THE INFLUENCE OF SEVERAL PHYSICAL AND CHEMICAL PROPERTIES OF MEAT ON TENDERNESS

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Introduction

Considerable research has been directed towards the study of several physical and chemical properties of muscle as they relate to meat tenderness. It is known that factors such as muscle fiber diameter, degree of contraction and distortion associated with rigor mortis, amount and molecular nature of collagen, fat content and degree of autolysis all contribute to the variation associated with meat tenderness.

Confounded with the many complex properties influencing tenderness is the method of assessing tenderness itself. Several objective and subjective techniques are available, but in each case the techniques are generally not considered to be very precise and are subject to considerable variation. Hence, an accurate partitioning of the variance associated with tenderness has been very difficult in light of the multi-variate influence on tenderness and the relatively poor methods of measuring tenderness per se.

Research findings indicating the relationships that have been found between several physical and chemical properties of muscle with tenderness are shown in Table 1.

It was the objective of this study to estimate the relative influence of several chemical and physical properties of muscle on tenderness in a comprehensive manner, whereby several factors were studied in relation to each other and in relation to tenderness.

Experimental

Rib roasts (6, 7, 8th ribs) from 99 Hereford steers of approximately the same age and weight were used. The steers were on slightly different feeding regimes and were housed under different conditions; however, all steers were slaughtered at approximately 454 kg. live weight. After slaughter, all carcasses were aged for 48 hours, rib sections removed, vacuum packaged and immediately frozen ($0^{\circ}C$). The roasts were stored frozen for a period ranging from one to three months. After approximately a 12 hour thawing period at room temperature, the roasts were divided into three 3 cm. steaks. The longissimus dorsi muscle was removed from each steak, as this was the only muscle studied. Steak one was used for histological and chemical analysis. Steak two was used for subjective tenderness evaluation. Steak three was used for objective tenderness evaluation.

Histological analysis

Three 1.27 cm. cores were taken from the longissimus dorsi muscle in steak one. The cores were then fixed in a 10% formalin fixative for at least one week. The remainder of the longissimus dorsi muscle in

TABLE I. THE RELATIONSHIP OF SEVERAL PHYSICAL AND CHEMICAL PROPERTIES OF MUSCLE WITH TENDERNESS

Muscle Property	Correlation(s)	Specie	Investigator(s)
Fibre diameter	.31 - .75	bovine	Hiner et al., 1953
	.34	bovine	Herring et al., 1965
	-.35	ovine	Cross et al., 1972
Sarcomere length	-.28	bovine	Herring et al., 1965
	.54	ovine	Cross et al., 1972
	-.06	porcine	Stanley et al., 1971
Fiber extensibility	.36	bovine	Wang et al., 1956
Collagen nitrogen	.56	bovine	Macintosh et al., 1936
Hydroxyproline	-.84	bovine	Parrish et al., 1962
Collagen content	.02	ovine	Cross et al., 1972
Soluble collagen %	.17	ovine	Cross et al., 1972
Marbling	-.12	bovine	Goll et al., 1965
	-.22	bovine	Cover et al., 1956
	.47	bovine	Deatherage and Reiman, 1946
Carcass fat	-.25	bovine	Cover et al., 1956
Ether extract	.27	ovine	Cross et al., 1972
Firmness of lean	.21	bovine	Cover et al., 1956
Moisture content	.03	bovine	Goll et al., 1965
	-.02	ovine	Cross et al., 1972
Alkali insoluble protein %	-.88	bovine	Deatherage and Reiman, 1946

steak one was ground and homogenized for chemical analysis. After fixation, the samples were analyzed for fibre diameter, sarcomere length and degree of fibre distortion according to the technique outlined by Gillis and Henrickson (1968). All samples were measured under phase microscopy.

Chemical analysis

All samples were freeze dried in a commercial freeze-drier for at least 72 hours. The dried samples were then analyzed for ether extractable fat, protein content and hydroxyproline content. The fat determinations were found by washing the samples with ether in a Soxlet apparatus for a period of 48 hours. Assuming a 3.5% ash content, protein content was calculated from the difference of the dried sample and the fat-free sample. Hydroxyproline content was determined according to the method described by Grant (1964).

Tenderness evaluation

Steak two (longissimus dorsi) was cut into 1.27 cm. squares and cooked in a deep fat fryer adjusted to 133.4°C. Special effort was made to uniformly cook samples from batch to batch, and from day to day. All meat samples were compared to a soybean standard by a trained taste panel (at least 6 members per panel). The soybean standard was assumed to be uniform between samples and therefore provided a good control when compared with the meat samples. The soybean standard was prepared first by rehydration in boiling water, brief oven drying and a final cooking in the deep-fat cooker. The taste panel evaluated the meat samples on a relative basis of tenderness desirability with the soybean standard. Chew count was also recorded in comparison with the standard. All results were analyzed as differences between the meat samples and the soybean standard.

Steak three (longissimus dorsi) was oven roasted at 147.3°C to an internal temperature of 67.6°C. After cooling to 1.1°C, 1.27 cm. core samples were removed. As many cores as possible were taken and ranged from 20 to 30 depending on the muscle size. The cores were sheared in a shearing device equipped with a chart recorder. Both the height and width of each peak was measured and expressed as shear force and shear duration, respectively.

Physical separation and gross observation

The 9-10-11th rib roasts were analyzed for marbling, separable lean and separable fat in conjunction with another body composition study. For purposes of this study, these variables were compared with tenderness as they may be important from a practical assessment of tenderness standpoint.

Statistical analysis

Means, standard deviations, simple and multiple correlation coefficients and multiple and standard partial regressions were calculated where appropriate.

TABLE 2. MEAN VALUES AND STANDARD DEVIATIONS OF VARIABLES STUDIED

Variable	Mean	Standard Deviation
Relative tenderness	-.63	2.13
Chew count	-1.17	8.53
Shear force (cm.)	15.46	2.86
Shear duration (cm.)	11.88	2.40
Fibre diameter (μ)	49.46	3.32
Sarcomere length (μ)	1.96	.10
Fibre distortion (%)	28.96	8.18
Fat content (%)	12.43	5.08
Protein content	84.07	5.07
Hydroxyproline content (mg/g)	1.49	.33
Marbling score	5.23	1.64
Separable lean (%)	53.86	5.71
Separable fat (%)	29.18	6.54

TABLE 3. SIMPLE CORRELATION COEFFICIENTS BETWEEN TENDERNESS, PHYSICAL, CHEMICAL AND HISTOLOGICAL VALUES

Variable	Code	1	2	3	4	5	6	7	8	9	10	11	12	13
Relative tenderness	1	1.00												
Chew count	2	.66**	1.00											
Shear force (cm.)	3	-.07	-.17	1.00										
Shear duration (cm.)	4	-.12	-.23*	.90**	1.00									
Fibre diameter (µ)	5	-.20*	-.06	-.16	-.06	1.00								
Sarcomere length (µ)	6	.00	.13	-.11	-.15	-.11	1.00							
Fibre distortion (%)	7	-.07	-.06	-.03	.06	.04	-.15	1.00						
Fat content (%)	8	.04	.12	-.33**	-.21*	.06	.20*	.00	1.00					
Protein content (%)	9	-.04	-.12	.33**	.21*	-.06	-.20*	-.00	-1.00	1.00				
Hydroxyproline content (mg/g)	10	.00	-.01	.04	.07	.01	.02	.12	-.20*	.20*	1.00			
Marbling score	11	-.18	-.09	-.04	.02	-.02	-.01	.12	.37**	-.37**	.03	1.00		
Separable lean (%)	12	.08	.03	.13	-.01	-.20*	.08	-.20*	-.46**	.46**	.13	-.33**	1.00	
Separable fat (%)	13	-.15	-.19	-.09	.04	.25**	-.08	.23*	.33**	-.33**	-.13	.23*	-.61**	1.00

*r $\pm$ .20 significant at P <.05 for n = 99

**r $\pm$ .25 significant at P <.01 for n = 99

TABLE 4. THE RELATIONSHIP OF SEVERAL ESTIMATES OF TENDERNESS WITH VARIOUS HISTOLOGICAL AND CHEMICAL PROPERTIES OF MUSCLE

Dependent Variable(s)	Intercept	Independent Variable Regression Coefficients: Fibre Diameter (μ)	Sarcomere Length (μ)	Fibre Distortion (%)	Fat Content (%)	Protein Content (%)	Hydroxy-proline Content (mg/g)	Reduction in Sum of Squares (%)	Standard Deviation of Dependent Variable
Relative Tenderness (1)	5.66	-.13						3.94	2.10
	6.03	-.13		-.02				4.27	2.11
	5.86	-.13		-.02	.02			4.51	2.11
	-181.82	-.13		-.02	1.96	1.95		4.72	2.12
	-186.89	-.13	-.95	-.02	2.04	2.01		4.90	2.13
	-186.22	-.13	-.98	-.02	2.04	2.01	.18	4.97	2.14
Chew count (2)	-23.66		11.50					1.79	8.49
	-22.43		9.82		.17			2.72	8.50
	-14.78	-.13	9.27		.17			2.99	8.53
	-12.72	-.13	8.75	-.04	.17			3.14	8.57
	-13.16	-.13	8.69	-.04	.18		.41	3.16	8.61
	-154.30	-.13	8.66	-.04	1.64	1.46	.40	3.17	8.66
Shear force (3)	17.79				-.19			11.12	2.71
	23.86	-.12			-.18			13.18	2.69
	27.75	-.13	-1.88		-.18			13.58	2.70
	281.59	-.13	-1.84		-2.81	-2.63		13.79	2.71
	265.98	-.13	-1.99	-.01	-2.64	-2.46		13.90	2.72
	265.45	-.13	-1.97	-.01	-2.63	-2.46	-.14	13.93	2.74
Shear duration (4)	13.12				-.10			4.44	2.36
	18.09		-2.61		-.09			5.56	2.35
	414.13		-2.56		-4.19	-4.11		6.27	2.36
	407.85	-.05	-2.74		-4.10	-4.01		6.66	2.37
	429.93	-.05	-2.53	.02	-4.34	-4.25		6.97	2.38
	430.66	-.05	-2.56	.02	-4.34	-4.26	.19	7.04	2.39

TABLE 5. THE RELATIONSHIP OF SEVERAL ESTIMATES OF TENDERNESS WITH VARIOUS HISTOLOGICAL AND CHEMICAL PROPERTIES OF MUSCLE

		Independent Variable Regression Coefficients							
Dependent Variable(s)	Intercept	Fibre Diameter (μ)	Sarcomere Length (μ)	Fibre Distortion (%)	Fat Content (%)	Protein Content (%)	Hydroxy-proline Content (mg/g)	Reduction in Sum of Squares (%)	Standard Deviation of Dependent Variable
Relative	-24.30		11.50					1.29	10.04
Tenderness +	-22.94		9.65		.18			2.09	10.05
Chew Count	-7.83	-.27	8.57		.20			2.86	10.07
(1 + 2)	-4.94	-.26	7.84	-.06	.20			3.07	10.11
	-5.57	-.26	7.75	-.06	.21		.59	3.10	10.16
	-340.51	-.27	7.68	-.06	3.68	3.47	.58	3.13	10.22
Shear force	30.91				-.29			8.11	4.94
+	38.81	-.16			-.28			9.20	4.93
Shear duration	48.53	-.18	-4.67		-.26			9.98	4.94
(3 + 4)	689.43	-.17	-4.58		-6.90	-6.65		10.38	4.95
	695.91	-.17	-4.52	.00	-6.97	-6.72		10.39	4.98
	696.11	-.17	-4.53	.00	-6.97	-6.72	.05	10.39	5.01
-1 (Relative	35.44				-.51			4.50	11.91
Tenderness	61.39		-13.61		-.45			5.69	11.90
+	58.21		-12.84	.06	-.46			5.85	11.95
Chew Count)	1027.15		-12.65	.06	-10.50	-10.05		6.01	12.00
+	1038.63	.09	-12.29	.06	-10.67	-10.22		6.07	12.06
Shear force	1036.62	.09	-12.21	.07	-10.65	-10.19	-.53	6.09	12.13
+									
Shear duration									
(1 + 2 + 3 + 4)									

TABLE 6. ESTIMATED PROPORTION (%) OF THE VARIATION ASSOCIATED WITH FOUR MEASUREMENTS OF TENDERNESS ACCOUNTED FOR BY THE VARIATION ASSOCIATED WITH SIX HISTOLOGICAL AND CHEMICAL PROPERTIES OF MUSCLE

Property	Relative Tenderness			Chew Count			Shear Force			Shear Duration		
	R_p^2 a/	R_{sp}^2 a/	r^2 a/	R_p^2	R_{sp}^2	r^2	R_p^2	R_{sp}^2	r^2	R_p^2	R_{sp}^2	r^2
Fiber diameter	3.94	4.37*	4.00	.27	.27	.36	2.06	2.08	2.56	.39	.33	.36
Sarcomere length	.18	.25	.00	1.79	.91	1.69	.40	.35	1.21	1.12	.79	2.25
Fiber distortion	.33	.69	.49	.27	.18	.36	.11	.03	.09	.33	.65	.36
Fat content c/	.24	.99	.16	.15	.04	1.44	11.12	1.01	10.89	4.44	3.92*	4.41
Protein content c/	.21	.98	.16	.01	.03	1.44	.21	.98	10.89	.71	3.89	4.41
Hydroxyproline content	.07	.06	.00	.02	.02	.01	.03	.02	.16	.07	.08	.49
Total reduction in sum of squares	4.97	5.73	-	3.17	3.19	-	13.93	14.73	-	7.04	10.17	-

a/ $R_p^2 \times 100$, $R_{sp}^2 \times 100$, $r^2 \times 100$

b/ R_p^2 = partial correlation coefficient squared

R_{sp}^2 = standard partial correlation coefficient squared

r^2 = simple correlation coefficient squared

c/ protein content not independent of fat content

* $P < .05$

Results and Discussion

On the average, the taste panel found that the meat samples were slightly less tender than the soybean standard as indicated by the relative tenderness score and chew count (Table 2). Comparatively, considerably more variation was associated with the chew count technique as compared to the relative tenderness rating; however, the two methods were significantly ($P < .01$) correlated ($r = .66$) as shown in Table 3. Both shear force and shear duration varied in similar directions to a very high degree ($r = .90$). The relationship of the subjective techniques with the objective techniques was very low, and with the exception of chew count with shear duration, did not significantly differ from zero at $P < .05$.

The only property of muscle studied that was remotely related, on a linear basis, to any of the measures of tenderness was fat content and fibre diameter. In terms of interrelationships of the muscle properties studied, all relationships found that were significant were of low value.

Neither of the subjective methods used for the assessment of tenderness were significantly related to the muscle properties measured (Table 4). However, significant relationships were found between shear force with the muscle properties with a resulting total reduction in sum of squares of the order of 13.93% ($P < .01$). Somewhat lower relationships were found when shear duration was compared with the muscle properties. Both objective methods, shear force and shear duration, were correlated with the combined muscle properties to an appreciably higher degree than either of the subjective methods, relative tenderness and chew count.

In an effort to increase the precision of tenderness assessment, both subjective and both objective methods were combined independently and in total (Table 5). For the combined two subjective methods, a decrease in the reduction of sum of squares accountable from the six muscle properties resulted, as compared to the use of either relative tenderness or chew count separately. The combined objective techniques resulted in an appreciably greater reduction in sum of squares as compared to the subjective techniques, but still lower than when shear force was used alone. When both subjective and objective techniques were considered in total, the reduction in sum of squares fell between that found for either technique when considered separately.

Fibre diameter was the most important variable of those studied in regards to reduction in sum of squares associated with relative tenderness. No other significant effects were found for this variable or for chew count. Fat content accounted for the highest proportion of shear force sum of squares followed by fiber diameter. Likewise, fat content was the greatest contributing effect in regards to shear duration. The results of Cross *et al.* (1972), where a similar study was conducted with lamb, indicate that there is no consistent pattern for several different muscles regarding the relationship between several muscle properties and tenderness. For the *vastus lateralis* muscles, significant effects were found for fiber diameter and fat content. In contrast, no significant effects were found for the *biceps femoris* muscle. These workers obtained a range of $R^2 \times 100$ values of 22.8% for the *biceps femoris* muscle to 46.8% for the vastus lateralis. The $R^2 \times 100$ values obtained in this study were considerably lower ($R^2 = 14.73\%$). It can be generally concluded that the muscle properties examined in this study play only a minor role in the ultimate determination of bovine longissimus dorsi tenderness. The very small proportion of the sum of squares associated with tenderness accounted for by the muscle properties studied is difficult to explain. First, the four methods of assessment of tenderness may not have been sufficiently precise to detect relationships that may exist with the muscle properties. Secondly, the methods of analysis of the muscle properties may not have been accurate enough, and, thirdly, and most likely, there are other factors in addition to those studied that influence tenderness. The third postulation raises the question of what these factors are? The findings of this study and others support the need for more comprehensive research on this subject.

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