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Round Muscle Profiling and Tenderness Markers in Beef

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Introduction

Lack of consistent tenderness is a major quality problem that significantly impacts the profitability of the beef industry. Conservative estimates indicate tenderness defects cost the beef industry over $216,000,000 annually (Morgan, 1995). Consumers rate tenderness as the top sensory trait considered when they are making purchasing decisions (Mennecke et al., 2007), and are willing to pay a premium in order to purchase a consistently tender product (Boleman et al., 1997; Miller et al., 2001; Platter et al., 2005).

The muscles of the round are particularly prone to being less tender than the higher value cuts of the strip loin and the rib. This generalization has historically limited the merchandizing of this wholesale cut. Recent muscle profiling data supported by The Beef Checkoff has documented the characteristics of many of these muscles, and several muscles appear promising to market as individual value cuts (NCBA, 2000). While the muscles of the round originate from a similar location, each has distinctly different fiber types and sensory properties (Kirchofer et al., 2002; McKeith et al., 1985). In addition to this, the muscles of the round traditionally have received similar treatment in regards to aging. Research examining differences in tenderness and rate of tenderization of these muscles provides insight into adding value to individual cuts from the round.

Historical Uses and Characteristics of the Beef Round

The round makes up a significant portion of the beef carcass. Depending on the style of cutting, it can make up anywhere between 22-25% of carcass weight or, to consider it in terms of the live animal, as much as 14-15% of live weight. The round is a diverse cut with a large number of muscles that vary in their eating characteristics. Most often, muscles of the round are merchandized as mixed-muscle roasts. Since many of the muscles contain relatively high amounts of connective tissue, moist heat is most commonly recommended as the cookery method of choice. Alternatively, many of the muscles are ground and sold as ground beef or ground round.

Key muscles

Top round, bottom round, knuckle, heel and shank are derived from the primal round. The top (also known as the inside) round contains primarily the *semimembranosus*, *sartorius*, *adductor*, *gracilis* and *pectineus* muscles. The major muscles in the bottom round (sometimes known as the gooseneck) are the *semitendinosus* and the *biceps femoris,* and depending on the cutting style, the bottom round may also contain the *gluteus medius*, *gluteus accessorius* and *gluteus profundus*. The knuckle contains primarily the *vastus intermedius*, *vastus lateralis*, *vastus medialis* and *rectus femoris*. It can also contain the *tensor fasciae lateae* and a portion of the *sartorius*.

Several of these muscles, especially the *gracilis*, *sartorius*, *vastus intermedius*, *adductor* and *semimembranosus*, may have merit to fabricate as individual cuts and be sold as steaks or value-added roasts. These muscles have several or all of the following traits that may make them desirable to consumers as whole-muscle products. They may have the capacity to tenderize with aging, and they may have desirable color, texture and/or flavor. The discussion that follows outlines major new findings with respect to the aging and palatability profiles of some of these key muscles.

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Major factors influencing tenderness

Biochemical differences in muscles of the round can explain much of the differences among them and will help point the way to developing new uses for these muscles. Variations in pH can alter the sensory characteristics of the product, including color, water-holding capacity, shear force and sensory juiciness (Bidner et al., 2004; Panea et al., 2008; Zhang et al., 2005).

Sensory/Physical Characteristics of the Muscles from the Beef Round

Sensory analysis

The *longissimus dorsi* (rib/loin) is generally accepted by consumers as a relatively tender muscle, and for this reason, it was chosen in this discussion as the muscle to which all other muscles were compared. If a muscle has attributes similar to the *longissimus dorsi,* then it might have the potential to be marketed as an individual cut and thus add value to the carcass. A comprehensive study characterizing the round muscles showed marked differences among the various round muscles the industry can capitalize on (Anderson et al., 2009; Anderson et al., 2007). Sensory analysis (Table 1) has shown that a number of differences exist among muscles. At one day postmortem, the *sartorius* was significantly more tender ($P < 0.05$) than the *longissimus dorsi*. At all other aging periods, the sensory tenderness scores of the *sartorius* were not different ($P > 0.05$) from the *longissimus dorsi*. Thus, the *sartorius* was more tender than the *longissimus dorsi* at early postmortem times. However, both muscles ultimately reached a similar sensory tenderness level by 14 days of aging. At all periods during aging, the sensory tenderness scores of the *vastus intermedius* and *gracilis* were not significantly different ($P > 0.05$) from the *longissimus dorsi*. The *vastus intermedius*, *gracilis* and *sartorius* had sensory tenderness characteristics similar to the *longissimus dorsi*, and may be suitable to market as individual cuts should the appropriate markets be identified.

At three and seven days postmortem, the *semimembranosus* and *vastus lateralis* were less tender ($P < 0.05$) than the *longissimus dorsi* (Anderson et al.,

Table 1. Sensory characteristics and star probe values of the longissimus dorsi and muscles of the round

	Day	LD	AD	GR	SAR	SM	VI	VL	SE[e]
Tenderness[f]	1d	5.50[ab]	5.07[a]	6.35[abc]	7.79[c]	4.99[a]	7.71[bc]	4.28[a]	0.80
	3d	7.52[bc]	5.57[ab]	6.62[abc]	8.01[c]	4.64[a]	7.21[bc]	4.84[a]	0.83
	7d	8.14[cd]	6.80[bc]	6.61[abc]	9.03[d]	5.18[ab]	8.00[cd]	4.67[a]	0.70
	14d	10.55[cd]	7.90[ab]	8.78[bc]	9.16[bcd]	6.04[a]	10.96[d]	6.19[a]	0.68
Juiciness[f]	1d	8.72[b]	6.45[a]	9.20[b]	7.57[ab]	8.43[b]	9.28[b]	8.07[ab]	0.62
	3d	9.73[cd]	6.36[a]	9.14[cd]	8.24[bc]	7.36[ab]	10.09[d]	9.31[cd]	0.61
	7d	9.71[cd]	5.42[a]	9.20[bcd]	7.75[b]	7.73[b]	10.17[d]	8.16[bc]	0.55
	14d	9.04[bc]	6.36[a]	10.10[c]	7.88[ab]	8.01[ab]	10.63[c]	9.47[bc]	0.66
Chewiness[f]	1d	9.77[c]	9.03[bc]	9.01[bc]	6.55[a]	8.91[abc]	6.79[ab]	9.95[c]	0.84
	3d	7.40	8.27	8.75	6.35	9.40	7.28	9.49	0.89
	7d	7.35[abc]	7.61[bcd]	8.68[cd]	5.49[a]	9.15[cd]	6.64[ab]	9.48[d]	0.70
	14d	4.61[ab]	6.09[b]	6.02[b]	4.79[ab]	8.68[c]	3.86[a]	8.53[c]	0.69
Beef Flavor[f]	1d	5.84	5.82	6.54	7.01	5.52	5.90	5.99	0.36
	3d	6.33	5.86	5.48	7.21	5.79	6.13	6.31	0.37
	7d	6.07	5.67	6.60	7.03	5.68	6.41	6.25	0.40
	14d	6.79	6.10	6.56	6.63	6.12	6.85	6.10	0.37
% Cook Loss	1d	28.76[ab]	32.94[c]	26.31[a]	29.47[abc]	30.82[bc]	29.08[ab]	30.99[bc]	1.24
	3d	28.22[ab]	33.52[c]	29.10[ab]	27.48[a]	31.12[abc]	28.96[ab]	31.96[bc]	1.42
	7d	28.96[ab]	35.32[c]	29.62[ab]	27.42[a]	31.46[b]	29.76[ab]	30.25[b]	0.95
	14d	27.99[a]	33.02[b]	27.33[a]	28.39[a]	33.05[b]	30.24[ab]	29.96[ab]	1.22

[a,b,c,d] *Means within same row with different superscripts differ at $P < 0.05$.*

[e] *Pooled standard error of the mean.*

[f] *Scored on a scale of 1-15 with 1 signifying a low degree of juiciness, tenderness, chewiness, or beef flavor and 15 signifying a high degree of juiciness, tenderness, chewiness, or beef flavor.*

2009; Anderson et al., 2007). At 14 days postmortem, the *semimembranosus*, *vastus lateralis* and *adductor* were less tender ($P < 0.05$) than the *longissimus dorsi* (Anderson et al., 2009). The tenderness of the *semimembranosus* compared to the *longissimus dorsi* is in agreement with previous observations of the *semimembranosus* (Shackelford et al., 1995b). Shackelford et al. (1995b) also showed that the *semimembranosus* had more abundant connective tissue than the *longissimus dorsi*, which may account for the difference seen in sensory tenderness between the *longissimus dorsi* and *semimembranosus*. From a sensory tenderness standpoint the *adductor*, *semimembranosus* and *vastus lateralis* were similar to the *longissimus dorsi* early postmortem, but during aging, these muscles failed to tenderize to the same extent as the *longissimus dorsi*, which may limit their usefulness as individual cuts.

Differences in chewiness were less pronounced than differences found in tenderness (Anderson et al., 2009; Anderson et al., 2007). At one day postmortem, the *sartorius* and *vastus intermedius* were less chewy than the *longissimus dorsi*. The *vastus lateralis* at seven and 14 days postmortem was chewier than the *longissimus dorsi*. In addition, the *sartorius* at 14 days postmortem was also chewier than the *longissimus dorsi*. No differences ($P > 0.05$) were detected in beef flavor. Juiciness scores were similar, in relationship to the *longissimus dorsi*, to tenderness scores. The *sartorius* was less juicy ($P < 0.05$) than the *longissimus dorsi* at seven days postmortem. However, at no other aging period were the *gracilis*, *sartorius* or *vastus intermedius* significantly different ($P > 0.05$) from the *longissimus dorsi* with regard to juiciness. The *vastus lateralis* was not different ($P > 0.05$) in juiciness when compared to the *longissimus dorsi*. However, the *semimembranosus* at three and seven days postmortem and the *adductor* at all times during aging were less juicy ($P < 0.05$) than the *longissimus dorsi*. The *adductor* had a higher percentage cook loss ($P < 0.05$) than the *longissimus dorsi* at all aging periods. The *semimembranosus* had a higher percentage cook loss ($P < 0.05$) than the *longissimus dorsi* at 14 days postmortem.

The *gracilis*, *sartorius* and *vastus intermedius* had similar tenderness and juiciness traits to that of the *longissimus dorsi*. This warrants further investigation into these muscles with respect to their potential to be marketed as individual cuts. However, the *adductor*, *semimembranosus* and *vastus lateralis* had lower tenderness scores when compared to the *longissimus dorsi*, which may limit their value as individual cuts. In addition to this, the *adductor* lacked the juiciness of the *longissimus dorsi* and had a higher amount of cook loss, which may further reduce its value. However, these muscles do have other significant advantages (such as size and shape) that make them good targets for further enhancement.

Instrumental Tenderness Analysis

The differences seen in star probe data (Table 2) were similar to the differences seen in tenderness scores (Anderson et al., 2009; Anderson et al., 2007). The *gracilis* at three and seven days postmortem, *sartorius* at seven days postmortem, and *vastus intermedius* at one and seven days postmortem required less force ($P < 0.05$) to be punctured than the *longissimus dorsi* on the same day. At all other aging periods, no differences ($P > 0.05$) were seen in the amount of force required to puncture steaks of the *longissimus dorsi* compared to the *gracilis*, *sartorius* or *vastus intermedius*. The *adductor* was not different ($P > 0.05$) from the *longissimus dorsi* in the amount of force required to puncture steaks at any aging period. However, both the *semimembranosus* at three and 14 days postmortem and the *vastus lateralis* at 14 days postmortem required more force ($P < 0.05$) to puncture steaks than the *longissimus dorsi* on the same day. As observed in the sensory analysis, the *gracilis*, *sartorius* and *vastus intermedius* had tenderness and texture characteristics similar to the *longissimus dorsi*, while the *semimembranosus* and *vastus lateralis* both exhibited inferior texture characteristics when compared to the *longissimus dorsi*. Star probe data were correlated to tenderness across all days and muscles ($r = -0.39$, $P < 0.01$) and maintained the differences reported in tenderness scores. The star probe data reiterate that the *gracilis*, *sartorius* and *vastus intermedius* have the potential for added value if marketed as individual cuts. Some of these

Table 2. Instrumental tenderness (star probe) values of specific beef round muscles

	Day	LD	AD	GR	SAR	SM	VI	VL	SE[e]
Star Probe*	1d	6.73^{bcd}	6.23^{abc}	5.81^{ab}	5.68^{ab}	8.04^{d}	5.10^{a}	7.43^{cd}	0.51
	3d	5.73^{bc}	6.50^{cd}	4.24^{a}	5.02^{ab}	7.36^{d}	4.96^{ab}	6.94^{cd}	0.43
	7d	6.79^{b}	6.69^{b}	4.99^{a}	5.31^{a}	7.69^{b}	5.29^{a}	7.05^{b}	0.48
	14d	5.43^{ab}	6.59^{bc}	5.15^{a}	5.24^{a}	7.84^{d}	5.08^{a}	7.55^{cd}	0.42

**kg force to puncture and compress the product to 20% of its original thickness.*

[a,b,c,d]Means within same row with different superscripts differ at P > 0.05.

[e]Pooled standard error of the mean.

muscles may require further development to make them highly profitable. For example, of the muscles mentioned in this report, the *sartorius* is a relatively small muscle, thus merchandizing it in a profitable manner may be challenging unless it can be made appealing to a specialty, high-end market.

The most apparent difference in the comparison of muscle pH at 24 hours postmortem (Figure 1) is that the pH of the *vastus intermedius* (5.77) was higher ($P < 0.05$) than the pH of all other individual muscles (Anderson et al., 2009; Anderson et al., 2007). This is consistent with previous reports of the *vastus intermedius* having a higher pH than other muscles in the round at 14 days postmortem (Christensen et al., 2004; Von Seggern et al., 2005). Correlations between 24-hour pH and sensory traits, including juiciness ($r = 0.24$, $P = 0.01$), tenderness ($r = 0.18$, $P = 0.07$) and cook loss ($r = -0.29$, $P < 0.01$), support the results seen in the *vastus intermedius*. The positive correlation between 24-hour pH and both juiciness and tenderness indicated that, with an increase in pH (as seen in the *vastus intermedius*), there is an increase in juiciness and tenderness of the product. Additionally, the pH of the *adductor*, *semimembranosus* and *vastus lateralis* was lower ($P > 0.05$) than the *longissimus dorsi* at 24 hours postmortem. Higher pH has been shown to be positively correlated to increased juiciness and increased tenderness (Huff-Lonergan et al., 2002; Panea et al., 2008). It is likely the high pH of the *vastus intermedius* at 24 hours aids in the juiciness and tenderness of the final product.

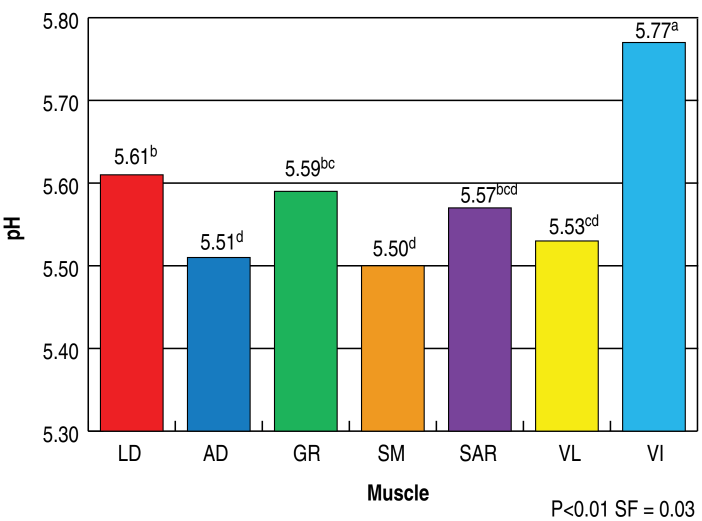

Figure 1. pH differences of key round muscles at 24 hours postmortem

Biochemical Differences

The round muscles studied demonstrated different rates of protein degradation (Anderson et al., 2009; Anderson et al., 2007). In a recent study, at 24 hours postmortem, the *longissimus dorsi* (control muscle), *gracilis*, *adductor*, *semimembranosus*, *sartorius*, *vastus lateralis* and *vastus intermedius* muscles were removed from ten market-weight beef cattle. The pH was measured in each muscle. Calpastatin activity was measured in each sample at 24 hours postmortem. Whole-muscle samples were made from all muscles for Western blot analysis of μ-calpain autolysis and SDS-PAGE analysis of titin degradation. Across muscles, pH was significantly correlated with 24-h calpastatin activity (0.475, $P < 0.0001$) and with the percentage of μ-calpain as the 76 kDa autolysis product (-0.311, $P < 0.05$). The *adductor*, *gracilis* and *longissimus dorsi* had a higher percentage of μ-calpain than the 76 kDa autolysis product, suggesting that calpain was activated earlier in those muscles. The *sartorius*, *semimembranosus*, *vastus lateralis* and *vastus intermedius* had a lower percentage of the 76 kDa autolysis product at 24 hours postmortem. The *vastus intermedius* had the highest calpastatin activity, followed by *gracilis*, *longissimus dorsi* and *vastus lateralis*. The lowest calpastatin activity was found in the *adductor*, *sartorius* and *semimembranosus* muscles. Differences in the degradation of titin, a substrate of μ-calpain, were found. The *sartorius* had little, if any, detectable intact titin at 24 hours postmortem.

The results of this study indicate that there are definite differences in the rate of proteolysis in the muscles studied. There are also differences in the enzyme μ-calpain and its inhibitor, calpastatin, which govern proteolysis and tenderness. Differences also exist in myosin heavy chain, a protein that has promise to be a marker of tenderness.

Differences between muscle fiber types, including fiber diameter, method of metabolism, and glycogen content, can potentially affect several aspects of meat quality. Fiber type, as defined by myosin heavy chain (MHC) isoforms, was found to influence palatability attributes of underutilized muscles from the round. The *vastus intermedius* had the highest percentage ($P < 0.01$) of type I fibers and the lowest percentage ($P < 0.01$) of type II fibers when compared to all other muscles (type I, 62.1%; type II, 37.9%). Across all muscles, the proportion of type I fibers was correlated to the intensity of LI ($r = -0.27$; $P = 0.02$) (LI and UI are indicators of protein degradation; higher numbers indicate less protein degradation), the intensity of the UI ($r = -0.48$; $P < 0.01$), and juiciness ($r = 0.26$; $P = 0.03$). The intensity of the 30kDa band (also an indicator of protein degradation; higher number indicates more degradation) tended to be correlated to pH ($r = -0.22$; $P = 0.07$) and the intensity of the UI was correlated to star probe ($r = 0.25$; $P = 0.03$). The data show that juiciness is associated with fiber type (Table 3).

Table 3. Correlations between myosin heavy chain isoforms and sensory characteristics

	MHC Type 1 (%)	MHC Type II a/x (%)	MHC Type I Ratio≠	MHC Type II a/x Ratio≠
pH	0.135	-0.135	0.112	0.093
Star Probe	-0.120	0.120	-0.126	-0.066
Juiciness	0.269*	-0.269*	0.127	-0.207†
Tenderness	0.133	-0.133	0.027	-0.024
Chewiness	-0.217†	0.217†	-0.078	0.089
Beef Flavor	-0.023	0.023	-0.013	0.016
30kDa Ratio≠	-0.122	0.122	-0.087	-0.043
LI Ratio≠	-0.261*	0.261*	-0.179	0.145*
UI Ratio≠	-0.494*	0.494*	-0.277*	0.422*

*†P<0.10; *P<0.05.*

≠Ratio of the protein band in the sample to its corresponding band in a reference sample.

LI and UI are indicators of protein degradation. A high value indicates less protein degradation; 30 kDa also refers to protein degradation, but a high number indicates more protein degradation.

Effects of Packaging Type on Specific Round Muscles

Modified atmosphere packaging (MAP) systems with 80% oxygen (O_2) and 20% carbon dioxide (CO_2) are widely used in retail meat markets because the bright red color of meat in this packaging system attracts consumers and the CO_2 aids in preventing microbial growth (Daun et al., 1971; Eilert, 2005; Seyfert et al., 2005; Stubbs et al., 2002). However, high oxygen levels are likely to increase the incidence of oxidative changes in the meat, thus negatively affecting meat quality characteristics such as off-flavor, discoloration and tenderness (Grobbel et al., 2008a; Zakrys et al., 2008). Lund et al. (2007) determined that a high level of oxygen can induce intermolecular cross-linking, which subsequently decreases tenderness and juiciness of pork meat. Besides protein aggregation, oxidative condition in early-postmortem muscle may affect the rate of tenderization by negatively influencing proteolytic activity of μ-calpain (Maddock et al., 2004; Rowe et al., 2004).

Surface redness

A very recent study done at Iowa State University took a comprehensive look at the differential effect of modified atmosphere on the *semimembranosus*, *adductor* and *longissimus* muscles (Kim et al., 2009). A HiOx-MAP had a significant effect on *a** values (indication of redness) of beef steaks from all three muscles. The surface redness values of steaks packaged in HiOx-MAP rapidly decreased ($P < 0.001$) after nine days of display, whereas steaks packaged in vacuum-packaged treatments had no significant change in redness during display. The *adductor* had the greatest decrease ($P < 0.05$) in surface redness followed by the *semimembranosus* and *longissimus*, indicating that the *adductor* might be more susceptible to myoglobin oxidation. These results are in agreement with the study from McKenna et al. (2005). Researchers in this study grouped different bovine muscles according to their color stability such as *adductor* as "low", *semimembranosus* as "moderate" and *longissimus* as "high" color stability muscles. Relatively lower color stability has been found in meat packaged in HiOx-MAP compared to other packaging systems such as vacuum, low-oxygen MAP or carbon monoxide-MAP systems (Grobbel et al., 2008a; John et al., 2005; Mancini et al., 2009; Sørheim et al., 1999). Several studies confirmed that the HiOx-MAP system creates a desirable red color of meat for the initial- and mid-display period, but much faster discoloration occurs afterwards compared to other low-oxygen or oxygen-free packaging systems (Grobbel et al., 2008b; Jayasingh et al., 2002; John et al., 2005; Sørheim et al., 1999).

Lipid oxidation

The most recent study completed at Iowa State University on modified atmosphere showed some interesting results with respect to lipid oxidation (Kim et al., 2009). HiOx-MAP packaged beef steaks showed an increase ($P < 0.05$) in lipid oxidation during display based on the chemical measure of lipid oxidation (thiobarbituric acid reactive substances (TBARS) values). *Adductor* steaks in HiOx-MAP had the greatest increase of lipid oxidation (0.14 to 1.57 mg maldonaldehyde/kg meat) during display at day one and day nine respectively, followed by *semimembranosus* (0.12 to 1.17) and *longissimus* (0.14 to 0.9), suggesting that these beef round muscles are more susceptible to oxidation than *longissimus*. In contrast, steaks packaged in vacuum packages did not exhibit production and accumulation of the TBARS values during nine days of display. Similar findings of increased lipid oxidation and decreased color stability of fresh meats packaged in HiOx-MAP have been reported by several studies due to the formation of metmyoglobin (Jayasingh et al., 2002; John et al., 2005; O'Grady et al., 2000; Zakrys et al., 2008). Lipid oxidation, which resulted in the production of oxy- and lipid-free radicals, is closely coupled with pigment oxidation (Faustman et al., 1989) since lipid oxidation is a promoter of myoglobin oxidation (Lin and Hultin, 1977).

Table 4. Least squares means for sensory characteristics[e] of beef steaks packaged in either a high-oxygen modified atmosphere (HiOx-MAP) or vacuum (VAC) displayed for nine days at 1°C

Item	Tenderness	Juiciness	Chewiness	Off-flavor	Beef flavor
MAP	6.3[a]	7.8[a]	7.6	0.4[a]	9.6[a]
VAC	7.7[b]	8.8[b]	6.7	0.2[b]	10.2[b]
SEM[d]	0.4	0.3	0.5	0.06	0.3
LL[c]	10.0[a]	8.8[a]	4.9[a]	0.3	10.0
SM[c]	5.6[b]	8.8[a]	8.3[b]	0.2	9.8
AD[c]	5.4[b]	7.4[b]	8.3[b]	0.3	9.9
SEM[d]	0.5	0.4	0.5	0.07	0.3

[a,b] Within a column of each sensory traits, different letters indicate difference between packaging types, or between muscles (P < 0.05).

[c]M. longissimus lumborum (LL), M. semimembranosus (SM), and M. adductor (AD).

[d] Standard errors of the mean.

[e] Sensory characteristics were rated for intensity on a one to 15 universal scale, lowest intensity to highest intensity.

Sensory analysis

There was a significant packaging type effect on sensory characteristics of beef muscles such as tenderness, juiciness, beef flavor and off-flavor (Table 4) (Kim et al., 2009). The HiOx-MAP system decreased ($P < 0.05$) tenderness and juiciness of beef muscles. *Longissimus* muscles had significantly higher tenderness scores compared to *adductor* and *semimembranosus*. Within each muscle, the *longissimus* steaks packaged in HiOx-MAP had a lower ($P < 0.01$) tenderness score (8.7) than the steaks packaged in vacuum packages (11.3). There was a trend ($P = 0.1$) of decreasing tenderness for the *adductor* steaks packaged in HiOx-MAP (4.7 ± 0.7 for HiOx-MAP, 6.2 ± 0.7 for vacuum packages), whereas similar tenderness ($P > 0.1$) scores were found in *semimembranosus* steaks packaged in either HiOx-MAP or vacuum packages. The high amount of connective tissue in the *semimembranosus* (Shackelford et al., 1995a) might be partially responsible for a lack of significant difference in tenderness of *semimembranosus* by packing types. There was no significant packaging type effect on chewiness values (Table 4). However, within a muscle, *longissimus* steaks in HiOx-MAP had a higher ($P < 0.05$) sensory chewiness score (6.1 ± 0.7) than the steaks in vacuum packages (3.7 ± 0.7). Beef steaks packaged in HiOx-MAP also were less juicy ($P < 0.05$) than steaks packaged in vacuum packages (Table 4). The sensory juiciness scores of *longissimus* and *semimembranosus* were not different ($P < 0.05$), but were significantly higher than *adductor*. Within each muscle, the *adductor* steaks only were affected by the HiOx-MAP condition resulting in decreased ($P < 0.05$) juiciness scores (6.2 ± 0.5) compared to steaks in vacuum packages (8.4 ± 0.5). There was a packaging effect ($P < 0.05$) on off-flavor and beef flavor scores (Table 4). Steaks packaged in HiOx-MAP had higher ($P < 0.05$) off-flavor and less beef flavor scores than steaks packaged in vacuum packages. Sensory results of decreased tenderness and juiciness and increased off-flavor of beef steaks in HiOx-MAP were in agreement with other studies (Grobbel et al., 2008a; Lund et al., 2007; Zakrys et al., 2008). Among muscles, steaks from the *longissimus* were most negatively affected by HiOx-MAP system in sensory attributes such as tenderness, chewiness and beef flavor and tended to develop off-flavor. Sensory tenderness, juiciness, beef flavor and off-flavor of the *adductor* were also affected (trend for tenderness; $P = 0.1$) by HiOx-MAP, but steaks from the *semimembranosus* were least affected by the packaging condition in sensory characteristics. The lesser changes by packaging types in sensory attributes of *semimembranosus* compared to *longissimus* might be due to the lower baseline sensory quality characteristics of the muscle (Shackelford et al., 1995a), regardless of packaging type.

Star probe analysis for packaging differences

Star probe data indicated that there was no significant packaging effect on instrumental texture levels of beef steaks (Kim et al., 2009). However, within a muscle, steaks from the *longissimus* packaged in HiOx-MAP had higher ($P < 0.05$) star probe values compared to the steaks in vacuum packages, which corresponds to the sensory tenderness data from Kim et al. (2009). In contrast, steaks from the *semimembranosus* and *adductor* were not affected ($P > 0.05$) by packaging types in instrumental texture values (Kim et al., 2009). Within vacuum-packaged steaks, the *longissimus* and *adductor* were not different ($P > 0.05$) in the level of star probe, but were lower than *semimembranosus* in star probe values. Corresponding findings were reported by Anderson et al. (2009) who determined that the *adductor* is not different ($P > 0.05$) in star probe values from the *longissimus* throughout 14 day postmortem aging, but had lower ($P < 0.05$) star probe values than *semimembranosus*. Texture analysis performed by star probe measurement revealed a similar result as the sensory data because the HiOx-MAP condition resulted in an increased amount of force required to puncture *longissimus* steaks, but did not significantly affect *semimembranosus* and *adductor* steaks.

Beef steaks from *adductor* and *semimembranosus* muscles packaged in HiOx-MAP, especially, had a rapid decrease in surface redness values and significant accumulation of lipid oxidation during display time. This suggests that these beef round muscles are more susceptible to myoglobin and lipid oxidation than *longissimus* when packaged in HiOx-MAP. Therefore, MAP systems with a lower oxygen mixture (low-oxygen MAP or carbon monoxide-MAP), or incorporation of antioxidants through injection enhancement to meat in HiOx-MAP, are recommended to minimize oxidation-induced quality deteriorations of beef round muscles.

Potential for Selected Muscles of the Beef Round and Future Opportunities and Challenges for Using Muscles of the Beef Round

Studies have evaluated many of the sensory and biochemical characteristics of the muscles of the round and evaluated their suitability to be utilized as individual cuts. From these studies, it has been shown that biochemical differences exist in pH, calpastatin activity and percentage of calpain autolysis among the muscles of the round. The *vastus intermedius* has a higher 24-hour postmortem pH than all other muscles evaluated. This increased pH may have an effect on some of the biochemical and sensory traits of that muscle including water-holding capacity, color and calpain activity. The *longissimus dorsi* has been accepted by consumers as a relatively tender cut and is sold as an individual cut. Some of the muscles of the beef round show sensory and biochemical traits that are similar to the *longissimus dorsi*. Therefore, some of these muscles potentially have the sensory and biochemical characteristics necessary to be marketed as individual cuts. The *semimembranosus* has relatively poor sensory tenderness traits when compared to the *longissimus dorsi*. This may be due to the high amount of connective tissue present in that muscle. The *adductor* and *vastus lateralis* also have relatively poor sensory traits in comparison to the *longissimus dorsi*. As a consequence of this, the *adductor*, *semimembranosus* and *vastus lateralis* may not be strong candidates to market as individual cuts. The *gracilis*, *sartorius* and *vastus intermedius* have sensory traits that are similar to, or in some cases better than, *longissimus dorsi*. While further investigation into the economic impact on isolating these muscles is needed, there is the specific potential to add value to the *gracilis*, *sartorius* and *vastus intermedius* by marketing them as individual cuts. The smaller size of the *sartorius* may require more creative modes of merchandizing this muscle compared to the others.

References

Anderson, M. J., S. M. Lonergan, C. Fedler, K. Prusa, J. Binning, and E. Huff-Lonergan. 2009. Round muscle profiling: Management of tenderness and sensory improvement of specific muscles with aging. Meat Science In preparation.

Anderson, M. J., S. M. Lonergan, and E. Huff-Lonergan. 2007. Round muscle profiling of tenderness and postmortem proteolysis. Journal of Animal Science 85: 380-381.

Bidner, B. S., M. Ellis, M. S. Brewer, D. Campion, E. R. Wilson, and F. K. McKeith. 2004. Effect of ultimate pH on the quality characteristics of pork. Journal of Muscle Foods 15: 139-154.

Boleman, S. J., S. L. Boleman, R. K. Miller, J. F. Taylor, H. R. Cross, T. L. Wheeler, M. Koohmaraie, S. D. Shackelford, M. F. Miller, R. L. West, D. D. Johnson, and J. W. Savell. 1997. Consumer evaluation of beef of known categories of tenderness. Journal of Animal Science 75: 1521-1524.

Christensen, M., P. Henckel, and P. P. Purslow. 2004. Effect of muscle type on the rate of post-mortem proteolysis in pigs. Meat Science 66: 595-601.

Daun, H. K., M. Solberg, W. Franke, and S. Gilbert. 1971. Effect of oxygen-enriched atmospheres on storage quality of packaged fresh meat. Journal of Food Science 36: 1011-1014.

Eilert, S. J. 2005. New packaging technologies for the 21st century. Meat Science 71: 122-127.

Faustman, C., R. G. Cassens, D. M. Schaefer, D. R. Buege, and K. K. Scheller. 1989. Vitamin E supplemenation of holstein steer diets improves sirloin steak color. J. Food Sci. 54: 485-486.

Grobbel, J. P., M. E. Dikeman, M. C. Hunt, and G. A. Milliken. 2008a. Effects of different packaging atmospheres and injection-enhancement on beef tenderness, sensory attributes, desmin degradation, and display color. Journal of Animal Science 86: 2697-2710.

Grobbel, J. P., M. E. Dikeman, M. C. Hunt, and G. A. Milliken. 2008b. Effects of packaging atmospheres on beef instrumental tenderness, fresh color stability, and internal cooked color. Journal of Animal Science 86: 1191-1199.

Huff-Lonergan, E., T. J. Baas, M. Malek, J. C. M. Dekkers, K. Prusa, and M. F. Rothschild. 2002. Correlations among selected pork quality traits. Journal of Animal Science 80: 617-627.

Jayasingh, P., D. P. Cornforth, C. P. Brennand, C. E. Carpenter, and D. R. Whittier. 2002. Sensory evaluation of ground beef stored in high-oxygen modified atmosphere packaging. Journal of Food Science 67: 3493-3496.

John, L., D. Cornforth, C. E. Carpenter, O. Sorheim, B. C. Pettee, and D. R. Whittier. 2005. Color and thiobarbituric acid values of cooked top sirloin steaks packaged in modified atmospheres of 80% oxygen, or 0.4% carbon monoxide, or vacuum. Meat Science 69: 441-449.

Kim, Y. H., S. M. Lonergan, E. Huff-Lonergan, and J. G. Sebranek. 2009. Influence of high oxygen modified atmosphere packaging system on biochmical, physiochemical and sensory characterisitics of early postmortem beef cuts. In preparaton.

Kirchofer, K. S., C. R. Calkins, and B. L. Gwartney. 2002. Fiber-type composition of muscles of the beef chuck and round. Journal of Animal Science 80: 2872-2878.

Lin, T. S., and H. O. Hultin. 1977. Oxidation of myoglobin in vitro mediated by lipid oxidation in microsomal fractions of muscle. Journal of Food Science 42: 136-140.

Lund, M. N., R. Lametsch, M. S. Hviid, O. N. Jensen, and L. H. Skibsted. 2007. High-oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. Meat Science 77: 295-303.

Maddock, K. R., E. Huff-Lonergan, L. J. Rowe, and S. M. Lonergan. 2004. Oxidation, ionic strength, and ph affect porcine skeletal muscle calpain and calpastatin activity. Journal of Animal Science 82: 14-14.

Mancini, R. A., S. P. Suman, M. K. R. Konda, and R. Ramanathan. 2009. Effect of carbon monoxide packaging and lactate enhancement on the color stability of beef steaks stored at 1°C for 9 days. Meat Science 81: 71-76.

McKeith, F. K., D. L. Devol, R. S. Miles, P. J. Bechtel, and T. R. Carr. 1985. Chemical and sensory properties of 13 major beef muscles. Journal of Food Science 50: 869-872.

Mennecke, B. E., A. M. Townsend, D. J. Hayes, and S. M. Lonergan. 2007. A study of the factors that influence consumer attitudes toward beef products using the conjoint market analysis tool. Journal of Animal Science 85: 2639-2659.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. Journal of Animal Science 79: 3062-3068.

Morgan, J. B. 1995. Enhance taste-palatability. National Cattlemen's Beef Association, Denver, CO.

Morzel, M., P. Gatellier, T. Sayd, M. Renerre, and E. Laville. 2006. Chemical oxidation decreases proteolytic susceptibility of skeletal muscle myofibrillar proteins. Meat Science 73: 536-543.

NCBA. 2000. Muscle profiling, National Cattlemen's Beef Association, Denver, CO.

O'Grady, M. N., F. J. Monahan, R. M. Burke, and P. Allen. 2000. The effect of oxygen level and exogenous α-tocopherol on the oxidative stability of minced beef in modified atmosphere packs. Meat Science 55: 39-45.

Panea, B., P. Alberti, J. L. Olleta, M. M. Campo, G. Ripoll, J. Altarriba, and C. Sannudo. 2008. Intrabreed variability and relationships for 41 carcass and meat traits in pirenaica cattle. Spanish Journal of Agricultural Research 6: 546-558.

Person, R. C., D. R. McKenna, J. W. Ellebracht, D. B. Griffin, F. K. McKeith, J. A. Scanga, K. E. Belk, G. C. Smith, and J. W. Savell. 2005. Benchmarking value in the pork supply chain: Processing and consumer characteristics of hams manufactured from different quality raw materials. Meat Science 70: 91-97.

Platter, W. J., J. D. Tatum, K. E. Belk, S. R. Koontz, P. L. Chapman, and G. C. Smith. 2005. Effects of marbling and shear force on consumers' willingness to pay for beef strip loin steaks. Journal of Animal Science 83: 890-899.

Rowe, L. J., K. R. Maddock, S. M. Lonergan, and E. Huff-Lonergan. 2004. Influence of early postmortem protein oxidation on beef quality. Journal of Animal Science 82: 785-793.

Seyfert, M., M. C. Hunt, R. A. Mancini, K. A. Hachmeister, D. H. Kropf, J. A. Unruh, and T. M. Loughin. 2005. Beef quadriceps hot boning and modified-atmosphere packaging influence properties of injection-enhanced beef round muscles. Journal of Animal Science 83: 686-693.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995a. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from bos indicus and bos taurus cattle. Journal of Animal Science 73: 3333-3340.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995b. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from bos-indicus and bos-taurus cattle. Journal of Animal Science 73: 3333-3340.

Sørheim, O., H. Nissen, and T. Nesbakken. 1999. The storage life of beef and pork packaged in an atmosphere with low carbon monoxide and high carbon dioxide. Meat Science 52: 157-164.

Stubbs, R. L., J. B. Morgan, F. K. Ray, and H. G. Dolezal. 2002. Effect of supplemental vitamin e on the color and case-life of top loin steaks and ground chuck patties in modified atmosphere case-ready retail packaging systems. Meat Science 61: 1-5.

Von Seggern, D. D., C. R. Calkins, D. D. Johnson, J. E. Brickler, and B. L. Gwartney. 2005. Muscle profiling: Characterizing the muscles of the beef chuck and round. Meat Science 71: 39-51.

Zakrys, P. I., S. A. Hogan, M. G. O'Sullivan, P. Allen, and J. P. Kerry. 2008. Effects of oxygen concentration on the sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. Meat Science 79: 648-655.

Zhang, S. X., M. M. Farouk, O. A. Young, K. J. Wieliczko, and C. Podmore. 2005. Functional stability of frozen normal and high pH beef. Meat Science 69: 765-772.

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