A RESEARCH NOTE

USE OF HYDRODYNAMIC PRESSURE PROCESSING AND BLADE TENDERIZATION TO TENDERIZE TOP ROUNDS FROM BRAHMAN CATTLE*

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ABSTRACT

Tenderization effects of hydrodynamic pressure processing (HDP), blade tenderization (BT) and a combination of BT followed by HDP (BT + HDP) were evaluated with 12 top rounds from Brahman cattle selected for toughness. Warner–Bratzler shear testing was performed on the day of treatment (D0) and after storage (D7). On D0, BT and HDP increased tenderness by 18% and BT + HDP yielded a 14% improvement over control steaks. Tenderness increased ($P < 0.05$*) for HDP and BT + HDP treatment between D0 and D7, whereas tenderness did not change for BT treatment. Control samples*

* Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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increased (P < 0.05) in tenderness because of aging alone (20% improvement). Overall tenderness improvements for BT + HDP and HDP (D7) versus control (D0) were 37 and 29%, respectively. BT provided instant tenderization but without additional improvement during aging. HDP and BT + HDP resulted in instantaneous tenderization that also increased over time and provided the greatest amount of overall improvement in tenderness.

INTRODUCTION

Beef tenderness inconsistency is a major problem in the meat industry. It is estimated that one out of every four Choice-grade steaks has a tenderness problem (NCA 1994). The beef round represents approximately 22% of the weight of the average carcass and contains some of the least tender muscles (Jones *et al.* 2001). Two of the least tender muscles of the hindquarter are the *semimembranosus* and *adductor* muscles. These two muscles also have a high amount of variability in tenderness within the muscles themselves (Reuter *et al.* 2002). Clearly, there is a need for new technologies to improve the tenderness of beef top rounds.

Aging and blade tenderization (BT) are commonly used by the meat industry to tenderize meat (Boyd *et al.* 1978; Savell *et al.* 1982; Jeremiah *et al.* 1999). Time is an important variable when aging at refrigeration temperatures, which allows naturally occurring biochemical processes to improve meat tenderness. During BT, the myofibrillar structure and connective tissue, which are the main components that affect tenderness, are severed by the use of needle or blade probes that cut into the muscle itself (Boyd *et al.* 1978; Jeremiah *et al.* 1999).

A recently introduced novel meat tenderization process is hydrodynamic pressure processing (HDP) (Solomon *et al.* 1997). In HDP, the meat is packaged, placed on a metal reflector plate in a water-filled container and an explosive charge is detonated over the meat. Shear force values were reduced by 49–72% in fresh or cold-shortened beef steaks (Solomon *et al.* 1997). The HDP process tenderizes meat by disrupting the myofibrillar structure (Zuckerman and Solomon 1998). Marriott *et al.* (2001) observed that collagen solubility was not affected by HDP in the evaluation of beef *longissimus* samples and proposed that connective tissue proteins may be more resistant to HDP treatment.

It was theorized that by combining BT and HDP, BT would disrupt the myofibrillar structure and intramuscular connective tissue, and HDP would provide further tenderization. Two previous studies were performed to tenderize meat from older cows and cuts with excessive connective tissue utilizing BT, HDP and the combination of the two treatments. Solomon *et al.* (2001)

found that the combination of BT with HDP improved the tenderness of *longissimus* from older cows compared to BT alone and control treatments. Schilling *et al.* (2003) evaluated the use of BT and HDP on U.S. Utility-grade *longissimus lumborum* muscles and found that aging (7 and 14 days) provided greater tenderization than BT, HDP or the combination (BT + HDP). When data from the two aging periods were combined, the BT + HDP treatment produced a significantly more tender meat than the control or BT treatment. The animals used were much older for slaughter than are typically used for retail meat cuts; thus, they had a higher amount of and more extensively cross-linked connective tissue. These studies indicate that BT + HDP improved the tenderness of muscles from older animals with excessive connective tissue; however, the effectiveness of BT + HDP to tenderize naturally tough cuts from typical slaughter-age animals is unknown.

Among beef breeds, Brahman cattle have many characteristics that are ideal for producers; however, meat from this breed is generally less tender than those from other breeds (Crouse *et al.* 1989; Riley *et al.* 2003). It is unknown if BT, HDP and BT + HDP, could provide the needed tenderization of naturally tough muscles from Brahman cattle at a typical slaughter age. The objective of this study was to evaluate the tenderization ability of HDP, BT and their combination on top rounds from Brahman cattle that were prescreened for toughness.

MATERIALS AND METHODS

Muscle Samples

Thirty-two top rounds from Brahman steers and heifers reared at the Sub Tropical Agriculture Research Station, Brooksville, FL, were frozen at 7 days postmortem and shipped to the Food Technology and Safety Laboratory (FTSL), Beltsville, MD. The top rounds were frozen because of the inability to process all the rounds when they were received. Genetics and slaughter information on these carcasses were described in Riley *et al.* (2003). From each frozen top round, one 2.5-cm thick steak was removed from the proximal end and thawed to screen for tenderness using the Warner–Bratzler shear test. Twelve of the toughest top rounds (shear force range: 6.8–9.8 kgf) were selected for this study.

Experimental Design

The experiment examined a control and three treatments: HDP, BT and BT + HDP. Ideally, each top round would be divided into four homogeneous

sections and the three treatments and control randomly applied, one per section, so that treatment comparisons would not contain among-animal variation; rather they would be based only upon intramuscular variation. Subsequently, each of the four sections would be divided in half to examine 0- and 7-day storage effect. Such an ideal experimental design could not be employed because of several known constraints.

Reuter *et al.* (2002) reported significant differences in shear force values in the ischial (origin) and distal (insertion) ends of the *semimembranosus* muscle and also between the superficial (medial) and deep sides; whereas the *adductor* muscle had no significant intramuscular differences in shear force values. To protect the treatment effects from contamination by these inherent intramuscular shear force differences, the design was modified. The single control section was omitted and each of the three treatment sections was divided in half to obtain muscle for a paired control. The treatment and paired control halves were subsequently divided in half again to obtain muscle for examination after 0 and 7 days of storage. By this design, a top round contains enough muscle to apply only two of the three treatments.

The final balanced incomplete block design with a split-split-plot (i.e., section) treatment structure was constructed to minimize and balance the effect of known inter- and intra-animal variations on examination of treatment differences. A complete replicate of treatment application was accomplished by applying each of the three possible pairings of the three treatments: (BT, HDP) (BT, BT + HDP) and (HDP, BT + HDP) to a separate top round (i.e., incomplete block) during the same processing day, each treatment assigned to two of the three top rounds comprising the replicate. Top rounds (i.e., blocks) were divided into two sections (i.e., whole-plots), parallel to the long axis of the *semimembranosus* muscle (from the origin to insertion end), and a treatment was applied to each section. Each treatment section was divided to remove a subsection (i.e., subplot) (approximately 5.5 cm thick) perpendicular to the long axis of the muscles prior to treatment to serve as the paired control. Each treatment and paired-control subsection was divided to obtain a sub-subsection of muscle to store either 0 or 7 days before evaluation. A total of four replicates were conducted to allow each treatment (and, hence, its associated paired control) to be assigned once to each of the four different locations within a top round (proximal to distal and medial to deep side).

Sample Preparation

Three frozen top rounds were thawed (2C) for 4–5 days for each processing day. On the day of treatment application, the *gracilis* muscle was removed

from each top round. The treatments and their paired control sections were removed as described in the experimental design. After treatment, the treated and paired control sections were cut into two 2.5-cm steaks and randomly assigned to D0 and D7 tenderness evaluation. The steaks designated for D7 were stored at 2C in 3-mil high-performance vacuum-packaging bags (model 030044, Koch, Kansas City, MO). D0 steaks were immediately prepared for cooking after treatment application.

Blade Tenderization

Because of the thickness of the top round, each section designated as BT or BT + HDP was rotated 90 deg (top of muscle or fat side was lying sideways) and placed into the blade tenderizer unit (2.3 penetrations/cm^2) (model MT-M5, Lumar Ideal Inc., Montreal, Quebec, Canada) for one pass parallel to the muscle fibers.

Hydrodynamic Pressure Processing

Two randomly selected treatments, BT + HDP and/or HDP, were packaged into a double-seamed Cryovac boneguard bag (model 620TBGW, Sealed Air Corporation, Duncan, SC), briefly heat-shrunk (97C) and placed onto a 1.3-cm thick flat metal plate inside a 98-L plastic explosive container filled with water. To create an air boundary around the container, it was suspended 25 cm above the floor. A 100-g cylindrical shaped binary explosive was placed 31 cm above the meat (along the long axis) and detonated to create the HDP treatment.

Cooking of Steaks

All steaks were trimmed of excess fat and equilibrated to 4C for approximately 30 min before cooking. Weights of raw steaks were recorded to determine cook loss. An electric grill (Indoor/Outdoor model GGR50B, 1600W, Salton, Mount Prospect, IL) was preheated at maximum setting (260–290C) for 10 min. Steaks were cooked according to the AMSA (1995) guidelines with the internal temperature monitored using an iron/constantan Type J thermocouple attached to a Progeny RSX video recorder (Honeywell, Freeport, IL). The steaks were turned once when the internal temperature reached the midpoint between the initial and end-point cooking temperature (71C). During cooking, the grill was covered with the vented, dome lid. The cooked steaks were removed from the grill, blotted and weighed for cooking loss determination. The steaks were cooled to room temperature before instrumental tenderness evaluation.

Shear Force Determination

For each steak, a minimum of six cores were removed using a 1.3-cm diameter corer parallel to the direction of muscle fibers. Each core was sheared once perpendicular to the muscle fibers using the Warner–Bratzler shear blade attached to the Universal Instron Testing Machine using a 100-kg load cell and a crosshead speed of 250 mm/min (model 1122, Instron Corporation, Canton, MA). Load at maximum load (kgf) for each shear was calculated by the Series IX software (Instron Corporation).

Although the experimental design of this study attempted to reduce the amount of variability within each top round through the use of a paired control from each treatment section, a large variation in shear force values within each steak was observed during the first replication. An example of this variability was a shear force range of 5.09–16.71 kgf obtained from one control steak at D0. To reduce this variability, the location and shear force values for each core within a steak were mapped for the remaining replications and each map was divided into quadrants. For replications 2 through 4, the percent improvement for each steak was determined by obtaining the mean of all pairwise differences between every core from a specific quadrant of the treated steak section and the same quadrant of the paired-control steak section. For each steak comprising the unmapped first replication, among-quadrant variability could not be removed, so the estimate of shear force percent improvement was calculated as the mean of all pairwise differences between every core from the treated steak section and each core from the paired-control steak section. Inclusion of the data from the first replication made detection of any significant treatment effects more difficult.

Statistical Analysis

Data collected using the incomplete block design were analyzed using SAS (Version 8.2, SAS Institute INC., Cary, NC, 2001–02) PROC MIXED. Analysis of variance factors (and factor levels) were defined as: Treatment (BT, HDP, BT + HDP); Application (Treatment, Control); Storage (D0, D7); TopRound (1, 2, . . . , 12); and HalfSection (1, 2).

For cook times, percent cook loss and Warner–Bratzler shear force values (Table 1), the PROC MIXED MODEL statement included all crossed (i.e., factorial) effects involving Treatment, Application and Storage as fixed effects. The RANDOM statement was used to specify TopRound and HalfSection × TopRound as random effects. Correlation between D0 and D7 Warner–Bratzler shear force values was modeled using (REPEATED Storage/ SUBJECT = TopRound * HalfSection * Application TYPE = CS). Least squares means were calculated for each Treatment × Type × Storage and LSD

TABLE 1.
LEAST SQUARE MEANS (STANDARD ERROR) OF COOK TIMES, PERCENTAGE COOK LOSS AND WARNER–BRATZLER SHEAR FORCE VALUES FOR TENDERIZED BRAHMAN BEEF TOP ROUND STEAKS AND THEIR PAIRED CONTROLS* AT DAYS 0 AND 7

Treatment	Day 0		Day 7	
	Control	Treated	Control	Treated
Cook time (min)				
BT	16.0 (0.9)	15.3 (1.0)	16.7 (0.9)	17.1 (1.0)
HDP	16.7 (0.9)	16.7 (1.0)	16.4 (0.9)	18.4 (1.0)
BT + HDP	15.6 (0.8)	17.2 (0.8)	15.6 (0.8)	16.6 (0.8)
Percent cook loss				
BT	27.8 (0.9)	28.6 (0.9)	25.9 (0.6)	26.8 (0.6)
HDP	29.2 (0.9)	28.7 (0.9)	26.0 (0.6)	26.6 (0.6)
BT + HDP	29.4 (0.9)	30.5 (0.9)	25.3 (0.6)	27.4 (0.6)
Warner–Braztler shear force values (kgf)				
BT	8.69^{a} (0.52)	6.58^{bc} (0.52)	7.32^{b} (0.52)	6.45^{bc} (0.52)
HDP	8.42^{a} (0.53)	6.44^{bc} (0.53)	6.62^{bc} (0.53)	5.37^{d} (0.52)
BT + HDP	8.94^{a} (0.52)	7.13^{b} (0.53)	6.82^{b} (0.52)	5.95^{cd} (0.52)

* For each treatment section within a top round, a paired control was evaluated at each of the aging periods.

[a,b,c,d] Means with different letters are significantly different at $\alpha = 0.05$ for any comparison within the same testing parameters.

BT, blade tenderization; HDP, hydrodynamic pressure processing; BT + HDP, combination treatment of blade tenderized followed by hydrodynamic pressure processing.

pairwise *t*-tests (i.e., LSMEANS Treatment*Type*Storage/DIFFS) were conducted to identify any significant ($\alpha = 0.05$) differences.

Each Warner–Bratzler shear force percent improvement value (Table 2) was calculated on both a "per storage day" basis, as the percent difference between values of a treated sample and its control from the same storage day, and an "overall" basis, as the percent difference between values of a 7-day stored treated sample and its 0-day stored control. Expressing Warner–Bratzler shear force as percent improvement effectively removed one of the splits from the split-split-section design. The PROC MIXED MODEL statement included Treatment, Storage and Treatment × Storage as fixed effects with the TopRound × HalfSection random effect and the correlation between D0 and D7 Warner–Bratzler shear force values modeled using (REPEATED Storage/SUBJECT = TopRound*HalfSection TYPE = CS). For the "per storage day" basis, least squares means of percent improvement values were calculated for each Treatment × Storage and separated using LSD pairwise *t*-tests (LSMEANS Treatment*Storage/DIFFS). For the "overall" basis, least squares means were calculated for each Treatment and separated using LSD pairwise *t*-tests (LSMEANS Treatment/DIFFS).

TABLE 2.
LEAST SQUARE MEANS (STANDARD ERROR) OF PERCENTAGE IMPROVEMENT FOR TENDERIZED BRAHMAN BEEF TOP ROUND STEAKS COMPARED TO THEIR PAIRED CONTROLS* AT DAYS 0 AND 7

Treatment	Day 0†	Day 7†	Overall‡
BT	18.2^{a} (7.9)	0.6^{b} (7.3)	16.9^{d} (6.3)
HDP	17.9^{ab} (7.9)	13.4^{ab} (7.3)	29.2^{cd} (6.3)
BT + HDP	13.8^{ab} (7.9)	5.0^{ab} (7.3)	37.3^{c} (6.3)

* For each treatment section within a top round, a paired control was evaluated at each of the aging periods.

† Percent improvement within each day and treatment is the least squares mean of all pairwise differences between every Warner–Bratzler shear force value from a specific quadrant of the treated steak and the same quadrant of the control steak.

‡ Percent overall improvement for each treatment is the least square mean of all pairwise differences between every Warner–Bratzler shear force value from a specific quadrant of the treated steak on day 7 and the same quadrant of the control steak on day 0.

a,b Means for percent improvement on D0 and D7 with different superscripts are significantly different ($\alpha = 0.05$).

c,d Overall percent improvement mean values with different superscripts are significantly different ($\alpha = 0.05$).

BT, blade tenderization; HDP, hydrodynamic pressure processing; BT + HDP, combination treatment of blade tenderized followed by hydrodynamic pressure processing.

RESULTS

No significant differences were found for cook times or percentage cook loss for the treatments or controls on either sampling day (Table 1). Thus, the treatments did not affect ($P > 0.05$) cooking properties of the top round steaks.

No significant differences in Warner–Bratzler shear force were detected among the paired controls associated with each treatment for either D0 or D7 (Table 1). On D0, all three treated steaks were more tender ($P < 0.05$) than their controls but no differences ($P > 0.05$) were observed among the three treatments. The percentage improvements in tenderness for D0 calculated using the means in Table 1 were 24.3, 23.5 and 20.2% for BT, HDP and BT + HDP, respectively.

Tenderness of control samples improved (20.3%, $P < 0.05$) between D0 and D7 (Table 1). Between D0 and D7, tenderness increased significantly for HDP and BT + HDP (16.6 and 16.5% tenderness improvement calculated using the means, respectively); however, no significant change was observed for BT treatment. On D7, BT (6.45 kgf) was not significantly different from its paired control (7.32 kgf), but HDP and BT + HDP were more tender than their paired controls (18.9 and 12.8% tenderness improvement calculated using the means, respectively). HDP was more tender ($P < 0.05$) than BT on D7. The

overall improvements in tenderness for the treatments over the 7 days of aging calculated using the means in Table 1 were 25.8, 36.2 and 33.4% for BT, HDP and BT + HDP, respectively.

The percent tenderness improvement obtained with the comparison of the specific quadrants of the treated steak to the same quadrant of the control steak are presented in Table 2. HDP and BT + HDP had similar increases ($P > 0.05$) in percent improvement of tenderness for D0 and D7. On D7, BT had significantly less improvement in tenderness than on D0. Aging effect among the control groups were not significantly different (data not shown); the percent improvements were 12.3, 14.2 and 16.6% for the BT, HDP and BT + HDP controls (standard error of 4.6), respectively. Overall tenderness improvements for HDP and BT + HDP D7 treatments compared to the D0 paired controls were greater than aging (Table 2). BT + HDP overall tenderness percent improvement was significantly higher than BT, which was not different than aging alone. Use of the pairwise comparisons to determine the percent tenderness improvements better reflected tenderization effects seen with the shear force values of HDP and BT + HDP in comparison to the controls and BT during the storage period.

DISCUSSION

None of the treatments had any effect on the cooking properties of the top round steaks. Previous studies have reported no effect on cooking times (Wheeler *et al.* 1990; Jeremiah *et al.* 1999) or a decrease in cooking times because of BT (Glover *et al.* 1977; Boyd *et al.* 1978). There are no published literature on the effect of HDP on cooking times. In previous research with HDP in beef and pork, no significant difference in cooking times were observed (personal communication, Janice A. Callahan, Janet S. Eastridge and Ernest Paroczay, U.S. Department of Agriculture, Agricultural Research Service).

Cooking loss results were consistent with those reported by Schilling *et al.* (2003) for BT, HDP and BT + HDP. However, several studies (Glover *et al.* 1977; Wheeler *et al.* 1990) found BT increased cooking losses. Boyd *et al.* (1978) noted that beef *semimembranosus* muscles blade-tenderized either once, twice or four times were not different ($P > 0.05$). Jeremiah *et al.* (1999) observed only the blade eye, defined as a blade combination of 10 muscles, had less cooking loss with BT when 14 different muscles and muscle groups were examined. In previous HDP studies, there was no effect on cooking loss in beef *longissimus* muscles (Marriott *et al.* 2001) or beef *biceps femoris* muscles (Schilling *et al.* 2002). O'Rourke *et al.* (1998) observed a 2.4% lower cooking loss in pork loin pieces when HDP treatment was applied

1 day postmortem; however, no differences were seen with paired loin pieces that were treated with HDP 1 day postmortem and then aged for 40 days.

Treatments enhanced tenderness of top round steaks on D0. Tenderness continued to improve for HDP, BT + HDP and the controls through 7 days of aging, whereas BT did not improve tenderness. Boyd *et al.* (1978) reported that BT of beef *semimembranosus* muscles resulted in tenderization similar to aging samples for 2 weeks. Unlike this study, Boyd *et al.* (1978) observed that Warner–Bratzler shear force values for the BT samples continued to decrease when aged for 2 and 4 weeks. BT in combination with other tenderizing techniques has produced various results. The effect of BT and electrical stimulation were evaluated in *longissimus* muscles from Brahman × Hereford crossbred cattle (Wheeler *et al.* 1990). Electrical stimulation and BT were similar in their ability to tenderize the muscles. The use of BT after electrical stimulation provided greater tenderization than BT alone; however, the improvement was not significantly different from electrically stimulated muscles. Savell *et al.* (1982) showed that BT alone or in combination with electrical stimulation was more tender than either the control or electrically stimulated beef strip loins and top sirloin butts. They reported a further increase in tenderness during aging. Savell *et al.* (1982) suggested that BT in combination with aging for 18 days was effective in reducing shear force values regardless of the initial tenderness, because this treatment is more severe. In the previous studies, BT was applied to muscles after the aging period.

Percent tenderness improvement observed in this study with HDP treatment was less than the 59% reported by Solomon *et al.* (1997) with frozen and thawed, hot-boned *semimembanosus* muscles. The percent tenderness improvement was similar to the 17–19% percent improvement in beef top rounds using electrically generated hydrodynamic shockwaves (Sagili and Claus 2003). The reasons for differences in percent improvement between studies are unknown. One possible explanation that has been reported is that the response to the shockwaves varies between different animals (Marriott *et al.* 2001; Schilling *et al.* 2003). More studies are necessary to describe the mechanism whereby shockwaves tenderize meat and to optimize the process.

The combination of BT and HDP has been used to improve the tenderness of muscles with mature collagen (Solomon *et al.* 2001; Schilling *et al.* 2003). Unfortunately, both studies had limited sample numbers, which may have affected the ability to detect treatment differences. Solomon *et al.* (2001) reported an improvement in beef *longissimus* ($n = 4$) and strip loins ($n = 2$) tenderness because of BT (4–13%); however, BT + HDP had a greater tenderization effect (17–21%). The effects of HDP plus aging were not evaluated. Schilling *et al.* (2003) found no significant difference in shear force at both 7 and 14 days postmortem during their evaluation of BT, HDP and BT + HDP in U.S. Utility-cull cow *longissimus lumborum* muscles ($n = 6$). Their data were

combined for D7 and D14 because the sampling time by treatment interaction was not significant. When data were combined for both sampling times, BT + HDP treated samples were significantly more tender than the control or BT samples (17 and 4%, respectively). They concluded that aging 14 days provided greater tenderization than other treatments. Authors postulated that there may have been statistical differences had the samples been tougher initially. The controls on D7 had a Warner–Brazler shear force average of 4.59 kgf.

CONCLUSIONS

All three methods of tenderization improved tenderness of Brahman top rounds and had minimal effect on cooking properties. Each treatment provided the same improvement in tenderness on the day of treatment (D0) that occurred with aging the paired controls for 7 days. BT provided instant tenderization but without any additional aging improvement. HDP and BT + HDP resulted in instant tenderization that also increased over time and provided the greatest amount of overall improvement in tenderness.

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