

The effect of zilpaterol hydrochloride on meat quality of calf-fed Holstein steers

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ABSTRACT: The objective of these studies was to evaluate the effects of zilpaterol hydrochloride (ZH), fed for 0, 20, or 30 d, on meat quality attributes of calf-fed Holstein steers. Steers were slaughtered at a commercial facility, and carcasses were selected by HCW to represent the pen mean. Further carcass selection was based on quality grade (Choice and Select) and yield grade. Proximate composition, measures of water holding capacity, and tenderness using Warner-Bratzler shear force after 7, 14, or 21 d postmortem were evaluated on the shoulder clod (triceps brachii), top butt (gluteus medius), and strip loin (longissimus lumborum). Percentage of purge for the 3 subprimals was not different ($P > 0.05$) among ZH treatments. Steers fed ZH for 20 d or 30 d had decreased ($P < 0.05$) percentages of fat in the triceps brachii, compared with 0-d ZH. Percentage of fat was less ($P < 0.05$) in the gluteus medius and longissimus lumborum when steers were fed ZH for 30 d compared with those steers fed ZH for 0 d. Percentage of fat was greater in Choice triceps brachii ($P < 0.05$) and longissimus lumborum ($P < 0.10$) com-

pared with Select. Thaw loss was not different ($P > 0.05$) for any muscle due to ZH treatment. Only longissimus had a greater ($P < 0.05$) cooking loss with ZH treatment. Cooking loss was not different ($P > 0.05$) for the gluteus medius or longissimus lumborum due to quality grade or aging day. At each aging day, the 20- and 30-d ZH longissimus lumborum had greater ($P < 0.05$) shear force values than 0 d; however, 20- and 30-d ZH had a greater absolute change in shear force from 7 to 21 d than that of 0 d ZH. Triceps brachii steaks were less tender ($P < 0.05$) after ZH treatment, but gluteus medius steaks were not different ($P > 0.05$). There was no difference ($P > 0.05$) in shear force due to quality grade. Results illustrate the use of ZH in calf-fed Holstein steers will have minimal effects on purge, thaw, or cooking loss. Percentage of intramuscular fat will decrease, especially when fed for longer durations. Steaks from ZH treated steers were tougher than steaks from control animals at all aging times, but ZH steaks became more tender with postmortem aging.

Key words: Holstein steer, meat quality, zilpaterol hydrochloride

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INTRODUCTION

Holstein steers represent an important segment of the beef industry because they account for approximate-

ly 8% of the fed beef for slaughter (Schaefer, 2005). However, Holstein steers are usually discounted due to lower dressing percentages, smaller ribeyes (Branaman et al., 1962; Knapp et al., 1989; Rust and Abney, 2005), and the perception that ribeyes are not similar in conformation to those of beef cattle (Thonney et al., 1991). To overcome some of these disadvantages, growth promoting compounds such as β -adrenergic agonists (BAA) can be used. The use of BAA has been

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Table 1. Distribution in quality grade for carcasses across all 3 studies¹

Study	Zilpaterol hydrochloride ²		
	0 d	20 d	30 d
Study 1			
Choice	19	22	20
Select	10	7	11
Study 2			
Choice	15	11	10
Select	17	17	21
Study 3			
Choice	15	14	12
Select	15	16	17
Total			
Choice	49	47	42
Select	42	40	49

¹Study 1 was conducted at California State Polytechnic University, San Luis Obispo; studies 2 and 3 were conducted at the University of Illinois at Urbana-Champaign.

²Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) fed at 8.3 mg/kg (100% DM basis) according to label direction. Steers were slaughtered at a commercial facility after a 3-d withdrawal.

extensively studied in beef cattle to produce animals that are heavier, have improved ADG, and have increased feed efficiency (Avendaño-Reyes et al., 2006; Abney et al., 2007). In addition, use of BAA produces carcasses that are heavier and yield leaner meat (Moloney et al., 1994). Whereas the use of BAA to improve production is evident (reviewed by Moody et al., 2000), without appropriate management some BAA can have a negative effect on meat quality, especially tenderness (Dikeman, 2007).

Current literature examining the effects of BAA has primarily focused on the meat quality attributes of the LM in beef cattle. However, few studies have examined the effects of BAA on meat quality attributes of muscles from Holstein steers. Our objective was to examine the effects of zilpaterol hydrochloride (ZH) on meat quality attributes, specifically indicators of water holding capacity, proximate analysis, and shear force

of the shoulder clod (triceps brachii), top butt (gluteus medius), and strip loin (longissimus lumborum) of calf-fed Holstein steers.

MATERIALS AND METHODS

No approval was obtained from the University of Illinois Institutional Animal Care and Use Committee because no animals were used in the experiment. Samples were obtained from a federally inspected slaughter facility.

Product

Three separate studies were conducted to determine the effect of ZH [Intervet Schering Plough Animal Health, DeSoto, KS; fed at 8.3 mg/kg (100% DM basis) according to label directions] on calf-fed Holstein steers. The first study was conducted at a large commercial feed yard with approximately 2,300 steers. The second and third studies were conducted in small pens with 359 and 320 steers (10 pens/treatment) per study, respectively. All feeding studies were conducted in the southwest region of the United States. At the end of each study and after a 3-d withdrawal from ZH, steers were slaughtered at a federally inspected facility. At the grading rail, 24 to 48 h postmortem, carcasses from steers fed ZH for 0, 20, or 30 d were selected by HCW to represent the mean of the pen, with further selection based on quality (QG; USDA Choice and Select; Table 1) and yield grades (USDA, 1997). From those carcasses (n = 89, 91, and 89 for studies 1, 2, and 3, respectively), the subprimal (USDA, 1996) shoulder clod (study 2; IMPS #114C), top butt (study 2 and 3; IMPS #184C), and strip loin (study 1, 2, and 3; IMPS #180C) were tagged with identification, removed from the carcass, vacuum packaged, and transported under refrigeration (<4°C) at 36 to 48 h postmortem to the respective university (Table 2). Upon arrival at the respective university, the product was held refrigerated (<4°C).

Table 2. Study analysis: calf-fed Holstein steers fed zilpaterol hydrochloride¹ for 0, 20, or 30 d

Study ² and subprimals	Subprimal purge loss	Proximate analysis	Thaw loss	Cooking loss	Warner-Bratzler shear force
Study 1					
Strip loin				X	X
Study 2					
Strip loin	X	X	X	X	X
Top butt	X	X	X	X	X
Shoulder clod	X	X	X	X	X
Study 3					
Strip loin	X	X	X	X	X
Top butt	X	X	X	X	X

¹Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) fed at 8.3 mg/kg (100% DM) according to label direction. Steers were slaughtered at a commercial facility after a 3-d withdrawal.

²Study 1 was conducted at California State Polytechnic University, San Luis Obispo; studies 2 and 3 were conducted at the University of Illinois at Urbana-Champaign.

Product Processing

At 7 d postmortem (studies 2 and 3), an in-bag weight was recorded for each subprimal. The subprimal was then removed from the bag and reweighed to calculate percent purge of each subprimal by $\{[\text{in bag weight} - (\text{out of bag weight} + \text{bag weight})]/\text{in bag weight}\} \times 100$. The triceps brachii was removed from the shoulder clod; the gluteus medius was removed from the top butt; and longissimus lumborum was removed from the strip loin. From each muscle (studies 2 and 3) an initial steak was cut for proximate analysis and stored at -30°C in Whirl-pak bags (Nasco, Fort Atkinson, WI). From the ventral end of the triceps brachii and anterior end of the gluteus medius, 3 steaks were cut for aging. From the anterior end of the longissimus lumborum, 9 steaks were cut for aging and other experiments. To minimize position effect within treatment (0, 20, and 30 d), steaks were rotated by 1 position for every new muscle. For all studies, steaks were individually vacuum packaged and frozen (approximately -30°C) at their respective aging days (AD; 7, 14, or 21 d) postmortem.

Proximate Analysis

Steaks for proximate analysis (studies 2 and 3) were thawed, trimmed of external fat, and homogenized in a food processor (Cuisinart, East Windsor, NJ). Percentages of moisture and fat were performed in duplicate as described by Novakofski et al. (1989). Briefly, samples were dried in a 110°C oven for at least 24 h and extracted with an azeotropic mixture of chloroform:methanol to determine moisture and fat percentage.

Warner-Bratzler Shear Force

Steaks for Warner-Bratzler shear force (WBSF) analysis (balanced by treatments) were thawed (0 to 4°C) overnight. On the day of WBSF analysis, each steak was weighed in bag, removed from the bag, and reweighed. A thaw loss value was determined by $\{[\text{in bag weight} - (\text{out of bag weight} + \text{bag weight})]/\text{in bag weight}\} \times 100$. Similar to Hilton et al. (2009), cooking loss and WBSF were determined on individual steaks. Before cooking, individual steaks were trimmed and weighed. Steaks were then cooked on a George Foreman Digital Grill (The Next Grilleration, model GRP99, Lake Forest, IL) to an internal temperature of 71°C . Immediately after cooking, steaks were reweighed to calculate percent cook loss by $[(\text{raw weight} - \text{cooked weight})/\text{raw weight}] \times 100$. Steaks were covered and refrigerated (0 to 4°C) overnight. On the following day, 6 cores (1.3 cm) per steak were removed parallel to the muscle fiber orientation and sheared on a Warner-Bratzler Shear Testing Machine (G-R Manufacturing Company, Manhattan, KS). Shear force was determined for each core and averaged for each steak.

Statistical Analysis

For longissimus lumborum (3 studies) and gluteus medius (2 studies), data from all studies were combined into one data set. For triceps brachii, there was only one study. Table 2 summarizes data collected from each study. Initial study and treatment interactions for the collected data (longissimus lumborum and gluteus medius) were tested using the GLM procedure (SAS Institute Inc., Cary, NC). The few study \times treatment interactions present ($P < 0.15$) were primarily due to magnitude difference for individual treatments across studies. Data were therefore analyzed with the MIXED procedure of SAS. Data were not analyzed to compare differences between subprimals or muscles. Analysis of percentage of purge data and proximate analysis data (percentage of moisture and percent fat) consisted of the fixed effects of ZH, QG, and the 2-way interaction. Study and all study \times treatment interactions were considered as random effects. The LSMEANS (least squares means) statement was used for means and SE calculations. Main effects and interaction means were separated using the PDIFF (probability of difference) option. Analysis of percentages of thaw loss, percent cooking loss, and WBSF consisted of the fixed effects of ZH, QG, AD, and all 2- and 3-way interactions. For percentage of cooking loss and WBSF data, final end point cooking temperature was used as a covariate. Study and all study \times treatment interactions were considered as random effects. When there was a significant interaction between main effects, the SLICE option was used to evaluate the different levels of one main effect, while holding the other main effect constant. Means for interactions were separated using the PDIFF (probability of difference) option when the SLICE effect was $P < 0.10$.

RESULTS AND DISCUSSION

Percentage of Purge of Subprimals

Data for percentage of purge of the 3 subprimals (strip loin, top butt, and shoulder clod) are presented in Table 3. Percentage of purge was less than 0.60% for all 3 subprimals, and there were no differences ($P > 0.05$) with ZH treatment. Minimal amounts of purge were expected because each of these subprimals had some fat cover, which would reduce the amount of possible moisture lost. Additionally, purge was measured at 7 d postmortem and may have been greater if held for a longer time postmortem (Hodges et al., 1974; Hippe et al., 1991).

Select shoulder clods had a greater ($P = 0.034$) percentage of purge than Choice shoulder clods. Percentage of purge was not different ($P > 0.05$) for QG in strip loins or top butts. An increase in purge percentage among select shoulder clods when compared with choice shoulder clods agrees with historical data. Hodges et al.

Table 3. Percentage of purge loss for calf-fed Holstein steer subprimals during vacuum package storage¹

Subprimal	Zilpaterol hydrochloride ²					Quality grade			
	0 d	20 d	30 d	SEM ³	Sig. ⁴	Choice	Select	SEM ³	Sig. ⁴
Shoulder clod	0.29	0.33	0.29	0.040	NS	0.25 ^a	0.35 ^b	0.035	*
Top butt	0.27	0.30	0.43	0.033	NS	0.34	0.32	0.028	NS
Strip loin	0.52	0.59	0.52	0.053	NS	0.52	0.57	0.044	NS

^{a,b}Within a row for the main effect of zilpaterol hydrochloride or quality grade, means without a common superscript letter differ ($P < 0.05$).

¹Percentage of purge was measured on subprimals at 7 d postmortem before muscle samples were removed.

²Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) fed at 8.3 mg/kg (100% DM basis) according to label direction. Steers were slaughtered at a commercial facility after a 3-d withdrawal from zilpaterol.

³SEM, largest value reported.

⁴Significance of F -test for main effect. P -value: * < 0.05 ; NS = not significant.

(1974) reported that leaner cuts of vacuum-packaged beef consistently showed greater purge loss than fatter cuts of vacuum-packaged beef. Lean carcasses also tend to have more exposed lean surface, and more moisture loss occurs from lean tissue than from fat tissue (Hippe et al., 1991).

Proximate Analysis

Data for proximate analysis of the triceps brachii, gluteus medius, and longissimus lumborum are presented in Table 4. Feeding ZH for 20 or 30 d did not change ($P > 0.05$) percentage of moisture of the 3 muscles. However, there was a difference in percentage of fat for the triceps brachii ($P < 0.001$), gluteus medius ($P = 0.087$), and the longissimus lumborum ($P = 0.094$). For triceps brachii, 20 d ($P = 0.018$) and 30 d ($P < 0.001$) of ZH resulted in a decreased percentage of fat compared with 0 d. For gluteus medius ($P = 0.044$) and longissimus lumborum ($P = 0.049$), muscles from 30-d ZH had less fat than 0-d ZH, but percentage of fat for the 20-d treatment was not different ($P > 0.05$) than 0-d ZH. Hilton et al. (2009) observed a decrease in longissimus lumborum fat percentage, with no change

in protein or moisture percentage in steers fed ZH. Additionally, other studies have also reported a decrease in percentage of fat of longissimus lumborum when the BAA L_{644,969} was fed to Friesian steers (Moloney et al., 1994) or clenbuterol to veal calves (Berge et al., 1993). Generally, BAA act to decrease fat (increased lipolysis/decreased lipogenesis) and increase protein (decreased degradation/increased synthesis) in livestock species (Ricks et al., 1984; Mersmann, 1998; Dunshea et al., 2005). The ability to deposit more protein has been demonstrated on a carcass basis in cattle fed ZH (Hilton et al., 2009; Leheska et al., 2009).

Data for proximate analysis of muscles for Choice and Select are also presented in Table 4. Percentage of moisture ($P = 0.028$) and fat ($P < 0.001$) were different for triceps brachii, with Choice possessing less moisture and greater fat than Select. Percentage of moisture and fat were not different ($P > 0.05$) for gluteus medius. Choice longissimus lumborum was less ($P = 0.094$) for percentage of moisture and greater ($P = 0.057$) for percentage of fat than Select longissimus lumborum. These results are expected because the amount of intramuscular fat in the longissimus lumborum at the 12th rib is used to assess USDA quality grade (USDA,

Table 4. Proximate analysis for calf-fed Holstein steer muscles¹

Muscle	Zilpaterol hydrochloride ²					Quality grade			
	0 d	20 d	30 d	SEM ³	Sig. ⁴	Choice	Select	SEM ³	Sig. ⁴
Triceps brachii									
Moisture, %	74.8	75.0	75.1	0.14	NS	74.8 ^a	75.1 ^b	0.13	*
Fat, %	4.5 ^b	4.0 ^a	3.7 ^a	0.14	**	4.4 ^b	3.7 ^a	0.12	**
Gluteus medius									
Moisture, %	73.6	73.5	73.9	0.17	NS	73.3	74.0	0.17	NS
Fat, %	4.6 ^b	4.3 ^{ab}	3.8 ^a	0.38	†	4.7	3.8	0.38	NS
Longissimus lumborum									
Moisture, %	72.8	73.2	73.3	0.25	NS	72.5	73.7	0.21	†
Fat, %	5.2 ^b	4.6 ^{ab}	4.2 ^a	0.16	†	5.4	3.9	0.12	†

^{a,b}Within a row for the main effect of zilpaterol hydrochloride or quality grade, means without a common superscript letter differ ($P < 0.05$).

¹Muscles were removed from the subprimals: shoulder clod (triceps brachii), top butt (gluteus medius), and strip loin (longissimus lumborum).

²Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) fed at 8.3 mg/kg (100% DM basis) according to label direction. Steers were slaughtered at a commercial facility after a 3-d withdrawal.

³SEM, largest value reported.

⁴Significance of F -test for main effect. P -value: ** < 0.01 ; * < 0.05 ; † < 0.10 ; and NS = not significant.

1997). Thus, Choice and Select carcasses should result in differences for proximate analysis of the longissimus lumborum. Brackebusch et al. (1991) reported the amount of fat within the longissimus lumborum was linearly related to the fat content of the major muscles within the beef carcass. The Choice triceps brachii had a greater percentage of fat than Select triceps brachii in our study. However, there was no difference in the gluteus medius between Choice and Select steers. This may be due to sampling location or not sampling the whole gluteal group, which was done in previous research (Brackebusch et al., 1991).

Steak Thaw and Cooking Loss

Data for the main effect of ZH, QG, and AD on percentage of thaw loss and percentage of cooking loss are presented in Table 5. For triceps brachii, there was a ZH \times QG ($P = 0.008$; Figure 1) and ZH \times AD ($P = 0.091$; data not presented in tabular form) interaction for percentage of thaw loss. For the ZH \times QG interaction (Figure 1), 0 and 30 d were similar ($P > 0.05$), but both were greater ($P = 0.025$ and $P = 0.031$, respectively) than 20 d within Choice QG. Within Select QG, 20 and 30 d were similar ($P > 0.05$), but both were greater ($P = 0.030$ and $P = 0.041$, respectively) than 0-d ZH. For the ZH \times AD interaction, there was no difference ($P > 0.05$) between 0-, 20-, and 30-d ZH at 7 or 14 d of aging. At 21 d of aging, thaw loss for 0-d ZH and 20-d ZH were similar ($P > 0.05$) and 20-d ZH and 30-d ZH were similar ($P > 0.05$). However, thaw loss for 0-d ZH (4.4%) was less ($P = 0.009$) than 30-d ZH (5.3%). Percentage of thaw loss was not different ($P > 0.05$) for gluteus medius or longissimus lumborum due to ZH, QG, or AD.

For triceps brachii, there were ZH \times AD ($P = 0.043$; Figure 2) and QG \times AD ($P = 0.093$; data not presented in tabular form) interactions for percentage of cooking loss. For the ZH \times AD interaction (Figure 2), there was no difference between the ZH treatments (SLICE effect, $P > 0.10$) for percentage of cooking loss at each AD. For the QG \times AD interaction, at 7 d of aging Choice (18.6%) had a greater ($P = 0.089$) percentage of cooking loss than Select (17.2%). At 14 d of aging, Choice (19.5%) had a greater ($P = 0.046$) percentage of cooking loss than Select (17.8%). Choice and Select were similar ($P > 0.05$) for percentage of cooking loss after 21 d of aging. There was no difference ($P > 0.05$) in cooking loss for gluteus medius due to ZH, QG, or AD treatment. Percentage of cooking loss was increased in longissimus lumborum at 20-d ($P = 0.042$) and 30-d ($P = 0.019$) ZH, compared with 0 d. The observed increase in cooking loss for the longissimus lumborum is contrary to other work that examined beef cattle fed ZH (Hilton et al., 2009; Leheska et al., 2009), veal calves fed clenbuterol (Berge et al., 1993), or heifers fed ractopamine (Quinn et al., 2008). As speculated by Geesink et al. (1993), increased cooking loss may be due to underlying muscle properties, such as larger muscle cells,

weaker supporting structure, or increased water:protein ratio. Differences within the current study for cooking loss may also be attributed to cooking procedures and type of cookery method utilized. Cooking loss was not different ($P > 0.05$) in longissimus lumborum for QG or AD.

WBSF

Because consumers rate tenderness as one of the most important attributes when consuming beef (Huffman et al., 1996; Robbins et al., 2003) and are willing to pay an increased price for tender beef (Miller et al., 2001), it is important for the meat industry to understand the impact of production on tenderness of the final product. As an estimate of sensory tenderness, this study measured WBSF (Table 5). There was a significant difference in WBSF due to ZH treatment within the triceps brachii. The 20-d ($P < 0.001$) and 30-d ($P < 0.001$) ZH had greater WBSF values than 0-d ZH, but there was no difference ($P > 0.05$) between 20- and 30-d ZH. There was no difference ($P > 0.05$) in WBSF for triceps brachii due to QG (Choice vs. Select), but as AD increased (7 to 14 d), the triceps brachii became more tender ($P < 0.001$). There was no further ($P > 0.05$) improvement in tenderness as triceps brachii samples were aged from 14 to 21 d. Interestingly, out of the 3 muscles the triceps brachii exhibited the least amount of change in WBSF from 7 to 14 d, 14 to 21 d, and over the 7- to 21-d aging period. In USDA Select carcasses, the majority of postmortem aging is completed by 21 d in triceps brachii, 27 d in gluteus medius, and 26 d for the longissimus lumborum (Gruber et al., 2006). For the upper two-thirds Choice, the majority of postmortem aging is completed by 16 d in triceps brachii, 21 d in gluteus medius, and 15 d for the longissimus lumborum (Gruber et al., 2006). From the data presented herein, it would appear that the triceps brachii completed the majority of postmortem aging at an earlier time than that of other muscles (Gruber et al., 2006).

There was no difference ($P > 0.05$) in WBSF between 0-, 20-, or 30-d ZH for gluteus medius. However, WBSF for 20 and 30 d were numerically greater than 0-d ZH. Lack of statistical difference may be because of the large variation found within these samples. This variation could be partially attributed to connective tissue, which was prevalent in the gluteus medius portions. There was no difference ($P > 0.05$) in WBSF for gluteus medius due to QG. Gluteus medius steaks that were aged 7 d were less tender than those aged 21 d ($P = 0.033$).

Shear force for longissimus lumborum was not different ($P > 0.05$) between Choice and Select QG. There was a ZH \times AD ($P = 0.062$) interaction (Figure 3) for WBSF. The WBSF for 0-d ZH was less than 20-d ZH after 7 d ($P = 0.001$), 14 d ($P = 0.015$), and 21 d ($P = 0.038$) of aging. In addition, 0-d ZH was also less than 30-d ZH for all 3 AD ($P < 0.01$); but 30-d ZH was not different ($P > 0.05$) from 20-d ZH at any

Table 5. Percentage of thaw loss, percentage of cooking loss, and Warner-Bratzler shear force for calf-fed Holstein steer muscles¹

Muscle	Zilpaterol hydrochloride ²				Quality grade				Aging day			Sig. ⁴		
	0 d	20 d	30 d	SEM ³	Sig. ⁴	Choice	Select	SEM ³	Sig. ⁴	7 d	14 d		21 d	SEM ³
Triceps brachii														
Thaw loss, ^{5,6} %	4.5	4.4	4.7	0.15	NS	4.3 ^a	4.8 ^b	0.13	**	4.2 ^a	4.6 ^{ab}	4.8 ^b	0.14	†
Cooking loss, ^{6,7} %	17.7	18.3	18.1	0.43	NS	18.5	17.6	0.38	†	17.9	18.6	17.6	0.42	NS
Shear force, kg	3.3 ^a	3.6 ^b	3.8 ^b	0.06	**	3.6	3.6	0.05	NS	3.8 ^b	3.5 ^a	3.4 ^a	0.06	**
Gluteus medius														
Thaw loss, %	7.4	7.2	7.4	0.75	NS	7.3	7.4	0.70	NS	7.1	7.5	7.4	0.69	NS
Cooking loss, %	18.4	19.6	19.1	0.37	NS	19.0	19.1	0.39	NS	18.9	19.2	19.0	0.36	NS
Shear force, kg	3.8	4.8	4.8	0.60	NS	4.4	4.5	0.57	NS	4.8 ^b	4.4 ^{ab}	4.1 ^a	0.57	†
Longissimus lumborum														
Thaw loss, %	4.0	4.5	4.3	0.30	NS	4.1	4.4	0.29	NS	4.2	4.2	4.3	0.33	NS
Cooking loss, %	13.4 ^a	14.3 ^b	14.5 ^b	0.74	*	14.0	14.1	0.74	NS	14.2	14.0	13.9	0.75	NS
Shear force, ⁶ kg	2.8 ^a	3.6 ^b	4.0 ^b	0.17	**	3.3	3.6	0.15	NS	4.0 ^c	3.3 ^b	3.0 ^a	0.14	**

^{a-c}Within a row for the main effect of zilpaterol hydrochloride, quality grade, or aging day, means without a common superscript letter differ ($P < 0.05$).

¹Muscles were removed from the subprimals: shoulder clod (triceps brachii), top butt (gluteus medius), and strip loin (longissimus lumborum).

²Zilpaterol hydrochloride (Intervet/Schering Plough Animal Health, DeSoto, KS) fed at 8.3 mg/kg (100% DM basis) according to label direction. Steers were slaughtered at a commercial facility after a 3-d withdrawal.

³SEM, largest value reported.

⁴Significance of F -test for main effect. P -value: ** < 0.01; * < 0.05; † < 0.10; NS = not significant.

⁵Interaction effect ($P < 0.10$) zilpaterol hydrochloride × quality grade.

⁶Interaction effect ($P < 0.10$) zilpaterol hydrochloride × aging day.

⁷Interaction effect ($P < 0.10$) quality grade × aging day.

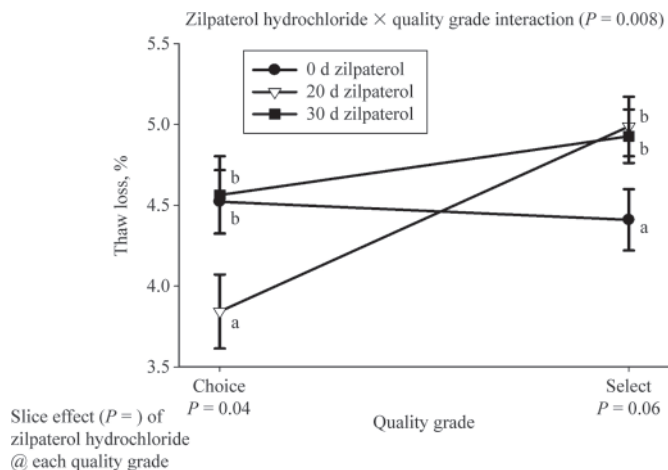


Figure 1. Triceps brachii thaw loss 2-way interaction between zilpaterol hydrochloride [Intervet Schering Plough Animal Health, DeSoto, KS; fed at 8.3 mg/kg (100% DM basis) according to label direction to calf-fed Holstein steers] and quality grade. The SLICE effect was used to test differences between zilpaterol hydrochloride treatments at each quality grade. ^{a,b}Within quality grade, means without a common letter are different at $P < 0.05$.

AD. Strydom and Nel (1999) reported that longissimus thoracis from steers treated with ZH for 30 or 50 d had decreased tenderness compared with control at 3 d of aging, but were similar after 10 d of aging. In this study, ZH-treated Holstein steers did not have similar WBSF at any AD compared with the control. With the observed increase in WBSF due to feeding ZH being previously documented in beef cattle (Avendaño-Reyes et al., 2006; Hilton et al., 2009; Leheska et al., 2009), it was not surprising to see an increase in WBSF due to feeding ZH to Holstein steers.

At 7, 14, and 21 AD, 0-d ZH always had a lesser WBSF than 20- or 30-d ZH. However, it appears that steaks from ZH-treated steers do respond to postmortem aging. From 7 to 21 d, 0-d ZH decreased 0.6 kg of WBSF (from 3.1 to 2.5 kg). Over the same AD, 20-d ZH samples decreased 1.2 kg of WBSF (from 4.3 to 3.1 kg) and the 30-d ZH decreased 1.4 kg (from 4.8 to 3.4 kg). So, whereas 0 d was more tender at each aging period, these data demonstrate that samples from 20- and 30-d ZH Holstein steers do age and become more tender over time. Strydom et al. (2009) fed 3 different BAA and reported that ZH and clenbuterol had increased WBSF at 2, 7, and 14 d postmortem compared with control and ractopamine. Yet, ZH, ractopamine, and control all aged similarly (Strydom et al., 2009). Wheeler and Koochmarai (1992) fed steers the BAA L_{644,969} and reported that treated steers had greater WBSF at 7 and 14 d, compared with control steers. In addition, WBSF did not decrease with aging for the treated steers, whereas the controls did become more tender with aging. The lack of tenderization in their treated steers was attributed, in part, to increased levels of calpastatin, which interacts with the calpains that contribute significantly to postmortem tenderization of meat (Geesink and Koochmarai, 1999; Geesink et al., 2006). Thus, whereas ZH-treated steers in this

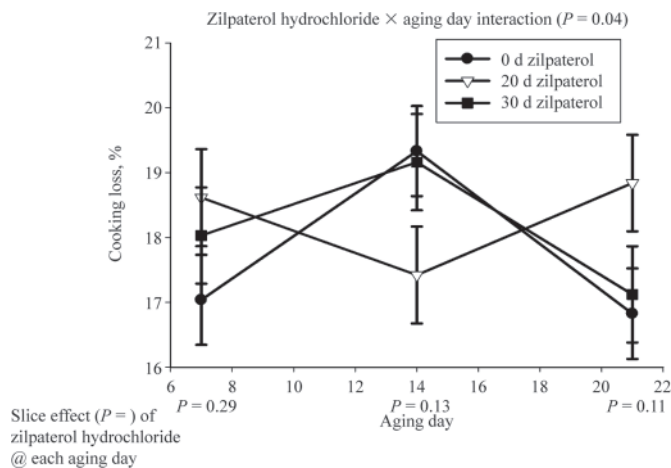


Figure 2. Triceps brachii cooking loss 2-way interaction between zilpaterol hydrochloride [Intervet Schering Plough Animal Health, DeSoto, KS; fed at 8.3 mg/kg (100% DM basis) according to label direction to calf-fed Holstein steers] and aging day. The SLICE effect was used to test differences between zilpaterol hydrochloride treatments at each aging day.

study had greater WBSF than controls, they were still able to undergo postmortem aging. Hilton et al. (2009) reported no differences in the activity of calpastatin or the calpains with ZH. Other factors affecting postmortem proteolysis may be responsible for the observed phenomenon within this study.

Although not directly compared, the effect of ZH on shear force was disproportional across muscles. For the triceps brachii 20- and 30-d ZH increased shear force by 10 and 15%, respectively, compared with 0-d ZH. For the gluteus medius ZH increased shear force by about 25% compared with 0-d ZH. In the longissimus lumborum, 20- and 30-d ZH increased shear force 39 and 54%, respectively, after 7 d of aging. After 21 d of aging, 20- and 30-d ZH increased shear force 24 and 36%,

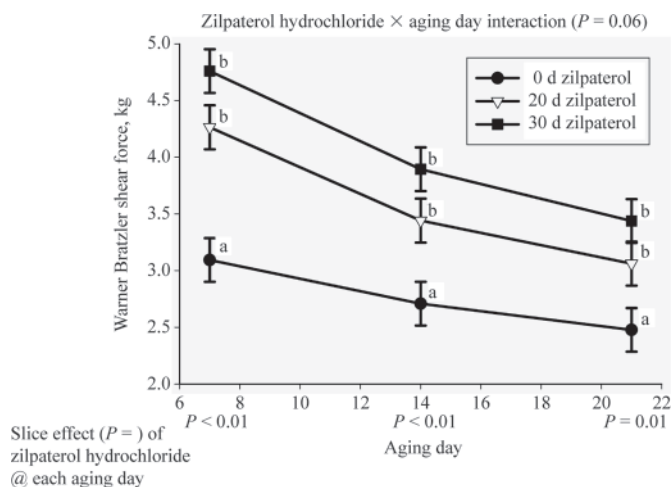


Figure 3. Strip loin Warner-Bratzler shear force 2-way interaction between zilpaterol hydrochloride [Intervet Schering Plough Animal Health, DeSoto, KS; fed at 8.3 mg/kg (100% DM basis) according to label direction to calf-fed Holstein steers] and aging day. The SLICE effect was used to test differences between zilpaterol hydrochloride treatments at each aging day. ^{a,b}Within aging day, means without a common letter are different at $P < 0.05$.

respectively, compared with 0-d ZH. The differences in WBSF for these muscles may be due to differences in fiber type. Kirchofer et al. (2002) classified the triceps brachii as an intermediate fiber-type muscle and the gluteus medius and the LM as white fiber-type muscles. Because the addition of BAA stimulates growth more specifically in fast-fiber type muscles (Moloney et al., 1990; Wheeler and Koohmaraie, 1992), the longissimus lumborum and gluteus medius may have been more responsive to the supplementation of ZH, which may explain the observed differences in WBSF.

Shackelford et al. (1991) reported a threshold limit for beef shear force of 4.6 kg for retail and 3.9 kg for foodservice. Huffman et al. (1996) indicated that 4.1 kg or less would ensure an increased level of consumer satisfaction. Although caution needs to be taken when trying to establish threshold limits for consumer acceptance, 20-d ZH at 14 AD and 30-d ZH at 21 AD had an average shear force value of 3.4 kg, a value well below the threshold for what consumers consider tender. So, with appropriate postmortem aging, steaks from ZH-treated Holstein steers should meet consumer expectations for tenderness based on past WBSF threshold limits (Shackelford et al., 1991; Huffman et al., 1996).

In conclusion, Holstein steers represent an important part of the US beef industry. Choice quality grade carcasses had more fat than Select carcasses, but minimal differences in shear force. With the addition of the BAA ZH, there will be a decrease in fat content. Zilpaterol hydrochloride will have minimal effects on purge loss, thaw loss, and cooking loss, but will increase shear force. However, with the appropriate postmortem management practices, the increase in shear force can be managed. This would include aging meat so that tenderness for ZH treated beef is within acceptable ranges to meet expectations of consumers for tender beef.

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