
S. T. Howard,*2 D. R. Woerner,* J. A. Scanga,† D. L. VanOverbeke,‡ G. G. Mafi,‡ J. L. Igo,* M. D. Salman,§ J. D. Tatum,* and K. E. Belk*3

*Center for Meat Safety and Quality, Colorado State University, Fort Collins 80523-1171; †Elanco Animal Health, Greenfield, IN 46140; ‡Department of Animal Science, Oklahoma State University, Stillwater 74078; and §Animal Population Health Institute, Colorado State University 80523-1164

ABSTRACT: Fifty-four stores in 30 U.S. cities were sampled from June 2011 through May 2012 to benchmark beef tenderness at retail, as assessed by Warner-Bratzler shear force (WBSF). Top loin (Longissimus dorsi; n = 980) and sirloin (Gluteus medius and Biceps femoris; n = 860) steaks were collected at random (Quality Grade and brand) and shipped via overnight delivery to Colorado State University. From June 2011 through November 2011, North American Beef Tenderness Survey (NABTS) Period 1, samples were shipped fresh and then frozen. Mean WBSF values during Period 1 were 2.9 and 3.5 kg for top loin and sirloin steaks, respectively. Frequencies of steaks classified as tough (WBSF ≥ 4.4 kg) were 8.6% and 17.7% for top loin and sirloin steaks, respectively. When shipped fresh, a disproportionately high frequency (16.9%) of top loin steaks had WBSF ≤ 2.0 kg, representing a deviation from previous works. Two trials were conducted to assess the effect of freezing, retail display, and shipping on WBSF and slice shear force (SSF) of beef top loin steaks. Freezing, retail display, and shipment reduced WBSF by 0.4, 0.3, and 0.0 kg during Trial 1, and by 0.4, 0.3, and 0.1 kg during Trial 2. Slice shear force was lower (P < 0.05) in steaks exposed to shipping conditions during Trial 1; however, this difference was not observed in Trial 2. Shipping decreased the frequency of steaks categorized as tough (SSF ≥ 20.0 kg) from 11.1 to 5.7% and from 30.5 to 28.6%, during Trial 1 and 2, respectively. During Trial 1, WBSF indicated that shipping increased incidence of tough samples from 0.0 to 3.8%, but this trend was reversed during Trial 2 when shipping reduced incidence of tough samples from 13.0 to 5.6%. Coefficients of variation for treatment effects suggested variance remained unchanged (±2.0%), with respect to shear force values. However, mean values were reduced as a result of shipping conditions. These findings dictated a change in NABTS protocol from December 2011 through May 2012 (Period 2), during which time samples were shipped frozen. Mean WBSF values were 3.4 and 4.0 kg for top loin and sirloin samples, respectively. Frequencies of steaks classified as tough were 14% and 23.5% for top loin and sirloin steaks, respectively. These findings suggest that freezing samples before shipment may influence shear force of steaks collected at the retail level. These data should be considered when evaluating beef tenderness surveys and in the design of future works.

Key words: beef, shear force, shipping and handling, tenderness survey


INTRODUCTION

Beef tenderness has been one of the most thoroughly investigated topics in the field of meat science. Summaries exist addressing preharvest influences (Tatum, 2006, Tatum et al., 2007), postharvest interventions (Smith et al., 2008), and prediction of beef tenderness (Woerner and Belk, 2008). Monitoring of beef tenderness has been achieved through national
surveys of retail locations (Morgan et al., 1991; George et al., 1999; Brooks et al., 2000; Voges et al., 2007; Savell, 2012). These works have demonstrated a trend for improved tenderness over time (Table 1). Despite this progress, the beef industry faces declining consumer demand (LMIC, 2013) in a marketplace that has demonstrated increased willingness to pay for more tender or guaranteed tender products (Boleman et al., 1997; Platter et al., 2005). This contrast necessitates evaluation of the systems used to determine acceptability of the tenderness of beef products at the consumer level.

Industry reliance on surveys to benchmark and monitor tenderness requires these works to be precise and accurate, while being able to quantify the effect of protocol on tenderness observations. The influence of freezing, thawing, cooking, and coring on Warner-Bratzler shear force (WBSF) has been examined by many workers (Parrish et al., 1973; Wheeler et al., 1994, 1996; Wulf et al., 1996, Shanks et al., 2002). Standardization of shear force protocol addresses a significant portion of potential variation among works. However, tenderness surveys require that all samples are exposed to shipping conditions before shear force determination, a practice that could be influential on tenderness observations. The effect of shipping and handling on shear force has never been quantified. The survey portion of this work was conducted to benchmark and monitor beef tenderness. Data generated for these purposes demonstrated the need to quantify the effect of shipping on WBSF and slice shear force (SSF) of beef top loin steaks.

**MATERIALS AND METHODS**

**Tenderness Survey**

Thirty-four cities in the United States and Canada were identified as potential sampling sites. Cities were selected within one of six geographic regions: Northeast, Southeast, Midwest, West, Texas, and Canada. Cities sampled were: Albuquerque, NM; Atlanta, GA; Billings, MT; Birmingham, AL; Boise, ID; Boston, MA; Charlotte, NC; Chicago, IL; Columbus, OH; Washington, DC; Des Moines, IA; Detroit, MI; Fayetteville, AR; Fort Collins, CO; Fort Worth, TX; Kansas City, KS; Las Vegas, NV; Los Angeles, CA; Miami, FL; Minneapolis, MN; Nashville, TN; New Orleans, LA; New York City, NY; Philadelphia, PA; Phoenix, AZ; Pittsburgh, PA; Portland, OR; Reno, NV; San Antonio, TX; San Francisco, CA; Seattle, WA; St. Louis, MO; Tampa Bay, FL; and Winnipeg, ON, Canada. Retailers in each city were identified based on regional market share (Supermarket News, 2011). Supermarket News was used to ensure representation of most major retailers in North America. Number of stores sampled per city was based on census data for the greater metropolitan area. A minimum of 2 retailers were sampled in all locations. Personnel from Elanco Animal Health were identified in each location and trained in sampling procedures. A minimum of 2 top loin (Longissimus dorsi) and 2 sirloin (Gluteus medius or Biceps femoris) steaks were collected at random (Quality Grade, brand, etc.) each month from each retail location. Some sirloin steaks were sold as “cap steaks,” which consisted of only the Biceps femoris. Cap steaks were included in survey data as sirloin steaks. Samples were collected over 12 months starting in June 2011 and ending in May 2012.

**Shipping and Handling**

Samples were transported from retail locations in polystyrene coolers containing ice packs. Two sizes of coolers (46 × 46 × 41 cm or 46 × 31 × 31 cm) were used, based on number of samples collected. Samples were shipped in materials used for retail display, stacked in the bottom of coolers with ice packs on top, or card stacked with ice packs in between. Within 24 h of purchase, samples were shipped via overnight air delivery to Colorado State University. During North American Beef Tenderness Survey (NABTS) Period 1 (June to November 2011), samples were shipped fresh from point of origin and frozen on arrival. This protocol was amended during NABTS Period 2 (December 2011 to May 2012), due to the effect of shipping on shear force. Methodology used to quantify this effect is described below. During NABTS Period 2, samples were frozen for 24 to 48 h in home refrigeration units before shipment. The change in protocol caused some cities to be removed from the survey.

**Table 1. Summary of sample population means for Warner-Bratzler shear force (WBSF) of top loin and sirloin samples from major tenderness surveys.**

<table>
<thead>
<tr>
<th></th>
<th>Top loin WBSF, kg</th>
<th>Sirloin WBSF, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>≥3.9 1</td>
</tr>
<tr>
<td>Morgan et al., 1991</td>
<td>3.25 4 to 21%2</td>
<td>3.56 4 to 21%2</td>
</tr>
<tr>
<td>George et al., 1999</td>
<td>1.91 to 3.19 13%</td>
<td>2.72 to 3.54 20.5%</td>
</tr>
<tr>
<td>Brooks et al., 2000</td>
<td>2.77 6.6%</td>
<td>3.04 11.0%</td>
</tr>
<tr>
<td>Voges et al., 2007</td>
<td>2.12 0.0%</td>
<td>2.50 0.0%</td>
</tr>
<tr>
<td>Savell, 2012</td>
<td>2.36 4.3%</td>
<td>2.45 2.2%</td>
</tr>
<tr>
<td>NABTS Period 1 2</td>
<td>2.87 15.0%</td>
<td>3.54 29.2%</td>
</tr>
<tr>
<td>NABTS Period 2 2</td>
<td>3.39 24.6%</td>
<td>4.00 53.5%</td>
</tr>
</tbody>
</table>

1WBSF ≥3.9 indicates samples predicted to be intermediate or tough, in terms of tenderness.

2Data separated by quality grade. Range represents inclusion of all grades analyzed.

from the survey, due to limitations associated with space in home refrigeration units. Period 1 included \( n = 586 \) top loin and \( n = 518 \) sirloin steaks, compared with \( n = 394 \) top loin and \( n = 342 \) sirloin steaks in Period 2.

**Receiving of Samples**

Samples were evaluated for temperature on arrival at Colorado State University. Samples unacceptable for temperature (NABTS Period 1: \( >7 \)°C, NABTS Period 2: \( >0 \)°C) were removed from the survey population. Packaging materials were cataloged and marketing claims, price, weight, store, and location were recorded. During NABTS Period 1, sample dimension data were taken on arrival. The freezing protocol used during NABTS Period 2 caused samples to swell. Consequently, dimensional data were collected immediately before shear force determination, after samples had been thawed. All samples were transferred from retail packaging, vacuum packaged, and frozen at \(-28.8 \)°C.

**Shear Force Determination**

Samples were thawed for 24 h at 4° C to a target precooking internal temperature of 1 to 3°C. Cooking was achieved using a GRP99 Next Generation Grill (Spectrum Brands Inc., Madison, WI). Samples were cooked to a target peak internal temperature of 71.1°C and allowed to cool to room temperature for 4 h before shear force determination. Warner-Bratzler shear force analysis was conducted on cores from the Longissimus dorsi of top loin steaks and Gluteus medius of sirloin steaks, except when the sirloin steak was collected as a cap steak and only the Biceps femoris was present. Warner-Bratzler shear force was conducted, according to the guidelines of AMSA (1995), on an Instron Universal Testing Machine, Model 4443 (Instron Corporation, Norwood, MA), with a cross-head speed of 200 mm/min.

**Trained Sensory Panel Evaluation**

Panelists (\( n = 10 \) per period) were trained for evaluation of 9 sensory attributes, including myofibrillar tenderness, connective tissue tenderness, overall tenderness, juiciness, beef flavor, buttery, metallic, livery, grassy, oxidized, saline, and soapy. Training was conducted using beef Longissimus dorsi, Biceps femoris, Gluteus medius, Infraspinatus, Semitendinosus, and Psoas major muscles. Flavor profile training was conducted using the standards published by Adhikari et al. (2011) and through use of steaks enhanced with saline solution. All samples remained frozen for at least 1 wk before the trained panel evaluation. Within each panel, top loin and sirloin steaks from adjacent months were represented. Thawing and cooking were conducted in a manner identical to that described for shear force determination. Samples were trimmed of external edges and connective tissue before being portioned into sensory samples (1.27 × 1.27 cm). Samples from top loin steaks that included a portion of the Gluteus medius (vein steaks) were only derived from portions of the Longissimus dorsi; sirloin samples were derived only from the Gluteus medius, when possible. Panelists were served two cubes under incandescent red lighting and provided with unsalted crackers, apple juice, and distilled water to cleanse the palate. Responses were marked on a 15-cm, unstructured, continuous line scale. Tenderness attributes, juiciness, and beef flavor were marked for all samples. Panelists had the option to write in up to three off-flavors from those described above and mark their presence on three additional 15-cm lines provided at the bottom of the ballot.

**Evaluation of the Effect of Shipping on Shear Force (Separate Study)**

Three cases of USDA low Choice strip loins were collected directly from the packaging line in a commercial processing facility in Colorado. Loins were removed from the box and transported on ice to Colorado State University. Upon arrival, loins were repackaged into the original boxes for aging at 4°C for 14 d from the box date. Eighteen loins were selected at random for fabrication into steaks. Each loin was divided into 3 sections (anterior, medial, and posterior), from which four 2.54-cm-thick steaks were cut. Steaks from within each section were randomly assigned to 1 of 4 treatments: 1) shear fresh, 2) shear following freezing, 3) display in a retail case for 68 h, freeze, and shear, 4) display in a retail case for 68 h, expose to either simulated shipping (Trial 1) or actual shipping (Trial 2), freeze, and shear. Steaks assigned to treatment 2, 3, and 4 were placed in polystyrene trays and overwrapped, using polyvinyl chloride packaging. Following packaging, steaks assigned to treatment 2 were frozen at \(-28.8 \)°C. Steaks assigned to treatments 3 and 4 were placed in coolers and transported on ice to an off-site location for retail display. Steaks were randomized in a 1.8-m-wide, 3-layer, fluorescently lit Hussmann (Hussmann Corporation, Bridgeton, MO) display case. During Trial 2, temperatures within the retail case were recorded every 10 min, using six Escort iLog Data Loggers (Escort Data Loggers, Inc., Buchanan, VA). However, light intensity was unable to be measured. In both trials, only the top two shelves of the case were used, due to sample numbers and the inability to appropriately fill all three layers in a manner similar to commercial retail displays. Following display, steaks were transported on ice to Colorado State University. Steaks assigned to treatment 3 were frozen immediately on arrival. During Trial 1, steaks assigned to treatment 4...
were placed randomly in polystyrene coolers (46 × 46 × 41 cm) with ice packs, boxed, and placed on the back of a cargo truck for 24 h to simulate shipping. During Trial 2, steaks assigned to treatment 4 were transferred directly from the retail case, randomly assigned to one of five polystyrene coolers (46 × 46 × 41 cm) containing ice packs, boxed, and shipped via overnight air delivery to Oklahoma State University. Head space in the coolers was filled with butcher paper and a temperature logger was fixed to the lid of the cooler. Upon arrival, samples were unpacked and frozen in a manner similar to that described above. Steaks remained frozen at Oklahoma State University for ~1 wk before return shipment to Colorado State University. Upon arrival, all samples were placed into storage at −28.8°C. Approximately 3 d later, samples from treatments 2, 3, and 4 were removed from overwrap packaging and vacuum packaged.

Shear Force Measurements

Thawing and cooking were conducted in a manner identical to that described above for NABTS samples. Slice and Warner-Bratzler shear force were conducted simultaneously on all steaks from anterior and medial sections, using methodology described by Lorenzen et al. (2010). Steaks from posterior sections were assessed using WBSF only. Warner-Bratzler shear force analysis was conducted according to the guidelines of AMSA (1995). All tests were conducted on an Instron Universal Testing Machine, Model 4443 (Instron Corporation, Norwood, MA). Warner-Bratzler shear force testing used a cross-head speed of 200 mm/min; SSF determination was conducted with a cross-head speed of 500 mm/min.

Statistical Methods

Statistical analysis was conducted using SAS v. 9.3 (SAS Inst. Inc., Cary, NC). Summary statistics were compiled using the MEANS and FREQ (SAS) procedures. Regression of panel responses against WBSF values was conducted to determine panel responses correlated to tenderness thresholds of 4.4 kg (Platter et al., 2005; ASTM, 2011). During NABTS Period 1, this value was 7.5 cm. During NABTS Period 2, this value was 8.1 cm. Normality of shear force data was determined using the W-statistic and through evaluation of a plot of residuals. Main effects and interactions were tested in mixed models (PROC MIXED, SAS) that contained the fixed effect of treatment and the random effects of individual loin and loin section (anterior, medial, posterior). General mixed linear models (PROC GLIMMIX, SAS) that had identical fixed and random effects to those summarized above were used to find the probability of tough steaks as a result of treatment. Denominator degrees of freedom were calculated using the Kenward-Roger approximation (Kenward and Roger, 1997) and means were separated using pairwise t tests and a significance level of 0.05.

RESULTS AND DISCUSSION

North American Beef Tenderness Survey Results—Period 1

Mean WBSF values from NABTS are presented in Table 1. Top loin steak WBSF data are most similar to the findings of Brooks et al. (2000), whereas sirloin steak data are most comparable with the results of Morgan et al. (1991) and George et al. (1999). Comparisons between survey data may or may not be valid due to variations in protocol between many of the aforementioned works. The protocol of Morgan et al. (1991) used a target internal temperature of 65°C, compared with all other works that used target peak internal temperatures of ~70°C. Brooks et al. (2000) wrapped steaks in plastic film immediately following cooking while tempering at 4°C for 10 h before WBSF determination. This tempering procedure contrasts with 4 h at room temperature used by Voges et al. (2007) and the present work.

Frequencies of WBSF observations ≥3.9 kg are reported in Table 1. The threshold of WBSF ≥3.9 kg allowed comparison among major tenderness surveys, as all works reported frequencies above and below this mark. Data from NABTS Period 1 are in general agreement with those of George et al. (1999) but had a higher incidence of steaks with WBSF ≥3.9 kg compared with other national beef tenderness surveys (Brooks et al., 2000; Voges et al., 2007; Savell, 2012). Sirloin steak data had a frequency of samples categorized as intermediate or tough that was 10% higher than any previous survey. Frequency distributions for WBSF of top loin and sirloin steaks by period are presented in Fig. 1 and Fig. 2, respectively. Top loin (Longissimus dorsi) steak shear force data from NABTS Period 1 demonstrated a heavy right-hand skew with a high number of observations <2.0 kg. This represented significant deviation from previous works that used similar shear force protocols to this study (Platter et al., 2005; Gruber et al., 2006). These observations were noted in the first 3 mo of data collection, prompting exploration of the effect of shipping on WBSF values. An informal study conducted from September 2011 to November 2011 demonstrated an approximate increase of 0.5 kg in WBSF of samples shipped frozen versus those shipped fresh (unpublished data). During NABTS Period 2, samples were shipped frozen from point of origin. A formalized experiment was conducted to quantify the effect of shipping on shear force observations; this work is summarized below.
North American Beef Tenderness Survey—Period 2

Means for WBSF data from NABTS Period 2 are reported in Table 1. The difference in WBSF data between NABTS Period 1 and Period 2 (~0.5 kg) was nearly identical to that difference observed in informal work. Top loin and sirloin sample populations had higher mean WBSF values than had been observed in any previous U.S. beef tenderness survey. Means for WBSF of top loin steaks from NABTS Period 2 were more similar to the findings of multiple nonsurvey-based works from a variety of institutions. Workers have reported mean WBSF values for top loin steaks between 2.6 and 4.4 kg, at either 14 or 21 d postmortem, when samples were sourced from a variety of Quality Grades (Shackelford et al., 1995; Belew et al., 2003; Lorenzen et al., 2003; Platter et al., 2005). Top loin steaks shipped frozen (NABTS Period 2) displayed a frequency distribution for WBSF that was more similar to that observed by Platter et al. (2005). North American Beef Tenderness Survey data from Period 2 found mean WBSF = 4.0 kg for sirloin steaks, which was ±0.5 kg from those means published by Shackelford et al. (1995) and Belew et al. (2003). When compared with the work of Gruber et al. (2006), who evaluated WBSF of fresh steaks, NABTS Period 2 means should be ~0.5 kg less, which would roughly correspond to the effect of freezing demonstrated by Shanks et al. (2002). The postmortem age of samples in tenderness surveys is substantially more variable than those in the aforementioned studies. However, the most recent National Beef Tenderness Survey published a mean aging time of 21.6 d for top loin steaks, with a trend for more cuts at retail to be <14 d postmortem, relative to 2005 to 2006 National Beef Tenderness Survey data (Voges et al., 2007; Savell, 2012), indicating comparisons to works using 14- and 21-d aging times may be acceptable.

North American Beef Tenderness Survey—Panel Data

Means for panel responses by period are reported in Table 2. All panelists were trained. However, experience of panelists during Period 1 was ~3 to 5 yr, compared with 1 to 3 yr during Period 2. Correlation coefficients

Table 2. Means (SD) for trained sensory panel ratings for beef top loin and sirloin steaks collected at retail locations across the United States

<table>
<thead>
<tr>
<th>Period</th>
<th>Cut</th>
<th>n</th>
<th>Overall tenderness</th>
<th>Myofibrillar tenderness</th>
<th>Connective tissue</th>
<th>Juiciness</th>
<th>Beef flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top loin</td>
<td>272</td>
<td>9.3 (1.9)</td>
<td>9.4 (2.0)</td>
<td>9.4 (2.0)</td>
<td>7.6 (1.5)</td>
<td>8.5 (1.3)</td>
</tr>
<tr>
<td></td>
<td>Sirloin</td>
<td>230</td>
<td>8.2 (1.9)</td>
<td>8.4 (1.8)</td>
<td>8.2 (1.9)</td>
<td>7.5 (1.6)</td>
<td>7.8 (1.2)</td>
</tr>
<tr>
<td>2</td>
<td>Top loin</td>
<td>191</td>
<td>9.3 (1.6)</td>
<td>9.4 (1.5)</td>
<td>9.4 (1.7)</td>
<td>7.5 (1.3)</td>
<td>7.6 (1.3)</td>
</tr>
<tr>
<td></td>
<td>Sirloin</td>
<td>169</td>
<td>8.6 (1.6)</td>
<td>8.9 (1.5)</td>
<td>8.6 (1.7)</td>
<td>7.5 (1.3)</td>
<td>7.1 (1.1)</td>
</tr>
</tbody>
</table>

1Ratings generated on a 15-cm line scale, with 0 = extremely undesirable and 15 = extremely desirable for each attribute.
2June 2011 through November 2011. Samples shipped fresh and frozen on arrival.
3December 2011 through May 2012. Samples shipped frozen.
between WBSF and overall tenderness ratings were −0.55 and −0.45 during NABTS Period 1 for top loin and sirloin steaks, respectively. This compared with −0.42 and −0.45 during NABTS Period 2 for top loin and sirloin steaks, respectively. During NABTS Period 2, WBSF determined 14.3% of top loin samples to be tough (WBSF ≥4.4 kg; Fig. 1). Sensory panel data from NABTS Period 2 found 20.3% of top loin steaks to have mean overall tenderness ratings <8.1 cm, which was approximately equal to 4.4 kg of WBSF as determined by regression analysis. Period 1 data found that 8.1% and 15.4% of top loin steaks were tough, based on WBSF and trained sensory panel determination, respectively (WBSF ≥4.4 kg; Fig. 1). Trained panel responses correlating to 4.4 kg of WBSF that were found approximately half the distance across the 15-cm line scale seem appropriate, as the designation of “slightly tough” has been reported halfway between 1 and 8 on hedonic systems used in trained panels during previous tenderness surveys (Morgan et al., 1991; George et al., 1999).

Effect of Shipping and Handling on Shear Force—Trial 1

Freezing, retail display, and simulated shipping reduced shear force values by varying magnitudes, depending on measurement (WBSF vs. SSF; Table 3). Freezing resulted in lower WBSF values (P < 0.05), which agrees with the findings of Shanks et al. (2002). Differences in WBSF were observed as a result of retail display (P < 0.05); however, no difference in WBSF was found as a result of simulated shipping (P > 0.05). This was contrasted by SSF data, in which the only difference was served tough samples. Slice shear force data showed a trend for the probability of less than tender samples (SSF ≥20.0 kg) to decrease as samples were frozen, displayed, and exposed to simulated shipping. Generally speaking, the sample population in Trial 1 was relatively tender. Warner-Bratzler shear force and SSF measurements may have plateaued on the extreme low end, making differentiation of the effect of simulated shipping on shear force more challenging. The results

### Table 3. Warner-Bratzler shear force (WBSF), slice shear force (SSF), frequency, and probability (P) ± standard error of low Choice top loin steaks failing to be certified as tender (WBSF ≥ 4.4 kg, SSF ≥ 20 kg) after different sample handling protocols.

| Trait | Treatment | SEM | P<sub>TRT</sub>|<sup>2</sup> |
|-------|-----------|-----|------------------|
|       | Shear fresh | Freeze/shear | Display/shear | Shipped |       |
| 1     | WBSF, kg   | 3.6<sup>a</sup> | 3.2<sup>b</sup> | 2.9<sup>c</sup> | 2.9<sup>d</sup> | 0.2 | <0.0001 |
|       | SSF, kg    | 16.2<sup>a</sup> | 16.0<sup>a</sup> | 15.9<sup>a</sup> | 14.7<sup>b</sup> | 0.9 | 0.0480 |
|       | WBSF ≥ 4.4 kg, % | 20.4 | 11.1 | 0.0 | 3.8 | – | – |
|       | SSF ≥ 20 kg, % | 19.4 | 13.9 | 11.1 | 5.7 | – | – |
|       | (P) WBSF ≥ 4.4 kg<sup>3</sup> | – | – | – | – | – | – |
|       | (P) SSF ≥ 20 kg<sup>3</sup> | 0.14 ± 0.08 | 0.09 ± 0.06 | 0.06 ± 0.05 | 0.03 ± 0.02 | – | 0.2757 |
| 2     | WBSF, kg   | 4.2<sup>a</sup> | 3.8<sup>b</sup> | 3.5<sup>c</sup> | 3.4<sup>c</sup> | 0.1 | <0.0001 |
|       | SSF, kg    | 19.2 | 18.5 | 18.6 | 18.3 | 0.5 | 0.4594 |
|       | WBSF ≥ 4.4 kg, % | 31.5 | 22.2 | 13.0 | 5.6 | – | – |
|       | SSF ≥ 20 kg, % | 36.1 | 36.1 | 30.5 | 28.6 | – | – |
|       | (P) WBSF ≥ 4.4 kg<sup>3</sup> | 0.23 ± 0.20<sup>a</sup> | 0.12 ± 0.12<sup>ab</sup> | 0.05 ± 0.06<sup>b</sup> | 0.02 ± 0.02<sup>c</sup> | – | 0.0012 |
|       | (P) SSF ≥ 20 kg<sup>3</sup> | 0.34 ± 0.13 | 0.34 ± 0.13 | 0.28 ± 0.11 | 0.27 ± 0.11 | – | 0.8698 |

<sup>a</sup>Means within a row lacking a common letter superscript differ (P < 0.05).

<sup>1</sup>Steaks aged 14 d, then sheared fresh, overwrapped, and frozen then sheared (freeze/shear), overwrapped displayed 68 h in retail case then sheared (display/shear) or displayed 68 h and exposed to shipping conditions. Trial 1 simulated shipping; samples placed on cargo truck for 24 h. Trial 2 samples shipped from Fort Collins, CO, to Stillwater, OK, via overnight air delivery.

<sup>2</sup>P<sub>TRT</sub> = Probability of difference between treatment means occurring when, in fact, no difference existed.

<sup>3</sup>Estimates could not be separated due to frequency of zero within display/shear treatment.

<sup>4</sup>Standard error of mean varies, based on magnitude of the estimate. Comparison of SE between treatments is not appropriate.
of Trial 1 indicated trends for reduced shear force values as a result of increased sample handling. Trial 2 was conducted to evaluate the effect of actual shipping conditions on shear force values.

**Effect of Shipping and Handling on Shear Force – Trial 2**

Temperatures recorded from inside the lid of coolers during shipment in Trial 2 had a range of 6.6°C between coolers, which represented potential for tenderness survey samples to be exposed to conditions that are likely deleterious to accurately reflecting tenderness at the retail level. Data from Trial 2 displayed similar trends to those in Trial 1 (Table 3). The reduction in mean shear force values of samples sheared fresh compared with those sheared following freezing, and those exposed to retail display was nearly identical between Trials 1 and 2. Samples exposed to shipping conditions during Trial 2 tended to produce lower WBSF values than those samples frozen immediately following display ($P = 0.22$). The frequency of tough samples within the sample population was reduced from an initial incidence of >30% to ~5% and >36% to nearly 28%, as determined by WBSF and SSF, respectively (Table 3).

**Conclusions**

Incidence of samples failing to meet shear force requirements to be certified as tender is likely reduced by shipping samples fresh. Shipping clearly represents an opportunity for tenderness survey samples to be exposed to adverse conditions that influence shear force measurement in a manner that less accurately reflects tenderness at retail. A frozen sample may be more tolerant to extreme temperature conditions during shipment, simply because it takes substantially longer to heat up to a level that impacts accuracy of tenderness observations. Tenderness surveys are valuable tools that allow the beef industry to monitor sensory attributes of beef at the retail level. However, results of these works are heavily influenced by protocols used during data collection. Without consideration of the influence of shipping, handling, and shear force protocol, the conclusions drawn among these works may be compromised. This no doubt affects the ability of tenderness surveys to monitor improvement in beef tenderness over time. If tenderness surveys are to be relied on to monitor progress and improve beef consumer demand, standardization of protocol is necessary to allow for comparison among works. Data demonstrate that a standardized protocol should call for shipment of samples in a frozen state, since survey data for samples shipped frozen were in closer agreement with controlled studies that evaluated shear force of top loin and sirloin steaks. Currently, NABTS data are in closest agreement with those from the early and late 1990s. This could demonstrate lack of progress by the industry in the area of beef tenderness or a fundamental shift in factors influencing this trait. These data should be considered in the analysis and design of future beef tenderness surveys.

**LITERATURE CITED**


Tatum, J. D. 2006. Pre-harvest cattle management practices for enhancing beef tenderness. Executive summary prepared for the National Cattlemen’s Beef Association, Centennial, CO.


