51st International Congress of Meat Science and Technology
August 7-12, 2005 – Baltimore, Maryland USA

PHYSICAL, CHEMICAL, AND HISTOLOGICAL CHARACTERISTICS OF 18 LAMB MUSCLES

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Key Words: Color; Lamb; Muscle characterization

Introduction

Consumer demand for meat products is determined by palatability, appearance, fat content, economic value, ease of preparation, and convenience (Ward, Trent, & Hildebrand, 1995). The demand for lamb products has declined over recent years in comparison to other meat sources, probably because lamb has not met these consumer driven criteria. Studies detailing the characteristics of individual muscles in beef and pork have identified muscles that can be marketed more effectively on an individual basis (Jones, Burson, & Calkins, 2001; Jones, Burson, Devine, Schafer, & Poday, 2000). The identification of lamb muscles that can be marketed this way could increase the demand for lamb products by improving the consistency of products and allowing processing technologies to be targeted toward maximum effectiveness, both of which could increase carcass value. Furthermore, marketing muscles in this manner allows the removal of seam fat, producing more attractive cuts with greater nutritional quality.

Objective

To quantify of factors affecting palatability and appearance of individual lamb muscles, with specific interest in identifying muscles suitable for use in individual muscle applications.

Methodology

Carcass selection and dissection

Lamb carcasses (n = 20) were selected to represent the commercially produced population, and were shipped to the Rosenthal Meat Science and Technology Center at Texas A&M University. Carcasses were selected from those with unchilled weights between 30.5 and 32.7 kg, and were ribbed at the 12th-13th rib interface with the following information obtained by Texas A&M personnel: fat thickness, adjusted fat

thickness, body wall thickness, ribeye area, leg conformation score, maturity score, and flank streaking score (USDA, 1992; Table 1).

Carcasses were dissected, and the following muscles were selected from both sides for further analysis: *M. adductor*, *M. gluteobiceps*, *M. gluteus medius*, *M. infraspinatus*, *M. latissimus dorsi*, *M. longissimus lumborum*, *M. longissimus thoracis*, *M. pectoralis profundus*, *M. psoas major*, *M. rectus femoris*, *M. semimembranosus*, *M. semitendinosus*, *M. supraspinatus*, *M. serratus ventralis*, *M. triceps brachii*, *M. tensor fasciae latae*, *M. teres major*, and *M. vastus lateralis*. The *M. gluteobiceps* was further separated into the proximal and distal portions. Following dissection, muscles from the left side of the carcass were denuded, individually vacuum packaged, and aged approximately 7 d in a 2 ± 2°C cooler.

Table 1

Simple statistics for carcass traits

Trait	Mean	SD	Minimum	Maximum
Carcass weight (kg)	30.3	0.8	28.7	31.4
Fat thickness at 12th rib (mm)	4.8	1.5	2.0	7.6
Body wall (mm)	23.4	3.8	17.7	31.6
M. longissimus thoracis area (cm^2)	17.6	1.6	15.2	20.7
Lean maturity[a]	149.5	10.5	140	170
Skeletal maturity[a]	157.0	9.8	140	180
Flank streaking[b]	11.4	0.8	10	13
Quality score[b]	11.4	0.8	10	13
Confirmation score[b]	12.3	0.8	11	14
Quality grade[b]	11.7	0.7	10	13

[a] A^{40} = 140, A^{50} = 150, A^{60} = 160, A^{70} = 170, A^{80} = 180.

[b] $Choice^-$ = 10, $Choice^o$ = 11, $Choice^+$ = 12, $Prime^-$ = 13, $Prime^o$ = 14.

Muscle dimensions

Weights and dimensions, including length, width, minimum thickness, and maximum thickness, were recorded on individual muscles from the left sides of carcasses. Weights were taken using an analytical scale (Model PB3002-S; Mettler Toledo, Switzerland), and minimum and maximum thickness measurements were taken from the thinnest and thickest portion of the muscle, respectively, using electronic digital calipers (Traceable Model 14-648-17; Control Company, Friendswood, TX). All other dimensions were measured with a metal ruler. Length was determined to be the longer of the two dimensions, and both length and width were taken across the longest line, or diagonal, of the muscle.

Warner-Bratzler shear force

Following aging, raw weights were recorded on individual muscles. Whole muscle roasts were cooked in a preheated (177°C for 20 min), forced-air convection oven (Model DNO97; Hobart Corp., Troy, OH) to an internal temperature of 70°C. Muscles were

grouped so that those of similar size were cooked together. Internal muscle temperatures were monitored using an Omega HH501BT thermometer (Omega Engineering, Inc., Stamford, CT). When muscles reached 70°C, they were removed from the oven and allowed to rest at room temperature for 10 min. Muscles then were weighed, wrapped in plastic film, and chilled at 4°C for 18 hours.

Chilled muscles were allowed to equilibrate to room temperature before being cut into 2.54 cm-thick slices. Four to six, 1.27 cm cores were removed parallel to muscle fiber orientation, and sheared once with an Instron Universal Testing Machine (Model 1011; Instron Corp., Canton, MA) equipped with a standard Warner-Bratzler attachment. Warner-Bratzler shear force reported is the mean force required to shear the cores from each muscle.

Color

Defatted individual muscles dissected from the right side of the carcass were cut into 2.54 cm-thick slices. The *M. serratus ventralis, M. latissimus dorsi, M. pectoralis profundus, M. teres major,* and *M. tensor faciae latae* muscles were left intact. Muscles were allowed to bloom for 15 min, and objective color measurements (*L**, lightness; *a**, redness; *b**, yellowness values) were taken using a Minolta Colorimeter (Model CR-200 Chroma Meter, Illuminant D65, 2° observer; Minolta Corp., Ramsey, NJ) on three chops selected at random. Thin muscles (i.e. *M. latissimus dorsi*) were left intact, and color measurements were taken from three different surface locations.

Expressible moisture and sarcomere length

Two cylindrical, raw cores (1.27 cm) were removed from each muscle and used for determination of expressible moisture following the centrifugation method of Jauregui, Regenstein, and Baker (1981). Additionally, two samples were taken for measurement of sarcomere length according to the Cross, West, and Dutson (1981) procedures. Remaining portions of each muscle were frozen, pulverized, and used for subsequent determination of pH and total collagen content.

pH

Approximately 3 g of pulverized muscle tissue was blended with 30 mL distilled, deionized water until a smooth slurry was formed. This slurry was filtered through Whatman #1 filter paper (Whatman®, Maidstone, Kent, UK), and a glass-tipped, bench-top pH probe (Accumet Basic, Fisher Scientific, Pittsburgh, PA) was inserted for 30 to 60 sec to allow for equilibration before reading.

Total collagen content

Total collagen content was determined by isolating hydroxyproline from pulverized muscle samples as described by Hill (1966). Hydroxyproline concentration was determined with a colorimetric assay described by Bergman and Loxley (1963), and used to calculate collagen content according to the method set forth by Cross, Carpenter, and

Smith (1973). Collagen content was not determined on the *M. teres major* or *M. tensor fasciae latae* due to insufficient product for sampling.

Statistical analysis

Data were analyzed using the PROC GLM procedure of SAS (SAS Institute, Cary, NC). Muscle effects were tested for each factor analyzed. When significant ($P < 0.05$), least squares means were generated and separated using the PDIFF option.

Results & Discussion

Muscle dimension

Differences ($P < 0.05$) in physical measurements were observed among the eighteen individual muscles (Table 2). On average, the largest muscles identified were the *M. gluteobiceps, M. gluteus medius, M. longissimus lumborum, M. longissimus thoracis,* and *M. semimembranosus*. Muscles such as the *M. latissimus dorsi, M. pectoralis profundus*, and *M. serratus ventralis* were thin, but possessed large surface areas. The *M. adductor, M. infraspinatus, M. psoas major, M. rectus femoris, M. semitendinosus, M. supraspinatus, M. triceps brachii*, and *M. vastus lateralis* were moderate in terms of all physical measurements and the *M. teres major* and *M. tensor fasciae latae* were the smallest.

Table 2
Least squares means for physical measurements

				Thickness (mm)	
Muscle	Weight (g)	Length (mm)	Width (mm)	Minimum	Maximum
M. adductor	184.2de	131.4a	59.1def	10.6abc	35.7h
M. gluteobiceps	379.2k	297.8	66.5f	5.9ab	33.6gh
M. gluteus medius	300.3i	172.1cd	102.2j	6.9ab	31.2fg
M. infraspinatus	215.7fg	205.6e	55.8cde	18.4c	27.1e
M. latissimus dorsi	152.6c	248.6f	101.6i	2.6a	11.4a
M. longissimus lumborum	493.5n	275.1g	77.2g	13.5bc	29.5ef
M. longissimus thoracis	345.5j	312.6i	47.8bc	7.6ab	31.9fg
M. psoas major	233.0g	347.6j	42.7ab	5.3ab	23.2d
M. pectoralis profundus	263.6h	370.7k	93.2hi	3.2a	11.9ab
M. rectus femoris	203.3ef	158.6bc	54.5cd	11.2abc	39.45i
M. semimembranosus	403.9l	164.6bc	76.4g	10.4abc	46.9j
M. semitendinosus	170.3cd	183.4d	43.9b	4.9ab	29.4ef
M. supraspinatus	171.5cd	163.6bc	53.2cd	5.8ab	32.4fg
M. serratus ventralis	444.2	423.3l	117.9k	3.7a	16.0c
M. triceps brachii	335.2j	164.7bc	91.5h	8.6ab	42.4i
M. tensor fasciae latae	91.1b	155.6b	63.2ef	5.0ab	13.8abc
M. teres major	47.1a	141.0a	34.3a	5.0ab	14.9bc
M. vastus lateralis	193.7e	157.9b	78.8g	6.4ab	31.9fg
SEM[a]	7.29	4.92	3.10	3.35	1.15

Means within a column lacking a common letter differ ($P < 0.05$).
[a]SEM is the standard error of the least squares means.

pH and expressible moisture

Least squares means for muscle pH and expressible moisture are reported in Table 3. Values for pH ranged from 5.9 for muscles such as the *M. longissimus thoracis, M. longissimus lumborum,* and the *M. semimembranosus,* to 6.5 for muscles such as the *M. serratus ventralis*. The *M. teres major* and *M. serratus ventralis* had the highest ($P < 0.05$) pH values of all the muscles evaluated. The pH values of the *M. longissimus thoracis* and *M. longissimus lumborum* (5.9) observed in this study were higher than the value of 5.74 reported for these muscles by Wheeler and Koohmaraie (1994).

The *M. triceps brachii, M, pectoralis profundus*, and *M. latissimus dorsi* were found to have among the lowest numerical expressible moistures, whereas the *M. adductor* and the *M. longissimus lumborum* had among the highest. As expected, higher expressible moisture values tended to correspond with lower muscle pH, and lower expressible moisture was associated with higher muscle pH.

Table 3
Least squares means for pH and expressible moisture

Muscle	pH	Expressible moisture, %
M. adductor	6.0bcde	39.4j
M. gluteobiceps- distal	6.0cde	37.1ghij
M. gluteobiceps- proximal	6.0bcde	38.1ij
M. gluteus medius	6.0abcd	37.7hij
M. infraspinatus	6.3gh	32.4bcd
M. latissimus dorsi	6.3h	29.4a
M. longissimus lumborum	5.9abc	39.7j
M. longissimus thoracis	5.9a	37.6hij
M. psoas major	6.0de	34.8defgh
M. pectoralis profundus	6.2f	29.3a
M. rectus femoris	6.2f	35.6efghi
M. semimembranosus	5.9ab	37.4ghij
M. semitendinosus	6.2fg	31.3ab
M. supraspinatus	6.2fgh	33.4bcdef
M. serratus ventralis	6.5i	31.7abc
M. triceps brachii	6.2f	29.2a
M. tensor fasciae latae	6.0cde	32.7bcde
M. teres major	6.4i	34.8defgh
M. vastus lateralis	6.1e	36.0fghi
SEM[a]	0.03	1.08

Means within a column lacking a common letter differ ($P < 0.05$).
[a]SEM is the standard error of the least squares means.

Sarcomere length, collagen content, and Warner-Bratzler shear force

Least squares means for sarcomere length, collagen content, and Warner-Bratzler shear force are reported in Table 4. The *M. psoas major* had the longest ($P < 0.05$)

sarcomere length, which is in agreement with McKeith, DeVol, Miles, Bechtel, and Carr (1985). The *M. adductor, M. gluteobiceps, M. gluteus medius, M. longissimus lumborum, M. longissimus thoracis,* and *M. semimembranosus* had among the shortest sarcomere lengths. Values reported for sarcomere lengths are similar to those reported by Cross, Smith, and Carpenter (1972) for lamb *M. gluteobiceps, M. rectus femoris, M. semimembranosus, M. semitendinosus,* and *M. vastus lateralis,* and Wheeler and Koohmaraie (1994) for lamb *M. longissimus lumborum.*

The *M. infraspinatus* had the highest ($P < 0.05$) total collagen content when compared to all other muscles; however, the standard deviation for this muscle also was the highest (3.6; not reported in tabular form). This muscle contains a layer of heavy connective tissue running through its center, which is likely the cause of these observations. The *M. longissimus lumborum, M. longissimus thoracis, M. adductor, M. semimembranosus,* and *M. semitendinosus* had among the lowest collagen contents in the muscles studied**.**

The *M. serratus ventralis* had among the lowest numerical WBS values. One of the features contributing to the tenderness of this muscle is a high fat content

Table 4

Least squares means for sarcomere length, total collagen content, and Warner-Bratzler shear force (WBS) of individual lamb muscles

Muscle	Sarcomere length, µm	Collagen, mg/g	WBS, N
M. adductor	1.7a	3.2abc	31.6e
M. gluteobiceps- distal	1.7a	5.0efg	26.5bc
M. gluteobiceps- proximal	1.7a	5.6fg	28.1cde
M. gluteus medius	1.7a	6.1g	30.7de
M. infraspinatus	2.3e	9.0h	27.0bcd
M. latissimus dorsi	2.9i	5.0efg	28.1cde
M. longissimus lumborum	1.7a	2.6a	25.6abc
M. longissimus thoracis	1.8ab	2.9ab	23.4ab
M. psoas major	3.1j	4.5def	28.4cde
M. pectoralis profundus	2.8h	5.0efg	28.7cde
M. rectus femoris	2.0c	4.3cde	26.9bcd
M. semimembranosus	1.7a	3.5abcd	42.6f
M. semitendinosus	2.4f	3.7abcd	31.1e
M. supraspinatus	2.2d	5.5fg	30.6de
M. serratus ventralis	2.1d	4.1cde	21.8a
M. triceps brachii	2.6g	5.0efg	29.7cde
M. tensor fasciae latae	2.9i	--	30.9de
M. teres major	2.6g	--	26.4bc
M. vastus lateralis	1.9b	3.9bcde	29.4cde
SEM[a]	0.04	0.41	0.33

Means within a column lacking a common letter differ ($P < 0.05$).
[a]SEM is the standard error of the least squares means.

(Brackebusch, McKeith, Carr, & McLaran, 1991). The *M. semimembranosus* had the highest WBS value of all of the muscles in the study (42.6 N). Belew, Brooks, McKenna, and Savell (2003) reported a similar value (4.53 kg or 44.4 N) for beef, and of the muscles represented in this study, the *M. semimembranosus* ranked last in terms of tenderness with only the *M. pectoralis profundus* being less tender. In agreement with our findings, Morgan et al. (1991) reported that steaks from the top round had the highest WBS values of the muscles evaluated. The WBS values for the *M. triceps brachii, M.*

supraspinatus, and *M. psoas major* from the current study (29.7, 30.6, and 28.4 N, respectively) are very similar to those reported for lamb by Shackelford, Wheeler, and Koohmaraie (1997).

Color

Least squares means for muscle color are shown in Table 5. Muscle *L** values indicated that the *M. latissimus dorsi* and *M. tensor fasciae latae* had the lightest ($P < 0.05$) colored lean (highest *L** values) and the *M. adductor* and *M. semimembranosus* had the darkest ($P < 0.05$) colored lean (lowest *L** values) when compared to all other muscles. The *M. supraspinatus* and *M. psoas major* had among the highest numerical redness (*a**) values.

Table 5
Least squares means for color measurements of individual lamb muscles

Muscle	*L**	*a**	*b**
M. adductor	41.0a	15.4ef	3.9cdef
M. gluteobiceps- distal	42.8b	16.0fgh	4.0cdef
M. gluteobiceps- proximal	43.8cde	16.3gh	4.2defg
M. gluteus medius	43.2bc	16.5hi	4.3efg
M. infraspinatus	46.3gh	16.9ij	3.9bcdef
M. latissimus dorsi	48.1i	14.0ab	3.3ab
M. longissimus lumborum	42.7b	14.7bcd	3.8bcde
M. longissimus thoracis	44.3de	15.6ef	4.2efg
M. psoas major	44.3de	17.4jk	4.4fg
M. pectoralis profundus	47.0h	13.9a	3.0a
M. rectus femoris	45.4fg	15.5ef	3.7bcd
M. semimembranosus	41.1a	15.3def	4.0cdef
M. semitendinosus	46.7h	15.2cde	4.2efg
M. supraspinatus	46.8h	17.7k	4.7g
M. serratus ventralis	46.5h	15.8efgh	4.1bcdef
M. triceps brachii	43.5bcd	15.7efg	3.5abc
M. tensor fasciae latae	48.2i	13.9a	3.9cdef
M. teres major	46.1gh	14.5abc	3.5abc
M. vastus lateralis	44.7ef	16.5hi	4.2defg
SEM[a]	0.34	0.26	0.20

Means within a column lacking a common letter differ ($P < 0.05$).
[a]SEM is the standard error of the least squares means.

Conclusions

With a better understanding of individual muscle characteristics, the meat industry may be able to maximize potential from individual muscles to help increase quality and consistency in lamb products. This process should open many new opportunities in value-added and new-product development. Further research is needed to evaluate consumer

acceptance of individual lamb muscles with marketing strategies developed to positively alter consumer perception of lamb products.

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