THE INFLUENCE OF MUSCLE FIBER SIZE ON TENDERNESS IN A-MATURITY HEIFERS[1]

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ABSTRACT

A total of 77 crossbred late-maturing or intermediate-maturing heifers were fed an 84% total digestible nutrient diet from 200 kg live-weight to slaughter at 433 kg. Carcass data and histochemical samples were obtained at 24 h postmortem, and shear and sensory panel evaluation samples were obtained from the longissimus dorsi muscle after 7 days of aging at 2 to 3°C. Average fiber size was correlated ($P< 0.01$) to sensory panel tenderness and shear force requirements. Cross-sectional areas of white, intermediate and red fibers were also correlated ($P< 0.01$) to shear force requirements. Percentages of white, intermediate and red fibers were not consistently correlated to sensory tenderness or shear force. Evidently, the number of myofibrils per unit of mass was associated with meat tenderness. Research needs to be done to determine if fiber size has a causal relationship with tenderness or is a correlated response to other factors that dictate tenderness.

INTRODUCTION

The tenderness of beef has been reported to be the result of numerous factors such as postmortem proteolysis, collagen content and solubility, sarcomere length and fat content of lean. One factor that should not be overlooked is that of muscle fiber size. Meat with large muscle fibers tends to be less tender than meat with small muscle fibers. For example, bulls tend to have larger fibers than steers and are less tender (Seideman *et al.* 1982). Muscles with large muscle fibers (i.e., semitendinosus) are less tender than meat with small muscle fibers

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(i.e., psoas major). Berry *et al.* (1971) reported that there was very little relationship between muscle fiber diameter and tenderness when the influence exerted by chronological age was removed, whereas, Lewis *et al.* (1977) found a low but significant correlation between fiber diameter and shear force. Tuma *et al.* (1962) observed a correlation of 0.47 between fiber diameter and shear force at 48 h postmortem and a low, nonsignificant correlation of −0.04 after 14 days of aging.

MATERIALS AND METHODS

Cattle

A total of 77 late-maturing crossbred heifers (Simmental sires × Angus or Hereford dams) or intermediate maturing heifers (Hereford × Angus cross) were slaughtered at 13 months of age at the Roman L. Hruska U.S. Meat Animal Research Center. After attaining live-animal weights of 200 kg, heifers were fed an 85% total digestible nutrient corn-corn silage diet supplemented with soybean meal (crude protein of the diet was 10.5%). Animals were slaughtered when they attained weights of 433 kg.

Carcasses

After slaughter, carcasses were chilled at 0.2 °C for 24 h and then moved into a holding cooler (2 °C). Carcasses were evaluated at 24 h for lean color (1 = dark red; 8 = bleached red), lean firmness (1 = very soft; 8 = very firm), lean texture (1 = very coarse; 8 = very fine), marbling (200–299 = slight; 300–399 = small; 400–499 = modest), fat thickness and ribeye area.

Fiber Type Characteristics

A center section of the longissimus muscle was removed at 24 h postmortem from the loin in the region of the 13th rib of each carcass. The section was frozen in liquid nitrogen, wrapped in aluminum foil and stored in an ultralow freezer (−63 °C). Transverse sections of each muscle sample were cut 10 μm thick using a cryostat and stained or alkali-stable ATPase as described by Guth and Samaha (1970). Serial sections were stained for succinate dehydrogenase activity according to procedures described by Troyer (1980). Sections were later photographed and enlarged. Fibers were then counted and classified as red, white or intermediate based on staining intensity. The area of ten fibers each type was then determined using a Bioquant particle size analyzer. Muscle fiber type characteristics are expressed as a percentage of red, intermediate, or white muscle fibers, mean area (μm^2) of red, intermediate or white muscle fibers and as percent areas of red, intermediate or white fiber types which were calculated from the percent and area of each fiber type.

Fat and Moisture in Longissimus Muscle

The longissimus muscle in the 13th rib region of each carcass was removed, frozen in liquid nitrogen and powdered in a Waring Blendor. The percentages of moisture and fat were determined by oven-drying 2 g at 100 °C for 12 h and ether extraction of the dried sample for 12 h (AOAC 1980).

Sensory Tenderness and Shear Force Determination

Loins were removed from carcasses 7 days postmortem and frozen at −30 °C. A frozen loin from each carcass was cut into 3 (2.5 cm thick) steaks starting from the 13th rib end or each loin. The middle steak was used for shear force determination and the first and third steaks were used for sensory tenderness rating.

Frozen steaks were tempered overnight at 4 °C and cooked to an internal temperature of 70 °C on Farberware Open Hearth broilers. The internal temperature of each steak was monitored by iron/constantan thermocouples placed in the geometric center of each steak. Steaks were cooled overnight (4 °C). A minimum of 6 cores (1.25 cm diameter) were removed from each steak parallel to fiber detection. Each core was sheared twice with a Warner-Bratzler shear device attached to an Instron Universal Testing machine (Model 1132) with a microprocessor (Microcon II). The machine was set at 75% fail criterion and 5 cm/min crosshead speed.

The two steaks for sensory evaluation were cooked as previously described. Steaks were then cut into cubes and presented to an 8 to 10 member descriptive attribute panel that had been trained and tested according to methods described by AMSA (1978) and Cross *et al.* (1978). Panelists were asked to evaluate the tenderness of samples (1 = extremely tough to 8 = extremely tender).

RESULTS

A description of the population used in this study is found in Table 1. Carcasses varied substantially in most carcass traits. Shear force values also showed substantial variation (3.24 to 9.78 kg) as did fiber type characteristics to include cross-sectional areas of various fiber types and average fiber sizes.

Correlation coefficients among carcass traits and meat properties are shown in Table 2. Lean color, lean firmness, lean texture, marbling and percentage of fat in the longissimus muscle were all positively correlated to sensory tenderness ratings and negatively correlated to shear force values. These correlations would tend to suggest that meat that was light in color, firm with fine texture and has greater levels of intramuscular fat was tender.

TABLE 1.
DESCRIPTION OF POPULATION IN STUDY

Trait and/or characteristic	Mean	Standard deviation	Minimum	Maximum
Carcass traits				
Lean color[a]	5.52	0.73	3.00	7.00
Lean firmness[b]	5.26	0.76	3.00	6.00
Lean texture[c]	5.08	0.86	3.00	6.00
Marbling[d]	448.00	106.82	240.00	840.00
Fat thickness, cm	1.22	0.40	0.64	2.29
Adjusted fat thickness	1.09	0.40	0.51	2.29
Ribeye area (cm^2)	72.00	7.49	59.35	107.74
Fat in longissimus (%)	5.50	1.44	2.38	8.69
Sensory tenderness rating[e]	5.30	0.34	4.29	5.94
Shear force (kg)	5.53	1.28	3.24	9.78
Fiber type characteristics				
Percentages				
White	55.88	7.11	33.33	76.64
Intermediate	19.46	7.06	7.38	43.43
Red	24.66	4.87	11.21	35.34
Cross-sectional areas (μm^2)				
White	4498	912	2449	6639
Intermediate	2812	818	1281	4799
Red	2671	812	1334	4690
Percentage area				
White	67.55	8.91	46.82	87.25
Intermediate	14.90	6.72	3.12	34.74
Red	17.55	4.99	6.93	29.53
Average fiber size[f]	3327	736	1902	4970
Average fiber size (proportionate basis)[g]	3728	752	2089	5580

[a]Lean color (very dark = 1 to bleached red = 8).
[b]Lean firmness (very soft = 1 to very firm = 8).
[c]Lean texture (very coarse = 1 to very fine = 8).
[d]Marbling (traces = 200 to 299; slight = 300 to 399; small = 400 to 499 etc).
[e]Sensory tenderness (extremely tough = 1 to extremely tender = 8).
[f]Average fiber size (cross-sectional areas of red, intermediate and white fibers divided by 3).
[g]Average fiber size adjusted for percentage of red, intermediate and white fibers.

Correlation coefficients among carcass and meat traits with muscle fiber type characteristics are presented in Table 3. Lean color and firmness were negatively correlated to the cross-sectional area of red muscle fibers. Sensory tenderness ratings and shear force values were significantly correlated with the cross-sectional areas of white, intermediate and red muscle fibers and average fiber size.

TABLE 2.
CORRELATION COEFFICIENTS BETWEEN CARCASS TRAITS AND MEAT PROPERTIES[a,b]

	Lean color	Lean firmness	Lean texture	Marbling	Fat thickness	Adj. fat thickness	Ribeye area	LD fat (%)	Sensory tenderness
Lean firmness	0.40								
Lean texture	0.46	0.64							
Marbling	0.04	0.22	0.18						
Fat thickness	0.13	0.05	0.10	0.04					
Adj. fat thickness	0.07	0.03	0.06	0.02	0.93				
Ribeye area	-0.03	0.16	-0.05	0.06	-0.13	-0.22			
LD Fat (%)	-0.03	0.02	0.04	0.57	0.14	0.19	-0.29		
Sensory tenderness	0.26	0.35	0.30	0.27	0.12	0.12	-0.08	0.27	
Shear force	-0.29	-0.32	-0.30	-0.24	0.00	0.00	0.12	-0.18	-0.72

[a]Correlations having absolute values ≥ 0.22 are statistically significant at the $P < 0.05$ level.
[b]Correlations having absolute values ≥ 0.28 are statistically significant at the $P < 0.01$ level.

TABLE 3.
CORRELATION COEFFICIENTS BETWEEN CARCASS/MEAT TRAITS AND MUSCLE FIBER TYPE CHARACTERISTICS[a,b]

	Muscle fiber type characteristics										
	Percentages			Cross-sectional areas			Percentage area				
Carcass/meat traits	White	Inter-mediate	Red	White	Inter-mediate	Red	White	Inter-mediate	Red	Ave. fiber size	Ave. fiber size (proportionate basis)
Lean color	0.09	-0.10	0.01	-0.16	-0.15	-0.23	0.13	-0.09	-0.11	-0.18	-0.21
Lean firmness	0.07	-0.15	0.11	0.04	-0.19	-0.23	0.22	-0.23	-0.09	-0.08	-0.14
Lean texture	0.12	-0.19	0.10	0.04	-0.04	-0.16	0.20	-0.20	-0.09	-0.01	-0.06
Marbling	-0.09	0.02	0.10	-0.03	-0.16	-0.16	0.04	-0.02	-0.05	-0.11	-0.13
Fat thickness	-0.07	0.09	-0.03	0.11	0.09	0.06	0.00	0.07	-0.10	0.09	0.10
Adj. fat thickness	-0.04	0.05	-0.01	0.08	0.01	0.02	0.04	0.02	-0.10	0.05	0.05
Ribeye area	-0.29	0.30	-0.01	0.15	0.08	0.08	-0.22	0.28	0.02	0.08	0.12
LD fat (%)	-0.01	-0.04	0.05	-0.06	-0.05	-0.06	0.03	-0.04	0.00	-0.06	-0.07
Sensory tenderness	0.12	-0.15	0.04	-0.28	-0.20	-0.26	0.12	-0.12	-0.05	-0.29	-0.29
Shear force	-0.08	0.22	-0.20	0.33	0.29	0.33	-0.12	0.19	-0.04	0.36	0.37

[a]Correlations having absolute values ≥ 0.22 are statistically significant at the $P < 0.05$ level.
[a]Correlations having absolute values ≥ 0.28 are statistically significant at the $P < 0.01$ level.

DISCUSSION

Results obtained from presently reported research show a negative relationship between ultimate tenderness and cross-sectional area of muscle fibers. Lewis *et al.* (1977) concluded that low but significant correlations were found between tenderness and fiber diameter. Herring *et al.* (1965) found a high correlation between fiber diameter and tenderness (r = 0.73), however, in that study the authors were comparing the tenderness of fiber diameter of muscles that were under tension while undergoing rigor with the same muscles that were under no tension during development of rigor. These workers also reported a high (r = −0.82) correlation between fiber diameter and sarcomere length. It is within reason to assume that as a muscle fiber shortens, as in the case of cold-shortening, the diameter of the fiber increases. In work reported presently, the lack of tenderness attributable to cold-shortening may in fact be due to the increased fiber diameter or cross-sectional area and not sarcomere length. Larger fibers are probably less tender than small fibers due to the increased number of myofibrils per unit area. Other than cold-shortening, other factors such as sex of animal and muscle location may also be sources of variation in fiber size. Bulls tend to have larger fibers than steers and tend to be less tender. Various muscles that are involved in locomotive functions have substantially larger fibers than steers and tend to be less tender. Various muscles that are involved in locomotive functions have substantially larger fibers than support muscles. Although the differences in tenderness of these muscles is generally attributable to connective tissue, it could be due to fiber size. Swanson *et al.* (1965) found that a great deal of variability in muscle fiber size existed among different positions along the longissimus dorsi. This might explain why tenderness also varies along this muscle. Various breeds of cattle have larger muscle fibers than others. In the Germ Plasm Evaluation project at the Roman L. Hruska U.S. Meat Animal Research Center, it has been observed that Bos Indicus (Brahman and Sahiwal) × Angus or Hereford tend to have substantially larger fibers than straight Bos Taurus breeds (Hereford × Angus) and produce less tender meat. In swine, Allen *et al.* (1966) concluded that the diameter of muscle fibers was a very highly heritable trait but Staun (1968) reported that the heritability estimates of muscle fiber diameter ranged from 0.17 to 0.31.

Tuma *et al.* (1962) found a correlation (r=0.47) between fiber diameter and shear force 48 h postmortem but the correlation was only −0.04 after 14 days of aging. This would suggest that average fiber size could play a major role in meat tenderness at early periods postmortem but loses its importance over time to postmortem proteolysis.

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