Effects of zilpaterol hydrochloride feeding duration and postmortem aging on Warner-Bratzler shear force of three muscles from beef steers and heifers

J. C. Brooks,*1 H. C. Claus,† M. E. Dikeman,‡ J. Shook,† G. G. Hilton,‡ T. E. Lawrence,§ J. M. Mehassey,* B. J. Johnson,* D. M. Allen,# M. N. Streeter,‖ W. T. Nichols,‖ J. P. Hutcheson,‖ D. A. Yates,‖ and M. F. Miller*

*Department of Animal and Food Sciences, Texas Tech University, Lubbock 79409; †Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506; ‡Department of Animal Science, Oklahoma State University, Stillwater 74078; §Department of Agricultural Sciences, West Texas A&M University, Canyon 79016; #Private Consultant, Derby, KS 63037; and ‖Intervet/Schering-Plough Animal Health, DeSoto, KS 66018

ABSTRACT: To determine the effects of zilpaterol hydrochloride (ZH; 6.8 g/t on 90% DM basis) feeding duration (0, 20, 30, and 40 d) on Warner-Bratzler shear force (WBSF) of longissimus lumborum (LL), triceps brachii (TB), and gluteus medius (GM) muscles, beef from feeding trials was collected and shipped to participating universities. Animals were slaughtered at commercial processing facilities across the United States. Strip loin, shoulder clod, and top sirloin butt subprimals (IMPS 180, 114, and 184, respectively) were obtained from a portion of USDA Choice and Select grade carcasses for WBSF using standardized procedures and equipment. Feeding ZH increased (P < 0.001) LL WBSF values of USDA Choice and Select steaks. A significant linear contrast existed for both quality grades, indicating increased WBSF values were associated with longer feeding durations. Increased postmortem aging decreased LL WBSF of control and treated steaks. Postmortem aging from 7 to 21 d decreased LL WBSF values by 17.6 and 16.4% for USDA Choice and Select steaks, respectively. The percentage of LL steaks from ZH-supplemented cattle with a WBSF value <4.5 kg was significantly less than control steaks for both quality grades. Postmortem aging from 7 to 21 d postmortem increased (P < 0.001) the percentage of LL Choice and Select steaks with WBSF <4.5 kg for all ZH feeding durations. Feeding ZH for 20, 30, or 40 d increased (P < 0.01) WBSF of USDA Choice TB and GM steaks compared with 0-d controls. Feeding ZH for 0, 20, and 40 d had a similar effect on WBSF of USDA Select GM steaks, and produced lesser values than steaks from cattle fed ZH for 30 d. Feeding ZH for 20, 30, and 40 d had no effect on WBSF values of USDA Select TB steaks. However, the 20-, 30-, and 40-d duration produced WBSF values greater (P < 0.05) than control (0 d) TB steaks. Postmortem aging decreased (P < 0.05) WBSF of USDA Choice and Select TB and GM steaks, but the percentage improvement in WBSF attributed to aging was less than observed for LL steaks. The results of this study indicate feeding ZH increased (P < 0.001) WBSF of LL, TB, and GM. The ZH feeding also decreased (P < 0.01) the percentage of steaks with WBSF <4.5 kg regardless of US quality grade, whereas postmortem aging increased (P < 0.01) the percentage of US Choice and Select steaks with WBSF <4.5 kg. Finally, postmortem aging reduced (P < 0.05) WBSF of steaks from ZH-supplemented beef cattle.

Key words: aging, β-adrenergic agonist, beef, shear force, zilpaterol hydrochloride

INTRODUCTION

Zilpaterol hydrochloride (ZH) is a β-adrenergic agonist that belongs to a group of compounds known as catecholamines. Beta-adrenergic agonists activate β-receptors in muscle and fat, causing increased lipolysis, decreased lipogenesis, increased protein accretion, or a combination of these (Mersmann, 1998). Supplementation of diets with β-agonists can increase ADG, feed efficiency, leanness, and dressing percentage (Moody et al., 2000). Supplementation also has been shown to decrease marbling scores, increase Warner-Bratzler shear...
force (WBSF), and adversely affect consumer sensory scores (Hilton et al., 2009; Leheska et al., 2009). Therefore, β-agonists can have positive and negative effects on meat animal production.

The literature indicates supplementation of β-agonists can increase WBSF from 7 to 300%. Clenbuterol supplementation has been shown to increase WBSF of beef steers and heifers from 14 to 113% when fed for 35 to 50 d (Miller et al., 1988; Schiavetta et al., 1990; Luño et al., 1999). Cimaterol also has been associated with increases of 46 to 300% in WBSF among young bulls and fed Holstein steers (Fiems et al., 1990; Chikhou et al., 1993; Vestergaard et al., 1994). Schroeder et al. (2003) reported a 12% increase in WBSF when beef steers were supplemented daily with 300 mg/kg of ractopamine hydrochloride. Finally, supplementation of ZH for 30 to 50 d has been shown to increase WBSF of steaks from South African beef steers by 20 to 28% (P.E. Strydom, Meat Industry Center, Agricultural Research Council, Animal Nutrition and Animal Products Institute, Irene, South Africa, personal communication; Strydom et al., 2002).

Zilpaterol hydrochloride was approved for use in the United States in 2006 and 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” (http://www.zilmax.com; last accessed August 19, 2009). Increased BW gains and feed efficiency, leading to increased carcass leanness and greater dressing percentage, can offset high feed costs and increase profitability. However, the impact of ZH on meat tenderness needs to be documented. Therefore, the objective of this study was to determine the effect of ZH feeding duration (0, 20, 30, and 40 d) on WBSF values of beef longissimus dorsi (LL), triceps brachii (TB), and gluteus medius (GM).

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because samples were obtained from federally inspected slaughter facilities.

Cattle Source and Duration Treatment

Five feeding trials were conducted at commercial feeding operations. For trial 1, 2,600 (n = 650 per treatment) Continental crossbred steers were fed and slaughtered in Texas. Trial 2 consisted of 2,300 British and British crossbred steers (n = 575 per treatment) fed and slaughtered in Texas. Trial 3 was conducted with 2,400 head of British crossbred steers (n = 600 per treatment) fed in Oklahoma and slaughtered in Kansas. Trial 4 was conducted at the Texas Tech University Burnett Center utilizing 560 head of British crossbred steers (n = 140 per treatment) and slaughtered at a nearby commercial processing facility. For trail 5, 2,400 (n = 600 per treatment) Continental crossbred heifers were fed and slaughtered in Texas.

Cattle were fed typical feedlot finishing diets supplemented without or with 6.8 g of ZH/t (90% DM basis, Intervet/Schering-Plough Animal Health, DeSoto, KS). Steers were implanted on arrival at the feedlot (d 0) and again on d 80 with a Revalor-IS (80 mg of trenbolone acetate and 16 mg of estradiol, Intervet/Schering-Plough Animal Health). Heifers were implanted on arrival (d 0) with Revalor-IH (80 mg of trenbolone acetate and 8 mg of estradiol, Intervet/Schering-Plough Animal Health) and reimplanted with Revalor-H (140 mg of trenbolone acetate and 14 mg of estradiol, Intervet/Schering-Plough Animal Health) 81 d before slaughter. Because combination feeding of ZH and melengestrol acetate (MGA) was not approved at the start of the trial, the heifer diet containing ZH did not contain MGA. Diets containing ZH were fed for the remaining 20, 30, or 40 d (control diet designated as 0 d) of the feeding period, and animals were slaughtered after a mandatory 3-d withdrawal of the supplement. The HCW for each treatment was calculated before the selection of carcasses for inclusion in this trial. All carcasses were subject to electrical stimulation approximately 15 to 30 min postmortem and chilled at 0 to 2°C for 24 to 36 h.

Selection of Subprimals

Subsets of carcasses were chosen from each feeding trial to represent ZH feeding duration treatments. Carcasses representing USDA maturity score A were selected to represent USDA Choice and Select quality grades and USDA 1, upper 2, lower 2, upper 3, lower 3, and 4 yield grades for each feeding duration. Beef strip loins, shoulder clods, and top sirloin butt subprimals (IMPS 180, 114, and 184, respectively; USDA, 1996) were collected at fabrication from carcasses representing cattle from feeding trials 3 and 5, and shipped to Oklahoma State University and Kansas State University, respectively. Beef strip loins were collected from carcasses representing feeding trials 1, 2, and 4, and shipped to West Texas A&M University, Kansas State University, and Texas Tech University, respectively. Subprimals were vacuum packaged, boxed, and shipped to each university at refrigerated temperatures. At 7-d postmortem, the subprimals were removed from their packaging and cut into steaks.

The USDA Choice data set for the LL consisted of 1,024 observations (n = 256 per duration) and the USDA Select data set consisted of 1,192 observations (n = 298 per duration). The USDA Choice and Select data sets for the TB and GM consisted of 320 (n = 80 per duration) and 384 (n = 96 per duration) total observations per muscle and quality grade, respectively.

Fabrication

The weight of each subprimal was recorded before portioning. Steaks measuring 2.54 cm in thickness were
fabricated using cutting guides to ensure uniformity and consistency. The anterior end of each strip loin was squarely faced, and 9 steaks were fabricated (progressing from the anterior to posterior) for WBSF force and consumer sensory evaluation (Mehaffey et al., 2009). For the first strip loin of each treatment, steaks 1, 2, and 3 were designated for 7, 14, and 21 d WBSF, respectively. Steaks 4 and 7, 5 and 8, and 6 and 9 were designated for 7, 14, and 21 d consumer sensory evaluation, respectively. For each subsequent strip loin, steak designations were rotated by one location toward the posterior of the strip loin (except position 9, which was rotated to position 1) to ensure all anatomical locations within the strip loin were represented in each group. The posterior portion of the strip loin containing the GM was not used. Beef shoulder clods were fabricated to produce the long head of the TB muscle (IMPS 114E; USDA, 1996). The ventral end of the subprimal was squarely faced, and three 2.54-cm-thick steaks were fabricated (universal product code 1162; URMIS, 2003). Steaks 1, 2, and 3 were assigned to 7, 14, and 21 d postmortem aging treatments. On subsequent subprimals, steak location was rotated by one place before postmortem aging assignment. The biceps femoris, gluteus accessorius, and gluteus profundus muscles were removed from beef top sirloin butts to generate center-cut top sirloin steaks (IMPS 184B; USDA, 1996). The anterior end of the center-cut top sirloin was squarely faced, and three 2.54-cm-thick steaks were removed. Steaks were assigned to 7-, 14-, and 21-d postmortem aging treatments. The assignment of steaks to postmortem aging treatment was rotated by one location for each subsequent subprimal to ensure all locations within the subprimal were represented in all aging treatments. All steaks were then weighed, vacuum-packaged at a minimum of 850 mbar, and frozen (minimum −29°C) on their designated postmortem aging time.

**Thawing and Cooking**

Individually packaged frozen steaks were thawed at 0 to 4°C for 24 h before cooking. Steaks were cooked on preheated (177°C) grills (George Foreman Digital Grill, model GRP99, Applica Inc., Miramar, FL) to an internal temperature of 71°C. Cook time and yield were recorded for each steak (data not reported). Temperature was monitored using calibrated thermocouples or temperature probes. The identification of each steak was maintained throughout. Cooked steaks were trayed, covered with plastic film, and held overnight at 0 to 4°C for shear force analysis.

**WBSF**

Six cores, measuring 1.27 cm in diameter, were removed from each steak parallel to muscle fiber orientation. Two cores from the lateral, medial, and middle portion of each steak were targeted. Meat cores containing heavy connective tissue or fat pockets were not used. Each core was sheared once on a Warner-Bratzler shear machine (G-R Elec. Mfg. Co., Manhattan, KS) equipped with a digital force gauge (Mecmesin BFG500N, G-R Elec. Mfg. Co.) calibrated by Dillon Quality Plus Inc. (Kansas City, MO). Warner-Bratzler shear machine and force gauge were the same at all institutions. Peak force (kg) was recorded for each core; the 6 cores were then used to calculate an average shear force value for each steak.

**Statistical Analysis**

Preliminary analysis indicated trial had a significant effect on WBSF. The effect of ZH feeding duration on WBSF within each trial was plotted. Although WBSF treatment means differed for each trial, the effect of duration on WBSF was similar. Thus, because the plane of response across duration treatments was similar for all trials, the WBSF values from each trial were pooled. In addition, USDA quality grade was a selection tool for inclusion in this study, so data analysis was conducted within a quality grade. Data for each muscle were analyzed using PROC MIXED procedures (SAS Inst. Inc., Cary, NC). The model included feeding duration (0, 20, 30, 40 d), postmortem aging (7, 14, 21 d), and the interaction of duration × postmortem aging. Because university participation and slaughter facility were trial dependent, the authors made use of the random statement (SAS Inst. Inc.) to account for trial and trial × duration contributions to the error.Means were separated using the PDIFF option (SAS Inst. Inc.). Least squares means and SE are reported and considered significant at P < 0.05, unless otherwise noted. Treatment effects also were tested using orthogonal contrasts to determine the linear effect of duration on WBSF.

![Figure 1. The percentage of Warner-Bratzler shear force (WBSF) values less than 4.5 kg from USDA Choice longissimus lumborum steaks aged 7, 14, and 21 d postmortem from cattle supplemented with 6.8 g/t (90% DM) of zilpaterol hydrochloride (ZH, Intervet/Schering Plough Animal Health, DeSoto, KS) for the last 0, 20, 30 and 40 d of the feeding period. (ZH, postmortem age, and ZH × postmortem age fixed effect; F-values were 0.0060, 0.0004, and 0.5710, respectively.)](https://academic.oup.com/jas/article-abstract/87/11/3764/4740633)
Table 1. The effects of zilpaterol hydrochloride\textsuperscript{1} feeding duration and postmortem aging (d) on the Warner-Bratzler shear force of longissimus lumborum steaks from USDA Choice and Select carcasses

| Grade     | Feeding duration (D), d | Postmortem age (P), d | P-value |
|-----------|------------------------|-----------------------|---------|
|           | 0  | 20  | 30  | 40  | SEM | 7  | 14  | 21  | SEM | D   | P     | D × P     |
| Choice    | 3.24\textsuperscript{a} | 3.84\textsuperscript{b} | 3.99\textsuperscript{b} | 4.21\textsuperscript{c} | 0.19 | 4.24\textsuperscript{a} | 3.73\textsuperscript{b} | 3.49\textsuperscript{b} | 0.18 | <0.0001 | <0.0001 | 0.2311     |
| Select    | 3.38\textsuperscript{a} | 4.03\textsuperscript{b} | 4.48\textsuperscript{b} | 4.55\textsuperscript{c} | 0.28 | 4.50\textsuperscript{a} | 4.07\textsuperscript{b} | 3.76\textsuperscript{c} | 0.26 | 0.0003  | <0.0001 | 0.5324     |

\textsuperscript{a–c}Least squares means lacking a common superscript letter differ (\(P < 0.05\)).

\textsuperscript{1}Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) dose = 6.8 g/t on 90% DM basis.

Further analysis was conducted to determine the effect of ZH feeding duration and postmortem aging on the percentage of steaks with a WBSF value less than 4.5 kg. The PROC FREQ procedure (SAS Inst. Inc.) was used to determine the number of WBSF observations <4.5 kg in each trial and were categorized by USDA quality grade, ZH duration, and postmortem aging. The PROC GLIMMIX (SAS Inst. Inc.) procedure was then used within each USDA quality grade to statistically determine the effect of ZH feeding duration and postmortem aging on the percentage of steaks with a WBSF <4.5 kg.

RESULTS AND DISCUSSION

Least squares means, SEM, and probability values for the effects of ZH feeding on WBSF of the LL muscle from USDA Choice and Select carcasses are presented in Table 1. Feeding ZH increased (\(P < 0.001\)) WBSF values of US Choice and Select LL steaks. A significant (\(P < 0.05\)) linear contrast existed for both quality grades, indicating increased WBSF values were associated with longer feeding durations. Increased postmortem aging decreased (\(P < 0.001\)) WBSF of control and treated steaks. Postmortem aging from 7 to 21 d decreased WBSF values by 17.6 and 16.4% for US Choice and Select steaks, respectively. The interaction between feeding duration and postmortem aging for Choice or Select was not significant. The lack of interaction indicates tenderness of control and treated steaks improved with aging, and the magnitude of change over time was similar for control and treated steaks.

The effects of ZH feeding observed in this study are consistent with published literature. Casey et al. (1997b) reported shear force values between control and ZH treated cattle did not differ. In a separate study in which ZH treated cattle had greater (\(P < 0.05\)) shear force values than controls, Casey et al. (1997a) observed that values from control and ZH-treated steaks of similar fat content did not differ. Hilton et al. (2009) reported WBSF significantly decreased from 7 to 21 d postmortem among steaks from animals supplemented with ZH for 30 d.

Reports in the literature also contradict our findings. Casey et al. (1997b) reported shear force values between control and ZH treated cattle did not differ. In a separate study in which ZH treated cattle had greater (\(P < 0.05\)) shear force values than controls, Casey et al. (1997a) observed that values from control and ZH-treated steaks of similar fat content did not differ. Hilton et al. (2009) reported WBSF significantly decreased from 7 to 21 d postmortem among steaks from animals supplemented with ZH for 30 d.

Table 2. The effects of zilpaterol hydrochloride\textsuperscript{1} feeding duration and postmortem aging (d) on the Warner-Bratzler shear force of gluteus medius and triceps brachii steaks from USDA Choice carcasses

| Muscle        | Feeding duration (D), d | Postmortem age (P), d | P-value |
|---------------|------------------------|-----------------------|---------|
|               | 0  | 20  | 30  | 40  | SEM | 7  | 14  | 21  | SEM | D   | P     | D × P     |
| Gluteus medius| 3.86\textsuperscript{a} | 4.28\textsuperscript{b} | 4.15\textsuperscript{b} | 4.55\textsuperscript{c} | 0.10 | 4.36\textsuperscript{a} | 4.23\textsuperscript{b} | 4.04\textsuperscript{b} | 0.08 | 0.0004 | 0.0095 | 0.8472     |
| Triceps brachii| 3.80\textsuperscript{a} | 4.08\textsuperscript{b} | 4.16\textsuperscript{b} | 4.11\textsuperscript{b} | 0.09 | 4.24\textsuperscript{a} | 3.96\textsuperscript{b} | 3.92\textsuperscript{b} | 0.07 | 0.0429 | <0.0001 | 0.1947     |

\textsuperscript{a–c}Least squares means lacking a common superscript letter differ (\(P < 0.05\)).

\textsuperscript{1}Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) dose = 6.8 g/t on 90% DM basis.
The effect of ZH feeding and postmortem aging on the percentage of USDA Choice and Select LL steaks with a WBSF <4.5 kg are presented in Figures 1 and 2. Feeding ZH for 20, 30, and 40 d significantly decreased the percentage of USDA Choice and Select steaks with a WBSF <4.5 kg compared with control (0 d) steaks. Postmortem aging from 7 to 21 d increased the percentage of USDA Choice and Select steaks with a WBSF <4.5 kg for all ZH feeding durations except for USDA Choice steaks from cattle supplemented with ZH for 40 d. Because the USDA quality of a beef animal is not known during the feeding period, the WBSF distribution data suggest feeding ZH to animals for more than 20 d could be detrimental if beef steaks are aged <14 d postmortem before consumption.

Effects of ZH feeding duration and postmortem aging on WBSF of GM and TB muscles from USDA Choice carcass are presented in Table 2. Feeding ZH for 20, 30, or 40 d increased ($P < 0.05$) WBSF of USDA Choice steaks compared with 0-d controls. Linear contrasts were not significant for feeding duration for GM and TB WBSF values. Postmortem aging decreased WBSF of control and treated steaks. The interaction between feeding duration and postmortem aging was not significant, suggesting the effects of duration and postmortem aging on WBSF are independent.

The effects of ZH feeding duration and postmortem aging on WBSF of USDA Select GM and TB steaks are presented in Table 3. The main effects of duration and postmortem aging were similar to those observed for USDA Choice steaks from the same muscles. Feeding ZH for 0, 20, and 40 d had a similar effect on the WBSF of USDA Select GM steaks and produced decreased ($P < 0.05$) WBSF values than steaks from cattle fed ZH for 30 d. Feeding ZH for 20, 30, and 40 d had no effect on WBSF values of USDA Select TB steaks. However, the 20-, 30-, and 40-d duration produced greater ($P < 0.05$) WBSF values than those of control (0 d) TB steaks.

Literature describing the effect of ZH on WBSF of muscles other than LL is limited, but Strydom and Nel (1996) documented the effect of ZH supplementation on the shear force of several muscles, including the TB. They found no difference between control and treated shear force values taken at 7 and 14 d postmortem.

Results of our study show ZH increased ($P < 0.001$) the WBSF of LL, TB, and GM steaks. Additional analysis indicated the feeding of ZH decreased ($P < 0.01$) the percentage of steaks with WBSF <4.5 kg regardless of US quality grade. Muscles from ZH-treated beef, however, respond to postmortem aging up to 21 d, and aging increased ($P < 0.01$) the percentage of US Choice and Select steaks with WBSF <4.5 kg. Nonetheless, the literature suggests several additional management strategies can be used to manage WBSF of steaks from ZH-supplemented animals. Strydom (2000) observed withdrawal from ZH for 10 d before slaughter improved WBSF values compared with no withdrawal. Strydom and Nel (1999) reported high-voltage electrical stimulation of carcasses from cattle supplemented with ZH significantly decreased shear force values compared with nonelectrically stimulated carcasses.

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