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Factors Associated with Tenderness in Young Beef *

S. C. Seideman,† M. Koohmaraie‡

United States Department of Agriculture, Clay Center, NE 68933, USA

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J. D. Crouse§

ARS, Roman L. Hruska US Meat Animal Research Center,
PO Box 166, Clay Center, NE 68933, USA

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SUMMARY

One hundred and twenty-two crossbred steers of varying percentages of Bos Indicus and Bos Taurus breeding were slaughtered to determine the relationship of carcass and meat characteristics to tenderness. Carcasses were graded and longissimus dorsi *muscle samples were evaluated for fibre type characteristics, sensory and shear force determination, sarcomere length, intramuscular fat content, collagen content and solubility and fragmentation index. Sarcomere length and collagen content and solubility were not significantly related to shear force values or sensory tenderness ratings. The fragmentation index was highly correlated to sensory tenderness ratings ($r = -0{\cdot}60$) and shear force values ($r = 0{\cdot}53$) indicating that variation in tenderness is associated with myofibrillar protein degradation. A four variable regression equation that included fragmentation index, lean colour, marbling and per cent red fibres accounted for 56% of the variation in sensory tenderness. Fragmentation index directly accounted for 30% of the variation in sensory tenderness in the four variable equation.*

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† Present address: Bryan Foods, PO Box 11771, West Point, MS 39773, USA.
‡ Present address: Department of Food Science, Michigan State University, East Lansing, MI 48814, USA.
§ Author to whom all corresponence should be addressed.

INTRODUCTION

Factors that have been associated with the tenderness of beef include sarcomere length (Jeremiah, 1978), the amount and solubility of collagen (Sims & Bailey, 1980), post-mortem proteolysis via calcium-activated factor or cathepsins (Goll *et al.*, 1983), pH and temperature decline (Asghar & Yeates, 1978), protein solubility, fragmentation index (Parrish, 1977), marbling or intramuscular fat (Smith & Carpenter, 1976) and muscle fibre characteristics (Tuma *et al.*, 1962; Lewis *et al.*, 1977; Olson *et al.*, 1977). Most of these factors are probably interrelated among each other. For example, marbling tends to be correlated with tenderness when evaluated over a wide range of tenderness values (Campion *et al.*, 1975); however, there may be a correlated response to variation in other muscle characteristics that are more important in determining tenderness. In order to study these interrelationships, one needs to sample a relatively large population of cattle and examine as many of the factors associated with tenderness as possible. The objective of the present study was to identify the factors that determine, or are related to, variation in tenderness within youthful cattle.

EXPERIMENTAL

Cattle

One hundred and twenty-two crossbred steers of Hereford, Angus, Pinzgauer, Brahman and Sahiwal breeding were slaughtered at 16 to 17 months of age. Brahman and Sahiwal were crossed with Hereford or Angus and were 25, 50 or 75% Bos Indicus. All cattle were born at about the same time and were fed a corn–corn silage finishing diet (86% total digestible nutrients) for about 120 days before slaughter.

Carcasses

After slaughter, carcasses were chilled in a 0°C chiller for 18 h and transferred to a 2 to 3°C holding chiller. After 24 h, carcasses were graded or evaluated for the following traits: lean colour (1 = very dark, 8 = bleached red); lean texture (1 = very coarse, 8 = very fine); lean, skeletal and overall maturity (100–199 = A, 100–299 = B); marbling (000–099 = devoid, 200–299 = traces, 300–399 = slight, 400–499 = small, etc.); fat thickness and *longissimus dorsi* muscle area.

Loin removal and processing

Loins were removed from the same side of each carcass 7 days post mortem. The first steak (2·5 cm thick) was removed from the 13th rib region of each loin. A sample was removed one-third the distance from the lateral end of the *longissimus dorsi* muscle of each steak for fibre typing and sarcomere length determination. The remainder of the *longissimus dorsi* muscle, less subcutaneous and intermuscular fat, was powdered in a blender with liquid nitrogen. The powdered sample was later used for percentage of intramuscular fat and collagen determination. The remainder of each loin was then vacuum packaged, frozen, and stored at −30°C. At a later date, frozen loins were cut into four steaks (2·5 cm thick) starting from the 13th rib end. The first and third steaks were used for sensory evaluation. The second steak was used for shear force determination. A thin (1 cm) steak was used for fragmentation index determination.

Intramuscular fat

The percentages of moisture and fat were determined on powdered muscle samples, in duplicate, by oven drying and ether extract, respectively (AOAC, 1980).

Fibre type characteristics

A section of *longissimus dorsi* muscle was removed from the 13th rib region at one-third the distance from the lateral end of the ribeye. The section was frozen in liquid nitrogen, wrapped in aluminium foil and stored in a freezer (−63°C). Transverse sections were cut 10 μm thick using a cryostat and stained for alkali-stable ATPase as described by Guth & Samaha (1970). Serial sections were stained for succinate dehydrogenase activity according to procedures described by Troyer (1980). Sections were later photographed and enlarged. Fibres were classified as red, white or intermediate, based on staining intensity, and counted. The areas of ten fibres of each type were then determined using a particle size analyzer.

Sarcomere length

Sarcomere length was determined on three fibres per steak, removed from the lateral end of each steak, by the neon laser diffraction method of Cross *et al.* (1980).

Fragmentation index

One steak was utilized for fragmentation index according to procedures outlined by Davis *et al.* (1980) using a Virtis (Model 45) homogenizer with the blades in the reverse position and filtering the homogenate through a 250 μm pore size screen.

Amount and solubility of collagen

Collagen content and solubility were determined according to procedures of Hill (1966) and Bergman & Loxley (1963). This procedure determined the total amount of collagen and the percentage of soluble collagen resulting from the heating of a sample for 70 min at 70°C.

Sensory and shear force tenderness determinations

Steaks for sensory evaluation and shear force determination were cooked on Farberware Open Hearth broilers (Model No. 450N) to an internal temperature of 40°C, turned over and removed from the broiler when the internal temperature reached 70°C. Internal temperature of each steak was monitored by iron/constantan thermocouples placed in the geometric center of each steak. Shear force was determined by allowing steaks to cool to 3 to 4°C and removing six 1·27 cm cores per steak parallel to the muscle fibre direction. Cores were sheared on a Warner–Bratzler shear device attached to an Instron Universal Testing machine (Model 1132) with a microprocessor (Microcon II).

Sensory evaluation was conducted using a 6 to 10 member panel trained and tested according to AMSA (1978) guidelines. Panelists were asked to evaluate tenderness (8 = extremely tender; 1 = extremely tough).

Data analyses

Data were analyzed by correlation and regression techniques (SAS, 1982). Correlations were computed from deviations about the overall sample means or from residual variation after fitting a least-squares model with breed groups (0, 25, 50, or 75% Bos Indicus breeding). Regressions were computed by stepwise procedures using $P < 0{\cdot}05$ as significance level for entry of independent variables in the equation. An equation for sensory tenderness or shear force was developed based on independent variables observed in the carcass. A second equation was developed based on all independent variables.

RESULTS AND DISCUSSION

Descriptions of the carcass traits of the population used in this study are presented in Table 1. Although all the cattle used in this study were A-maturity and were fed alike, large variations were observed in marbling scores (CV = 25%) and fat thickness (CV = 47%).

Descriptions of various muscle or meat characteristics of cattle used in this study are shown in Table 2. The various meat or muscle characteristics varied considerably in this population. Of particular interest is the large variation in the percentage of fat in the *longissimus dorsi* muscle (CV = 40%), fragmentation index (CV = 23%), total collagen (CV = 36%), percentage soluble collagen (CV = 32%), cross-sectional areas of various muscle fibre types and shear force values. Sarcomere length was relatively invariant in these data.

Correlation coefficients of carcass traits and various muscle and meat characteristics are presented in Table 3. Lean colour, marbling, fat thickness, adjusted fat thickness and ribeye area were all positively correlated to sensory tenderness scores and negatively correlated to shear force values. The relationship between marbling and tenderness was considerably greater than observations that have been previously made (Campion *et al.*, 1975; Crouse *et al.*, 1977). Crouse *et al.* (1977) reported that various bovine quality grades accounted for only 2–3% of the variation in sensory panel tenderness

TABLE 1
Population Descriptions for Various Carcass Traits

Carcass traits	*Population descriptions*			
	Mean	*Standard deviation*	*Minimum*	*Maximum*
Lean colour[a]	5·37	0·76	3·00	7·00
Lean texture[b]	5·22	0·84	3·00	7·00
Lean maturity[c]	136·66	6·13	130·00	150·00
Skeletal maturity[c]	136·93	7·03	130·00	160·00
Overall maturity[c]	136·68	5·66	130·00	155·00
Marbling[d]	368·20	92·47	120·00	610·00
Fat thickness (cm)	0·96	0·45	0·13	2·51
Adj. fat thickness (cm)	0·86	0·40	0·13	2·41
Ribeye area (cm^2)	71·41	8·24	52·91	93·55

[a] Very dark = 1; bleached red = 8.
[b] Very coarse = 1; very fine = 8.
[c] A = 100–199; B = 200–299.
[d] Traces = 200–299; slight = 300–399; small = 400–499; etc.

TABLE 2
Population Descriptions for Various Muscle or Meat Characteristics

Muscle or meat characteristics	*Population descriptions*			
	Mean	*Standard deviation*	*Minimum*	*Maximum*
Longissimus *muscle*				
Fat (%)—intramuscular	3·89	1·54	0·92	8·84
Sarcomere length (μm)	1·73	0·13	1·47	2·09
Fragmentation index	4·91	1·15	2·07	8·15
Total collagen (mg g^{-1})	5·83	2·09	1·73	13·12
Soluble collagen (%)	14·76	4·72	4·20	26·53
Fibre type characteristics				
Percentages				
White	47·83	5·91	32·14	64·00
Intermediate	23·73	5·25	8·47	36·36
Red	28·44	5·53	13·95	44·64
Cross-sectional areas (μm^2)				
White	3595	804	1894	6133
Intermediate	2120	438	1246	3450
Red	1859	372	849	2811
Percentage areas				
White	62·14	6·89	40·22	77·79
Intermediate	18·50	5·11	6·15	31·60
Red	19·36	4·60	10·26	32·04
Cooked meat properties				
Sensory tenderness[a]	5·37	0·56	3·12	6·38
Shear force (kg)	4·99	2·14	2·08	13·03

[a] Extremely tender = 8; extremely tough = 1.

ratings and 6–8% of the variation in overall satisfaction. Numerous other studies have indicated that neither marbling nor fat thickness have made major contributions directly to meat tenderness but are, perhaps, correlated indices of some biochemical or biophysical phenomena that actually contributes to tenderness (Campion *et al.*, 1975). It was noted in this study that ribeye area was negatively correlated ($P < 0{\cdot}01$) to shear force values. Post-mortem proteolysis of muscle is possibly an important contributor to meat tenderness. Since proteolysis is a result of temperature dependent enzymes, it seems plausible that larger ribeye muscles would require longer to chill and endogenous proteolytic enzymes would have longer periods of optimal temperatures to degrade this myofibrillar structure. The relatively small amount of variation in sarcomere length (Table 2, CV = 8%) indicates that cold shortening, as measured by shortened sarcomeres, was not a source of variation in tenderness in these data. However, small variation in

TABLE 3
Correlation Coefficients of Carcass Traits and Various Muscle and Meat Characteristics[a,b]

Carcass traits	*Muscle and meat characteristics*						
	Fat (%)	*Sarcomere length*	*Fragmentation index*	*Total collagen*	*Percentage soluble collagen*	*Sensory tenderness*	*Shear force*
Lean colour	0·36	0·13	−0·21	0·10	0·10	0·49	−0·57
Lean texture	0·29	0·19	0·04	0·02	−0·10	0·10	−0·13
Lean maturity	−0·03	−0·12	0·04	−0·05	−0·05	−0·02	0·06
Skeletal maturity	0·08	0·07	−0·05	0·06	−0·17	0·12	−0·11
Overall maturity	0·03	−0·07	0·00	−0·01	−0·15	0·04	−0·04
Marbling	0·70	0·12	−0·19	0·09	0·09	0·46	−0·51
Fat thickness	0·51	0·24	−0·03	0·09	0·03	0·19	−0·23
Adj. fat thickness	0·55	0·26	−0·04	0·06	0·21	0·21	−0·25
Ribeye area	0·02	0·03	−0·22	−0·02	0·05	0·21	−0·24

[a] Correlations ≥ 0·17 are significantly different from zero at the $P < 0{\cdot}05$ level.
[b] Correlations ≥ 0·23 are significantly different from zero at the $P < 0{\cdot}01$ level.

sarcomere length, particularly less than 1·80 μm, could cause large variation in shear force values.

Although collagen content and solubility were not correlated ($P > 0{\cdot}05$) to carcass traits, fragmentation index was negatively correlated to lean colour ($P < 0{\cdot}05$), marbling score ($P < 0{\cdot}05$), and ribeye area ($P < 0{\cdot}01$); and sarcomere length was positively correlated to lean texture ($P < 0{\cdot}05$), and measurements of fat thickness ($P < 0{\cdot}01$) (Table 3). The relationship of marbling and ribeye area to fragmentation index is of particular interest. Ribeye area may also result in differences in fragmentation index due to the rate of post-mortem temperature decline. Fragmentation index is a procedure that measures the degree of myofibrillar protein fragmentation due to degradation. Davis *et al.* (1979) have also shown that the *longissimus dorsi* muscles of A-maturity cattle with greater amounts of intramuscular fat also have lower fragmentation index values.

Correlation coefficients among various muscle and meat characteristics are shown in Table 4. Shear force was highly correlated to sensory tenderness scores ($r = -0{\cdot}83$). The per cent fat in the *longissimus dorsi* muscle and fragmentation index were both significantly ($P < 0{\cdot}01$) correlated with sensory tenderness scores and shear force values while sarcomere length and collagen content and solubility were not correlated ($P > 0{\cdot}05$) to these.

Numerous studies have found the fragmentation index procedure to be highly related to shear force and sensory tenderness ratings (Davis *et al.*, 1979, 1980; Calkins *et al.*, 1980; Calkins & Davis, 1980; Cole & Davis, 1981). This procedure in principle measures the fragmentation of myofibrils. Sarcomere length has been found to account for 12% of the variation in tenderness of beef (Hostetler *et al.*, 1972). Numerous other researchers

TABLE 4
Correlation Coefficients Among Various Muscle and Meat Characteristics[a,b]

	Sarcomere length	*Fragmentation index*	*Total collagen*	*Percentage soluble collagen*	*Sensory tenderness*	*Shear force*
Fat (%)	0·21	−0·16	0·18	0·12	0·37	−0·45
Sarcomere length		0·00	0·17	0·12	0·06	−0·06
Fragmentation index			−0·24	0·10	−0·60	0·53
Total collagen				−0·02	0·14	−0·10
Per cent soluble collagen					−0·04	−0·01
Sensory tenderness						−0·83

[a] Correlations ≥ 0·17 are significantly different from zero at the $P < 0{\cdot}05$ level.
[b] Correlations ≥ 0·23 are significantly different from zero at the $P < 0{\cdot}01$ level.

(Marsh & Leet, 1966; Marsh *et al.*, 1968; Locker *et al.*, 1975; Lochner *et al.*, 1980) have also found that cold shortening and the resulting shorter sarcomeres can influence the tenderness of beef. Reagen *et al.* (1976) concluded that an animal's chronological age and the total collagen content of muscles were the most important determinants of variability in the tenderness of beef. Davis *et al.* (1979) studied the tenderness of beef quality grades and found that collagen amount and solubility were not very important in A-maturity beef.

Correlation coefficients among various carcass traits and muscle fibre type characteristics are shown in Table 5. Average fibre size and fibre size weighted for relative percentage of fibre type were correlated ($P < 0{\cdot}01$) to sensory tenderness scores and shear force values and to other known indices of tenderness (e.g. fat thickness, marbling, percentage fat in the *longissimus dorsi* muscle and fragmentation index). The correlations between sensory tenderness ratings and shear force values and indices of tenderness were also observed in the cross-sectional area of white and intermediate muscle fibres. Lewis *et al.* (1977) and Tuma *et al.* (1962) also observed a significant relationship between muscle fibre diameter and tenderness. Large muscle fibres are generally indicative of less tender beef; however, since proteolysis of myofibrillar proteins that occurs during post-morten ageing is probably more important to ultimate tenderness than fibre size, the influence of fibre size may not always be observed in meat that has been aged for 7 to 10 days.

A positive correlation ($P < 0{\cdot}01$) was found between the percentage of red muscle fibres and fragmentation index ($P < 0{\cdot}01$) and shear force ($P < 0{\cdot}05$) (Table 5). Olson *et al.* (1977) compared several muscles and found that muscles containing a high percentage of red fibres (*psoas major*) had less CAF (calcium activated factor) activity than muscles with more white fibres (*longissimus dorsi*).

TABLE 5
Correlation Coefficients Among Various Carcass Traits and Muscle Fibre Type Characteristics[a,b]

Carcass traits or muscle/meat characteristics	*Muscle fibre type characteristics*										
	Percentages			*Cross-sectional areas*			*Percentage area*			*Average fibre size*	*Adjusted average fibre size*
	White	*Intermediate*	*Red*	*White*	*Intermediate*	*Red*	*White*	*Intermediate*	*Red*		
Carcass traits											
Lean colour	0·27	−0·09	−0·20	−0·12	−0·23	−0·24	0·29	−0·16	−0·26	−0·21	−0·15
Lean texture	0·14	−0·04	−0·11	−0·19	−0·24	−0·05	0·06	−0·10	0·02	−0·21	−0·20
Lean maturity	−0·22	0·09	0·15	−0·15	0·12	0·08	0·35	0·23	0·28	−0·03	−0·11
Skeletal maturity	−0·09	−0·01	0·10	−0·20	−0·01	−0·10	−0·17	0·10	0·15	−0·16	−0·20
Overall maturity	−0·18	0·04	0·15	−0·20	0·07	−0·02	−0·30	0·18	0·24	−0·10	−0·17
Fat thickness	0·20	−0·10	−0·12	−0·23	−0·20	−0·06	0·09	−0·12	0·00	−0·22	−0·20
Adj. fat thickness	0·22	−0·12	−0·12	−0·21	−0·21	−0·00	0·14	−0·15	−0·04	−0·22	−0·19
Ribeye area	−0·04	0·17	−0·12	−0·07	0·04	−0·05	−0·08	0·21	−0·02	−0·04	−0·06
Marbling	0·19	−0·07	−0·14	−0·25	−0·23	−0·16	0·12	−0·08	−0·09	−0·27	−0·23
Muscle and meat characteristics											
Fat (%)	0·20	−0·02	−0·19	−0·28	−0·22	−0·04	−0·03	−0·04	0·05	−0·25	−0·22
Sarcomere length	−0·06	0·10	−0·03	−0·01	0·09	0·03	−0·01	0·13	−0·09	0·03	0·01
Fragmentation index	−0·20	−0·13	0·34	0·37	0·17	0·00	0·13	−0·17	0·04	0·28	0·27
Total collagen	0·16	−0·03	−0·14	−0·21	0·01	−0·09	−0·08	0·08	−0·01	−0·14	−0·15
Percentage soluble collagen	−0·04	0·04	0·01	0·13	0·05	0·08	−0·02	0·00	0·01	0·12	0·11
Sensory tenderness	0·13	−0·01	−0·13	−0·27	−0·13	−0·17	−0·08	0·04	0·02	−0·25	−0·24
Shear force	−0·22	0·05	0·19	0·27	0·20	0·18	0·14	0·03	−0·11	0·28	0·24

[a] Correlations ≥ 0·17 are significantly different from zero at the $P < 0{\cdot}05$ level.
[b] Correlations ≥ 0·23 are significantly different from zero at the $P < 0{\cdot}01$ level.

TABLE 6
Standard Partial Regression of Carcass and Meat Traits Estimating Sensory Tenderness and Shear Force[a]

Dependent variables	*Independent variables*[b]						
	Intercept	*Fragmentation index*	*Per cent red fibres*	*Lean colour*	*Overall maturity*	*Marbling*	R^2
Sensory tenderness	3·23			0·36		0·32	0·32
	4·49	−0·55	0·15	0·30		0·26	0·56
Shear force	23·51			−0·50	−0·16	−0·30	0·44
	18·95	0·37		−0·63	−0·17	−0·27	0·59

[a] Based on deviations about the sample means.
[b] Dependent variables entered equation at $P < 0{\cdot}05$ probability level.

Standard partial regression equations estimating sensory tenderness and shear force are given in Table 6. Coefficients squared give the percentage of variation of the independent variable that is directly associated with the independent variable in making the estimation. Fragmentation index, per cent red fibres, lean colour, overall maturity and marbling were observed carcass and (or) meat traits more important in making predictions. Lean colour and marbling were of about equal importance in estimating sensory tenderness and accounted for 32% of the variation in sensory tenderness. Lean colour, overall maturity and marbling were important in estimating shear force.

Fragmentation index was the most important trait in estimating sensory tenderness, followed by lean colour, marbling and percentage red fibres. Fragmentation index directly accounted for 30% of the variation in sensory tenderness. The four variable equation accounted for 56% of the variation in sensory tenderness.

Results indicate that muscle fibre characteristics were of minor importance in determining meat tenderness given knowledge of the fragmentation index, color of lean and marbling. Percentage of red fibres was negatively correlated ($P > 0{\cdot}05$) to sensory panel tenderness, but made a significant ($P < 0{\cdot}05$) positive contribution to the prediction equation.

Percentage of red fibres is more important in estimating sensory tenderness at constant fragmentation index, lean colour and marbling. This relationship is also positive.

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