TENDERNESS IMPROVEMENT IN FRESH OR FROZEN/THAWED BEEF STEAKS TREATED WITH HYDRODYNAMIC PRESSURE PROCESSING*

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ABSTRACT

Tenderness improvement in fresh (F) or frozen/thawed (FT) beef steaks treated with hydrodynamic pressure processing (HDP) technology was examined. In Experiment 1, the effect of HDP and meat state at 48 h postmortem (fresh, never frozen compared to frozen at 48 h postmortem followed by thawing at 6 d postmortem) on meat tenderness at both day 1 and day 6 after HDP was evaluated. The effect of HDP was sustained throughout day 6 of aging.FT samples were 1 kg lower at day 1 compared to F samples and 0.8 kg lower at day 6. In Experiment 2, 40 boneless, rib-eye sections (5 d postmortem) were used. One control steak was cooked fresh, while a second was frozen for 60 d. HDP was performed on the 40 F rib-eye sections. Twenty of the HDP-treated rib eyes were frozen after HDP treatment. The remaining 20 F HDP-treated samples were cooked 24 h after treatment for tenderness determination. Sixty days after HDP treatment, the frozen control and HDP-treated samples were thawed and cooked. Control (never frozen) steaks prior to HDP treatment had shear values of 6.5 kg. A 29% reduction in shear force was observed for HDP-treated (F) samples. Freezing accounted for a 14% reduction in shear force. HDP treatment followed by freezing resulted in a 30% reduction in shear force compared to the frozen control samples.

* Mention of brand or firm names does not constitute an endorsement by the United States Department of Agriculture over others of a similar nature not mentioned.

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PRACTICAL APPLICATIONS

Postmortem storage at refrigerated temperatures has been clearly demonstrated to improve meat tenderness. Freezing and then thawing meat has been shown to either improve tenderness, increase toughness or have no effect at all on meat tenderness. The use of hydrodynamic pressure processing (HDP) in conjunction with freezing meat either before or after HDP treatment was evaluated. Use of HDP, whether on fresh or frozen/thawed meat, successfully tenderized meat. Whether one freezes the meat before performing HDP or after HDP treatment, both successfully improve meat tenderness and the improvements are maintained even after frozen storage. Although freezing alone did show signs of improving meat tenderness, the magnitude of improvement was much less than the tenderness improvements found when using HDP technology.

INTRODUCTION

Of the three factors that determine beef palatability (tenderness, juiciness and flavor), tenderness is considered the most important sensory characteristic of meat. Consumers, retailers and restaurateurs all agree that meat tenderness is one of their top quality concerns (Huffman *et al.* 1996). Tenderness has proven to be the most difficult palatability factor for meat producers and meat packers to manage. The variation in meat tenderness is because of a multitude of ante- and postmortem factors (Dransfield 1974; Asghar and Pearson 1980; Morgan *et al.* 1991). Technology to enhance tenderness is economically important to consumers, processors and producers because increased consumer satisfaction stimulates additional sales and profits. Presently, no single technique is accepted industry-wide for improving meat tenderness because of implementation costs, inefficiencies, inconveniences, or adverse effects on other sensory properties.

Postmortem storage at refrigerated temperatures (aging) has been used for years as a means of improving tenderness and other sensorial characteristics but has been shown to be inconsistent in improving meat tenderness. The aging process is cost prohibitive for major meat processors because of the need to store large quantities of meat for extended periods. Several research studies have been designed exploring the effects of freezing on beef tenderness in conjunction with aging samples, e.g., storing the samples frozen, thawing and then cooking the samples. The findings from most of these studies are very inconsistent, but much of the differences have been because of differences in the experimental designs. Some researchers have found that freezing causes an increase in tenderness (Hankins and Hiner 1940; Hiner and Hankins 1951;

Law *et al.* 1967; Smith *et al.* 1968; Winger and Fennema 1976) while others have reported negative effects on tenderness (Pearson and Miller 1950; Guenther and Henrickson 1962; Smith *et al.* 1968; Jakobsson and Bengtsson 1973; Roberts *et al.* 1976). Some studies have reported that the effect due to freezing is dependent on the length of time the samples are stored frozen or whether the meat is aged prior to freezing or aged after freezing. Smith *et al.* (1968) found no difference in shear force when samples were stored frozen for less than 6 weeks but reported a decrease in shear force when samples were stored frozen for 4 months. Wheeler *et al.* (1990) found no difference in shear force when samples were compared at similar postmortem aging periods (chilled 13 d postmortem versus chilled 14 d and then frozen). When meat was aged after freezing, some studies have reported lower shear values (Crouse and Koohmaraie 1990; Whipple and Koohmaraie 1992). Stuby *et al.* (1993) and Stuby-Souva *et al.* (1994) found aging either prior to freezing or aging after freezing resulted in similar shear values. Shanks *et al.* (2002) reported that freezing decreased shear values but was dependent on postmortem aging periods. They found that 6 or 7 d shear force values from frozen/thawed (FT) beef samples best predicts fresh (F; never frozen) aged (14–21 d) shear values.

Within the last decade, a pressure-based technology, hydrodynamic pressure processing (HDP), has emerged as a potential method for tenderizing meat (Solomon *et al.* 1997; Solomon 1998; Zuckerman and Solomon 1998). HDP involves using a small amount of high-energy explosive to generate a supersonic-hydrodynamic shock wave in water. The shock wave passes through the water and through objects such as meat that are an acoustical match (similar mechanical impedance) as the water (Kolsky 1980; Solomon *et al.* 1997). The effects of freezing either before or after performing HDP on shear force measurements have not been determined. As meat is a perishable product and shear force often changes with refrigerated storage, many experimental conditions and time constraints necessitate that meat samples be frozen for a period of time before performing the experimental tests and tenderness assessments.

The objectives of these two studies were to determine the effect of HDP on F or FT meat or the effect of HDP on F meat followed by a period of frozen storage. Additionally, combining HDP with aging was evaluated for any additional improvement in tenderness.

MATERIALS AND METHODS

Experiment 1. Meat Source and Preparation

This study was replicated over 4 successive days. A total of 16 (low end of the Select quality grade), yield grades 2 and 3 beef strip loins (IMPS 180;

USDA, 1996), were purchased from a commercial processor at 48 h post-slaughter. After removing the tail and gluteus muscle, each strip loin (35 cm) was divided transversely into three sections (11.3 cm in length). The sections from each loin were vacuum packaged (550A MC-40, Sipromac Inc., Canada), randomly assigned within a strip loin to treatments and immediately frozen (–30C) for 7 d. Forty-eight hours prior to the experiment, frozen meat sections were thawed (3C). Samples were designated as FT for untreated controls and HDP treatments.

Twenty-four hours prior to the day of the experiments, a second group of eight F strip loins were obtained from the same commercial packing plant 48 h post-slaughter and trimmed, and sectioned as described earlier but never frozen.

Packaging. On the day of the experiment, three sections of each F or FT strip loins were randomly allocated (within a strip loin) to the following treatments: (1) nontreated controls; (2) HDP using a rectangular (REC)-shaped explosive; and (3) HDP using a cylindrical (CYL)-shaped explosive. One F and FT section in a treatment group were packaged together in a multilayer barrier bag (B650 TBGP; Cryovac) then dipped in 90C water to shrink the package. All samples were maintained at 3C except during preparation and treatment handling.

HDP. Only two samples of meat were treated by HDP at a time. Replications were conducted over 4 successive days using each explosive shape twice each day for a total of eight HDP treatments. The sealed multilayer barrier bag containing one F and FT sample was submerged under water in a 98-L plastic explosive container that was fitted with a 1.3-cm thick steel reflector plate. To produce an air barrier around the plastic container, the container was suspended 28 cm above the floor. Ice was added to the water to maintain a constant temperature. A binary explosive (100 g) was used for all HDP treatments and differed only in shape. A CYL- (15×2 cm diameter) or REC- ($4.5 \times 7 \times 2$ cm) shaped explosive was immersed into the water to a distance of 30.5 cm above the meat package and detonated.

Cooking and Shear Force Determination. Steaks (2.5 cm thick) were removed from the control and HDP sections at 1 and 6 d post HDP treatment. The steaks were cooked on an electric indoor-outdoor barbeque grill (GGR50B, Salton-Maxim Housewares, Inc., Mount Prospect, IL). To monitor the temperature, a microprocessor thermometer with a type-J thermocouple (HH-21, Omega Engineering, Stamford, CT) was inserted into the geometric center of each steak. Steaks were turned once when the internal temperature reached 40C (midpoint temperature) and cooked to a final internal temperature of 71C according to AMSA (1995) cooking guidelines.

After allowing the cooked steaks to reach room temperature, a 1.3-cm diameter coring tool was used to remove 10 or more cores from each steak parallel to the direction of the muscle fibers for shear force determination. Each core was sheared once with a Warner-Bratzler (WB) meat shear blade (1.8 mm thick, inverted V-notch) mounted on a texture measurement instrument (Model TMS-90, Food Technology Corp., Sterling, VA). The peak shear value (WBS, kg) was recorded for each core and the values for all cores from the same steak were averaged to obtain the shear force value of each steak. Percent improvement was calculated by the following equation: control WBS kg – HDP-treated WBS kg/control WBS kg × 100.

Statistical Analysis. The data were analyzed as a completely randomized block design 2 × 3 factorial split-plot where the date of the experiment replication was the block effect. The meat source (F versus FT) was the whole plot and the subplot was explosive shape (HDP-CYL and HDP-REC) and control and HDP sections at 1 and 6 d post HDP treatment. The data analysis was performed using the PROC MIXED procedure of SAS (version 8.2, Statistical Analysis System, SAS Institute, Cary, NC). Least square means and pair-wise comparisons were employed for mean separations whenever significant differences ($P < 0.05$) were detected.

Experiment 2. Meat Source and Preparation

Meat for this study came from a cooperative study with the USDA-ARS El Reno research center to evaluate tenderness in slightly finished cattle. Forty carcasses from forty different cattle were processed and portions of boneless rib-eye muscles (loin end) (one rib-eye muscle from each carcass) were shipped and received at the Beltsville-Food Technology and Safety Laboratory, ARS-USDA within 5 d of slaughter. Two 2.5-cm thick control steaks were removed from the loin end of each rib-eye section ($N = 40$) at 5 d postmortem. One control steak was cooked fresh while the other was frozen for 60 d and later cooked after thawing overnight at 3C for shear force determination. Ten-centimeter thick pieces from the remaining rib-eye sections were removed at 5 d postmortem and packaged for HDP processing as described earlier. HDP was performed in suspended 98-L plastic explosive containers using 100 g of a binary, REC-shaped explosive placed at a distance of 31 cm from the surface of the packaged meat. A 1.3-cm thick flat steel reflecting plate was used to support the meat on the bottom of the container. To create the air boundary around the container, it was suspended 25 cm above the floor.

Twenty out of the forty HDP-treated rib-eye sections were randomly selected and frozen immediately after HDP treatment. Two 2.5-cm thick steaks were removed from the remaining (F) 20 HDP-treated samples 24 h after HDP treatment and cooked for shear force determinations (see earlier procedures). Sixty days after HDP treatment, the frozen samples (both the control steak piece and the HDP-treated samples that were cut into 2.5-cm thick steaks) were thawed overnight at 3C. All steaks were cooked and evaluated for shear force following the procedures described earlier.

Statistical Analysis. Data were analyzed as a randomized incomplete block design in a split-plot 2 × 2 factorial arrangement. The HDP test number was the block effect, the whole plot was the postharvest handling treatment (F versus FT) and the subplot was treatment effect of controls versus HDP-treated samples. Statistical analysis was performed using SAS (version 8.2, Statistical Analysis System, SAS Institute, Cary, NC) (SAS 2002). The PROC UNIFORM procedure was used to test shear force data for outlier values that were deleted from the data set and for diagnostics test of normality and correlation of variances. The PROC MIXED procedure was used for analysis of variance of the factorial split-plot model, and the PDMIX routine was run to generate means separation as needed.

RESULTS AND DISCUSSION

Experiment 1. HDP Effect on Tenderness of F or FT Meat

Shear force tenderness of FT samples was 1 kg lower at day 1 of the start of the experiment compared to F, never frozen samples (4.3 versus 5.3 kg) and 0.8 kg lower at day 6 of aging (3.6 versus 4.4 kg). Both shapes of explosives improved ($P < 0.01$) shear force on day 1 (CYL 4.6 versus 5.4 kg; REC 4.4 versus 5.4 kg) compared to controls (pooled data of both HDP-treated samples and non-HDP-treated controls). The effect of HDP was sustained ($P < 0.01$) throughout day 6 of aging, with the CYL shape reaching 3.9 kg and the REC shape reaching 3.6 kg compared to controls (4.5 kg). Although not significant, the difference between the two explosive shapes for the HDP treatment was ($P < 0.06$). FT samples were 1 kg lower ($P < 0.01$) at day 1 compared to F samples (4.3 versus 5.3 kg) and 0.8 kg lower ($P < 0.01$) at day 6 (3.6 versus 4.4 kg). There were no significant interactions for meat state and HDP treatments. The percentage of samples with HDP improvements >10% was higher ($P < 0.01$) for the REC-shaped explosive (81%) compared to the CYL shaped (56%). Furthermore, the percentage of samples with HDP improvements >10% was numerically higher but not significant for F meat samples (75%) compared to FT samples (69%). The percentage of samples that improved greater than the aged control was 100% for REC, 88% for CYL ($P < 0.05$), but not significantly different for F samples (94%), and 81% for FT samples. These results suggest that both HDP and early postmortem freezing followed by thawing are successful treatments for improving meat tenderness and are better than extended conventional aging (Table 1).

Control steak shear values were lower in FT meat compared to F samples. This phenomenon is common when meat cuts are subjected to freezing followed by a thaw cycle (Hiner and Hankins 1951; Guenther and Henrickson 1962; Law *et al.* 1967; Smith *et al.* 1968; Winger and Fennema 1976; Duckett *et al.* 1998). Some researchers have reported that freezing causes negative decreases in meat tenderness (Pearson and Miller 1950; Jakobsson and Bengtsson 1973; Roberts *et al.* 1976). Smith *et al.* (1968) reported that freezing of resultant meat tenderness was dependent on the time the frozen samples were stored or aged prior to freezing. Shanks *et al.* (2002) supported the findings that freezing decreased shear force but was dependent on postmortem aging periods. However, it should be noted that different thawing methods and frozen time intervals should be taken into consideration when comparing these various research studies.

Information from personal communications with Richard Lee (U.S. Navy, Surface Warfare Center Division, Indian Head, MD) has revealed that the shape of the explosive used during HDP can affect the dynamics of the shock wave, thereby affecting the magnitude of tenderness improvement. Testing was performed using the REC-shaped explosive and it was proven that a direct shock wave was produced. With this evidence, it was postulated (personal communications, Morse B. Solomon) that a CYL-shaped explosive would create a planar (sheet) shock wave. Eastridge *et al.* (2002) showed that the shape of the explosive used for HDP for tenderizing meat may influence the magnitude of tenderness improvement. For previously FT beef rib-eye samples, a CYL explosive charge resulted in a more consistent tenderness improvement (range 12–18%) among samples, as well as between replications of treatment, with an overall 15.8% improvement. When a more compact (same explosive shape as REC used in this study) shape was used, the degree of tenderness improvement was greater (38%), although this was not consistent among samples treated at the same time, that is, some samples had negative or no change for overall 8.8% tenderness improvement. The results of this study support the results of Eastridge *et al.* (2002) with the same trend of tenderness improvement and consistency between replications for the REC- and CYL-shaped explosive used during HDP treatment of beef strip loins.

According to the definition of a successful instantaneous HDP treatment that our lab has arbitrarily established for baseline results (>10% tenderness improvement), HDP was successful in tenderizing samples for both explosive shapes in F and FT meat under the freezer storage time and aging time used.

TABLE 1.
MAIN EFFECTS AND *P*-VALUES FOR MEAT STATE PRIOR TO HYDRODYNAMIC PRESSURE (HDP) TREATMENT EXPLOSIVE SHAPE

Trait	Meat state[a]		Explosive shape[b]			Statistical significance *P*-value[c]		
	Fresh	Frozen/thawed	CON	CYL	REC	Meat	Shape	Meat*shape
Day 1								
Shear force, kg	5.3^{h}	4.3^{i}	5.4^{h}	4.6^{i}	4.4^{i}	0.01	0.01	NS
±SEM[d]	0.3	0.2	0.2	0.2	0.2			
Improvement, %	18	12	–	13	17	NS	NS	NS
Day 6								
Shear force, kg	4.4^{h}	3.6^{i}	4.5^{h}	3.9^{i}	3.6^{i}	0.01	0.01	NS
±SEM	0.2	0.2	0.2	0.2	0.2			
Improvement, %	14	15	–	11	19	NS	0.06	NS
Aging response, %[e]	17	14	16	14	16	NS	NS	NS
Percentage of day 1 samples with HDP improvement >10%[f]	75	69	–	56	81	NS	0.01	NS
±SE	1.1	1.1	–	1.1	1.1			
Percentage of day 1 samples that improved greater than the aged control, %[g]	94	81	–	88	100	NS	0.05	NS
±SE	0.5	0.5		0.05	0.05			

[a] Meat was treated fresh or after a freeze-thaw cycle.
[b] Explosive shape for the HDP treatment were no treatment (CON), CYL or REC shape explosive charge.
[c] *P*-values obtained from statistical analysis using PROC MIXED of SAS; NS indicates not significant ($P > .05$).
[d] SEM for shear force.
[e] Aging response, % = (day 1–day 6) ÷ day 1.
[f] Percentage of samples with day 1 HDP effect >10% = 100 * (number of samples/total samples).
[g] Percentage of samples where day 1 HDP treatment effect >6 d aging for controls = 100 * (number of samples/total samples).
[h,i] Means in a row within a main effect not having common superscripts differ ($P < .05$).
SEM, standard error of the mean; CON, control; CYL, cylinder; REC, rectangle, SE, standard error.

TABLE 2.
HYDRODYNAMIC PRESSURE PROCESSING (HDP) TREATMENT AND POST-TREATMENT HANDLING[a] ON SHEAR FORCE, AND TENDERNESS IMPROVEMENT LEAST-SQUARE MEANS AND STANDARD ERROR (SE) OF MEAN OF BEEF RIB EYES

Trait	Fresh			FT		
	Control	HDP	SE	Control	HDP	SE
Shear force, kg	6.53[d]	4.65[f]	0.10	5.63[e]	3.92[g]	0.10
Tenderness improvement, %	–	29	0.8	–	30	0.8

[a] After treatment, all samples were chilled overnight before cutting a steak for shear force determination. Half the samples (HDP treated and its respective control) were cooked immediately (fresh), and the remaining were frozen for 60 d before thawing (FT) and cooking for shear force evaluation.
[d,e,f,g] Means in a row having different superscripts differ ($P < 0.05$).
FT, frozen/thawed.

This would suggest that for experimental purposes, either meat source could be used to verify the effectiveness of the system.

Experiment 2. HDP Effect on Tenderness of F Followed by FT Meat

Control (never frozen) steaks prior to HDP treatment had shear values of 6.53 kg. A 27% reduction in shear force (4.65 kg) was observed for the HDP-treated (F) samples. Freezing accounted for a 14% reduction in shear force (5.63 kg) compared to fresh controls (6.53 kg). HDP treatment followed by freezing for 60 d resulted in shear values of 3.92 kg, a 30% reduction compared to the frozen control samples. Results from this experiment suggest that HDP treatment yields instantaneous improvements in tenderness, and the improvements are maintained even after freezing. Freezing alone for 60 d resulted in shear force value improvements of a 14% magnitude as compared to an instantaneous 29% improvement in shear force for HDP treatment (Table 2).

CONCLUSIONS

The use of HDP, whether on F or FT meat, successfully and instantaneously tenderizes meat. Whether you freeze the meat before performing HDP or after performing HDP, both successfully improve meat tenderness and the improvements are maintained even after freezing. Although freezing alone did show signs of improving meat tenderness, the magnitude of tenderness improvement was much less than the tenderness improvements found when using HDP technology.

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