A RESEARCH NOTE

HYDRODYNAMIC PRESSURE-PROCESSED BEEF *SEMITENDINOSUS* MUSCLE USING A STEEL REFLECTOR BOWL*

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ABSTRACT

Hydrodynamic pressure (HDP) technology, used to tenderize meat, has been previously conducted in both stationary steel hemisphere-shaped tanks (1060-L commercial and 54-L laboratory scale steel units) as well as in plastic explosive containers (PEC) fitted with a flat metal reflector plate. It was hypothesized that the bottom surface of the container may affect the magnitude of tenderness improvement during the HDP process. A steel reflector bowl was constructed to fit inside the PEC to mimic the shape of the bottom of the stationary steel vessel. Beef semitendinosus *(ST) muscles treated with HDP (150-g binary explosive detonated inside a water-filled 98-L PEC) were more tender (*$P < 0.05$*) than controls (5.37 versus 5.74 kgf). ST response to HDP was highly variable (–8.6 to 24.5%). Although the improvement in ST tenderness was significant (*$P < 0.05$*), using the steel reflector bowl in the PEC was not an efficient method to tenderize ST muscles.*

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INTRODUCTION

The hydrodynamic pressure (HDP) process is a technology that uses an explosive charge to instantaneously create underwater supersonic shock waves to tenderize meat (Solomon 1998). Because meat is a close acoustical match to water, these shock waves pass through the meat and then reflect off any objects that are not an acoustical match to water (Kolsky 1980). As the shock waves pass through the meat, microscopic tearing occurs in the myofibrillar structure of the muscle (Zuckerman and Solomon 1998).

Numerous studies using HDP and its ability to tenderize various meat cuts have been conducted in three types of vessels: (1) disposable plastic containers (PEC); (2) a 1060-L commercial steel unit (CSU) built with a hemisphere bottom; and (3) a 54-L laboratory scale steel unit (LSU) also built with a hemisphere bottom (Solomon *et al*. 1997, 1999a; Solomon 1998; Moeller *et al*. 1999; Claus *et al*. 2001; Schilling *et al*. 2002). HDP in a PEC fitted with a flat steel reflector plate has successfully tenderized beef, pork and lamb muscles (Solomon *et al*. 1997; Solomon 1998; Zuckerman and Solomon 1998; Spanier *et al*. 2000; Zuckerman *et al*. 2002). Studies using HDP in CSU have been reported by Solomon (1998); Moeller *et al*. (1999); Claus *et al*. (2001) and Schilling *et al*. (2002), with improvements in tenderness being highly variable. Studies that compared two explosive vessels (PEC versus CSU) have found that HDP treatment in a PEC improved the tenderness of beef more than CSU (Solomon and Eastridge 1999; Solomon *et al*. 1999a). The PEC was observed to have a greater magnitude of tenderness improvement than the LSU with boneless beef loins (Solomon and Berry 2000). All three types of explosive vessels used to conduct HDP have been shown to improve the tenderness of meat, but these improvements have varied in magnitude because of the type of vessel used. HDP conducted in a CSU improved the tenderness of beef *semitendinosus* (ST) muscles between 17 and 23% (Solomon *et al*. 1999b). Hot boned beef ST muscles improved 56% in tenderness when treated with HDP in a PEC (Solomon *et al*. 1997). Eastridge *et al*. (2001) reported a 21% overall tenderness improvement for HDP-treated ST in a PEC.

Additional experiments have been conducted in an effort to maximize the effectiveness of the HDP process. Eastridge *et al*. (1998) observed that the type and amount of explosive used to create HDP resulted in different shock wave pressure fronts which affected the amount of tenderness improvement of four beef muscles (*longissimus*, *semimembranosus*, *biceps femoris* and ST). Beef ST muscle fiber orientation (horizontal or vertical position) on the reflector plate played an important role in HDP tenderization (Solomon *et al*. 1999b). O'Rourke *et al*. (1999) studied the effect of muscle fiber orientation when HDP was applied to beef ST muscle (horizontal versus vertical), and found somewhat different proteolytic profiles using electrophoresis as a result of

fiber orientation during HDP and reported that horizontally oriented samples were significantly more tender ($P < 0.05$) than vertically oriented ones.

Acceptable beef tenderness (*longissimus dorsi*) to the consumer has been determined to be less than 4.6 kgf (Warner–Bratzler Shear) (Shackelford *et al*. 1991). Brooks *et al*. (2000) reported in the 1998 National Beef Tenderness Survey that 26.6% of ST retail steaks were tougher than 4.6 kgf. This survey concluded that retail cuts from the beef round were inconsistent and reduced tenderness, which need improvement. Kuber *et al*. (2004) concluded that post mortem processing technologies and/or cookery methods may be more necessary in improving ST tenderness than genetic selection alone.

For the current study, it was hypothesized that fitting a steel (weld cap) reflector bowl inside the PEC would mimic the hemispherical shape of the bottom of the CSU and LSU. The objective of this study was to determine the tenderization effect of HDP on beef ST muscles using a steel reflector bowl inside a plastic explosive container.

MATERIALS AND METHODS

Meat Preparation

Fourteen fresh ST muscles (Canada Grade A) were purchased from Better Beef Ltd., Guelph, Canada. At 6 d postmortem, each ST muscle was divided into two 15-cm sections, distal and proximal and then randomly assigned to control (C) or HDP-treated (HDP). The sections designated for HDP were individually vacuum-packaged in 8-mil multilayer barrier boneguard bags (B650TBGW, Cryovac/Sealed Air Corp., Duncan, SC) and heat shrunk (approximately 2 s at 88C) to eliminate air pockets.

HDP Treatment

A 38.6-cm-wide, 18.0-cm-tall and 1.5-cm-thick steel reflector bowl (weld cap) was fitted to the inside bottom of the PEC. Two 15-cm-thick ST sections designated for HDP treatment were placed (muscle fibers oriented horizontally to the bottom of the steel reflector bowl) inside a suspended 98-L plastic explosive container (Rubbermaid, Inc., Wooster, OH) and filled with water (6.2C). A 150-g rectangular-shaped binary explosive was suspended 31 cm above the meat and detonated to create the shock wave treatment. Two ST sections were treated at the same time during HDP treatment. All seven HDP treatments were performed on the same day. Control (non-HDP-treated) sections were kept chilled in a cooler (3C) while designated sections were treated with HDP.

Cooking Method

Immediately after HDP treatment, a 3.2-cm-thick steak was removed from each HDP and C sections for instrumental tenderness analysis. HDP and C steaks were chilled (3C) for 30 min before cooking on a preheated (10 min) electric grill set on maximum heat setting between 260 and 290C (Indoor/Outdoor model GGR50B, Salton, Mount Prospect, IL). The steaks were cooked according to the American Meat Science Association (AMSA 1995) guidelines, with the internal temperature monitored using iron/constantan Type J thermocouples (Omega Engineering, Inc., Stamford, CT) attached to a Honeywell Progeny RSX Video Recorder (Honeywell, Freeport, IL). The steaks were turned once when the internal temperature was halfway between the initial and final (71C) cooking temperature. During cooking, the grill was covered with the vented dome lid supplied with the grill. Cooking time and loss were recorded for each steak. After cooking, the steaks were covered with plastic wrap, cooled at room temperature for 2 h and then refrigerated overnight (3C).

Shear Force Determination

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

Statistical Analysis

Cooking times, percent cooking loss and Warner–Bratzler shear force values were analyzed using SAS (Version 8.2, SAS Institute Inc., Cary, NC, 2001–02) Proc general linear model with a model that included individual sample identification as a random effect. Least square means were calculated for each treatment and separated using pairwise *t*-tests (LSMEANS/DIFFS option).

RESULTS AND DISCUSSION

No differences were observed in cooking time and loss for control and HDP-treated ST steaks (Table 1). In previous research with HDP using PEC for beef and pork, there was no significant difference in cooking times observed because of HDP compared to controls (pers. comm., Janet Eastridge

TABLE 1.
EFFECT OF HYDRODYNAMIC PRESSURE (HDP) PROCESSING TREATMENT ON THE COOKING PROPERTIES AND WARNER–BRATZLER SHEAR FORCE OF BEEF *SEMITENDINOSUS* STEAKS COOKED TO 71C

	Control	HDP	Standard error	Significance
Cook time (min)	22.16	22.48	0.72	NS
Cook loss (%)	30.32	30.54	0.72	NS
Warner–Bratzler shear force (kgf)	5.74	5.37	0.11	$P < 0.05$

NS, not significant.

and Ernest Paroczay, U.S. Department of Agriculture, Agricultural Research Service). Schilling *et al*. (2002) reported that cook loss was not affected by HDP treatment (CSU vessel) of beef *biceps femoris* steaks.

In this study, ST muscles HDP-treated in a PEC with the steel reflector bowl were statistically more tender ($P < 0.05$) than the control samples (5.37 versus 5.74 kgf) (Table 1). The overall tenderness improvement for HDP-treated ST muscles was 5.3%. Arbitrarily, we define the success of HDP as a treatment that results in greater than 10% tenderness improvement of muscles. Although the tenderness improvement of the ST muscles was slight, the individual ST response to treatment was highly variable for HDP (–8.6 to 24.5%) (Fig. 1). Five out of 14 of the HDP-treated muscles improved in tenderness (>10%) and four were nonresponders (<0%) to the HDP treatment. Even though the ST muscles varied in tenderness response to HDP, more than half of the muscles had a positive tenderness improvement (1.2–24.5%) as a result of HDP treatment. Why some meat samples do not respond or vary in tenderness improvement related to HDP treatment is not fully understood. The magnitude of tenderness improvement not only depends on the physiological differences between the animals and their muscles, but also is affected by HDP shock wave processing parameters (Solomon *et al*. 2005).

One of the factors affecting the magnitude of tenderization may be the location within the ST muscle. ST muscles are highly variable in tenderness because of the location within the muscle (Reuter *et al*. 2002). Eastridge *et al*. (2001) reported that the ST proximal end responded less to HDP (PEC) than the distal end (10.9 versus 27.3% tenderness improvement, respectively). In this experiment, HDP treatment was randomly assigned to the ST; however, the location (proximal and distal sections) was not recorded. When examining the response of ST muscles by HDP treatment (two ST muscles/treatment), the tenderness improvement was always less for one of the muscles. It is possible that sections that had smaller tenderness improvements were from the distal end of the ST.

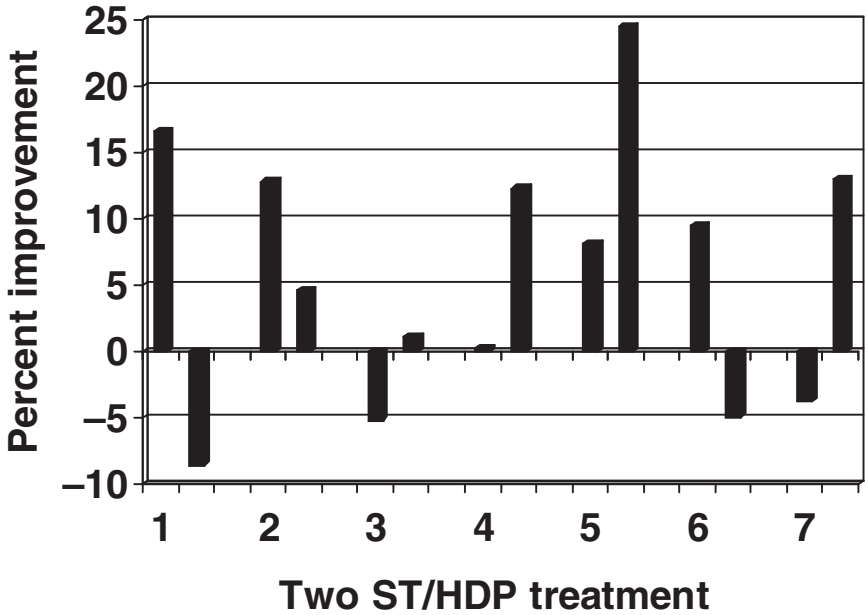

FIG. 1. *SEMITENDINOSUS* (ST) RESPONSE (TENDERNESS IMPROVEMENT) TO HYDRODYNAMIC PRESSURE (HDP) PROCESSING BY TREATMENT
ST were randomly assigned to HDP process (treatments 1–7). Seven HDP treatments occurred in 1 day. Location within muscle (distal and proximal) were randomly assigned.

The position of the muscle fibers in relation to the explosive charge has been shown to affect the amount of tenderness improvement of ST muscles. O'Rourke *et al*. (1999) studied the muscle fiber orientation of beef ST and concluded that the horizontal positioning of the muscle fibers in the CSU yielded greater tenderization results than vertical positioning (24 versus 16%, respectively). Another study by Solomon *et al*. (1999b) also reported that the horizontal position of the ST muscle fibers during HDP (CSU) increased the magnitude of tenderization (23%). Marriott *et al*. (2001) concluded that the magnitude of tenderization of beef *longissimus* may be affected not only by animal-to-animal variation, but the position and placement of meat inside the explosive vessel during HDP treatment could also have an effect. In this study, the muscle fiber orientation was maintained as horizontal to the explosive in order to maximize the tenderization effect of the HDP treatment.

Early HDP studies on a variety of beef muscles (Solomon 1998) conducted in the CSU showed beef tenderness improvements in the range of 37–57% for hot boned/cold shortened *longissimus* muscles. In later studies with the CSU, tenderness improvements were less with 24% improvement in beef ST

(O'Rourke *et al*. 1999) and 20% improvement in beef *biceps femoris* (Schilling *et al*. 2002). One possible explanation for these differences in tenderness improvement may be that the number of shock absorbers (suspension supports) were different in the aforementioned referenced studies of the CSU. Solomon and Eastridge (1999) observed that the magnitude of tenderization decreased with each additional CSU shock absorber modification that increased the shock absorbers initially from four to a final number of 16. Compared to the LSU unit, the PEC with a flat reflector plate was more effective in improving beef tenderness according to Solomon and Berry (2000). In that study, beef strip loins treated with HDP in the PEC had a greater tenderness improvement than those treated in the LSU (40 versus 28%). These studies suggest that HDP treatments using a PEC with flat reflector plate improved meat tenderness more than the CSU and LSU explosive vessels. The tenderness improvement observed in this present study using the PEC with the steel reflector bowl were less than those studies using PEC with flat plate, CSU or LSU.

Spanier *et al*. (2000) studied the effect of HDP using the 5-cm-tall steel collared flat plate placed inside a PEC. The PEC was either suspended 23 cm above the floor or placed directly on a Styrofoam-padded base. Beef strip loin tenderness was improved 40.2% when the PEC was suspended in air compared to 21.0% improvement when the PEC was placed onto the padded base. Regardless of PEC position, the steel collared flat plate effectively improved strip loin tenderness. The difference in tenderness improvement using the 5-cm collared reflector plate compared to using the reflector bowl from this study could be attributed to the height of the wall (5 versus 18 cm, respectively) and the shape of the bottom of the reflector plate.

The small overall tenderness improvement of HDP-treated ST muscles did not meet the minimum criteria for success, which was defined as at least 10% improvement in tenderness. A highly variable response to HDP tenderization was obtained using a PEC with a reflector bowl. Recent studies have shown that HDP may not always have instantaneous results; but the combination of HDP and aging improved beef tenderness more than aging alone (Paroczay *et al*. 2002; Solomon *et al*. 2002). Because of the ST size, not enough steaks could be obtained to assess the HDP tenderizing effect during aging in this study. Using the reflector bowl for HDP does not appear to be an efficient method to tenderize beef ST muscles.

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