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Muscle profiling: Characterizing the muscles of the beef chuck and round

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Abstract

To fully characterize properties of the muscles of the beef chuck and round, and to reveal potential opportunities to upgrade the value, 39 different muscles were dissected from 142 beef carcasses differing in carcass weight, yield grade, and quality grade. Numerous physical and chemical properties of the muscles were determined. Muscle effects were observed for all traits (objective color, expressible moisture, proximate composition, emulsion capacity, pH, total collagen content, total heme-iron concentration, and Warner–Bratzler shear force). USDA quality grade generally had the most effect on muscle traits, with carcass weight and yield grade having lesser effects. These muscle profile data will allow for more informed decisions to be made in the selection of individual muscles from the beef chuck and round for the production of value-added products.

Keywords: Beef muscle profiling; Bovine myology; Muscle characterization; Muscle traits; Beef chuck; Beef round

1. Introduction

Using USDA data (archived at USDA, 2005), the Cattle Fax organization provided impetus for a major research initiative when they observed a disturbing five-year trend: between 1993 and 1998 the wholesale value of beef ribs and loins (cuts traditionally yielding steaks) had increased just 3–5% when adjusted for inflation, while the wholesale value of the chucks, rounds, and trimmings had dropped 25–26%. From an economic perspective, it was obvious that considerable value was being unrealized in the majority of the meat from beef carcasses. Within this situation lay the opportunity to upgrade these underutilized cuts of beef if their traits were known. The approach was to establish an extensive database for muscles from the chuck and round. Thus, the objective of this research was to create a profile of the most noteworthy characteristics of muscles from the beef chuck and round.

One of the things that makes the present study unique is the extensive number of carcasses (142) and muscles (>5000) that were sampled. In addition, the data were gathered in a way as to allow evaluation of quality grade, yield grade, and weight effects on the traits. Not only has the database been established, but the research led to renewed interest in opportunities to upgrade underutilized cuts of beef. Today, the wholesale value of the beef chuck has risen significantly and consumer demand has increased the value of a beef carcass. Conservatively, assigning half of the five-year increase in carcass value to the chuck suggests this research (which led to the development and application of value-added technology) has added $50 to $70 per head to market steers and heifers in the US. Not all of this increase can be attributed to the beef muscle profiling research initiative, but certainly a significant portion can rightly be claimed.

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It would be inaccurate to claim that the research described in this paper was the first to characterize the traits of beef muscles. Some of the early work by Butterfield and May (1966), Ramsbottom and Strandine (1948), and Ramsbottom, Strandine, and Koonz (1945) sought to describe the gross morphology of bovine muscles. In the US, Hiner and Hankins (1950) helped describe sensory traits of beef muscles. Notable studies on the physical and compositional traits of beef muscles have been conducted over the years. These range from the connective tissue work of Light, Champion, Voyle, and Bailey (1985), Prost, Pelczynska, and Kotolua (1975a), Wilson, Bray, and Phillips (1954) to the muscle characterization studies of Doty and Pierce (1961) and Walter et al. (1965). Less known is some of the work by Choi et al. (1987a, 1987b). Other characterization studies have been conducted on smaller sets of animals and/or as a consequence of other experimental objectives (Brackebusch, McKeith, Carr, & McLaren, 1991; Cecchi, Huffman, Egbert, & Jones, 1988; Hedrick et al., 1981; Hunt & Hedrick, 1977; Martin, Fredeen, & Weiss, 1971; McBee & Wiles, 1967; Romans, Tuma, & Tucker, 1965a, Romans, Tuma, & Tucker, 1965b). Recently, a thorough characterization of muscles of the chuck has been published by Johnson et al. (1988), building on the work of Patterson and Parrish (1986). In 1985, McKeith, DeVol, Miles, Bechtel, and Carr (1985) published a study of thirteen major beef muscles, although the extent of the characterization was less than the research we conducted. Still others have focused on the tenderness and sensory properties of various beef muscles (Breidenstein, Cooper, Cassens, Evans, & Bray, 1968; Christensen, Johnson, West, Marshall, & Hargrove, 1991; Prost, Pelczynska, & Kotolua, 1975b; Zinn, Goskins, Gann, & Hedrick, 1970). Other notable studies have been conducted by Browning, Huffman, Egbert, and Jungst (1990), Carmack, Kastner, Dikeman, Schwenke, and Garcia Zepeda (1995), Garrett and Hinman (1971), Kropf and Graf (1959), Strandine, Koonz, and Ramsbottom (1949).

Rhee, Wheeler, Shackelford, and Koohmaraie (2004) conducted an in-depth study of within muscle variation for several traits. Polkinghorne (in press) characterized the properties of Australian beef muscles, particularly as they are affected by animal production and postmortem handling practices, in building Meat Standards Australia. Ovine muscles have been characterized in several papers (Cross, Smith, & Carpenter, 1972; Jeremiah, Smith, & Carpenter, 1971; Smith & Carpenter, 1970; Smith, Carpenter, King, & Hoke, 1970a, Smith, Carpenter, King, & Hoke, 1970b). Muscles from poultry and pork also have been profiled and early works include publications on veal (Paul & McLean, 1946). No doubt many other examples exist where muscles have been characterized.

It seems appropriate to pause and reflect on the phenomenon that followed release of the muscle profiling data. In light of the fact that other, though perhaps less complete, characterizations of muscles have been published, one might ask why this research has created such an impact. Timing is part of the answer. Given the undervaluation of the primals described earlier, it is logical to conclude that the economic incentives were there to drive implementation. The success of the ''flat iron'' steak (*Infraspinatus* muscle), cut in a unique way to remove the internal connective tissue seam, exemplifies the valuable utilization of these data by various segments of the meat/food industry. Much credit is due the funding organization – the Cattlemen's Beef Board – that, working with the National Cattlemen's Beef Association (NCBA), invested resources to develop the ''value cuts'' as a consequence of the results.

Effective communication of the results is due in large part to Steven Jones of the University of Nebraska, who led the design and development team that created the muscle profiling web site (Jones, Calkins, Johnson, & Gwartney, 2005). There were too many data to be contained within this manuscript, particularly as it related to main effects and interactions of carcass weight, yield grade, and quality grade. Readers are referred to the muscle profiling web site for the entire data set and to the complete statistical treatment and discussion of the results presented in Brickler (2000) and Von Seggern (2000).

2. Materials and methods

2.1. Industry advisory group

Once the issue of diminished wholesale values of the chuck and round was identified, the NCBA issued a call for proposals. The two universities collaborated on the project and personnel from one or both of the universities met with company representatives from the retail, processing, and fabrication sectors to discuss project goals and design.

2.2. The final design

The study was a $3 \times 4 \times 3$ factorial design (quality grade, yield grade, and carcass weight, respectively). For each combination, four A-maturity carcasses were selected (on five separate periods spanning five months). The quality grades were upper 2/3 Choice, low Choice, and Select. The yield grade classes were 1, 2, 3, with 4 and 5 together. There were three carcass weight ranges: 250–295, 296–385, and 386–431 kg. Carcasses were selected at a commercial packing plant. Although the initial design called for 144 carcasses, there were two carcasses that were not found during the selection

periods – both were Select grade, yield grade 4 or 5, and 250–295 kg carcass weight.

Cross-cut chucks were removed between the 5th and 6th ribs and rounds were cut about 3 cm anterior to the aitch bone. There were 27 and 12 individual muscles/groups removed from each chuck and round, respectively (Table 1). Muscles were weighed at three levels of trim – ≈2.3 cm of fat trim (termed commodity trim), 6 mm of fat trim, and denuded (all external fat and the epimysial tissue that was so thick that underlying muscle could not be discerned). After the final trim, maximal muscle thickness, length and width were determined. Muscles were allowed to oxygenate for 1 h so an objective color measure could be made (described below). They were then vacuum packaged and shipped to the appropriate university for testing. The University of Nebraska determined expressible moisture, pH, proximate composition, total collagen content, and heme-iron concentration while the University of Florida determined Warner–Bratzler shear and sensory panel evaluations. To ensure sufficient sample size, Nebraska samples came from the heavy and light weight carcasses and muscles from the intermediate carcasses were used by the University of Florida.

Table 1
Identification of muscles

Muscle name	Muscle code
Chuck muscles	
Biceps brachii	BIB
Brachialis	BRA
Brachiocephalicus omo-transversarius	BOT
Complexus	COM
Cutaneous omo-brachialis	COB
Deep pectoral	DEP
Deltoideus	DEL
Dorsalis oblique	DSO
Infraspinatus	INF
Intertransversales	INT
Latissimus dorsi	LAD
Levatores costarum	LVC
Longissimus capitus et Atlantis	LCA
Longissimus costarum	LGC
Longissimus dorsi	LGD
Multifidus/Spinalis dorsi	MSD
Rhomboideus	RHM
Scalenus dorsalis	SCD
Serratus ventralis	SEV
Splenius	SPL
Subscapularis	SUB
Superficial pectoral	SPP
Supraspinatus	SUP
Tensor fascia antibrachii	TFA
Teres major	TEM
Trapezius	TRA
Triceps brachii	TRB
Round muscles	
Adductor	ADD
Biceps femoris	BIF
Gluteus medius	GLM
Gracilis	GRA
Pectineus	PEC
Rectus femoris	REF
Sartorius	SAR
Semimembranosus	SEM
Semitendinosus	SET
Vastus intermedius	VAI
Vastus lateralis	VAL
Vastus medialis	VAM

2.3. Sample preparation

At the University of Florida, samples for tenderness and sensory analysis were received and frozen when time postmortem was 14 days. Muscles were then tempered and cut into 2.5-cm-thick steaks on a band saw. They were then stored frozen until cooked, generally less than 6 months storage time.

At the University of Nebraska, fresh (unfrozen) muscles were opened and a slice (about 6 mm thick) from the center of each muscle was obtained. Approximately 3 g of muscle was retained for determination of expressible moisture (described below).

To reduce the number of samples needed for analysis, identical muscles of two carcasses within a given quality grade-yield grade-carcass weight combination were combined. The composite sample was created by grinding the muscles together through a 0.95 cm plate using a Toledo Chopper (Toledo Scale Co., Toledo, OH). From the ground, composite sample, two subsamples were obtained, a small composite sample about 30 g, and a large composite sample about 70 g. The small sample was frozen at −80 °C in an ultralow freezer and later homogenized (powdered) in liquid nitrogen using a Waring blender (Waring Products Division, New Hartford, CT). The small sample was used to determine total collagen content, total heme-iron content, and proximate composition. The large sample was held at 4 °C for emulsion capacity measurement and was subsequently frozen. Muscle pH was determined from this thawed, large composite sample. When repeat measures were needed, the small composite sample was used. All analytical procedures were conducted in duplicate.

2.4. Objective color

Objective color of the external surface of the muscles was measured using a Hunter Lab Mini-Scan XE Plus (Reston, VA). The device had a 2.54 cm port and was standardized using a black tile and a white tile. Readings were taken from three random locations on each muscle and the average of the readings for L^*, a^*, and b^* was recorded. Illuminate A and a 10° standard observer were used.

2.5. Expressible moisture

Water holding capacity (expressible moisture) was measured on duplicate samples of individual muscles

using the centrifugation procedure of Jauregui, Regenstein, and Baker (1981). Two pieces of Whatman #3 filter paper were folded around one piece of Grade 410 filter paper to form a thimble. Approximately 0.3 g of muscle was inserted into the filter paper thimble and then into a 50 mL centrifuge tube. Tubes were centrifuged at 32,566*g* for 15 min at 4 °C. Expressible moisture was the percentage of weight lost from the original sample weight.

2.6. Emulsion capacity

A portion of raw, large, ground sample was used to determine emulsion capacity using a modification of the method described by Swift, Lockett, and Fryar (1961). Samples were never frozen. The method delivers oil at a constant rate to a blender apparatus where oil is added to a meat sample until the emulsions fails. A 50 g sample was diced and placed in a Sorvall Omni Mixer (Ivan Sorvall Inc., Norwalk, CT) can. Cold (4 °C) 1 M NaCl (200 mL) was added and the solution was mixed for 2 min at full speed (1800 rpm, speed position 10). During the homogenizing process, the can was immersed in an ice bath. A 12.5 g aliquot of the slurry was then weighed into a glass jar and homogenized at 10,200 rpm (speed position 6). A burette filled with corn oil transferred oil into the jar, near the mixer blades, at a rate of 0.8 mL per second until the emulsion collapsed. The modification of the Swift et al. (1961) method was an objective determination of emulsion collapse through a change in resistance, which was determined using a Digital Multitester Model #GDT-190 A (GB Electrical, Inc., Milwaukee, WI). The resistance method is based on the principle that oil and fat are non-conductors, whereas the combination of protein and water has high conductivity (Webb, Ivey, Craig, Jones, & Monroe, 1970). The resistance method has a more distinct endpoint and is an objective measurement for dilute protein-based emulsions. Data were expressed as mL of oil emulsified per 2.5 g of lean meat.

2.7. Measurement of pH

A 10 g portion of either the powdered, small, composite sample or the large composite sample was used for pH determination. The meat was added to a beaker with 100 mL of distilled, deionized water, and homogenized for 30 s at 10,800 rpm (setting 5) with a Polytron (Brinkman Instruments, New York, NY). The pH was measured with a spear tip electrode (Corning Model 476580, Corning Inc., Corning, NY) with an Orion SA 720 pH meter (Orion Research, Inc., Boston, MA).

2.8. Proximate composition

Moisture and ash were determined on a portion of the small, composite sample using a LECO Thermogravimetric Analyzer-601 (Model 604-100-400, LECO Corp., St. Joseph, MI). The machine is programmed to calculate moisture and ash following a predetermined sequence of heating. Fat content was determined on another sample by Soxlet ether extraction using AOAC (1990) procedures.

2.9. Total collage content

Only muscles from yield grade 2 carcasses for all three quality grades and both weight ranges were evaluated using the method of Hill (1966). Hydroxyproline was quantified using the spectrophotometric assay outlined by Bergman and Loxley (1963) and modified by using a stronger buffer in the oxidant solution, which negated the need to raise the pH of the filtrate (Kolar, 1990). A factor of 7.25 was used to convert hydroxyproline values into total collagen values (Goll, Bray, & Huekstra, 1963). Collagen values are reported as mg of collagen per g of sample.

2.10. Total pigment and heme-iron content

The extraction method of Hornsey (1956), as modified by Lee, Hendricks, and Cornforth (1998), was used to determine total heme-iron concentration. Total pigment was determined by taking the absorbance at 640 nm times 680. Total heme iron was calculated as total pigment × 8.82/100.

2.11. Warner–Bratzler shear

One half of the muscle repetitions (i.e., two carcasses) per each of the four yield grade and three quality grade categories, from carcasses weighing 296–385 kg, for a total of 24 samples of each muscle, were cooked utilizing a dry heat cookery method.

Samples were thawed at 4 °C for 24 h and then broiled to 71 °C on a Farberware Open-Hearth Grille (Yonkers, NY). Internal temperature was monitored using a copper-constantan thermocouple (Omega Engineering, Inc., Stamford, CT). Samples were turned after reaching 35 °C. After cooking, samples were cooled at 4 °C for 24 h. Cores (1.27 cm in diameter) were removed parallel to the longitudinal orientation of the muscle fibers and sheared using a Warner–Bratzler shear device (crosshead speed = 200 mm/min) attached to an Instron Universal Testing Machine (Instron Corp., Canton, MA).

The other half of the muscle repetitions were cooked by a moist cookery method. After thawing as described above, each cut was individually placed in a preheated (204 °C) non-stick electric frying pan (Westbend Co., West Bend, WI) that was lightly sprayed with a non-stick cooking spray (Great Value, Wal-Mart Stores, Inc., Bentonville, AR). Cuts were browned for 60–90 s

on each side, depending on cut size (small cuts less, larger cuts more). After browning, a thermocouple was placed into the geometric center. The cut was then placed on a wire rack in an oven-safe Pyrex Dutch oven with 50 mL of water. The cuts were then covered and cooked to an internal temperature of 71 °C in a 135 °C oven. After reaching the endpoint temperature, cuts were promptly removed from the oven and uncovered. Samples were cooled, cored, and sheared as described for dry heat cookery.

2.12. Statistical analysis

Individual muscles and/or composite samples within each cell were analyzed statistically using the Proc Mixed and LS Means procedures of SAS (SAS Inst., Inc., Cary, NC) to test main effects and interactions at $P < 0.05$. To visualize the results, overall means were allocated into arbitrary categories of high, medium, or low.

3. Results and discussion

3.1. Objective color

Objective color (L^*, a^*, and b^*) was more affected by weight of carcass than quality grade or yield grade. Seven, eight, and six muscles for L^*, a^*, and b^*, respectively, were affected by weight ($P < 0.05$). For each of these properties (L^*, a^*, and b^*) the value increased as weight of the carcass increased. This supports observations made by Murray (1989) that smaller and leaner carcasses yielded a higher frequency of dark-colored beef (low L^* values in lighter carcasses). The majority of muscles that showed significance due to quality grade were not found to increase or decrease in a linear fashion with an increase in quality grade, suggesting that quality grade effects were minimal. Only one, two, and zero muscles for L^*, a^*, and b^*, respectively, showed a significant interaction between quality grade and weight (see Table 2).

Objective color (L^*, a^*, and b^*) means and standard deviations were 41.06 ± 4.55, 29.57 ± 4.05, and 22.78 ± 4.32, respectively, across all 39 muscles studied. Tables 3 and 6 show each muscle's mean and standard deviation for the chuck and round, respectively. The muscle abbreviations used throughout this paper are defined in Table 1. The COB muscle was found to have the highest L^* value (52.08); it was also found to be lighter ($P < 0.05$) over the other 38 muscles. The VAI muscle had the lowest L^* value (35.22, Table 6). This result can be explained by the COB muscles' external location and the visibly dense connective tissue (total collagen equaled 26.03 mg/g, and was higher ($P < 0.05$) than the other 38 muscles) due to its function for the animal. The VAI muscle on the other hand is a muscle located adjacent to the femur, and through other chemical analysis of this muscle it was observed to be significantly higher in heme-iron concentration (27.27 ppm) over the other 38 muscles and it ranked third in pH (6.14). This high pH is related to the muscle's observable color, as pH is indicative of the muscle's ability to retain water (expressible moisture equaled 39.26%) and reflect light. The SEM muscle was found to be more ($P < 0.05$) red ($a^* = 32.56$) and yellow ($b^* = 27.00$) than the other 38 muscles. No explanation can be given for these results. O'Keeffe and Hood (1982) observed that the color of beef is related to muscle type. Various muscles discolor at different rates and the shelf-life of a multiple-muscle meat cut, such as beef chuck steak, is determined by the least color-stable muscle within the cut (Faustman & Cassens, 1990). Muscle differences can be explained by an individual muscle's biological and biochemical properties.

3.2. Expressible moisture

The overall mean and standard deviation for expressible moisture over all muscles was $37.50 \pm 5.15\%$ weight loss due to centrifugation. The SAR and ADD muscles had higher ($P < 0.05$) expressible moisture values (41.74% and 41.56%, Tables 3 and 6, respectively). This can be partly explained by the lower pH (SAR = 5.61 and ADD = 5.48), which ranks them 31 and 36 out of 39 muscles (highest to lowest), respectively. The COB muscle on the other hand was observed to have the lowest expressible moisture (30.45%), was ranked fourth highest out of 39 muscles for pH (6.10), and was ranked the lowest for moisture content (64.88 mg/g). This, however, is not the sole explanation for its low expressible moisture, as the COB muscle itself is a very thin muscle located on the external surface of the beef carcass, making it more prone to dehydration. Variation in expressible moisture within the present study is supported by Hamm (1960) who observed that even within the same muscle, differences of WHC seem to occur.

In this study, expressible moisture was found to be affected the most by weight of carcass as compared to quality grade and yield grade. Six muscles out of 39 studied showed differences ($P < 0.05$) in expressible moisture due to weight, 5 of which increased as carcass weight increased. No specific reason was determined for this increase, but it may be possible that high temperature and slow chilling causes a denaturation of proteins which could potentially lead to increased moisture loss.

Yield grade × quality grade, yield grade × weight, and quality grade × weight interactions were shown to affect one, three, and two muscles, respectively. Of the three muscles showing differences due to yield grade × weight interaction, the heavier carcass weight (386 + 431 kg) tended to show higher amounts of expressible moisture.

Table 2
Description of superscripts on the least square means and standard error tables

[a] Category = main effects, two-way interactions, and three-way interactions
[b] EC = emulsion capacity (measured in mL oil emulsified/2.5 g lean)
[c] EM = expressible moisture (measured as % loss due to centrifugation)
[d] L^* = L^*-value (objective color measurement)
[e] a^* = a^*-value (objective color measurement)
[f] b^* = b^*-value (objective color measurement)
[g] Collagen = total collagen content (measured in mg/g)
[h] Heme = total heme-iron content (measured in ppm)
[i] pH = negative log concentration of hydrogen ions
[j] Fat = a component of proximate composition (measured in mg/g)
[k] Moisture = a component of proximate composition (measured in mg/g)
[l] Ash = a component of proximate composition (measured in mg/g)
[m] UC, LC, and SE = upper 2/3 choice, low choice, and select
[n] Y1, Y2, Y3, and Y4,5 = yield grade 1, yield grade 2, yield grade 3 and yield grade 4 & 5 (together)
[o] HW and LW = heavy weight and light weight
[p,q,r,s,t,u,v,w,x,y,z,a′,b′,c′,…] Values having different superscripts are significant at $P < 0.05$ level

The information gathered on muscles of the beef chuck and round as to their respective expressible moisture values may be indicative of a particular muscle's protein structure. The data can be used to select muscles that have low expressible moisture values, which therefore have a higher water holding capacity property. Muscles, which have higher water holding capacity, can best be optimized in enhanced or marinated type products which will retain the moisture and other flavor enhancing ingredients. Knowledge of a particular muscle's expressible moisture value can, therefore, lead to opportunities in creating very palatable products and to the increased economic value of that muscle.

3.3. Proximate composition

The overall mean and standard deviation for fat, moisture and ash were 6.86 ± 3.45, 72.28 ± 2.83, and 1.26 ± 0.28 mg/g, respectively. Tables 4 and 7 show each muscle's mean and standard deviation for the chuck and round, respectively, and Tables 5 and 8 present the same findings (for fat only) in graphic form. Variation in the composition of muscles of the beef carcass has been observed by many workers (Brackebusch et al., 1991; Cecchi et al., 1988; Doty & Pierce, 1961; Johnson et al., 1988). Sex of animal, yield grade, quality grade, weight of carcass, and activity and location of muscle can all play a part in the variation of composition.

Quality grade as compared to yield grade and weight of carcass had the most common effect on chemical

Table 3
Least square means and standard errors of emulsion capacity, expressible moisture, L^*, a^*, and b^* for chuck muscles

Muscle	Emulsion capacity[b]		Expressible moisture[c]		L^*-Value[d]		a^*-Value[e]		b^*-Value[f]	
	Mean	SD	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
BIB	177.55^{rst}	(14.8)	$36.65^{yaw'}$	(3.42)	$38.56^{fig'}$	(3.56)	$28.65^{c'd'e'f'}$	(3.75)	$21.85^{a'b'c'd'e'}$	(4.32)
BOT	170.83^{wxyz}	(17.9)	$35.46^{a'b'}$	(4.55)	42.66^{tu}	(2.70)	$28.79^{c'd'e'}$	(3.27)	$21.61^{c'd'e'f'}$	(3.34)
BRA	176.79^{rstuv}	(11.9)	38.26^{vwx}	(3.85)	$38.87^{d'e'f'g'}$	(4.03)	$28.08^{e'f'g'}$	(3.74)	$20.41^{g'h'}$	(4.28)
COB	$159.12^{b'}$	(22.0)	$30.45^{f'}$	(10.30)	52.08^{p}	(5.63)	$19.51^{j'}$	(4.54)	$14.68^{j'}$	(4.45)
COM	169.85^{yz}	(8.5)	$36.37^{za'}$	(5.26)	$40.58^{yza'b'}$	(2.47)	31.10^{rstu}	(3.00)	23.69^{uvwx}	(3.56)
DEL	$174.28^{rstuvwxyz}$	(16.9)	37.49^{wxyz}	(4.36)	43.80^{rst}	(3.68)	$27.47^{g'h'}$	(3.33)	$20.71^{f'g'h'}$	(3.39)
DEP	169.96^{yz}	(12.6)	39.02^{tuv}	(3.72)	41.31^{xyz}	(3.08)	$29.79^{xyza'b'}$	(3.23)	$22.56^{yza'b'c'}$	(3.52)
DSO	178.76^{rs}	(14.1)	$34.36^{b'c'}$	(4.30)	43.35^{st}	(2.64)	30.09^{vwxyz}	(3.34)	$22.79^{xyza'b'}$	(3.72)
INF	$171.89^{stuvwxyz}$	(10.0)	38.48^{uvw}	(4.10)	$38.85^{d'e'f'g'}$	(2.60)	31.25^{qrst}	(3.08)	24.82^{rst}	(3.64)
INT	178.00^{rs}	(17.2)	$32.97^{d'e'}$	(3.84)	$39.30^{c'd'e'f'}$	(4.04)	$29.98^{wxyza'b'}$	(3.17)	$22.82^{xyza'}$	(3.71)
LAD	170.31^{yz}	(12.7)	37.26^{xyz}	(3.89)	41.51^{vwxy}	(3.50)	$29.07^{b'c'd'}$	(4.03)	$22.05^{za'b'c'd'}$	(4.35)
LCA	171.47^{uvwxyz}	(11.1)	$35.92^{a'}$	(3.49)	$39.71^{b'c'd'}$	(3.83)	$29.90^{xyza'b'}$	(4.17)	$22.63^{yza'b'c'}$	(4.57)
LGC	188.56^{pq}	(15.9)	$30.94^{f'}$	(3.95)	$40.01^{a'b'c'}$	(4.31)	$27.08^{h'}$	(3.77)	$19.90^{h'}$	(3.84)
LGD	$173.22^{stuvwxyz}$	(20.6)	37.75^{wxy}	(3.90)	$40.55^{yza'b'}$	(3.03)	31.13^{rst}	(3.46)	23.98^{tuvw}	(4.00)
LVC	177.32^{rstu}	(13.9)	$32.61^{e'}$	(4.84)	$39.33^{c'd'e'f'}$	(3.87)	$29.14^{za'b'c'd'}$	(3.62)	$22.34^{yza'b'c'd'}$	(3.88)
MSD	$174.62^{rstuvwxyz}$	(15.5)	$33.90^{c'd'}$	(4.76)	$38.08^{g'}$	(3.34)	30.60^{stuvwx}	(3.87)	23.20^{wxy}	(4.94)
RHM	169.38^{z}	(11.4)	$35.83^{a'}$	(3.63)	41.35^{wxyz}	(3.04)	$28.43^{d'e'f'g'}$	(3.48)	$20.99^{e'f'g'}$	(3.90)
SCD	187.56^{q}	(35.6)	$36.57^{yza'}$	(3.82)	44.61^{qr}	(3.67)	$29.55^{yza'b'c'}$	(3.72)	$21.74^{b'c'd'e'f'}$	(3.92)
SEV	176.81^{rstuv}	(13.2)	$36.55^{yza'}$	(4.80)	$39.64^{b'c'd'e'}$	(2.98)	31.42^{qrs}	(2.87)	24.61^{rstu}	(3.49)
SPL	171.79^{uvwxyz}	(18.8)	37.57^{wxyz}	(3.92)	$40.49^{za'b'}$	(2.88)	$29.40^{yza'b'c'd'}$	(3.78)	$21.98^{za'b'c'd'e'}$	(4.19)
SPP	$173.09^{stuvwxyz}$	(13.1)	$34.47^{b'c'}$	(4.04)	44.09^{qrs}	(3.75)	$28.10^{e'f'g'}$	(3.06)	$20.78^{f'g'h'}$	(3.07)
SUB	171.22^{vwxyz}	(18.3)	37.46^{wxyz}	(4.00)	$38.65^{e'f'g'}$	(4.09)	30.30^{tuvwxy}	(2.86)	23.45^{vwxy}	(3.46)
SUP	170.46^{xyz}	(14.1)	39.67^{rstu}	(3.77)	$40.82^{yza'}$	(3.35)	30.92^{stuvw}	(3.03)	23.83^{tuvwx}	(3.51)
TEM	$161.45^{b'}$	(15.5)	38.64^{uvw}	(3.60)	41.48^{vwxyz}	(3.75)	$29.98^{wxyza'b'}$	(3.74)	23.02^{wxyz}	(4.21)
TFA	$175.71^{rstuvwxy}$	(24.5)	39.06^{tuv}	(3.62)	42.47^{tuv}	(3.17)	$28.03^{e'f'g'h'}$	(3.86)	$20.40^{g'h'}$	(4.11)
TRA	171.10^{vwxyz}	(16.7)	$34.51^{b'c'}$	(5.10)	44.89^{q}	(4.69)	$25.65^{i'}$	(4.64)	$18.44^{i'}$	(5.41)
TRB	179.82^{r}	(19.4)	40.21^{qrst}	(3.59)	$39.47^{c'd'e'f'}$	(2.80)	31.50^{qrs}	(3.62)	24.78^{rst}	(4.38)

Refer to Table 1 for muscle codes and Table 2 for description of superscripts.

Table 4
Lease square means and standard errors of total collagen, total heme-iron, pH, fat, moisture, and ash for chuck muscles

Muscles	Total collagen[g]		Total heme-iron[h]		pH[i]		Fat[j]		Moisture[k]		Ash[l]	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
BIB	22.34^{q}	(12.20)	24.70^{qrs}	(2.88)	5.91^{wxy}	(0.28)	6.79^{x}	(2.17)	72.74^{vwx}	(1.66)	1.07$^{a'b'c'd'}$	(0.19)
BOT	17.44^{rst}	(5.17)	16.86$^{i'}$	(3.12)	5.63$^{d'e'f'}$	(0.23)	6.40^{xyz}	(2.14)	73.10^{uv}	(1.47)	1.14^{yz}	(0.18)
BRA	7.91$^{za'b'c'd'e'}$	(1.55)	23.84^{rstu}	(2.85)	5.85^{yz}	(0.32)	4.04$^{f'}$	(1.23)	75.41^{p}	(1.19)	1.43st	(0.22)
COB	26.03^{p}	(7.29)	15.20$^{j'k'}$	(6.47)	6.10^{rs}	(0.26)	14.03^{p}	(4.19)	64.88$^{h'}$	(6.70)	1.04$^{b'c'd'e'}$	(0.19)
COM	10.31$^{wxyza'b'}$	(3.43)	22.14^{wxyz}	(2.13)	5.69$^{b'c'd'}$	(0.23)	8.37^{vw}	(1.88)	72.02^{xyz}	(1.48)	1.48^{r}	(0.08)
DEL	15.32^{tu}	(4.65)	16.72$^{i'}$	(2.09)	5.85^{yz}	(0.28)	6.45^{xyz}	(1.75)	73.32^{uv}	(1.71)	1.23^{x}	(0.17)
DEP	8.47$^{za'b'c'd'}$	(1.54)	19.90$^{e'f'g'}$	(3.25)	5.50$^{i'j'}$	(0.14)	5.49$^{a'b'}$	(1.93)	72.66^{vwx}	(1.32)	1.41st	(0.23)
DSO	12.22^{uvw}	(4.03)	18.35$^{h'}$	(2.18)	6.09^{rst}	(0.27)	9.07^{uv}	(2.32)	71.91$^{yza'}$	(1.89)	1.12$^{za'}$	(0.18)
INF	19.94^{qr}	(7.09)	23.55^{stuv}	(2.87)	5.97^{uvw}	(0.25)	9.18^{u}	(2.54)	70.81$^{b'c'}$	(2.05)	1.08$^{za'b'c'd'}$	(0.11)
INT	17.25^{rst}	(5.28)	23.39^{tuv}	(2.92)	6.00^{uv}	(0.24)	8.56^{uv}	(2.45)	71.86$^{yza'}$	(1.96)	1.03$^{c'd'e'}$	(0.14)
LAD	8.56$^{yza'b'c'd'}$	(1.21)	18.37$^{h'}$	(2.94)	5.64$^{c'd'e'f'}$	(0.20)	5.99$^{yza'}$	(1.51)	72.34^{wxy}	(1.41)	1.23^{x}	(0.16)
LCA	11.15^{wxy}	(2.29)	21.44$^{xyza'b'c'}$	(3.83)	6.03^{stu}	(0.22)	6.49^{xy}	(1.92)	73.23^{uv}	(1.37)	1.07$^{a'b'c'd'}$	(0.12)
LGC	19.54^{qr}	(5.82)	23.00^{uvw}	(3.40)	6.28^{p}	(0.18)	10.06^{s}	(3.48)	69.65$^{e'}$	(2.75)	1.08$^{za'b'c'd'}$	(0.20)
LGD	4.40$^{f'}$	(0.85)	22.02^{wxyz}	(4.48)	5.76$^{a'b'}$	(0.33)	7.74^{w}	(1.95)	70.52$^{c'}$	(1.58)	1.20^{xy}	(0.14)
LVC	18.70^{rs}	(4.29)	21.77$^{xyza'}$	(1.96)	6.20^{pq}	(0.28)	9.86^{t}	(2.45)	70.39$^{c'd'}$	(1.95)	1.09$^{za'b'c'}$	(0.17)
MSD	11.89^{vwx}	(3.82)	24.93^{qr}	(2.45)	5.97^{uvw}	(0.32)	14.22^{p}	(2.67)	68.04$^{g'}$	(2.11)	1.01$^{d'e'}$	(0.21)
RHM	8.49$^{za'b'c'd'}$	(2.61)	20.69$^{a'b'c'd'e'}$	(3.45)	5.72$^{a'b'c'}$	(0.21)	6.35^{xyz}	(1.93)	72.08^{xyz}	(1.43)	1.38^{tu}	(0.15)
SCD	8.56$^{yza'b'c'd'}$	(2.86)	15.75$^{i'j'k'}$	(1.99)	5.89^{xy}	(0.30)	9.11^{uv}	(3.11)	71.22$^{a'b'}$	(2.53)	0.98$^{e'f'}$	(0.18)
SEV	6.97$^{c'd'e'f'}$	(1.66)	24.33^{qrst}	(3.13)	5.92^{wxy}	(0.23)	12.21^{q}	(3.05)	68.77$^{f'}$	(2.43)	1.02$^{d'e'}$	(0.11)
SPL	9.76$^{wxyza'b'c'}$	(2.75)	19.37$^{g'h'}$	(3.18)	5.55$^{g'h'i'}$	(0.14)	4.35$^{e'f'}$	(1.44)	74.43^{qr}	(1.39)	1.33^{uv}	(0.24)
SPP	16.16st	(4.48)	20.15$^{d'e'f'g'}$	(4.97)	5.94^{vwx}	(0.30)	10.66^{r}	(2.90)	69.79$^{d'e'}$	(2.29)	1.10$^{za'b'}$	(0.09)
SUB	15.33^{tu}	(7.02)	20.55$^{b'c'd'e'f'}$	(2.39)	6.02^{tuv}	(0.31)	4.60$^{c'd'e'f'}$	(1.26)	73.21^{uv}	(1.19)	1.31^{vw}	(0.20)
SUP	9.46$^{wxyza'b'c'd'}$	(2.04)	21.47$^{xyza'b'c'}$	(3.25)	5.69$^{b'c'd'}$	(0.24)	4.95$^{b'c'd'e'}$	(1.08)	74.29^{qrs}	(0.95)	1.37^{tuv}	(0.15)
TEM	8.56$^{yza'b'c'd'}$	(3.94)	19.94$^{e'f'g'}$	(2.33)	5.66$^{c'd'e'}$	(0.29)	5.25$^{a'b'c'}$	(1.29)	73.54^{stu}	(1.11)	1.23^{x}	(0.31)
TFA	8.74$^{xyza'b'c'd'}$	(2.36)	14.74$^{k'}$	(2.91)	5.72$^{a'b'c'}$	(0.31)	4.57$^{c'd'e'f'}$	(1.36)	74.08^{rst}	(1.16)	1.24^{wx}	(0.15)
TRA	19.10^{qrs}	(5.20)	16.03$^{i'j'}$	(3.19)	5.90^{wxy}	(0.29)	8.65^{uv}	(1.91)	71.62$^{yza'}$	(2.06)	0.93$^{f'}$	(0.11)
TRB	10.47$^{wxyza'b'}$	(2.61)	21.53$^{xyza'b'}$	(2.43)	5.66$^{c'd'e'}$	(0.24)	5.65$^{za'b'}$	(1.55)	73.23^{uv}	(1.27)	1.44st	(0.17)

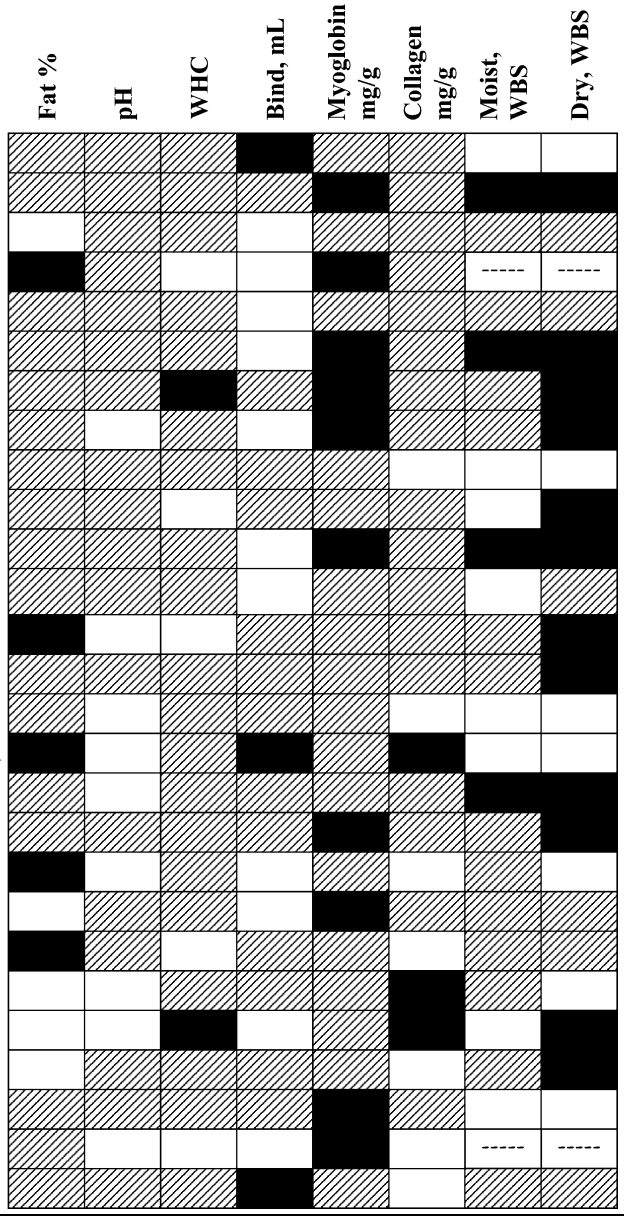
Refer to Table 1 for muscle codes and Table 2 for description of superscripts.

composition (fat, moisture, and ash) in muscles of the beef chuck and round. Thirty-one (fat), twenty-three (moisture), and fifteen (ash) muscles, respectively, were affected ($P < 0.05$) by quality grade. Fat increased as quality grade increased in 26 out of the 31 muscles showing differences. As marbling increases fat content also increases, and water content decreases in a linear fashion (Brackebusch et al., 1991; Hedrick et al., 1981; McBee & Wiles, 1967; Romans et al., 1965a). This is consistent with the present results, as moisture (19 out of 23 muscles) and ash (6 out of 15 muscles) decreased in a linear fashion with an increase in quality grade. These results are further supported by Walter, Goll, Kline, Anderson, and Carlin (1965) who observed that percentage moisture decreased and percentage ether extract (fat) increased with increased marbling scores.

3.4. Emulsion capacity

Emulsion capacity reflects the ability of meat proteins to stabilize fat in a model system (Swift & Sulzbacher, 1963). Knowledge of the capacity of various types of meat to emulsify fat is of considerable economic importance in the manufacture of sausage products (Acton & Saffle, 1969). The beef chuck and round muscles had an overall mean and standard deviation of 174.2 ± 18.8 mL oil emulsified/2.5 g of lean for emulsion capacity. Tables 3 and 6 show each muscle's mean and standard deviation for the beef chuck and round, respectively, and Tables 5 and 8 present the same findings in graphic form. The SEM muscle was found to have the highest ($P < 0.05$) emulsion capacity value (194.1 mL oil/2.5 g lean) of the 39 muscles studied, while the PEC muscle had the lowest emulsion capacity value (157.9 mL oil/2.5 g lean). The observed variation can best be explained by the differences in salt-soluble protein content among the 39 muscles studied. Although salt-soluble content was not analyzed in our study, it has been proposed that the ability to form stable emulsions is due to the different amounts of soluble protein which could be extracted from different meats (Carpenter & Saffle, 1964). This is further supported by Carpenter and Saffle (1964) who found a correlation coefficient of $r = 0.956$ between mg/mL of soluble protein and mL of oil emulsified. Saffle (1968) stated that there is considerable variation in the amount of protein extracted during batter formation because of the relatively wide variation in pH among various animals and even among various muscles of the same animal. The amount of salt-soluble protein is likely the major factor affecting the quantity of fat, which may be emulsified.

Table 5
Classification of beef chuck muscles by trait



The white cells represent fat <5%, pH > 5.8, WHC (expressible moisture) <36%, bind >175 mL, heme-iron >25 ppm, collagen <10 mg/g, Warner–Bratzler shear (WBS) force for moist or dry cooking <37.76 N, while the black cells represent fat >10%, pH < 5.7, WHC >38%, bind <170 mL, heme-iron <20 ppm, collagen >15 mg/g, and WBS >47.96 N. The values represented by the striped cells are intermediate.

In this study, quality grade was the most common factor influencing emulsion capacity. Of the 39 muscles studied, 17 were affected by quality grade ($P < 0.05$). However, of these 17 muscles, only three muscles increased with an increase in quality grade (from Select to upper 2/3 Choice) and one muscle decreased as quality grade increased. All other muscles (13) showing significance due to quality grade were found to be non-linear with quality grade (either increasing or decreasing). Only two muscles showed an interaction of quality grade and yield grade.

Results of emulsion capacity of muscles from the beef chuck and round can assist in the production of sausage-type products. This may be done by choosing muscles that have a high emulsion capacity. Although muscles showing higher emulsion capacity values are able to hold more fat, it may be possible to use less lean meat (when the emulsion capacity is known for a particular muscle) to create a stable emulsion/batter and a desirable product. This characteristic of muscles from the beef chuck and round can, therefore, lead to economically efficient utilization of muscles.

Table 6
Least square means and standard errors of emulsion capacity, expressible moisture, L^*, a^*, and b^* for round muscles

Muscles	Emulsion capacity[b]		Expressible moisture[c]		L^*-Value[d]		a^*-Value[e]		b^*-Value[f]	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
ADD	176.50^{rstuvw}	(18.9)	41.56^{p}	(3.95)	42.32 ^{uvw}	(4.08)	31.09^{rstu}	(3.71)	25.47^{r}	(3.00)
BIF	176.10^{rstuvwx}	(18.1)	40.81^{pqr}	(3.06)	41.38^{wxyz}	(2.78)	32.14^{pq}	(2.61)	26.55^{pq}	(2.62)
GLM	161.52$^{a'b'}$	(21.5)	37.60^{wxyz}	(4.35)	44.53^{qr}	(3.55)	27.74$^{f'g'h'}$	(4.42)	22.47$^{yza'b'c'}$	(3.14)
GRA	175.72^{rstuvwxy}	(16.5)	40.53^{pqr}	(4.65)	36.15$^{h'}$	(2.92)	30.89^{stuvwx}	(3.05)	23.48^{uvwxy}	(3.54)
PEC	157.86$^{b'}$	(16.5)	40.30^{qrs}	(3.26)	42.10^{uvwx}	(4.54)	31.96^{pqr}	(2.14)	25.44^{r}	(2.51)
REF	174.93^{rstuvwxyz}	(20.0)	40.33^{qrs}	(3.32)	41.08^{yz}	(3.01)	30.29^{tuvwxy}	(3.32)	25.16^{rs}	(2.38)
SAR	168.61$^{za'}$	(17.1)	41.74^{p}	(3.81)	40.79$^{yza'}$	(3.07)	29.10$^{a'b'c'd'}$	(3.13)	21.39$^{d'e'f'g'}$	(3.15)
SEM	194.11^{p}	(31.7)	40.77^{pqr}	(2.71)	39.44$^{c'd'e'f'}$	(2.96)	32.56^{p}	(2.53)	27.00^{p}	(2.57)
SET	171.88^{tuvwxyz}	(17.1)	39.06^{tuv}	(3.88)	44.39^{qr}	(3.11)	30.06$^{vwxyza'}$	(2.23)	24.27^{stuv}	(2.11)
VAI	189.93^{pq}	(16.6)	39.26^{stuv}	(4.18)	35.22$^{h'}$	(2.99)	30.16^{uvwxy}	(1.81)	23.32^{vwxy}	(2.27)
VAL	176.08^{rstuvwxy}	(15.8)	40.33^{qrs}	(4.62)	39.45$^{c'd'e'f'}$	(2.75)	31.95^{pqr}	(2.35)	25.65^{qr}	(2.70)
VAM	179.84^{r}	(19.8)	41.39^{pq}	(3.72)	35.38$^{h'}$	(3.53)	31.03^{rstuv}	(2.65)	24.26^{stuv}	(3.51)

Refer to Table 1 for muscle codes and Table 2 for description of superscripts.

3.5. Muscle pH

The overall mean and standard deviation for pH was 5.78 ± 0.32. Tables 4 and 7 show each muscle's mean and standard deviation for the chuck and round, respectively, and Tables 5 and 8 present the same findings in graphic form. In our study, the LGC muscle (pH 6.28) was observed to be higher ($P < 0.05$) than the other 38 muscles (Tables 4 and 7) and the GLM muscle had the lowest pH (5.45). Variation in pH has been shown between muscles as well as within a particular muscle (Gariepy, Jones, & Robertson, 1990).

Callow (1939) suggested that proximity to bone might be one reason for variation in muscle pH. Neutralization of lactic acid by calcium carbonate in the bone may cause a rise in pH, but Bate-Smith (1948) felt a more likely explanation was variation in connective tissue. As the muscle narrows towards its tendinous insertion, the relative amount of tendon to muscle increases, the lactic acid produced per gram of tissue decreases, and the fall in pH will be correspondingly reduced (Bate-Smith, 1948).

The effect of quality grade on muscle pH was most prominent, as 16 muscles were influenced ($P < 0.05$) by quality grade. The relationships were inconsistent, however, as seven of the 16 muscles showed an increase in muscle pH as quality grade increased (from Select to upper 2/3 Choice), one muscle decreased with an increase in quality grade and the remaining muscles (8) had no linear relationship to quality grade. Breidenstein et al. (1968) observed that muscle pH was unaffected by marbling or maturity of the beef carcass. Their findings are in agreement with Doty and Pierce (1961), who also found no relation between pH and carcass grade or weight.

3.6. Total collagen content

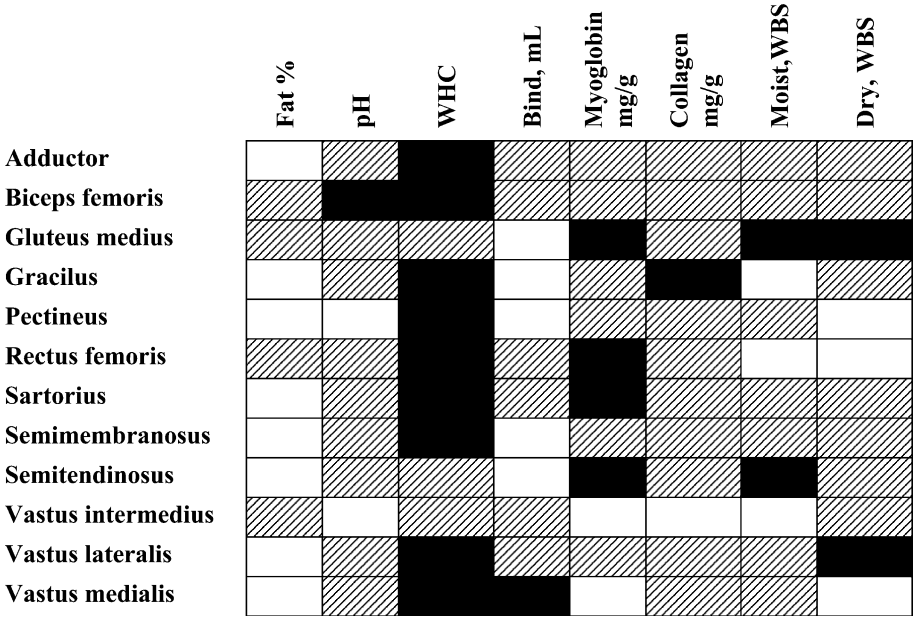
Considerable variation in total collagen content among the 39 muscles was evident, with a mean and

Table 7
Least square means and standard errors of total collagen, total heme-iron, pH, fat, moisture, and ash for round muscles

Muscles	Total collagen[g]		Total heme-iron[h]		pH[i]		Fat[j]		Moisture[k]		Ash[l]	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
ADD	6.47$^{d'e'f'}$	(1.94)	22.57^{vwx}	(2.70)	5.48$^{i'j'}$	(0.11)	4.57$^{c'd'e'f'}$	(1.21)	72.86^{uvw}	(0.87)	1.49^{q}	(0.23)
BIF	10.57$^{wxyza'}$	(1.77)	22.43^{vwxy}	(3.48)	5.48$^{i'j'}$	(0.12)	6.86^{x}	(1.65)	71.61$^{za'}$	(1.29)	1.29^{vw}	(0.17)
GLM	15.06^{tuv}	(5.37)	19.76$^{e'f'g'}$	(2.57)	5.45$^{j'}$	(0.18)	5.94$^{yza'}$	(1.69)	71.44$^{za'b'}$	(1.51)	1.40st	(0.16)
GRA	8.61$^{xyza'b'c'd'}$	(1.79)	24.31^{qrst}	(4.22)	5.69$^{b'c'd'}$	(0.13)	3.93$^{f'g'}$	(1.24)	74.78^{pqr}	(1.06)	1.51^{q}	(0.17)
PEC	7.11$^{b'c'd'e'f'}$	(3.53)	21.28$^{yza'b'c'd'}$	(2.64)	5.63$^{d'e'f'g'}$	(0.17)	3.16$^{g'h'}$	(0.83)	74.45^{qr}	(0.83)	1.56^{q}	(0.18)
REF	8.33$^{za'b'c'd'}$	(2.52)	19.60$^{e'f'g'}$	(3.10)	5.58$^{f'g'h'}$	(0.17)	5.11$^{b'c'd'}$	(1.79)	73.33^{uv}	(1.22)	1.50^{q}	(0.17)
SAR	5.00$^{f'}$	(2.30)	19.40$^{f'g'h'}$	(2.87)	5.61$^{e'f'g'h'}$	(0.16)	3.14$^{h'}$	(1.29)	74.69^{qr}	(1.11)	1.54^{q}	(0.27)
SEM	6.51$^{d'e'f'}$	(1.25)	21.22$^{za'b'c'd'}$	(3.29)	5.54$^{h'i'}$	(0.12)	4.36$^{e'f'}$	(1.24)	72.79^{vw}	(0.78)	1.75^{p}	(0.26)
SET	8.33$^{za'b'c'd'}$	(1.05)	14.65$^{k'}$	(2.16)	5.45$^{j'}$	(0.11)	4.08$^{f'}$	(0.90)	73.27^{uv}	(0.77)	1.53^{q}	(0.15)
VAI	11.08^{wxyz}	(3.46)	27.27^{p}	(2.92)	6.14^{qr}	(0.36)	8.43^{uvw}	(2.56)	72.91^{uvw}	(1.77)	0.98$^{e'f'}$	(0.11)
VAL	7.52$^{a'b'c'd'e'f'}$	(1.73)	20.29$^{c'd'e'f'g'}$	(3.18)	5.78$^{za'}$	(0.21)	4.44$^{d'e'f'}$	(1.15)	73.54^{tu}	(0.97)	1.53^{q}	(0.26)
VAM	8.29$^{za'b'c'd'}$	(3.32)	25.45^{q}	(3.58)	5.68$^{b'c'd'e'}$	(0.18)	4.35$^{e'f'}$	(1.27)	75.02^{pq}	(1.14)	1.47^{s}	(0.33)

Refer to Table 1 for muscle codes and Table 2 for description of superscripts.

Table 8
Classification of beef round muscles by trait



The white cells represent fat <5%, pH > 5.8, WHC (expressible moisture) <36%, bind >175 mL, heme-iron >25 ppm, collagen <10 mg/g, Warner–Bratzler shear (WBS) force for moist or dry cooking <37.76 N, while the black cells represent fat >10%, pH < 5.7, WHC >38%, bind <170 mL, heme-iron <20 ppm, collagen >15 mg/g, and WBS >47.96 N. The values represented by striped cells are intermediate.

standard deviation of 11.69 ± 6.54 mg of collagen/g of lean tissue. Tables 4 and 7 show each muscle's mean and standard deviation for the chuck and round muscles, respectively, and Tables 5 and 8 present the same findings in graphic form. As shown in Tables 4 and 7, the COB muscle had a higher ($P < 0.05$) collagen content (26.03 mg/g) than the other 38 muscles studied. This result may again be explained by its location and function in the beef carcass. The LGD muscle had the lowest collagen content (4.40 mg/g). Johnson et al. (1988), Light et al. (1985), McKeith et al. (1985) and Prost et al. (1975b) studied 7, 6, 13 and 33 different muscles, respectively, and observed variation in total collagen percentage. In comparing muscles from the studies of Johnson et al. (1988) and McKeith et al. (1985), a majority of the muscles in the present study showed higher amounts (mg/g) of collagen than the same muscles of the other two researchers.

Total collagen content has not been studied extensively in relation to quality grade, yield grade, and weight of carcass. In our study, quality grade affected ($P < 0.05$) four of the 39 muscles studied. None of them increased or decreased in a linear fashion with an increase in quality grade. Wilson et al. (1954) failed to find consistent effects on collagen associated with the grade or the amount of intramuscular fat in beef carcasses. Only two muscles showed an interaction of quality grade and weight. For these two muscles, the higher quality grades (upper 2/3 Choice and low Choice) were higher in collagen than the Select quality grade. The results of total collagen content in muscles of the beef chuck and round can be used to identify muscles having the opportunity to be used in value-added type products.

3.7. Total heme-iron concentration

The mean and standard deviation for total heme-iron concentration was 20.78 ± 4.43 ppm (parts per million) across all 39 muscles studied. Tables 4 and 7 show each muscle's mean and standard deviation for the chuck and round, respectively, and Tables 5 and 8 present the same findings in graphic form. As seen in Tables 4 and 7, the VAI muscle has a higher ($P < 0.05$) heme-iron concentration (27.27 ppm) than the other 38 muscles studied. As stated earlier in Section 3, this muscle also has a high pH (6.14) and the lowest L^* value (35.22), both of which may play important roles in determining the heme-iron concentration of a muscle. The SET muscle, on the other hand, had the lowest heme-iron concentration (14.65 ppm), the second to lowest pH (5.45), and was ranked fifth out of 39 (highest to lowest) in L^* value

(44.39). Giddings (1977) stated that the basis of color in muscle foods resides in the intracellular heme protein myoglobin with a lesser and more variable contribution by the closely related blood pigment, hemoglobin. This agrees with Wismer-Pedersen (1958), who stated that meat color depends on the pigment concentration and on the meat structure. The muscle heme pigment myoglobin is the principal but not the whole source of meat color as hemoglobin, the blood pigment, will comprise 20–30% of the total pigment present (Fox, 1966). Fleming, Blumer, and Craig (1960), Hunt and Hedrick (1977), Rickansrud and Henrickson (1967) and Schricker et al. (1982) observed differences in the proportion of hemoglobin and myoglobin in varying muscles of a beef carcass.

Rickansrud and Henrickson (1967) reported that residual blood (hemoglobin) varies between muscles, which would result in the varying proportions of these pigments. Lawrie (1950) stated that physical activity is the fundamental factor responsible for controlling the amount of the pigment found in any muscle. The variation in concentration of myoglobin can affect color not only in fresh meat applications (whole muscle), but in processed meat applications (frankfurters, sausage and cured meat products) as well.

Quality grade, yield grade, and weight showed little to no effect on total heme-iron concentration across the 39 muscles studied. Romans et al. (1965b) observed that marbling had no effect on myoglobin or hemoglobin concentration. This is in agreement with Doty and Pierce (1961) who observed that extractable pigment was unrelated to carcass grade or weight. In this study, four and five muscles, respectively, had yield grade × quality grade and yield grade × weight interactions ($P < 0.05$), but no consistent patterns were evident.

For comparative purposes (Tables 5 and 8), muscles were classified as tender (shear force <37.76 N), intermediate (shear force <47.96 and >37.76 N) or tough (shear force >47.96 N). Muscles within all three categories were found both within the chuck and within the round. This suggests underutilized muscles may exist within these cuts. The full results of this portion of the study can be found in a publication by Brickler (2000).

4. Conclusions

Variation was observed in all traits (objective color, expressible moisture, emulsion capacity, pH, proximate composition, total collagen content, and total heme-iron concentration) among the 39 muscles studied. It was generally observed that quality grade most often had an effect, with weight and yield grade having fewer effects. This information now allows informed decisions to be made in the process of selecting individual muscles from the beef chuck and round for the production of added-value products.

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