showed ground beef, strip loin, and gluteus medius steaks from zilpaterol hydrochloride-treated steers had increased color scores and decreased metmyoglobin concentrations throughout the retail display period when compared with control samples. These data indicate zilpaterol hydrochloride has no detrimental effect on carcass, ground beef, and steak lean color scores and can enhance color scores, color stability, and increase the shelf-life of beef animals.

Shear Force

Supplementation of β-agonists has been shown to increase shear force by 7 to 300% across various trials. The increased shear force has been speculated to be the result of increased calpastatin activity, reduced calpain activity, increased fiber diameter, change in muscle fiber type, and a possible increase in heat-stable collagen.

Zilpaterol feeding for 45 d significantly increased force by 28% in steers fed in South Africa, whereas feeding the supplement for less than 30 d did not affect shear force for longissimus muscle (Strydom et al., 2002). Buys and Strydom (2000) observed shear force increased by approximately 20% when zilpaterol hydrochloride was fed for 30 and 50 d before slaughter with no differences between treatments. Strydom and Nel (1996) reported shear

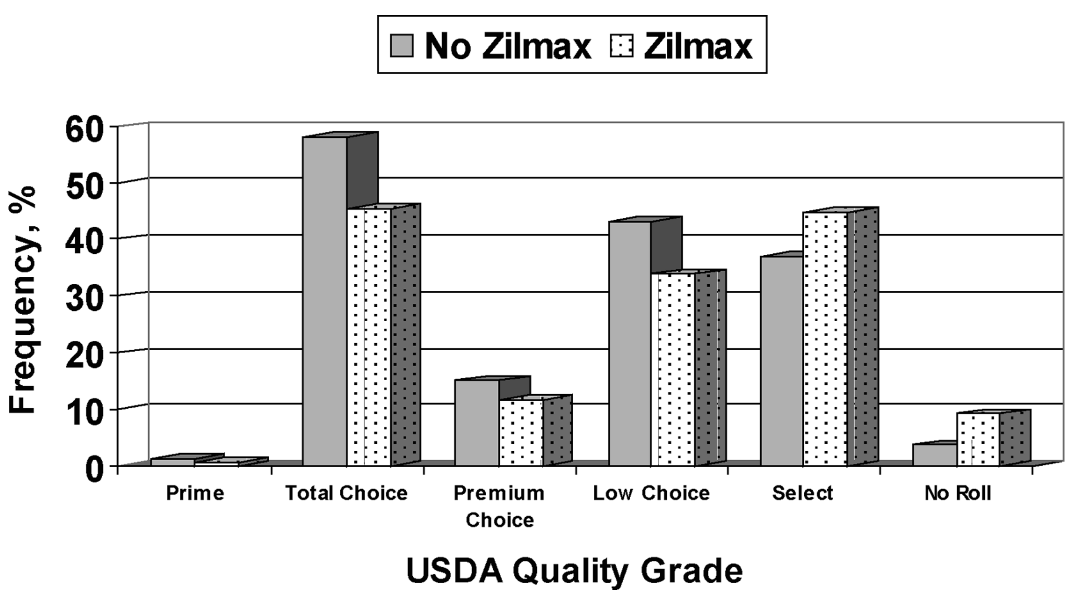

Figure 5. Effect of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d before slaughter on USDA Quality grade distribution. Source: Montgomery et al. (2008b).

Item	Prime	Total Choice	Premium Choice	Low Choice	Select	No roll
No Zilmax	1.19	58.20	15.05	43.15	37.00	3.61
Zilmax	0.61	45.46	11.63	33.83	44.80	9.31
χ^2 probability	0.07	<0.0001	0.002	<0.0001	<0.0001	<0.0001

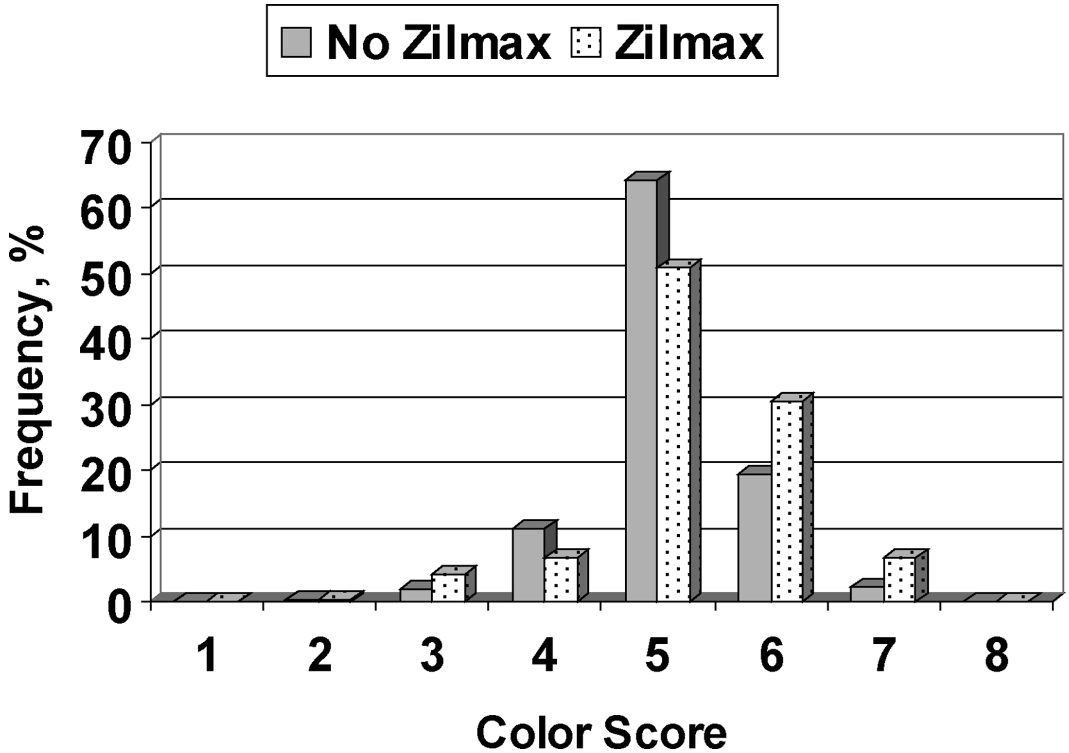

Figure 6. Effect of feeding zilpaterol hydrochloride (7.6 g/ton, DM basis) to feedlot steers for 30 d before slaughter on color score distribution. Source: Hilton et al. (2008).

Item	Color score 2	Color score 3	Color score 4	Color score 5	Color score 6	Color score 7
No Zilmax	0.6	2.1	11.3	64.2	19.4	2.5
Zilmax	0.4	4.2	6.9	50.9	30.5	6.9

force decreased from 7 to 14 d for zilpaterol hydrochloride-treated steaks – demonstrating an aging response to postmortem storage (Table 6). Buys and Strydom (2000) also documented an aging response between 3 and 10 d postmortem with approximately 10% improvement in zilpaterol hydrochloride shear force. Casey et al. (1997a) found zilpaterol hydrochloride-treated South African Bonsmara-type steers had steaks that were higher in force than the controls, but shear force values for treated steers were not different from control steers of similar fat content. In a separate study, Casey et al. (1997b) observed no differences in shear force values in steaks from zilpaterol hydrochloride treatment cattle compared with the control cattle. More recently, Leheska et al. (2008) observed an increase in Warner-Bratzler shear force from 3.29 to 4.01 kg when steers and heifers were treated with zilpaterol hydrochloride for 30 d (Table 7). Hilton et al. (2008) reported an increase in Warner-Bratzler shear force from 3.18 to 3.45 kg for zilpaterol hydrochloride steers treated 30 d (Table 8) but also indicated Warner-Bratler shear force significantly decreased from 7 to 21 d postmortem. The aging effect of zilpaterol hydrochloride-treated beef exceeded control groups, revealing a 1.35-kg reduction (vs. 0.48-kg reduction for control steaks) from 7 to 21 d, postmortem. A review of shear force values across studies indicates duration of zilpaterol hydrochloride feeding can have a moderating effect on shear force values. When durations of 30 to 50 d are administered, an increase of 20 to 28% in shear force was observed (Buys and Strydom, 2000; Strydom et al., 2002) between control and treated

Table 6. Percentage improvement in shear force[a] from 7 to 14 d of aging in South African Bonsmara-type cattle fed zilpaterol hydrochloride for 50 d[b]

	% improvement from 7 to 14 d of age	
Muscle[c]	Control	Zilmax
Biceps femoris	6.2	10.5
Semitendinosus	10.8	6.7
Longissimus thoracis	16.7	11.9
Triceps brachii	12.3	17.1
Psoas major	8.6	3.0
Pectoralis profundus	4.7	4.0

[a]Core diameter was 2.54 cm for all muscles except the m. pectoralis profundus, which was 1.25 cm.

[b]Data source: Strydom and Nel (1996).

[c]Zilmax treatment effect ($P < 0.05$) for shear force was observed for the longissimus dorsi, psoas major, and pectoralis profundus at 7 and 14 d postmortem.

Table 7. Effects of zilpaterol hydrochloride on longissimus muscle (LM) Warner-Bratzler shear force (WBSF), cooking loss, and sensory panel traits of 28-d postmortem steaks[a]

Item	Site	Control	Zilmax	SEM	Pr > F[b]
LM cook loss, %	CA	14.32	13.92	0.03	0.51
	ID	13.53	13.94	0.04	0.56
	TX	13.84	14.63	0.02	0.01
	Pooled[c]	13.89	14.16	0.02	0.52
LM WBSF, kg	CA	3.06	3.69	0.03	0.0001
	ID	3.11	3.73	0.03	0.0001
	TX	3.75	4.70	0.04	0.0003
	Pooled[c]	3.29	4.01	0.07	0.0005
Average overall juiciness[d]	ID[c]	6.27	5.81	0.10	0.001
Average overall tenderness[d]	ID	6.48	5.83	0.13	0.001
Average flavor intensity[d]	ID	6.56	6.30	0.05	0.002
Average beef flavor[d]	ID	6.65	6.45	0.06	0.02
Average off-flavor[e]	ID	1.01	1.01	0.01	0.89

[a]Data source: Leheska et al. (2008).

[b]Probability of an effect of zilpaterol hydrochloride.

[c]In the pooled analysis, all data from the 3 different sites, California, Idaho, and Texas, were combined and analyzed. Sensory panel analysis was only conducted on longissimus muscle samples collected from only the Idaho site.

[d]1 = extremely dry, extremely tough, extremely bland, extremely uncharacteristic; 8 = extremely juicy, extremely tender, extremely intense, extremely characteristic.

[e]1 = none; 5 = extremely off-flavor.

animals, whereas Hilton et al. (2008) and Leheska et al. (2008) reported a 7.8 to 18% increase in Warner-Bratzler shear force at a 30-d feeding duration.

These studies indicate zilpaterol hydrochloride significantly increases Warner-Bratzler shear force. Strip loins from zilpaterol hydrochloride-treated beef exhibit an aging effect, however, reducing the Warner-Bratzler shear force significantly with postmortem aging up to 21 d. In addition, Strydom (2000) observed withdrawal from zilpaterol hydrochloride during the feeding period improved meat tenderness. Strydom and Nel (1999) reported a significant decline in shear force in electrically stimulated carcasses from zilpaterol hydrochloride-fed cattle compared with nonelectrically stimulated carcasses. These data suggest increases in Warner-Bratzler shear force values observed among zilpaterol hydrochloride-fed animals can be decreased with feeding duration, postmortem aging of 21 d, electrical stimulation, and, perhaps, withdrawal times at the end of the feeding period.

Sensory Measurements

Customer satisfaction of beef is driven by palatability, which is defined as the tenderness, juiciness, and flavor of cooked beef products. Research indicates meat tenderness and flavor are key drivers of customer satisfaction, with juiciness subject to preparation technique and intramuscular fat content. The following sections will summarize the effect of zilpaterol hydrochloride on meat palatability traits.

Table 8. Effects of zilpaterol hydrochloride on Warner-Bratzler shear force (WBSF) and cooking loss of longissimus muscle (LM) at 7, 14, and 21 d postmortem[a]

Item	Control	Zilmax	SEM	Pr > F[b]
LM cook loss, %	15.27	16.25	0.48	0.16
7 d postmortem Warner-Bratzler shear force, kg	3.66	4.70	0.12	0.001
14 d postmortem Warner-Bratzler shear force, kg	3.60	4.00	0.07	0.001
21 d postmortem Warner-Bratzler shear force, kg	3.18	3.45	0.05	0.002

[a]Data source: Hilton et al. (2008).

[b]Probability of an effect of zilpaterol hydrochloride. There was an aging × zilpaterol hydrochloride interaction ($P < 0.05$) for WBSF.

Table 9. Effects of zilpaterol hydrochloride on trained sensory panel scores of longissimus muscle (LM) at 14 d postmortem[a]

Item	Control	Zilmax	SEM	Pr > F[b]
Initial juiciness[c]	6.06	5.67	0.06	0.001
Sustained juiciness[c]	6.32	5.91	0.06	0.001
Initial tenderness[c]	6.16	5.37	0.09	0.001
Sustained tenderness[c]	6.35	5.50	0.10	0.001
Beef flavor intensity[c]	6.33	5.97	0.05	0.001
Beef flavor[c]	6.52	5.95	0.11	0.001
Overall mouth feel[c]	6.16	5.40	0.10	0.001
Off-flavor[d]	1.03	1.02	0.01	0.40

[a]Data source: Hilton et al. (2008).

[b]Probability of an effect of zilpaterol hydrochloride.

[c]1 = extremely dry, extremely tough, extremely bland, extremely uncharacteristic, and extremely beef-like uncharacteristic; 8 = extremely juicy, extremely tender, extremely intense, extremely characteristic, and extremely beef-like characteristic.

[d]1 = none; 5 = extremely off-flavor.

Tenderness

Strydom et al. (1998) reported decreases in initial and sustained tenderness (19 and 15%, respectively) in cattle supplemented with zilpaterol hydrochloride for 45 d. Leheska et al. (2008) reported a decrease in tenderness scores of 11% (6.27 and 5.81 for control and zilpaterol hydrochloride, respectively; Table 4). Similarly, a decrease in tenderness scores due to zilpaterol hydrochloride treatment was reported by Hilton et al. (2008), who indicated a 13% decrease in trained sensory panelist scores, but only a 4% decrease in consumer panelist tenderness scores (Table 9 and 10). In the same trial, Hilton et al. (2008) also reported no difference in consumer acceptability of tenderness between control and zilpaterol hydrochloride beef steaks aged 14 d postmortem (Table 10). The data further revealed that zilpaterol hydrochloride treatment resulted in 92.8% acceptability in consumer tenderness, whereas control steaks had 89.1% consumer acceptability in tenderness (Hilton et al., 2008). Furthermore, zilpaterol hydrochloride supplementation resulted in an overall consumer acceptability of 92.4 and 94.4% for control and zilpaterol hydrochloride, respectively.

Juiciness

Juiciness ratings have been shown to be directly linked to degree of doneness (Behrends et al., 2005) and can be greatly affected by a consumer's degree of doneness preference. Nonetheless, controlled studies have suggested β-agonists can decrease juiciness scores of trained and consumer panelists (Luño et al., 1999; Schroeder et al., 2003a; Leheska et al., 2008). Strydom et al. (1998) reported that zilpaterol hydrochloride-treated animals exhibited a 15% reduction in juiciness scores compared with control steaks. Hilton et al. (2008) observed a 3% reduction in juiciness consumer scores (Table 10) attributed to zilpaterol hydrochloride. Furthermore, Leheska et al. (2008) reported similar results, showing a 7% decrease in trained sensory panel scores for juiciness. Leheska et al. (2008) attributed the decrease in juiciness scores to decreased intramuscular fat in animals fed β-agonists.

Flavor

Beef flavor can be equally important to meat tenderness when evaluating customer satisfaction. Some researchers have observed flavor to be the most important palatability characteristics (Behrends et al. 2005), whereas others have found flavor to be as important as tenderness in determining overall like (Neely et al., 1998). Consumer perception of beef flavor is often related intramuscular fat content, in scientific literature. Therefore, decreasing intramuscular fat by the feeding of β-agonists could result in reduced flavor scores. Hilton et al. (2008; Table 10) reported a 6% decrease in consumer beef flavor scores in zilpaterol hydrochloride-treated steaks. Leheska et al. (2008) reported a 3% decrease in trained sensory panel flavor scores when animals are treated with zilpaterol hydrochloride.

Table 10. Effects of zilpaterol hydrochloride on consumer sensory panel scores of longissimus muscle (LM) at 14 d postmortem[a]

Item	Control	Zilmax	SEM	Pr > F[b]
Overall acceptability,[c] % acceptable	92.4	94.4	1.33	0.41
Tenderness acceptability,[c] % acceptable	89.1	92.8	1.87	0.29
Overall quality[d]	6.37	6.19	0.07	0.07
Beef flavor[d]	6.29	6.22	0.07	0.43
Juiciness[d]	6.02	5.87	0.08	0.17
Tenderness[d]	6.25	6.00	0.08	0.03

[a]Data source: Hilton et al. (2008). There were a total of 564 consumers who participated in the study.

[b]Probability of an effect of zilpaterol hydrochloride.

[c]Acceptability scores were acceptable or unacceptable.

[d]Sensory scores were on an 8-point scale: 1 = extremely dislike, uncharacteristic beef flavor, extremely dry, extremely tough; 8 = extremely like, extremely characteristic beef flavor, extremely juicy, and extremely tender.

Summary

A review of the current literature indicates that zilpaterol hydrochloride feeding increases hot carcass weights by 3 to 5%, longissimus muscle area by 0.9 to 1.5 in^2, and consistently improves carcass dressing percentage by 1.5%. Zilpaterol hydrochloride feeding for 20 to 40 d had no effect on internal or external carcass fat measures. These carcass traits combine to improve subprimal yield by 3.2% over control cattle, which increased the value of zilpaterol hydrochloride-treated carcasses by approximately US$50 per head using 2005 USDA-AMS pricing. Zilpaterol hydrochloride has also been shown to either improve or have no detrimental effect on meat color. The USDA Quality grade and marbling scores are decreased with zilpaterol hydrochloride feeding. Feeding for 20 and 30 d resulted in a decline in marbling of 4 to 29 degrees, as well as a 3.4 and 9.3% decrease in USDA premium Choice (modest and moderate marbling) and low Choice (small marbling) carcasses. Feeding zilpaterol hydrochloride for 20 to 50 d increased shear force values 7.8 to 28% in cattle fed in the United States, Mexico, and South Africa. Postmortem aging of treated subprimals up to 21 d reduced Warner-Bratzler shear values 1.35 kg and improved shear force values by 10 to 11.9%. Electrical stimulation and extended withdrawal of zilpaterol hydrochloride from treated animals before slaughter also improved shear force values. Zilpaterol hydrochloride reduced trained panelist's scores for tenderness by 11 to 19%, juiciness scores by 3 to 15%, and flavor scores by 3 to 6%. Finally, zilpaterol hydrochloride reduced consumer tenderness scores by 4% and shared similar consumer acceptance percentages for overall like and tenderness when compared with control samples.

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