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Effect of Subcutaneous Fat and High Temperature Conditioning on Bovine Meat Tenderness

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ABSTRACT

Effects of subcutaneous fat cover and high temperature conditioning on tenderness of meat were studied using 16 steer carcasses. Longissimus *subcutaneous fat cover was completely removed from eight carcasses and the right and left sides were stored at either 0°C or 26°C. After 6 h at 26°C, the sides were transferred to the 0°C room; and after 24 h, all sides were transferred to a 1°C room for the duration of the experiment. Cold temperature and removal of fat cover reduced (*$P < 0{\cdot}05$*) the* longissimus *muscle temperature at 6, 9 and 12 h post-mortem. The pH of the* longissimus *muscle was lower (*$P < 0{\cdot}05$*) as the result of high temperature conditioning and fat cover 6, 9 and 12 h post-mortem. Consequently, conditions existed which would have been expected to promote cold shortening, yet high temperature conditioning and fat cover had no consistent effects on myofibrillar fragmentation index, sarcomere length or shear values.*

INTRODUCTION

Since the initial discovery of cold-shortening (reduced sarcomere length) by Locker & Hagyard (1963), much of the variation in tenderness observed in lamb and beef has been assigned to cold-shortening (Lochner *et al.*, 1980).

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However, Locker & Daines (1976) and Dutson (1977) have reported that markedly different tenderness can be produced in muscles having identical sarcomere lengths.

Subcutaneous fat cover is thought to act as an insulator, retarding the rapid rate of temperature decline and consequently preventing toughness due to cold-shortening (Marsh, 1977). According to Marsh (1977), prevention of cold-shortening is perhaps the only significant function of subcutaneous fat.

It is now widely recognized that consumers do not accept meat with excessive quantities of fat. If consumer demand for lean persists, the meat industry will be forced to change its production system to produce leaner animals or trim excessive fat. If the reported function of subcutaneous fat is indeed correct, one would expect to encounter an increased incidence of cold-shortening in lean beef and consequently greater meat toughness. Because of these concerns, the objectives of this experiment were to examine the effects of the removal of subcutaneous fat prerigor and high temperature conditioning on beef tenderness.

MATERIALS AND METHODS

Animals

Eight Hereford × Angus and eight Brahman crossbred steers, about 15 months of age, were used to examine the effect of high-temperature conditioning (HTC) and subcutaneous fat cover on the tenderness in bovine *longissimus* muscle. The first group of animals (eight) consisted of four Hereford × Angus and four Brahman crosses. Immediately after slaughter, the carcasses were split and one side was transferred to a 0°C (about 30–35 min after slaughter) cooler and the other side held at 26°C for 6 h (HTC). The second group of animals also consisted of four Hereford × Angus and four Brahman crosses. Immediately after slaughter, the carcasses were split and the subcutaneous fat cover over the *longissimus* muscle was completely removed. As before, one side was transferred to a 0°C cooler and the other side held at 26°C for 6 h. After 6 h, the HTC sides from both groups were transferred to the 0°C cooler. All sides were transferred to a different 1°C cooler 24 h after slaughter where they were held for the duration of the experiment. Table 1 presents the carcass descriptions for the animals used in this study.

Temperature and pH decline

Temperature and pH were determined at 6, 9, 12 and 24 h post-mortem.

TABLE 1
Characteristics

Trait	*With subcutaneous fat*		*Without subcutaneous fat*	
	Mean	*SD*	*Mean*	*SD*
Chilled side weight (kg)	139·9	10·6	138·0	15·4
Lean color[a]	5·37	0·92	4·62	0·74
Lean maturity[b]	143·7	7·4	151·2	3·5
Marbling[c]	328·8	84·7	360·0	91·2
Fat thickness (cm)	1·24	0·52	—	—
Ribeye area (cm^2)	67·5	3·6	66·4	5·1
Estimated kidney, heart and pelvic fat (%)	2·91	0·32	3·06	0·61
Extractable fat in *longissimus* (%)	3·11	1·4	4·35	1·98

[a] Scored: 8 = light, grayish red to 1 = black.
[b] Scored: 100–199 = A to 200–299 = B.
[c] Scored: 000–100 = devoid to 900–1 000 = abundant.

Temperature was measued with a fluke (Model 8020A) digital multimeter and temperature probe (Model 80T-150). Temperature was recorded to the nearest °F and then mathematically converted to °C. Muscle pH was measured with a glass stab electrode (Orion No. 91–63) attached to an Orion ionanalyzer (Model 69A). Temperature and pH at each post-mortem time were measured between the 8th and 11th rib, with the previous locations being avoided on each subsequent observation.

Grading

Carcasses were ribbed between the 12th and 13th rib at 24 h post-mortem. Carcasses were then graded for lean color (8 = light, grayish red; 1 = black), lean maturity (100–199 = A; 200–299 = B), marbling (000–100 = devoid; 900–1000 = abundant), fat thickness, ribeye area, and per cent kidney, pelvic and heart fat.

Sarcomere length

Sarcomere length was measured after 24 h of post-mortem storage according to the procedure described by Cross *et al.* (1980) using the neon laser diffraction technique.

Fat and moisture

Fat and moisture analyses were determined at 24 h post-mortem (AOAC, 1980).

Myofibrillar Fragmentation Index (MFI)

Three samples were removed from a steak/side/evaluation period (6 h, 1, 3, 8 and 14 days post-mortem) from medial, central and lateral positions of the *longissimus*, and MFI was determined according to the procedure described by Olson *et al.* (1976).

Shear force

Shear force was measured at 1, 3, 8 and 14 days post-mortem as described by Crouse *et al.* (1984). Briefly, steaks were 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 (1·27 cm diameter by 5 cm long) were removed from each steak parallel to fiber direction. Each core was sheared twice with a Warner–Bratzler shear device attached to an Instron Universal Testing machine (Model 132) with a microprocessor (Microcon II).

Statistical analysis

Data were analyzed by least-squares procedures (SAS, 1985). Fat trim and breed treatments were considered a whole-plot effect and the temperature treatment was considered a split-plot effect. All two-way and three-way interactions were examined, variation among animals was used as an error term for fat trim treatment, and residual variation as an error term for temperature treatment. When significant ($P < 0{\cdot}05$) interactions were observed, means were separated by *t*-test.

RESULTS

Temperature data for the treatment groups are reported in Table 2. After 6 h at 0°C, the defatted group had an internal temperature of 10·8°C while the control sides had an internal temperature of 15·6°C. The elevated temperature of the HTC group was maintained at the 9 and 12 h periods. The data also indicate that the HTC treatment maintained a higher temperature for the 6, 9 and 12 h treatment period than the treatment chilled at 0°C. At 6 h post-mortem, an interaction between HTC and subcutaneous

TABLE 2
Effect of Subcutaneous Fat and High Temperature Conditioning on Temperature Decline (Least-Squares Means)

Treatment	*Hours post-mortem (temperature, °C)*			
	6	*9*	*12*	*24*
$P > F$ of interaction	0·001	0·065	0·101	0·573
With subcutaneous fat at 0°C	15·6[a]	10·0	6·0	1·5
With subcutaneous fat at 26°C	23·6[b]	15·0	8·5	1·5
Without subcutaneous fat at 0°C	10·8[c]	6·0	3·4	1·2
Without subcutaneous fat at 26°C	21·4[d]	11·5	5·3	1·0
High temperature conditioning:				
0°C	13·2[a]	8·0[a]	5·0[a]	1·4[a]
26°C	22·5[b]	13·2[b]	6·9[b]	1·2[b]
Subcutaneous fat:				
With	19·6[a]	12·5[a]	7·2[a]	1·4
Without	16·1[b]	8·7[b]	4·4[b]	1·2
Residual standard deviation	0·6	0·4	0·4	0·2

Values within a column within interaction or main effect with different superscripts (a, b, c, d) ($P < 0·05$).

fat cover on temperature of the *longissimus* muscle was observed. Differences in temperature of the *longissimus* muscle with or without fat cover were greater for the 0°C treatment than the HTC treatment. Caution must be taken in interpreting main effect means, however, when significant interactions were observed.

The pH for the treatment groups is reported in Table 3. The difference among treatments (interaction) was statistically significant at all times, except 6 h. The HTC treatment had an effect ($P < 0·05$) on pH at 6, 9 and 12 h while fat removal effect was only significant ($P < 0·05$) at 9 and 12 h post-mortem. The data demonstrate the effect of temperature on the process of rigor development as characterized by pH. Regardless of subcutaneous fat cover, reduction in pH seems to be completed at 6 h for the HTC treatment groups. The effect of temperature on pH is even more evident at 0°C. At 0°C, in the case of defatted carcasses, reduction in pH is not completed even after 24 h post-mortem, while in the case of control sides, the ultimate pH is attained after 9 h post-mortem. Interaction at 9 h post-mortem indicates that the pH was relatively lower ($P < 0·05$) with fat cover than without fat cover for the HTC as compared to 0°C group. While interactions of treatments on pH were significant at 12 and 24 h, the practical importance of these interactions was questionable.

TABLE 3
Effect of Subcutaneous Fat and High Temperature Conditioning on pH Decline (Least-Squares Means)

Treatment	*Hours post-mortem (pH)*			
	6	*9*	*12*	*24*
$P > F$ of interaction	0·062	0·004	0·042	0·004
With subcutaneous fat at 0°C	5·65	5·52[a]	5·50[a]	5·50[a]
With subcutaneous fat at 26°C	5·46	5·48[a]	5·48[a]	5·53[a]
Without subcutaneous fat at 0°C	6·00	5·84[b]	5·73[b]	5·61[b]
Without subcutaneous fat at 26°C	5·54	5·48[a]	5·50[a]	5·52[a]
High temperature conditioning:				
0°C	5·81[a]	5·68[a]	5·62[a]	5·56
26°C	5·50[b]	5·48[b]	5·50[b]	5·52
Subcutaneous fat:				
With	5·56	5·50[a]	5·50[a]	5·52
Without	5·76	5·66[b]	5·61[b]	5·56
Residual standard deviation	0·16	0·13	0·13	0·04

Values within a column within interaction or main effect with different superscripts (a, b) differ ($P < 0·05$).

Sarcomere length data for the treatment groups are reported in Table 4. No significant differences ($P < 0·05$) between treatment groups (interaction and main effects) were observed. According to Locker & Hagyard (1963), cold-shortening commences immediately upon exposure of muscle to temperatures below 14°C within a few hours after slaughter. The

TABLE 4
Effect of Subcutaneous Fat and High Temperature Conditioning on Sarcomere Length (Least-Squares Means)

Treatment	*Sarcomere length (μm)*
$P > F$ of interaction	0·444
With subcutaneous fat at 0°C	1·74
With subcutaneous fat at 26°C	1·67
Without subcutaneous fat at 0°C	1·70
Without subcutaneous fat at 26°C	1·66
High temperature conditioning:	
0°C	1·72
26°C	1·67
Subcutaneous fat:	
With	1·71
Without	1·68
Residual standard deviation	0·45

TABLE 5
Effect of Subcutaneous Fat and High Temperature Conditioning on Shear Force (Least-Squares Means)

Treatment	*Days post-mortem (kilograms of force/1·27 cm)*			
	1	*3*	*8*	*14*
$P > F$ of interaction	0·062	0·643	0·277	0·536
With subcutaneous fat at 0°C	8·29	6·77	5·62	5·00
With subcutaneous fat at 26°C	8·52	6·92	6·33	5·63
Without subcutaneous fat at 0°C	10·13	6·63	5·50	4·50
Without subcutaneous fat at 26°C	8·66	6·49	5·51	4·85
High temperature conditioning:				
0°C	9·24	6·70	5·57	4·75[a]
26°C	8·59	6·70	5·92	5·24[b]
Subcutaneous fat:				
With	8·40	6·84	5·97	5·32
Without	9·40	6·56	5·51	4·68
Residual standard deviation	1·17	0·93	0·86	0·61

Values within a column within interaction or main effect with different superscripts (a, b) differ ($P < 0·05$).

TABLE 6
Effect of Subcutaneous Fat and High Temperature Conditioning on Myofibril Fragmentation Index (Least-Squares Means)

Treatment	*6 h*	*Day 1*	*Day 3*	*Day 8*	*Day 14*
$P > F$ of interaction	0·345	0·156	0·504	0·311	0·381
With subcutaneous fat at 0°C	29·5	41·0	50·9	66·2	77·7
With subcutaneous fat at 26°C	35·6	44·0	64·1	65·9	80·7
Without subcutaneous fat at 0°C	31·1	40·1	54·8	59·6	81·8
Without subcutaneous fat at 26°C	31·5	50·1	64·4	62·5	81·5
High temperature conditioning:					
0°C	30·3	40·6[a]	52·8	62·9	79·8
26°C	33·5	47·0[b]	64·3	64·2	81·1
Subcutaneous fat:					
With	32·5	42·5	57·3	66·1	79·3
Without	31·3	45·1	59·6	61·1	81·7
Residual standard deviation	8·2	6·6	7·4	4·3	5·1

Values within a column within interaction or main effect with different superscripts (a, b) differ ($P < 0·05$).

temperature data (Table 2) indicated that the defatted carcasses held at 0°C had reached the potentially cold-shortening temperature. The same group also had the highest pH at 6 h post-mortem. Therefore, in terms of temperature and pH, conditions seemed to be favorable for cold-shortening to occur. However, based on the sarcomere length data no detectable cold-shortening took place.

The data for shear force and MFI determinations are reported in Tables 5 and 6, respectively. These results demonstrate that neither of these measurements of textural properties were consistently affected by the treatments imposed.

DISCUSSION

It is now widely recognized that consumers do not accept cuts of meat with excessive fat. To accommodate demand by consumers, packers and retailers have begun to trim excessive fat. Therefore, the need for fat cover has to be questioned. According to Marsh (1977), 'The principle and perhaps the only significant function served by massive fat deposition in the feedlot is to insulate the carcasses against cold-shortening and its attendant ill effects during the early chilling period.' Fattening of animals is an expensive proposition (for review see Marsh, 1977). According to Locker (1985), toughness induced by cold-shortening is irreversible and post-mortem storage cannot overcome the effects of cold-shortening. Therefore, if fat is indeed functioning to prevent cold-shortening and the tenderness problems associated with it, it would seem reasonable to suggest that fat deposition might be justified under these circumstances. The main purpose of this experiment was to answer the question, i.e. will cold-shortening occur in the absence of subcutaneous fat under the temperature conditions and muscle chill rates used in the present work.

Subcutaneous fat over the *longissimus* muscle was completely removed and sides were held for the first 24 h post-mortem at a temperature of 0°C and subsequently stored at 1°C for the remainder of the study. According to the theory regarding the role of subcutaneous fat (Marsh, 1977; Locker, 1985), we expected to observe cold-shortening as a result of subcutaneous fat removal. To examine if HTC can prevent the occurrence of cold-shortening (if it occurs), the other side of defatted carcasses were subjected to 26°C (room temperature) treatment for 6 h. The HTC treatment should have accelerated the rigor processes (depletion of ATP), and therefore HTC should have prevented the occurrence of cold-shortening (for review, see West, 1979).

Results of temperature and pH measurements indicate that removal of

subcutaneous fat and exposure to 0°C produced conditions that should have been favorable for cold-shortening. These conditions are 10°C or less and pH of 6·0 or higher (Lockner *et al.*, 1980). At 6 h post-mortem the defatted group held at 0°C had a pH of 6·0 and a temperature of 10·8°C. Based on data obtained by other investigators (Lochner *et al.*, 1980; George *et al.*, 1980), these conditions (i.e. 10·8°C and pH of 6·0) are borderline for causing cold shortening. The data indicate that cold-shortening was not detected under these conditions, based on the sarcomere length data (Table 4) and also tenderization as a result of post-mortem storage (Tables 5 and 6). According to Locker & Hagyard (1963), the toughness induced by cold-shortening (40% shortening) cannot be overcome by post-mortem storage.

Results of the present experiments demonstrate that although subcutaneous fat did have an important role in pH and temperature decline, removal of fat did not adversely affect tenderness. Smith *et al.* (1976) and Meyer *et al.* (1977) have also examined the effect of subcutaneous fat removal on the tenderness of lamb and cattle, respectively. Smith *et al.* (1976) reported that loins from defatted and control lambs had shear force values of 6·8 and 6·1, respectively. Meyer *et al.* (1977) reported that defatted and control sides from cattle shear force values of 6·68 and 5·91, respectively. In the present work, defatted carcasses held at 0°C for 24 h post-mortem had the highest shear values (Table 5); however, the difference disappeared by the third day of post-mortem storage. Smith *et al.* (1976) concluded that increased quantities of subcutaneous fat increase meat tenderness via changes in post-mortem chilling rate. According to Smith *et al.* (1976) the reduced chilling rate enhances the activity of proteases involved in post-mortem tenderization of beef. Data reported herein supports this hypothesis. Defatted carcasses held at 0°C, which had the lowest temperature at 6 h post-mortem (Table 2) possessed the greatest shear values at 24 h post-mortem. However, after 3 days of post-mortem storage they had the same shear force value as the rest of the treatments. The behaviour of defatted carcasses held at 0°C can be explained on the basis of their temperature at 6 h post-mortem. This group had a temperature of 10·8°C at 6 h post-mortem and would be expected to have reduced protease(s) activity and, therefore, would require more time to obtain the effect of proteolysis.

Many studies have been conducted to examine the effect of subcutaneous fat on meat tenderness (Smith *et al.*, 1976; Bowling *et al.*, 1977; Lochner *et al.*, 1980; Jeremiah & Martin, 1982; Lee & Ashmore, 1985). Jeremiah & Martin (1982) found no relationship between fat thickness (4·57 to 19·56 mm) and meat tenderness. Crouse & Smith (1978) observed that fat cover and marbling contributed equally to tenderness, but the combined effects only accounted for 3% of the variation in tenderness. However, others have found a direct relationship between subcutaneous fat thickness and meat

tenderness (Smith *et al.*, 1976; Bowling *et al.*, 1977; Lochner *et al.*, 1980). A troublesome aspect of these conclusions (Smith *et al.*, 1976; Bowling *et al.*, 1977; Lochner *et al.*, 1980) is that these authors have not considered the possible role of antemortem conditions on meat tenderness. To study the relationship between subcutaneous fat and meat tenderness, Lochner *et al.* (1980) used lean animals and fat animals. They produced lean animals by feeding 15-month-old steers alfalfa hay for 180 days, while fat animals had an *ad libitum* diet of corn and corn silage for the same period of time. Mean average daily gains during this period were 1·0 kg and 0·20 kg for the fat and lean groups, respectively. It is quite possible that these drastic antemortem conditions could play a significant role in the meat tenderness. Indeed, their tenderness measurements reveal such an effect. Additionally, Lee & Ashmore (1985) reported that, regardless of environmental temperature, grass-fed steers showed greater toughness than the feedlot fed and conventionally chilled carcasses. Therefore, studies indicate that antemortem condition (production system) indeed can contribute to meat tenderness. Aberle *et al.* (1981) concluded that growth rate of cattle before slaughter affects meat palatability, particularly meat tenderness and that growth rate may be a more important determinate of tenderness than the length of time that cattle are fed a high energy diet. It is, therefore, possible that in previous studies (Smith *et al.*, 1976; Lochner *et al.*, 1980), the differences between lean and fat animals were due to antemortem effects rather than fat cover *per se*. Indeed, our experiment supports this view.

Results of the present experiment suggest that cold induced toughness caused by post-mortem contraction of muscle associated with rapid chilling may not be a serious problem in hot-fat-trimmed carcasses or lean carcasses that are processed under industry conditions similar to our experiment. The question of the effects of hot boning of lean meat followed by rapid muscle chill rates similar to those observed presently on tenderness remains open.

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