BEEF MUSCLE pH IN RELATION TO POST-MORTEM CHANGES IN COLOR AND TENDERNESS OF THE LONGISSIMUS DORSI

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The relationship between several measures of muscle pH and color and tenderness of the longissimus dorsi was studied with carcasses of 168 steers, 147 heifers and 259 bulls all slaughtered within the age range of 12 to 16 months.

The average pH of the trapezius cervicales ranged from 6.99 (heifers) to 7.04 (bulls) for the warm carcass and from 5.86 (steers) to 6.00 (heifers) after a 24-hour chill period. The minimum pH for all sexes was recorded at 48 hrs post-mortem (longissimus dorsi) but the change from 24 to 48 hours was less than 0.1 except for heifers. Sexes differed in the range of 24 hour pH of the longissimus dorsi with none of the steers, 8% of the heifers and 49.2% of the bulls having values greater than 6.0.

Neither the absolute pH values nor degree of post-mortem pH change were useful predictors of tenderness of the longissimus dorsi for steer and heifer carcasses (r values ranging to ± 0.25). For bull carcasses, pH of the trapezius cervicales at 0 and 24 hrs post-mortem was uncorrelated with measures of tenderness taken at 24 hrs to 13 days post-mortem but the pH of the

longissimus dorsi at 24 hrs was moderately correlated (r = -0.7) with these estimates of tenderness. This sex difference appeared to be conditioned by the wide sex difference in range of the 24 hr pH of the longissimus dorsi.

Subjective meat color scores and pH of the longissimus dorsi at 24 hrs post-mortem were moderately correlated with high pH values associated with dark color. This relationship was particularly marked for bulls that had been subjected to pre-slaughter stress. For this sex, objective color brightness scores were also correlated (+0.7) with pH readings taken 24 hrs post-mortem.

INTRODUCTION

Energy for muscular work is provided by a complex series of chemical reactions involving the breakdown of muscle glycogen. In living tissue, the course of these reactions coupled with the normal buffering properties of the tissue, maintains pH at or near neutrality (pH = 7.0). However, under the anaerobic conditions which prevail after death the chemical reactions are incomplete and lactic acid, an intermediary by-product, accumulates. This results in a post-mortem decline in pH with both the rate and ultimate pH being influenced by a variety of pre- and post-mortem factors (e.g. Briskey et al., 1966, 1970).

The rate and extent of post-mortem glycolysis influence several attributes of eating quality. High ultimate pH results in increased tenderness

of beef muscle but flavor and juiciness are diminished (Lawrie, 1960) and color becomes darker (Hedrick et al., 1959). The latter authors suggest that a pH of 6.4 or greater results in dark cutting beef whereas a pH of 5.4 is characteristic of light colored beef. A procedure for utilizing pH of the longissimus dorsi to identify potential dark cutters has been described by Munns and Burrell (1966).

Post mortem time trends of red muscle pH are influenced in some degree by the muscle chosen (Lawrie et al., 1959) and there is research evidence that ultimate pH (13 to 16 days after slaughter) is slightly higher than at 48 hrs (Wierbicki et al., 1956). However, correlations of initial and subsequent pH values have not been reported. The purpose of the research documented in this paper was to investigate the utility of initial pH (immediately after slaughter) as a predictor of ultimate pH, meat color and tenderness of beef muscle.

MATERIALS AND METHODS

This study involved carcasses of 574 animals of three sexes (168 steers, 147 heifers and 259 bulls). These were obtained from three sources, commercial feed lots in central Alberta and the C.D.A. Research Stations at Lacombe and Lethbridge. All were transported by truck to the same abbatoir and slaughtered within one hour after delivery. Total transportation time for the Lethbridge animals, 66 steers and 174 bulls, was approximately 7 hours. The remaining animals were in transport for less than one hour. Age at

slaughter ranged from 12 months to 18 months. Additional details of the pre-slaughter history of these animals have been published by Fredeen et al.

The initial pH reading was taken approximately 20 minutes after slaughter by direct insertion of a probe-type electrode into the trapezius cervicales. A second pH reading was taken in this same muscle 22-26 hrs post mortem. At this time pH was also recorded for the longissimus dorsi at the 11-12 rib interface with additional pH readings taken on this muscle at 48 hrs, 72 hrs, 6 days and 13 days post mortem.

The pH readings were taken with an ILI (Instrumentation Laboratory Inc.) Portomatic pH meter model no. 175 fitted with a spike tip electrode specifically adapted for meat samples. Calibration was according to manufacturer's instructions. The meat temperatures for all except the initial pH ranged from 1 to 2° C.

Color of the longissimus dorsi cross section at the 11-12 rib was rated subjectively at 24 hrs post mortem using a scale of 1 (light) to 3 (dark). Color of the same muscle was also measured objectively by a photo electric brightness meter manufactured by Ernst Schütt Laboratories, Göttingen, Germany. This meter operated through a range of 0 to 100 with higher values associated with increasing darkness of the meat surface.

As each carcass was processed at 24 hr post mortem the excised l. dorsi from the left rib cut (4th to 11th rib) and the untrimmed short loin

from the right side (13th rib to 5th lumbar vertebra) were taken to the laboratory for storage at 2° C (± 1°) and 94% (± 6%) relative humidity pending subsequent sampling. Serial samples of these two sections were taken for tenderness evaluation at 24, 48 and 72 hrs. for the rib section and 48 hr, 72 hr, 6 days and 13 days post mortem for the loin section. Each sample was a cross sectional slice 3.2 cm thick with such trimming between sampling periods as required to provide a "fresh" surface of each slice. These slices were cooked according to a standardized procedure in a microwave oven, sealed in plastic and refrigerated at 1° C for 18-24 hrs prior to coring for tenderness evaluation. Three cores, each 2 cm in diameter, were sheared in a Warner-Bratzler apparatus with the shear force electronically recorded on a scale 0 - 100 with 100 representing 13,000 g of force.

Additional details of these procedures have been published by Martin et al. (1970, 1971).

Standard statistical analyses of variance and covariance were applied to the data.

RESULTS

Averages for initial pH recorded 20 min. after slaughter ranged from 6.99 for heifers to 7.0 for bulls (Table 1). Source of the animals had no influence on this pH reading except for heifers which differed by 0.30 ($P < 0.01$). The minimum pH for all sex-source sub-groups was recorded at

48 hrs post mortem but the change from 24 to 48 hrs was statistically non-significant except for heifers. Again this sex showed a source difference with the commercial heifers showing a greater pH change from 0 to 24 hrs (1.15 vs 0.91) and less from 24 to 48 hrs (0.17 vs 0.60) than the Lacombe heifers. Final pH (13 days) was similar for steers, heifers and Lacombe bulls but the Lethbridge bulls maintained an average pH in excess of 6.0 through this period. Except for the Lethbridge steers, all groups showed a slight rise in pH of the longissimus dorsi over the period from 48 hrs to 13 days post mortem.

Sex and source differences were also evident in meat color and shear values (Table 1). The highest color scores, both subjective and objective and the lowest initial shear values were recorded for the Lethbridge bulls. Lacombe bulls, with a significantly lower color rating ($P < .01$) had substantially higher shear values ($P < .01$). The same pattern of association between average color brightness score and initial shear values was observed with the steers where the group with the lowest average color rating (commercial steers) had significantly higher shear values. For heifers, this association was reversed (Table 1).

(Table 1 near here)

Overall correlations were calculated among the several traits studied for each sex group. However, because of the specific source effects already discussed it was evident that the correlations of primary interest

would be those from which source differences had been eliminated. These are presented in Tables 2 and 3 for commercial steers, commercial heifers and Lethbridge bulls.

The pH readings almost invariably dropped during the first 24 hrs post mortem whether the second measurement was taken in the trapezius cervicales or the longissimus dorsi. Thus the correlations between initial pH value (0 hrs) and pH change to 24 hrs were high and positive. However, the correlations between the absolute values for initial and 24 or 48 hr pH were generally small and unimportant, indicating that the variance observed in one reading accounted for less than 10% of the variance in a subsequent reading. The only exceptions were the correlations between the 24 and 48 hr pH readings of the longissimus dorsi for bulls (.82) and heifers (0.46). There were sex differences in the sign of statistically significant ($P < 0.01$) correlations but, because of the low coefficients of determination involved (i.e. r^2 values) these sex differences would appear to be of limited importance (Table 2).

Correlations of the subjective and objective color scores with the pH readings indicated that muscle which retained a relatively high pH in the l. dorsi at 24 and/or 48 hrs tended to be dark in color. This was particularly evident with the bull carcasses (Table 2). Correlations between color scores and pH change of the longissimus dorsi from 24 to 48 hrs were essentially zero. The subjective and objective color scores were more highly correlated for bulls (.70) than for steers (.22) and heifers (.38).

(Tables 2 and 3 near here)

Initial tenderness (shear value) of the rib and loin sections of the longissimus dorsi were not predictable from either of the two pH readings taken on the trapezius cervicales and only for bulls were the pH readings on the longissimus dorsi itself meaningfully correlated with tenderness. For this sub-class, high pH readings at 24 or 48 hrs were associated with low shear values (Table 3). However, none of the pH readings or changes in pH were useful in predicting the magnitude of change in tenderness which occurred during the aging periods.

The sex differences in association between pH and shear values were also evident in the correlations between meat color and shear values. These were moderately high and negative for bulls but of little real consequence for steers and heifers. However, the reversal of sign for the steer correlations (i.e. + 0.33 and + 0.29 respectively for the rib and short loin sections of the longissimus dorsi) suggests that color brightness for this sex requires a different interpretation than for bulls. Meat color was not indicative of percentage change in tenderness during aging of the carcass.

DISCUSSION

Carcasses of bulls, steers and heifers were quite similar in frequency distribution, range and mean value for pH of the trapezius cervicales at 0 hrs (within 30 minutes of slaughter). None of the 574 carcasses had a pH less than 6.2 and 93% were in the pH range of 6.7 to 7.3. However, bulls differed singularly from steers and heifers in their frequency

distribution for 24 hr pH of the longissimus dorsi (Figure 1). Their pH values ranged from 5.3 to 7.0 with 49.2% in excess of 6.0 whereas none of the steers and only 8% of the heifers had a pH greater than 6.0.

(Figure 1 near here)

The consequences of this sex difference in terms of color brightness and tenderness are illustrated in Figure 2. Over the pH range shared in common by the three sexes (i.e. below 6.0) there was no evidence of correlation between 24 hr pH and either color or tenderness. However, definite trends were established as pH increased above 6.0. Thus bulls, which had this pH range almost exclusively to themselves, produced the only significant correlations of the pH reading with color and tenderness of the longissimus dorsi.

(Figure 2 near here)

Bulls from Lethbridge, exposed to approximately 7 hours of stress during transport to slaughter, differed markedly in post-mortem pH change from steers exposed to the same stress and from the Lacombe bulls which were in transport less than one hour (Table 1). These observations would suggest that knowledge of both sex and pre-slaughter treatment might be useful in predicting post mortem pH, meat color and tenderness. However, it is clear that individual bulls may differ widely in their physiological response to stress (Figure 1) and, for this reason, a prediction procedure based on sex

and pre-slaughter history would not be particularly sensitive or reliable.

Although initial pH as here recorded (i.e. trapezius cervicales) was of no value for predicting either the rate or extent of post-mortem pH change in the longissimus dorsi, the fact that muscles differ in post mortem pH gradient (Lawrie et al., 1959) might suggest that use of a different muscle and/or time for estimating initial pH could have predictive value. However, the evidence obtained in this study offers little support for this suggestion. Neither absolute pH values nor post mortem changes in pH were meaningfully correlated with measures of tenderness of steer or heifer carcasses and the associations observed for bull carcasses were restricted to carcasses with ultimate pH greater than 6.0.

Considering the bull carcasses alone, the importance of high 24-hour pH values of the longissimus dorsi in determining the nature of the pH-meat color and/or pH-shear force relationships is portrayed by Figure 3. Forty-eight percent of the Lethbridge bull carcasses had a pH of 6.1 or greater. Of these, 79% were below average in shear force (53.5) at 13 days post mortem (i.e. more tender than average) and 75% had color scores of 80 or above. Viewed in the context of meat color (Figure 4), 85% of the carcasses with color scores of 80 or above were below average in shear force and 84% had a pH greater than 6.0. These observations suggest that color brightness may merit consideration as a technique for predicting potential tenderness of bull carcasses. However, this study provides no evidence that the same criterion of color would be appropriate to carcasses from steers or heifers.

Further, dark cutting beef is considered undesirable by the meat trade and its potential for superior tenderness is unlikely to modify this view. It is also possible that beef exhibiting extreme tenderness will not in fact meet with high consumer acceptance.

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Table 1. Means and standard errors for pH, shear values and meat color for beef carcasses of 6 sex-source sub-groups.

	Steers				Heifers				Bulls			
	Comm		Leth		Comm		Lac		Lac		Leth	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
No. of carcasses	102		66		100		47		85		174	
Initial pH (0 hrs)	7.03	.02	6.98	.02	6.89	.02	7.19	.02	7.01	.02	7.05	.02
pH 1. dorsi 48 hrs	5.56	.01	5.68	.01	5.57	.02	5.68	.02	5.64	.02	6.09	.03
Final pH (13 days)	5.67	.02	5.66	.02	5.60	.02	5.73	.02	5.76	.02	6.12	.03
Post mortem change in pH												
(Initial vs 24 hr t. cerv.)	1.21	.03	1.05	.04	0.99	.03	0.97	.04	1.06	.03	1.23	.03
(Initial vs 24 hr 1. dorsi)	1.42	.02	1.26	.03	1.15	.04	0.91	.04	1.26	.03	0.96	.04
(24 vs 48 hr 1. dorsi)	0.05	.02	0.04	.03	0.17	.02	0.60	.03	0.11	.02	-0.03	.02
Subjective color score	1.03	.02	1.11	.04	1.04	.02	1.00	.00	1.05	.03	1.86	.06
Color brightness	54.3	1.0	62.8	1.0	61.5	1.0	50.6	1.6	57.6	1.3	73.0	0.9
Shear values												
1. dorsi (proximal) 24 hr	71.4	1.5	60.9	1.6	68.6	1.5	57.5	1.6	79.4	1.6	55.8	1.6
change 24 - 48 hr	7.3	0.8	5.2	.09	7.7	1.1	2.9	1.3	8.1	1.0	3.4	0.8
change 48 - 72 hr	5.5	0.7	5.9	.07	0.1	1.0	3.2	1.2	4.9	0.9	2.6	0.7
1. dorsi (distal) 48 hr	75.6	1.5	69.0	1.8	81.7	1.6	76.9	2.5	82.7	1.4	70.1	1.6
change 48 - 72 hr	-1.0	1.2	-5.6	1.5	-0.7	1.2	-0.9	1.6	-2.8	1.2	1.5	0.9
change 48 hr - 6 day	12.0	1.2	18.5	1.3	10.6	1.1	11.4	1.3	6.6	1.1	8.6	0.8
change 6 day - 13 day	5.4	1.0	4.0	1.2	10.1	1.2	0.9	1.3	10.6	1.0	6.4	0.8
Total change in tenderness as a % of initial value												
% change in rib to 72 hr	17.9	1.3	18.2	2.3	9.1	2.0	10.6	2.4	16.3	1.7	7.8	1.7
% change in loin to 13 day	20.2	1.4	24.5	2.1	23.3	1.5	14.8	2.3	17.4	1.6	21.5	1.4

Table 2. Correlations among pH readings, post-mortem changes in pH and color of longissimus dorsi for bulls, steers and heifers.

		pH t. cervicales		pH of l. dorsi	Color of l. dorsi	
		0 hr	24 hr	24 hr		
					subjective	objective
pH t. cervicales:						
0 hr	Bulls				.27	.23
	Steers				.14	-.01
	Heifers				.12	.45
24 hr	Bulls	-.02			.05	.10
	Steers	-.10			.08	.11
	Heifers	-.09			-.28	-.14
pH l. dorsi:						
24 hr	Bulls	.18	.14		.71	.75
	Steers	.13	-.07		.47	.11
	Heifers	-.14	.29		.48	.09
48 hr	Bulls	.28	.09	.82	.65	.73
	Steers	-.26	.26	.02	-.03	.31
	Heifers	-.01	-.29	.46	.70	.24
pH change from 0 hr for t. cervicales to:						
24 hr t. cerv.	Bulls	.79			.17	.08
	Steers	.72			.04	-.08
	Heifers	.83			.25	.43
24 hr l. dorsi	Bulls	.35	-.22		-.55	-.60
	Steers	.83	-.06		-.14	-.07
	Heifers	.79	-.24		-.21	.26

Absolute magnitude of correlations required for significance

	$P < 0.05$	$P < 0.01$
Bulls	0.15	0.19
Steers	0.20	0.25
Heifers	0.20	0.25

Table 3. Correlations of pH readings and muscle color ratings with estimates of tenderness (shear force) for bulls, steers and heifers.

	pH of t. cervicales		pH of l. dorsi		Color of l. dorsi	
	1	2	3	4		
	0 hr	24 hr	24 hr	48 hr	subjective	objective
Shear force, rib section of l. dorsi at 24 hrs						
Bulls	-.23	-.09	-.71	-.68	-.61	-.56
Steers	.06	-.05	-.08	-.09	-.02	.33
Heifers	.08	.06	-.08	-.20	-.26	.06
Shear force, short loin section of l. dorsi at 48 hrs						
Bulls	-.15	-.11	-.74	-.74	-.55	-.55
Steers	-.02	-.16	.10	.07	.17	.29
Heifers	-.01	.11	-.08	-.25	-.28	.07
% Change in shear force for rib section 24 to 72 hrs						
Bulls	.00	-.02	-.17	-.18	-.08	-.10
Steers	.12	-.12	.22	.07	.11	.26
Heifers	.16	-.14	-.12	-.12	.01	.09
% Change in shear force for short loin section 48 hrs to 13 days						
Bulls	-.08	-.06	-.22	-.28	-.27	-.24
Steers	-.08	.18	-.01	.03	-.08	.13
Heifers	.14	.00	-.09	-.24	-.13	-.09

Absolute magnitude of correlations required for significance:

	$P < 0.05$	$P < 0.01$
Bulls	0.15	0.19
Steers	0.20	0.25
Heifers	0.20	0.25

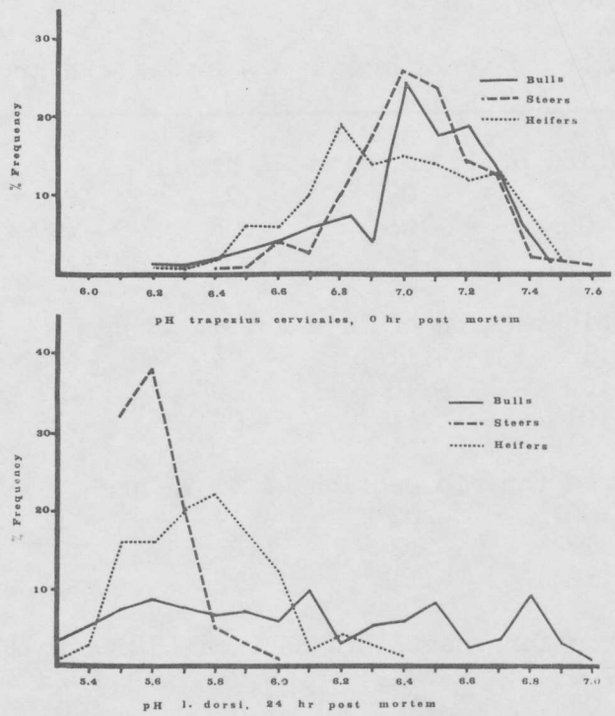

FIGURE 1: Frequency distribution of pH at 0 hrs (trapezius cervicales) and 24 hrs (l. dorsi) for bulls, steers, and heifers.

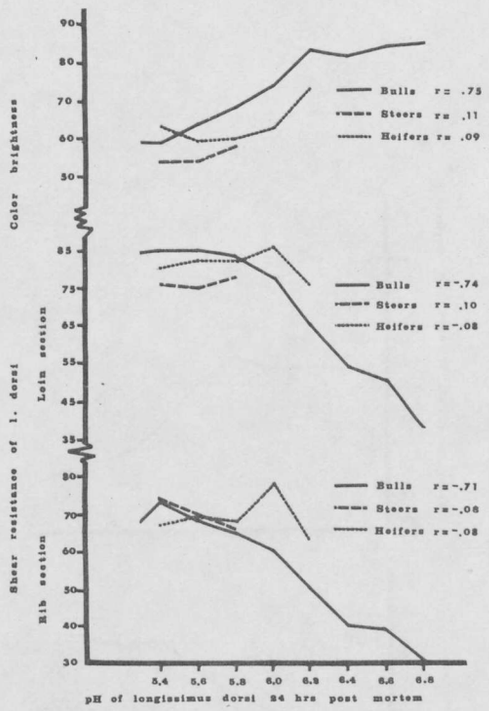

FIGURE 2: Relationship of color brightness and two measures of shear resistance (tenderness) with 24 hr post mortem pH of the longissimus dorsi.

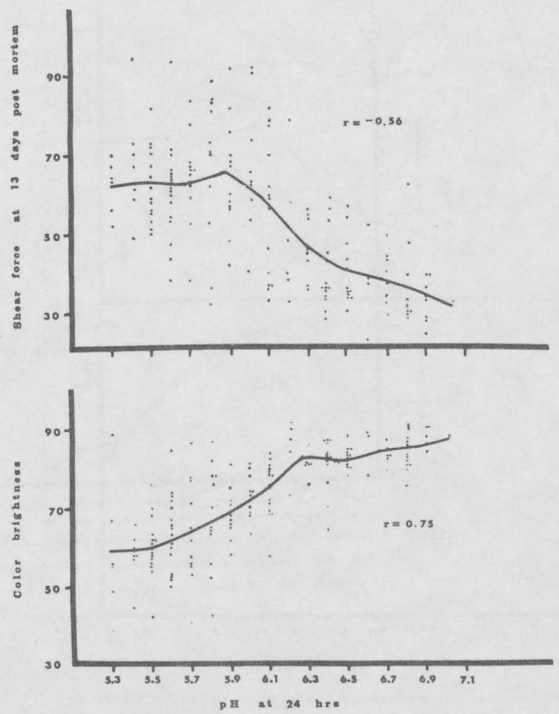

FIGURE 3: Scatter diagrams of relationships between pH of longissimus dorsi at 24 hrs post mortem and color brightness and shear values (bulls only).

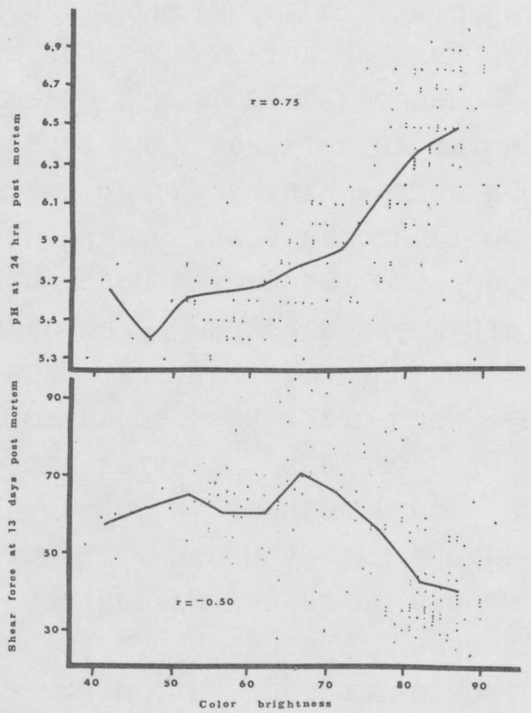

FIGURE 4: Scatter diagram of relationships between color brightness of the longissimus dorsi at 24 hrs post mortem and pH of the same muscle at this time and shear value at 13 days post mortem.