VARIATION IN THE TENDERNESS OF BEEF STRIP LOINS AND IMPROVEMENT IN TENDERNESS BY USE OF HYDRODYNAMIC PRESSURE PROCESSING (HDP)[1]

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ABSTRACT

Shear force (SF) in 71C broiled steaks was compared along the length of beef strip loins (LM) and between medial and lateral (M&L) portions of individual steaks. A high degree of variation in SF (mean range of 3 kg) existed within individual steaks along the length of the LM. No difference in SF was observed between M&L sections of individual 2.54 cm steaks along the LM. Hydrodynamic pressure (HDP) treatment was employed on the LM to determine if variation in SF could be reduced. HDP treatment led to both a decrease in variation and an improvement in tenderness for both the M&L portions of the steak (within steak) and along the entire LM (within LM). These data show inconsistency in tenderness both along the LM and within each LM steak of control steaks. Furthermore, these data suggest that HDP can increase tenderness and reduce tenderness variation.

INTRODUCTION

Tenderness ranks among the first quality criteria a consumer considers when making a purchase decision for a cut of meat. Of the organoleptic properties of meat, tenderness has proven to be the most difficult quality factor for meat

[1]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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producers and meat packers to manage (Alsmeyer *et al.* 1965a; Morgan *et al.* 1991; Shackelford *et al.* 1997). The variation is due not only to factors such as the age, breed, sex, muscle cut, feeding regimen, method of slaughter, etc. (Dransfield 1998; Goll *et al.* 1997; Morgan *et al.* 1991), but also to the complex biochemical changes and interactions that occur during the conversion of muscle to edible meat (Asghar and Pearson 1980; Faustman 1994; Valin and Ouali 1992). This inconsistency and variation is seen not only among breeds of the same species, but also within the same cut in a given breed, and has been identified as a major problem facing the meat industry (Morgan *et al.* 1991). For example, Wheeler *et al.* (1996) and others have reported that location of steaks within the longissimus (lumbar region) did not affect tenderness; however, other studies have indicated that the cranial end (Martin *et al.* 1970), the caudal end (Ramsbottom *et al.* 1945), or the 12^{th} rib location of the longissimus (Smith *et al.* 1969) were more tender than other sections of the longissimus.

Within the last decade, a pressure-based technology, hydrodynamic pressure processing (HDP; high pressure shock waves for an extremely short time interval) has emerged as a potential method for tenderizing meat and has been discussed in detail elsewhere (Solomon 1998; Solomon *et al.* 1997; Zuckerman and Solomon 1998). Briefly, 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 with the water (Solomon 1998). The HDP process has been shown to contribute as much as a 66% improvement in tenderness of boneless strip loins with 100 g of explosive (Solomon *et al.* 1997). The objectives of this current investigation were to (1) determine the degree of variation in tenderness along the length of and within individual steaks of strip loins and (2) utilize HDP treatment to decrease or minimize this variation.

MATERIALS AND METHODS

Meat (Source and Handling)

Twelve boneless, U.S. Select grade, strip loin (*longissimus muscle*, LM) pairs (left and right sides) were received within 6 days after slaughter from a local beef packing facility. Upon delivery, a 2.54 cm thick steak was removed from the anterior (rib) end of each LM. These steaks were cooked, cored, and the shear force was determined to serve as an indicator of the initial tenderness of the LM. Only those strip loins having an initial screening shear force value (kg) of 6.0 or higher were used for this study since continued storage/aging leads to a decrease in shear force values or enhancement in tenderness (Staab *et al.* 1999). Determination of the screening shear force typically occurred within 24 h prior to examination or treatment in order to minimize storage-dependent changes in tenderness.

Hydrodynamic Pressure (HDP) Treatment

Individual strip loins were packaged to prevent water or residue incursion into the strip loin during the HDP treatment since this technique involves immersing the samples in the same water as the explosive charge. Each strip loin was first individually packaged in a polyolefin resin bag (Cryovac®/Sealed Air Corporation, Saddle Brook, N.J.); this single packaged strip loin was then inserted into a "bone guard" plastic bag (Cryovac® /Sealed Air Corporation, Saddle Brook, N.J.) to serve as the final outer packaging. Each layer of bag was heat shrunk around the strip loins after vacuum packaging to minimize the presence of air pockets. Processing of whole strip loins by hydrodynamic shock wave technology was performed using a 98.4 L Rubbermaid® plastic explosive container (PEC; Rubbermaid Incorporated, Wooster, Ohio) raised 23 cm above the floor of our treatment facility by either (a) four ropes tied to the container's handles ensuring that the vessel was surrounded by an air-interface or (b) by mimicking an air-boundary by placing Styrofoam® padding under the PEC.

An individual packaged strip loin was placed on top of a 1.25 cm thick, 40.6 cm diameter, 5.0 cm collared, steel plate. The strip loin was secured in place on the steel plate by wrapping with elastic cargo netting. Samples were placed into the PEC. Binary explosive (100 g mixture) was submerged in the PEC to 30.5 cm above the top of the strip loin (Solomon *et al.* 1997; Solomon 1998). After HDP-treatment the control and treated whole strip loins were sectioned into individual steaks 2.54 cm in thickness and were chilled to refrigerated temperature for cooking as described below. Individual steaks were labeled alphabetically going from the posterior to the anterior (rib) end of the strip loin. The total number of identification letters varied depending upon the length of the strip loin. All figures in this study go through the letter H representing the shortest strip loin in the study.

Cooking of all Samples

Cooking of all LM was performed using AMSA guidelines (1995). As described previously (Solomon 1998), strip loin sections were cooked using Farberware® Open-Hearth Broilers (Model T-4850, Hanson Corp., Bronx, N.Y.) to an internal end-point cooking temperature of 71C. Steaks were turned mid-way between the initial temperature and the final temperature of 71C. Internal meat-temperature was monitored using iron-constantan thermocouples attached to a SpeedomaxJ multipoint recording potentiometer (Model 1650, Leeds and Northrup, North Wales, Pa.). After cooking, steaks were allowed to cool to room temperature (~25C) and then covered with plastic wrap to chill overnight in a refrigerator before coring for shear-force determination.

Measurement of Shear Value

All coring and shear value determinations were performed following AMSA guidelines (1995). Six or more cores (1.27 cm diameter) were removed from both the medial and lateral portion of each 2.5 cm thick steak from each strip loin. Cores were removed parallel to the muscle fiber orientation. The epimysial connective tissue at its subcutaneous entrance into the strip loin was used as a marker for separating the lateral and medial sections of each steak. Each core from the control (C) or HDP strip loin steaks was sheared one time at right angles to the fiber orientation using a Warner-Bratzler shear test cell mounted on a Food Texture Corporation (FTC) tenderness measurement system (Model TMS-90, FTC, Chantilly, Va.) using a 3.18 mm thick flat bottom blade with an inverted V-shape to surround the core during cutting. The crosshead speed was set to 25 cm/min.

Statistical Analysis

After determination of the shear force value, the data were transcribed to a QuatroPro® spreadsheet (Corel® Office Professional 8, Ottawa, Ontario, Canada) for determination of mean, standard deviation, and standard error of the mean and for plotting graphically. Data were analyzed to determine the mean, standard deviation, and standard error of the mean of each section (medial or lateral) of successive anatomical location (steaks) within the strip loin obtained from each treatment group (C and HDP). Block transfer of the data was made from QuatroPro® to Sigma Plot® for subsequent regression analysis and for visualization by 2D line plot.

RESULTS AND DISCUSSION

Control (Untreated) Strip Loin Tenderness

Variation along the Strip Loin. Table 1 reflects the average high and low shear force values per individual steak from four individual strip loins (LM, longissimus muscle) as well as the mean for the four strip loins. The difference between high and low shear values in individual strip loins ranged from approximately 2 kg in one LM to almost 5 kg in another strip loin. Differences in high and low shear force values in individual strip loins was not significantly different in this study. However, statistical analysis of the average high and low shear force values of the four strip loins reveals that the difference in shear force along the LM (3.01 kg) is real ($P \geq 0.05$). This variation in shear value along the LM is depicted graphically in the plot of the data (Fig. 1) which shows a pattern similar to a rough topographical map filled with hills and valleys. This observed variation in shear force is similar to the variation in shear values for steaks

TABLE 1.
AVERAGE HIGH AND LOW SHEAR FORCE VALUES OF INDIVIDUAL STEAKS OBTAINED FROM ALONG THE LENGTH OF FOUR BEEF STRIP LOINS

Strip Loin	Shear Force (kg ± SD)[1]		Difference[2]	P[3]
	High	Low		
1	6.74 ± 2.34	4.86 ± 1.75	1.88	n. s. (≥ 0.50)
2	5.43 ± 3.61	2.71 ± 2.74	2.72	n. s. (≥ 0.50)
3	5.81 ± 2.59	4.33 ± 3.19	2.48	n. s. (≥ 0.60)
4	6.45 ± 4.21	1.51 ± 2.93	4.94	n. s. (≥ 0.25)
Column mean ± SD	6.11 ± 0.52	3.35 ± 1.33	3.01	≤ 0.05

[1]difference in shear force (kg) between steak with high and steak with low shear force value
[2]High and low shear force refer to the steak along the strip loin with the highest and lowest mean shear force. Shear force determined from a minimum of 6 cores in each steak along the length of a strip loin
[3]n.s. represents not significantly different at the level indicated

following 7, 14, and 28 days of aging reported by Staab *et al.* (1999). Thus, Fig. 1 shows the relative unevenness (or nonuniformity) of the shear values not only along the entire LM, but also between the shear values of the medial and lateral sections of individual LM steaks. This observation is opposite to that reported by Wheeler *et al.* (1996) who examined the shear force values of only the 5th, 11th, and 17th 2.5 cm thick steaks within the *longissimus thoracis et lumborum*. Only steak # 5 from their caudal (our posterior) end of the strip loin could be compared to our strip loin steaks and would match our steak labeled E (Fig. 1). Other studies have also shown that there is variation in shear value in different sections of the strip loin, i.e. in the caudal end (Ramsbottom *et al.* 1945), cranial end (Martin *et al.* 1970) or the 12th rib or medial section (Smith *et al.* 1969) of the LM. The variation observed in this current study seems to agree with Hansen's (1973) observation which demonstrated, through statistical analysis of shear data, that the frequency of the readings deviating from the mean was much greater than would be expected on assuming a strictly normal distribution. Since our present investigation paid particular attention to coring technique (AMSA 1995) and instrumental analysis for shear force, it is felt that the observed variation in tenderness (shear values) of control beef steaks is a result of some factors other than measurement of shear force. Many factors can affect final tenderness levels and are discussed elsewhere (Dransfield *et al.* 1980-81; Goll *et al.* 1997; Hansen 1973; Klont *et al.* 1998). Based on our data and the mixed results published in the literature, we conclude

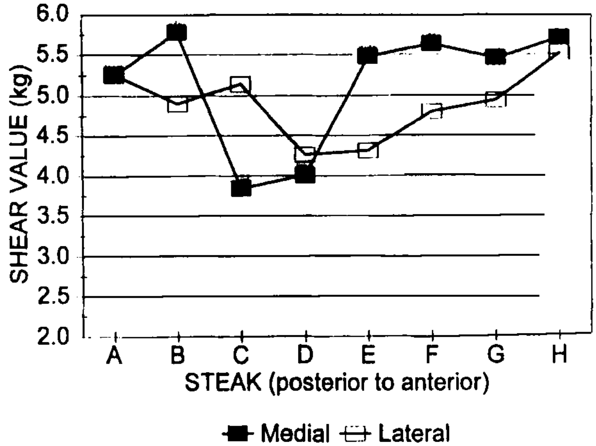

FIG. 1. SHEAR FORCE VALUES (KG) OF THE MEDIAL (CLOSED SQUARE) AND LATERAL (OPEN SQUARE) PORTION OF BEEF STRIP LOIN STEAKS

Each steak is lettered A - H representing the steak's position along the strip loin from the posterior to the anterior (rib) end, respectively. Each data point represents the mean tenderness value of six or more cores obtained from 2.54 cm thick steaks from four separate strip loins.

that there is a significant variation in the shear force in different regions of beef LM.

Variation Within Individual Steaks of the LM

The mean shear values (1) for the medial side of the strip loin, (2) from the lateral side of the strip loin, and (3) from an entire strip loin were determined by averaging the data from the medial and lateral sections of the 8 LM-steaks (A-H) comprising the 4 individual strip loins (Table 2). Student t-distribution indicated that no significant difference existed between medial and lateral sections of individual steaks (not shown) nor in their average along the entire strip loin (Table 2). Statistical P values for steaks having the greatest deviation in mean shear value was not greater than 0.50. However, a comparison of differences between medial and lateral sections of the strip loin indicated that the lateral portion of the steak showed slightly more variation (based on the greater SD) than the medial portion of the steak; this may be a result of some potential cold-shortening in the lateral section (Berry 1993; Berry and Leddy 1990; Smith *et al.* 1969) or due to minor differences in obtaining core samples of the medial and lateral portions of the strip loin which have been observed to have a different fiber orientation in these sections (Alsmeyer *et al.* 1965a, b).

TABLE 2.
SHEAR VALUE ALONG THE LENGTH OF CONTROL (NOT HDP-TREATED) STRIP LOINS

	Warner-Bratzler Shear (kg)		
Region of Strip Loin Steaks	Mean	SD	SEM
(*medial*)	5.13	0.77	0.34
(*lateral*)	4.99	1.14	0.51
(*whole* steak)	4.93	0.98	0.44

The variation for the medial and lateral portion of the LM followed no consistent pattern (Fig. 1). However, regression analysis showed that there appeared to be a very slight increase in shear value as one proceeded from the posterior end to the anterior (rib) end of the LM (slope of regression analysis for whole LM, medial section, and lateral section are 0.099 kg, 0.011 kg, and 0.023 kg, respectively). The low fit to linearity (r^2) determined from a regression analysis of the data plotting steak shear value against its location along the strip loin (not shown) lends support to the high degree of variation both in shear values along the total strip loin (r^2 = 0.0103) as well as in individual sections (medial section, r^2 = 0.1008; lateral section, r^2 = 0.0043).

Hydrodynamic Pressure Treatment of Strip Loins

PEC Seated on Styrofoam® Base. The shear force of the medial and lateral sides of steaks from HDP-Styrofoam® loins taken from along the length of the strip loin are shown in the plot in Fig. 2. The data show a more uniform appearance along [posterior to anterior (rib)] and across [medial and lateral section of steak] the entire strip loin of the HDP treated steaks. This suggests that the hydrodynamic pressure treatment improved the tenderness (lowered the shear value) along the entire strip loin when compared to the control or untreated strip loins. The average tenderness (shear value) per HDP steak was determined to be 5.04 kg ± 2.04 while the comparable control strip loin shear value averaged 6.38 kg ± 0.31 (Table 3). Only the A steaks from the posterior end of the strip loin showed a nonuniformity (lower shear value) with the remainder of the steaks in the LM (Fig. 2). This was thought to be a result of differences in the physics of the shock waves acting on the A steak and to a degree the B steaks) which were close to the 5 cm high steel collar on the supporting steel plate.

The shortest strip loins used in these experiments provided steaks through the H steak while the longest loins provided steaks through the L steak. Comparisons

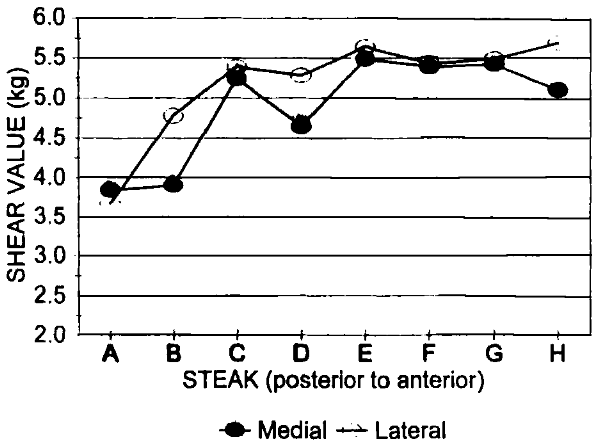

FIG. 2. SHEAR FORCE VALUES (KG) OF HDP-TREATED MEDIAL (CLOSED CIRCLE) AND LATERAL (OPEN CIRCLE) PORTIONS OF 2.54 CM THICK STEAKS FROM THE POSTERIOR REGION (A) OF THE STRIP LOIN TO THE ANTERIOR REGION (H) OF THE STRIP LOIN: SUSPENDED ON STYROFOAM®

Beef strip loins (n=2) were placed in a plastic, explosive-holding container (PEC) and the PEC seated above 23 cm of Styrofoam® for hydrodynamic pressure treatment. Selection of strip loins was based on a screening-control shear value of 6.0 kg or greater. Mean shear value for screening controls were 6.38 ± 0.31 kg (Table 3).

TABLE 3.
EFFECT OF DIFFERENT HDP-TREATMENTS ON THE SHEAR VALUE (KG) OF BEEF STRIP LOINS

GROUP	Control[1] (Shear Value, kg)		HDP Strip Loins (Shear Value, kg)
STYROFOAM (n^2 = 2)			
Shear value (kg)	6.38 ± 0.31		5.04 ± 2.04
% Improvement in shear		21.0 %[3]	
AIR (n^2 = 3)			
Shear value (kg)	6.00 ± 0.15		3.59 ± 1.95
% Improvement in shear		40.2 %[4]	

[1]Control steaks were obtained from either the rib-end of the strip loin or from the D or E steak of matched pair samples (if available) 24 h prior to experimentation.

[2]Number of strip loins in group

[3]$P \leq 0.25$

[4]$P \leq 0.05$

of data could only be among data in all steaks or that reflecting the shortest strip loin. It should be noted that those strip loins whose steaks abutted the steel collar of the steal plate had a greater improvement in tenderness. Thus, the H steak of the longer strip loins did not abut against the steel color of the steel plate thereby not being affected as greatly (Fig. 2-4).

While HDP treatment on Styrofoam® appeared to equalize the tenderness across the length and width of the strip loin (Fig. 2), it only improved the tenderness an average of 21.0% (Table 3) over that of the nontreated control strip loins. However, even though the total improvement was 21% over the control it was not significantly different at $P \geq 0.25$ (Table 3).

PEC Suspended in Air by Plastic Ropes

In the event a Styrofoam® support platform for the PEC did not truly represent an air interface or boundary around the entire PEC, HDP treatment in the PEC was performed by suspending the entire PEC in air using four polyethylene ropes. As seen with the Styrofoam® (Fig. 2), HDP treatment of strip loins suspended in air (Fig. 3) made the level of tenderness (shear value) more uniform both along the length of the strip loin [posterior end to anterior (rib) end] and within each steak [medial and lateral section]. The average shear value for HDP treated steaks along the strip loin was 3.59 kg ± 1.95 with control steaks having a shear value of 6.0 kg ± 0.15 (Table 3). Unlike the strip loins suspended on the Styrofoam®, the strip loins in the PEC suspended in air showed a greater improvement in tenderness (40.2%) over the controls and a significant difference at $P \leq 0.05$.

Data in Fig. 4 summarize the effect of HDP treatments shown in Fig. 2 and 3. Examination of the data in Fig. 4 along with that in Table 3 indicate that HDP treatment of strip loins improved the overall tenderness of both HDP treated strip loin groups. Furthermore, the data indicate that HDP treatment of air-suspended strip loins demonstrate a greater improvement in tenderness than strip loins suspended on Styrofoam®. The greater improvement in the A steaks of both groups is thought to be a result of these steaks' proximity to the steel collar.

The mechanism of action of pressure treatment is suspected to be a result of a combination of factors involving both "direct" (physicochemical) and "indirect" (redistribution of tissue components with associated proteolysis) action of the pressure on meat proteins (Barbosa-Cánovas *et al.* 1977; Bouton *et al.* 1977; Cheftel and Culioli 1997; Locker and Wild 1984; Solomon 1998; Ueno *et al.* 1999; Zuckerman and Solomon 1998). Whatever the mechanism, HDP is known to have an effect on meat tenderness based on ultrastructural observations of tearing at the site of the Z-line, spreading and disruption of the I-band, and tearing in the A-band regions (Zuckerman and Solomon 1998). Whether HDP treatment causes a direct physicochemical effect on meat proteins or whether HDP treatment causes a secondary redistribution of structural and hydrolytic proteins or both is

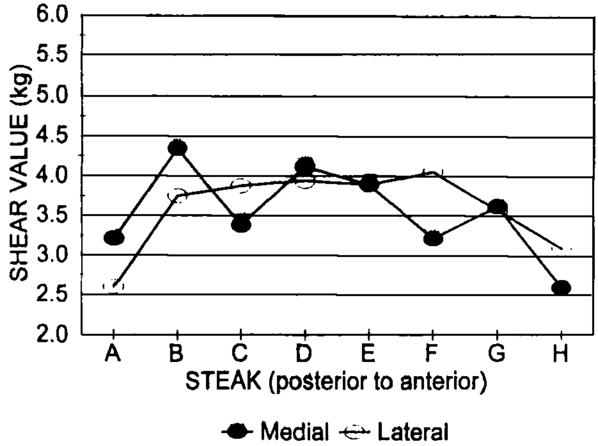

FIG. 3. SHEAR FORCE VALUES (KG) OF HDP-TREATED MEDIAL (CLOSED CIRCLE) AND LATERAL (OPEN CIRCLE) PORTIONS OF 2.54 CM THICK STEAKS FROM THE POSTERIOR REGION (A) OF THE STRIP LOIN TO THE ANTERIOR REGION (H) OF THE STRIP LOIN: SUSPENDED IN AIR

Strip loins (n=3) were placed in a plastic, explosive-holding container (PEC) and suspended in air for hydrodynamic pressure (HDP) treatment. Mean shear value for screening controls were 6.00 ± 0.15 kg (Table 3).

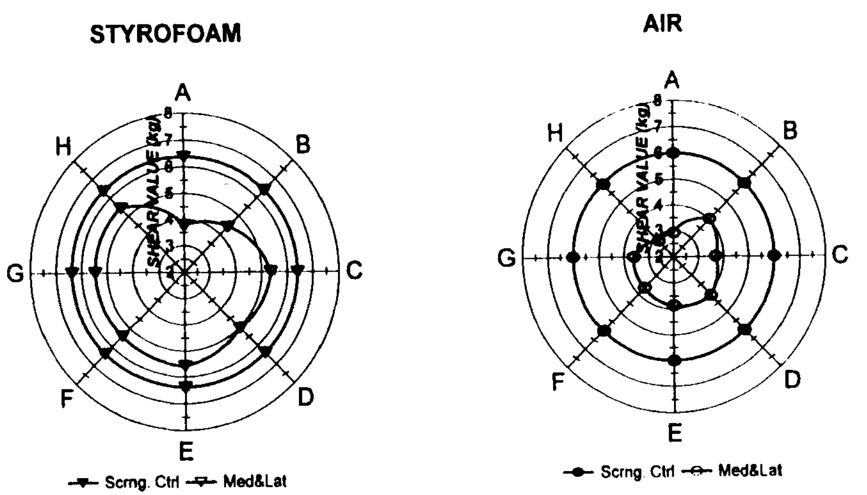

FIG. 4. TARGET PLOT SUMMARY OF MEAT TENDERNESS DATA (MEASURED AS SHEAR FORCE, KG) IN THE SCREENING CONTROLS* (CLOSED SYMBOLS) AND HDP-TREATED STRIP LOINS (OPEN SYMBOLS)

The plot on the left (inverted triangles) represents strip loins that were HDP-treated while the PEC was placed atop 23 cm of Styrofoam® (Fig. 2). The plot on the right (circles) represents strip loins that were HDP-treated with the PEC suspended in air by 4 ropes (Fig. 3). Each 2.54 cm steak from the beef strip loin was cut and labeled sequentially (A-H) beginning at the posterior end and working towards the anterior (rib) end of the loin. * represents data of coring of one screening steak per strip loin.

unknown at this time and is a matter of continuing investigation. However, we speculate that it is reasonable to suggest that HDP treatment may lead to an environment facilitating the activation and/or inhibition of the meat proteases similar perhaps to that seen in postmortem aging (Beaty *et al.* 1999; McDonagh *et al.* 1999; Ouali 1990; Spanier *et al.* 1997), in marinated beef (Ertbjerg *et al.* 1999), in electrically stimulated meat (Morton *et al.* 1999), or in vitamin E-deficiency induced myodegeneration (Bird *et al.* 1977, 1978).

SUMMARY

Strip loin steaks show a high degree of variation in shear force (a measure of tenderness) along the length of the strip loin (Fig. 1) with a possible negligible increase in shear force (decline in tenderness) as the steaks proceed from the posterior to the anterior (rib) end of the strip loin. Hydrodynamic pressure processing, HDP, not only makes the shear force (and thereby the tenderness) more uniform and less variable along the length of the strip loin, but also within individual strip loin steaks (Fig. 2 and 3). Further research is currently being performed to ensure that the process will become optimized, cost effective, and amenable to automation.

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