1973

Correlation Studies of Tenderness Parameters in Straightbred and Crossbred Cattle.

Ronald Louis Luckett

Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Recommended Citation


https://digitalcommons.lsu.edu/gradschool_disstheses/2553

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradtd@lsu.edu.
INFORMATION TO USERS

This material was produced from a microfilm copy of the original document. While the most advanced technological means to photograph and reproduce this document have been used, the quality is heavily dependent upon the quality of the original submitted.

The following explanation of techniques is provided to help you understand markings or patterns which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting thru an image and duplicating adjacent pages to insure you complete continuity.

2. When an image on the film is obliterated with a large round black mark, it is an indication that the photographer suspected that the copy may have moved during exposure and thus cause a blurred image. You will find a good image of the page in the adjacent frame.

3. When a map, drawing or chart, etc., was part of the material being photographed the photographer followed a definite method in "sectioning" the material. It is customary to begin photoing at the upper left hand corner of a large sheet and to continue photoing from left to right in equal sections with a small overlap. If necessary, sectioning is continued again — beginning below the first row and continuing on until complete.

4. The majority of users indicate that the textual content is of greatest value, however, a somewhat higher quality reproduction could be made from "photographs" if essential to the understanding of the dissertation. Silver prints of "photographs" may be ordered at additional charge by writing the Order Department, giving the catalog number, title, author and specific pages you wish reproduced.

5. PLEASE NOTE: Some pages may have indistinct print. Filmed as received.

Xerox University Microfilms
300 North Zeeb Road
Ann Arbor, Michigan 48106
74-18,349

LUCKETT, Ronald Louis, 1941-
CORRELATION STUDIES OF TENDERNESS PARAMETERS
IN STRAIGHTBRED AND CROSSBRED CATTLE.

The Louisiana State University and Agricultural
and Mechanical College, Ph.D., 1973
Agriculture, animal culture

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THIS DISSERTATION HAS BEEN MICROFILMED EXACTLY AS RECEIVED.
CORRELATION STUDIES OF TENDERNESS PARAMETERS

IN STRAIGHTBRED AND CROSSBRED CATTLE

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Animal Science

by
Ronald Louis Luckett
B.S., University of Kentucky, 1964
M.S., University of Kentucky, 1966
December, 1973
ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. Auttis M. Mullins and Dr. Thomas D. Bidner for their guidance, assistance and constructive criticism throughout the course of study. He is especially grateful to his committee members, Dr. George L. Robertson, Dr. Jordan G. Lee, Dr. Prentiss E. Schilling, Dr. Charles E. Vincent and Dr. J. L. Kreider, for their assistance in directing his program.

Special thanks are given Mr. Emilio A. Icaza, Dr. J. W. Turner and Dr. Schilling for their aid and advice in statistical analyses.

The author is also thankful to Mr. Lee Bertrand and Mr. Thomas Barnes for their help in collecting data during this study.

Special thanks go to Mr. James Wood and Mr. Ron Harrell for their aid in laboratory analyses and microscopic examinations.

Sincere thanks are offered to Dr. Robertson for making available the facilities and funds which made this study possible.

Sincere thanks are extended his wife, Nancy, for her encouragement, patience and love during the period of study.

This dissertation is dedicated to the author's father, William Leo Luckett, whose love of livestock provided the initial encouragement for work in Animal Science.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>REVIEW OF LITERATURE</td>
<td>3</td>
</tr>
<tr>
<td>Armour Tenderometer</td>
<td>3</td>
</tr>
<tr>
<td>Warner-Bratzler Shear</td>
<td>6</td>
</tr>
<tr>
<td>Sarcomere Length</td>
<td>8</td>
</tr>
<tr>
<td>The Effects of Stress on Tenderness</td>
<td>11</td>
</tr>
<tr>
<td>Breed Effects on Tenderness</td>
<td>17</td>
</tr>
<tr>
<td>MATERIALS AND METHODS</td>
<td>21</td>
</tr>
<tr>
<td>Temperature Determination</td>
<td>24</td>
</tr>
<tr>
<td>pH Measurement</td>
<td>24</td>
</tr>
<tr>
<td>Sarcomere Length Determination</td>
<td>25</td>
</tr>
<tr>
<td>Warner-Bratzler Shear Determiniation</td>
<td>26</td>
</tr>
<tr>
<td>Statistical Analyses</td>
<td>26</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>29</td>
</tr>
<tr>
<td>Comparison of Warner-Bratzler Shear Values</td>
<td>29</td>
</tr>
<tr>
<td>to Carcass Traits</td>
<td></td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Comparison of Warner-Bratzler Shear Values to Tenderometer</td>
<td>34</td>
</tr>
<tr>
<td>Comparison of Armour Tenderometer Values to Carcass Traits</td>
<td>38</td>
</tr>
<tr>
<td>Comparison of Warner-Bratzler Shear Value to Temperature, pH and Sarcomere Length</td>
<td>39</td>
</tr>
<tr>
<td>Correlation of Warner-Bratzler Shear Values with Carcass Temperature</td>
<td>42</td>
</tr>
<tr>
<td>Relationship of Warner-Bratzler Shear to pH</td>
<td>44</td>
</tr>
<tr>
<td>Relationship of Warner-Bratzler Shear to Sarcomere Length</td>
<td>46</td>
</tr>
<tr>
<td>Relation of Warner-Bratzler Shear to Texture</td>
<td>47</td>
</tr>
<tr>
<td>Multiple Regression Analysis to Predict Warner-Bratzler Shear</td>
<td>49</td>
</tr>
<tr>
<td>Breed Differences for Tenderness Related Traits</td>
<td>51</td>
</tr>
<tr>
<td>Quality Grade</td>
<td>51</td>
</tr>
<tr>
<td>Fat Thickness</td>
<td>56</td>
</tr>
<tr>
<td>Rib-Eye Area</td>
<td>57</td>
</tr>
<tr>
<td>One Hour Temperature</td>
<td>58</td>
</tr>
<tr>
<td>Average Sarcomere Length</td>
<td>59</td>
</tr>
<tr>
<td>Six-Day pH</td>
<td>59</td>
</tr>
<tr>
<td>Warner-Bratzler Shear Value</td>
<td>59</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>61</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>63</td>
</tr>
<tr>
<td>VITA</td>
<td>72</td>
</tr>
<tr>
<td>Number</td>
<td>Table Title</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Composition of Ration</td>
</tr>
<tr>
<td>2.</td>
<td>Breeds and Numbers of Steers</td>
</tr>
<tr>
<td>3.</td>
<td>Correlation Between Warner-Bratzler Shear Values and Some Carcass Traits</td>
</tr>
<tr>
<td>4.</td>
<td>Overall Means and Standard Deviations of Carcass Traits Within Straightbreds</td>
</tr>
<tr>
<td>5.</td>
<td>Correlations Among Hot Weight, Rib-Eye Area and Conformation Score</td>
</tr>
<tr>
<td>6.</td>
<td>Correlation Between Armour Tenderometer Values and Some Carcass Traits</td>
</tr>
<tr>
<td>7.</td>
<td>Breeds and Numbers of Steers</td>
</tr>
<tr>
<td>8.</td>
<td>Correlations Between Warner-Bratzler Shear Values and Temperature, pH, Sarcomere Length and Texture</td>
</tr>
<tr>
<td>9.</td>
<td>Temperature, pH, Sarcomere Length and Texture Comparisons Within Breed</td>
</tr>
<tr>
<td>10.</td>
<td>Correlations Among Temperature, pH, Sarcomere Length and Texture</td>
</tr>
<tr>
<td>11.</td>
<td>Analyses of Variance for Selected Traits</td>
</tr>
<tr>
<td>12.</td>
<td>Least-Square Means for Selected Traits</td>
</tr>
<tr>
<td>13.</td>
<td>Correlation of Warner-Bratzler Shear Values With Selected Variables Within Lines</td>
</tr>
</tbody>
</table>
ABSTRACT

Two-hundred sixty purebred and crossbred steers (Angus, Brahman, Hereford and Charolais and their backcrosses and three-breed crosses containing 1/4 Brahman) were slaughtered for tenderness studies. Carcass information, tenderometer and Warner-Bratzler shear (WBS) values were obtained on 124 steers slaughtered in 1971. In addition, zero and 1 hour carcass temperatures (0 HT and 1 HT), 1 hour and 6-day pH (1 HpH and 6 DpH) and sarcomere lengths were obtained on 136 steers slaughtered in 1972.

Zero hour temperature was obtained by inserting a temperature probe into the throat cavity following bleeding of the animal. One hour temperature was obtained on the longissimus muscle at the twelfth rib. One hour postmortem pH was measured on the diaphragm muscle. Surface pH of five areas in the muscle was measured and the pH readings were averaged to obtain the final 1 hour pH. Approximate 6-day or ultimate pH was determined on the longissimus muscle originating from the eleventh rib. The longissimus muscle from the eleventh rib was also used for measurement of the sarcomere length. At 5 days postmortem sarcomere length was determined on 10 g dorsal and lateral muscle samples. Five adjacent sarcomeres were measured at five separate areas of a microscope slide.

Means, standard deviations and correlation coefficients vi
with WBS were: carcass weight, $236.0 \pm 32.3$ kg, $-0.25^{**}$; age, $475.7 \pm 20.4$ days, $-0.14^{**}$; quality grade, $9.1 \pm 1.2$ ($G^\approx=9.0$), $-0.21^{**}$; marbling score, $4.6 \pm 2.4$ ($tr^* = 5.0$), $-0.13^{*}$; rib-eye area, $64.5 \pm 10.8$ cm$^2$, $-0.33^{**}$; conformation score, $12.3 \pm 1.5$ ($Ch = 12.0$), $-0.29^{**}$; 1 HT, $39.0 \pm 1.3^{\circ}$ C, $-0.20^{**}$; 6 DpH, $5.4 \pm 0.1$, $0.53^{**}$; and sarcomere length, $1.66 \pm 0.07$ u, $-0.37^{**}$.

The latter three correlation coefficients show that less tender meat was associated with carcasses having a lower 1 hour temperature, a higher 6-day pH and shorter sarcomere length at 5 days postmortem. The magnitude of the correlation coefficient between WBS and 6 day pH suggests that the measurement of 6-day pH is useful for segregating carcasses into tenderness groups.

Tenderometer values were not significantly (P > .05) correlated with WBS values as indicated by the correlation coefficient of 0.08. Thus, tenderometer values do not enable the prediction of the ultimate cooked tenderness. Factor analysis studies which consider the intercorrelation among variables also revealed that the WBS and tenderometer were measuring different carcass characteristics.

Tenderometer values were significantly (P < .01) correlated with U.S.D.A. quality grade (r = 0.20) and marbling score (r = 0.16). These coefficients indicate that higher tenderometer values were associated with higher quality grades and marbling scores.

The optimum equation to predict WBS was: $WBS = 98.91 + 26.29 \times (6 \text{ DpH}) - 0.81 \times \text{(quality grade)} - 5.28 \times \text{(fat thickness, in)}$.
- 1.48 (rib-eye area, sq in). This equation explained 45.66% of the variation in WBS. A separate analysis revealed that line effects did not significantly contribute to the source of variation in WBS. Thus, most of the differences among lines were accounted for by ultimate pH, quality grade, fat thickness and rib-eye area.

Within line comparisons showed that Brahman steers were significantly (P< .01) tougher than the average of the other straightbreds while Charolais backcrosses (C x CB) were significantly (P< .01) more tender than the average of Angus and Hereford backcrosses (A x AB + H x HB).
INTRODUCTION

Because tenderness is such an important component of the eating satisfaction of meat, scientists have long been interested in finding a simple objective measure of meat tenderness. The Warner-Bratzler shear (WBS) is considered to be the best objective measure of meat tenderness. However, its use on raw carcass meat is cumbersome and results in the destruction of a portion of muscle. The Armour Tenderometer was developed for the purpose of predicting the tenderness of cooked meat, based on a measure obtained on the carcass. The technique of obtaining tenderometer readings is fast, simple to use, and nondestructive to the muscle. If it could be shown that the tenderometer does accurately predict cooked meat tenderness, beef could be marketed on a basis more nearly approaching its true value.

Certain carcass traits are measured routinely by U.S.D.A. employees in the process of grading. However, the relationship of some of these traits to palatability is not clear. If it could be shown that these easily obtainable traits were closely related to tenderness, carcasses could be placed into tenderness categories based on their values of particular carcass traits.

According to Mullins et al. (1969), the two factors primarily responsible for meat tenderness are the distribution and molecular state of connective tissue and the molecular state of
contractile proteins at the time of sampling. Nevertheless, Locker (1960) has indicated that there are differences between muscles that are not dependent upon connective tissue content or contraction state. These differences include such factors as muscle pH at various times after slaughter, stress tolerance of the animal and the many interrelationships associated with pH and stress.

With these problems in mind, this study was conducted with the following objectives: (1) to determine the effectiveness of the tenderometer in predicting beef tenderness using the WBS as the standard of comparison, (2) to determine the relationship of carcass traits to tenderness and (3) to fix the relationship of sarcomere length, carcass pH and temperature at various times after slaughter to beef tenderness, taking into account specific breed effects which might exist.
REVIEW OF LITERATURE

Armour Tenderometer

The Armour Tenderometer was developed in an attempt to stratify beef carcasses into tenderness desirability groups (L. J. Hansen, personal communication). Hansen (1972) found that raw WBS values were the best predictors of cooked WBS values as indicated by the correlation between the two variables of 0.82 (P < .01). Consideration of salt soluble fibrillar protein, fat content, connective tissue content and pH only increased the multiple correlation coefficient to 0.86 (P < .01). The high correlation of raw and cooked WBS values disagrees with the findings of Warner (1928) who found a correlation of 0.30 between raw and cooked WBS values. Similarly, Szczesniak and Torgeson (1965) reported in their review article that Black, Warner and Wilson (1931) found a zero correlation between raw WBS values and cooked samples. McBee and Naumann (1959) reported that the raw WBS value was of less use for measuring tenderness than cooked WBS due to the greater variability associated with raw WBS value.

Hansen (1972) determined the effectiveness of the tenderometer by comparing it to both WBS values and taste panel scores. He utilized 25 Choice and 20 Good short loins in this study. There was a highly significant correlation between tenderometer and taste panel in both the Choice and Good populations of 0.77 and 0.69,
respectively. When tenderometer values were correlated with WBS, a significant 0.42 correlation was found within the Choice grade but only a non-significant 0.30 correlation was found within the Good grade. The correlations between WBS values and trained taste panel scores for Choice and Good samples were -.68 and -.70, respectively. These results are in agreement with the work of Dikeman et al. (1972) who found a correlation of -.67 between the two variables. These results show that tenderometer and WBS are not measuring the same factors or are not measuring these factors in the same manner, although both devices tend to measure part of the overall tenderness impression experienced by the taste panel judges.

Dikeman et al. (1972) found a significant (P < .05) correlation of tenderometer with WBS and taste panel scores (r=0.29 and r= -.30, respectively), but concluded that the correlations were too low to be of value for predictive purposes. Luckett, Bidner and Turner (1972) reported a non-significant correlation of -.11 between tenderometer and WBS. However, Luckett et al. (1973) obtained a highly significant correlation coefficient of 0.48 between WBS and tenderometer. Tenderometer values were also significantly (P < .01) associated with carcass weight (r= -.32), yield grade (r= -.40) and fat thickness (r= -.32). Martin et al. (1971) found a significant (P < .05) correlation of 0.45 between marbling score and tenderometer. Consequently, these workers stated that tenderometer readings must be adjusted for variation in marbling score. Work conducted by Dikeman et al. (1972) and Hansen (1972) also demonstrated that higher marbling scores are associated with
higher tenderometer values.

These findings are reflected in the way the "Armour Test Tender" beef is merchandised (L. J. Hansen, personal communication). Good carcasses can have a tenderometer value of 15 pounds or less and qualify under this label. However, Choice carcasses can have a tenderometer value of 18 pounds or less and still qualify as "Test Tender" beef.

Carpenter, Smith and Butler (1972) reported a highly significant correlation of tenderometer with WBS (R=0.35) and with taste panel (r= -.35) within the Choice grade. However, the correlations of tenderometer with WBS and taste panel for the Good grade were not significant. The authors explained that the nonsignificant relationship of tenderometer with WBS and taste panel within the Good grade was because of greater error of tenderometer readings. These workers postulated that this error was partially due to the softer muscle tissue of Good carcasses causing a dimpling effect around the tenderometer probes. The authors also stratified carcasses into desirability groups by use of WBS values with steaks from carcasses yielding shear values of less than 3.9 kg designated tender, while those greater than 3.9 kg were considered tough. Whether the total population or the Choice group was considered, tenderometer values were significantly (P < .05) lower for the tender groups than the tough groups (7.73 vs. 8.37 and 7.61 vs. 8.31, respectively). However, the tenderometer values were not significantly lower for the tender group (7.33) than the tough group (7.82) for the Good carcasses. These results strengthen the idea
that the tenderometer values are more reliable for separating tenderness variations within Choice cattle as compared to Good cattle.

Huffman and Powell (1973) found low correlations of tenderometer with WBS (0.22), taste panel (−0.05), marbling score (0.27) and quality grade (0.22). However, low correlations were also found when quality grade was correlated with WBS (−0.14) and taste panel (0.39). These workers plotted the data to determine the frequency of correct judgements (acceptable or unacceptable tenderness) by quality grade and tenderometer when compared to the taste panel. This study revealed that there were 78% correct judgements when tenderometer was compared to taste panel contrasted to 59% correct judgements when quality grade was compared to taste panel. From these results, the authors concluded that the tenderometer was superior to quality grade as a means of placing cattle into homogenous tenderness groups.

Warner-Bratzler Shear

The use of a trained taste panel for the determination of meat tenderness is slow and subjective. Hence, there is the need for a simple, objective measure of cooked meat tenderness.

The first reported work done to develop an objective technique for measuring tenderness was that conducted by Lehman (1907). He developed a device which measured the breaking strength of meat and another instrument which determined the force required to shear meat between two cutting edges. Warner (1928) reported on the development of a shear which was later modified by Bratzler
(1932) and called the Warner-Bratzler shear (WBS). Although many other objective tenderness measures have been developed, Schultz (1957), in his review of objective tenderness measures, concluded that the Warner-Bratzler shear was "the most widely used and the best" instrument for measuring tenderness. The WBS is a motorized device which shears a standard size core and the force required is indicated on a dynamometer. The higher the reading, the tougher the meat sample (Szczesniak and Torgeson, 1965).

Alsmeyer et al. (1968) compared the Slice Tenderness Evaluator and the modified Tenderness Press to the WBS, utilizing a taste panel as the standard of comparison. Three-hundred seventy-five standing rib roasts from steer and bull carcasses of Utility to Choice grade were used to test the objective tenderness measures. It was found that the correlation of WBS with taste panel was higher than any other objective tenderness measure studied.

Several studies have been conducted to correlate WBS values to taste panel analyses. Bratzler (1932) reported a correlation of -.91 between cooked WBS value and taste panel. This finding appears to agree with the -.79 correlation between the same two variables reported by Warner (1928). Webb, Kahlenberg and Naumann (1964) and Dikeman et al. (1972) found an identical -.67 correlation of WBS with taste panel. Kropf and Graf (1959) and Herring et al. (1967) found correlations between the two variables of -.78 and -.81, respectively. However, Deatherage and Garnatz (1952) and Fielder et al. (1963) found lower correlations of -.24 and -.32, respectively, between WBS and taste panel.
Bratzler (1932) pointed out some of the precautions to be taken when using the WBS as the measure of tenderness: (1) samples should be cooked uniformly, (2) care should be exercised in removal of the core from the meat sample, (3) samples should be taken parallel to the muscle fibers, and (4) connective tissue and heavy fat deposits should be avoided.

Sarcomere Length

The degree of muscle contraction was reported by Mullins et al. (1969) and Smith, Arrango and Carpenter (1971) to be an important factor in tenderness and may be estimated simply and objectively from the sarcomere length of the myofibril. Locker (1960) reported that relaxed muscles are more tender than partly contracted muscles and Locker and Hагyard (1963) demonstrated that the relaxed muscles had longer sarcomeres.

Hostetler et al. (1972) found that sarcomere length accounted for 12% of the variation in tenderness utilizing WBS values as the measure of tenderness. Dikeman, Tuma and Beecher (1971) found that sarcomere length in combination with protein solubility and texture score accounted for 88% of the variation in shear force. Howard and Judge (1968) compared sarcomere length to other variables in predicting tenderness. They concluded that sarcomere length did not account for tenderness variation that was unaccounted for by combinations of other commonly used carcass variables. Covington and Tuma (1970) reported that sarcomere length was not significantly correlated with shear force values. Hostetler et al. (1973)
also found that a mean sarcomere length would not give a good prediction of animal tenderness as measured by a sensory panel.

Position in the muscle affects tenderness according to Howard and Judge (1968) and Covington and Tuma (1970). Both studies revealed that the medial muscle position was less tender than the lateral position.

According to Marsh and Leet (1966), the relationship between muscle shortening and tenderness is complex. The authors found that toughness increased rapidly with shortening beyond 20% of the excised length, reaching a maximum at 40% shortening. With still further shortening, the meat became progressively more tender until at about 55-60% shortening, it was cleaved about as easily as meat in which less than 20% shortening had occurred. Hostetler and Landmann (1970) also found that equal changes in sarcomere length did not produce equal changes in tenderness. Although Bouton et al. (1973) found that shear force values were highly dependent on muscle contraction state in muscles of normal pH (5.4-5.6), they emphasized that simple relationships between sarcomere length and tenderness could not always be assumed because the change in fiber length brought about by cooking varied with both ultimate pH and sarcomere length.

Locker (1959) indicated that the contraction process occurring at the onset of rigor mortis was the same as contraction of the living muscle fibers. Sink et al. (1965) showed that the decrease in muscle extensibility at the onset of rigor mortis was accompanied by shortening or contraction and was related to adenosine triphosphate breakdown. Furthermore, the amount of sarcomere
shortening was highly dependent upon the time course of rigor mortis. When the delay phase of rigor was of long duration, the shortening of the sarcomere was less severe than when the delay phase was of short duration. Specifically, the authors found that 81% of the variation in sarcomere length of the myofibril was due to the duration of the delay phase. Smith, Arrango and Carpenter (1971) stated that the degree of postmortem muscle contraction which occurs during development of rigor is related to the temperature at which the carcass is stored during the initial cooling period. The authors observed a 40.2% increase in longissimus tenderness by chilling the carcass at 16° C. during the first 16 to 20 hours of chill. McCrae et al. (1971) found that rapid chilling of pre-rigor excised unrestrained muscle promoted shortening and consequently, toughening.

Locker (1960) suggested that it was possible to improve tenderness of muscles by hanging carcasses in such a way as to stretch the muscles. McCrae et al. (1971), working with lambs, found no difference among lamb muscles in their potential to shorten and toughen. Rather, the difference was due to the degree of stretch or slack imposed on the muscles by their attachment to the skeleton. Hostetler et al. (1971) and Herring et al. (1967) improved the tenderness of beef muscles by preventing shortening during the onset of rigor. Hostetler and Landmann (1970) demonstrated that by varying the position of the carcass, it was possible to change the sarcomere length of various muscles. Herring et al. (1967) showed that excised muscle allowed to shorten during rigor
tended to be tough following cooking. Conversely, excised muscle prevented from shortening during rigor was more tender. Herring, Cassens and Briskey (1965) determined that vertical suspension allowed certain muscles to shorten and toughen, while other muscles such as the psoas major were stretched and became more tender. The authors demonstrated that the psoas major of horizontally placed beef sides was drastically reduced in tenderness as compared to carcasses hung the conventional way. Hostetler et al. (1972) found that changes in carcass position that produce shortening of sarcomeres in one muscle may produce lengthening in its opposing muscles or in other muscles.

The Effects of Stress on Tenderness

The study of the relationship of antemortem stress factors to the postmortem physiological state of the animal has taken on much importance in recent years, especially in relation to pale, soft exudative (PSE) pork carcasses and dark cutting beef. Selye (1951) in his review on stress stated that "animals exposed to certain agents such as infections, intoxications, trauma, nervous strain, heat, cold and muscular fatigue always react by altering some of the physiological processes which are carried out inside the organism." During stress, there is an increased secretion of hormones from the adrenal cortex and medulla which affects a variety of physiological processes (Funkenstein, 1955; Hedrick, 1965). Hartman and Brownell (1949) reported that the adrenal cortex could be stimulated by any type of stress of sufficient magnitude and
duration. Addis et al. (1965) found no clear cut relationship between adrenal gland size and tenderness of the longissimus muscle.

According to Himwich (1955), centers in the posterior hypothalamus are responsible for controlling temperature as well as other responses in the body of humans. Goodell, Graham and Wolff (1950) and Diez (1970) reported that elevation of body temperature was a normal consequence of nervous tension, while Weldy et al. (1964) observed an increased rectal temperature in heat stressed cattle.

The temperature at which the carcass is chilled can affect tenderness of the cooked meat. Although beef carcasses are normally held at temperatures just above freezing to retard microorganism growth and to facilitate a fast rate of chill, there is evidence that rapid chilling decreases meat tenderness due to cold shortening (Price and Schweigert, 1971; Locker and Hagyard, 1963; Fields, Carpenter and Smith, 1971; Smith, Arrango and Carpenter, 1971). Locker and Hagyard (1963) observed that maximum shortening (47.7%) occurred at 0° C. At temperatures above this, there was a rapid decline in shortening to a minimum value of less than 10% shortening between 14° to 19° C. Smith, Arrango and Carpenter (1971) also reported that chilling beef carcasses in a 16° C. cooler for the first 16 hours postmortem resulted in a significant increase in tenderness with no additional labor expense and without any irregularity in carcass form. Work by Fields, Carpenter and Smith (1971) substantiates the finding of increased toughness with decreasing temperature of storage postmortem. These workers reported that
holding beef carcasses for 20 hours at 16° C. followed by 28 hours at 2° C. resulted in significantly more tender meat than in carcasses which had been held the entire 48 hour period at 2° C. They suggested that carcasses could be stored at higher temperatures and processed more quickly, thereby increasing the available cooler space for storage.

Briskey and Wismer-Pedersen (1961) reported four distinct pH patterns in swine and related these patterns to muscle quality. The PSE muscle condition was found to be associated with a sharp significant decrease in pH to about 5.1 at 1 1/2 hours after slaughter with a subsequent rise to 5.3 to 5.6. Wismer-Pedersen and Briskey (1961a) stated that the postmortem glycolytic rate was a more important determiner of ultimate muscle quality than the total amount of glycogen present in the muscle at the time of slaughter. Soft exudative tissue also resulted when pH was decreased to about 5.4 while tissue temperature remained above 25° C. (Wismer-Pedersen and Briskey, 1961b). Rapidly chilling the tissues tended to prevent the extreme pH variations and undesirable alterations in muscle structure.

Carpenter, Kauffman and Bray (1961) discovered dark, firm and dry (DFD) muscle to be more tender and juicy than paler, softer muscle. Dildey et al. (1970) found a negative relationship between tenderness and leanness. Because leaner pigs tend to be PSE more frequently than fatter pigs, the authors suggested that PSE muscle was less tender than normal muscle. In contrast to these studies, Deethardt and Tuma (1971) found that PSE loins were
significantly more tender than normal or DFD loins as judged by a taste panel. Shear values also indicated that DFD muscle was the least tender.

The effects of stress on muscle properties utilizing epinephrine injections and/or electric shock have been studied (Hedrick et al., 1959; Lewis, Brown and Heck, 1959; Anglemier et al., 1961; Hedrick et al., 1961; Lewis, Brown and Heck, 1962a; Lewis, Brown and Heck, 1962b; Bramblett, Judge and Vail, 1963; Hedrick et al., 1963; Webb, Kahlenberg and Naumann, 1964; Lewis, Brown and Heck, 1965a; Lewis, Brown and Heck, 1965b; Ashmore et al., 1971). Epinephrine injections mimic the condition produced by natural stress (Ashmore et al., 1971). These workers found that injection of heifers with 0.06 mg/kg epinephrine at 48 and 24 hours prior to slaughter resulted in meat having a high pH, low glycogen reserve and a dark color. Hedrick et al. (1959) found that preslaughter injections of epinephrine had no effect on beef tenderness or other palatability factors. Webb, Kahlenberg and Naumann (1964) found that non-stressed control cattle were significantly more tender than the cattle that received epinephrine injections one hour prior to slaughter. Lewis, Brown and Heck (1962a) and Lewis, Brown and Heck (1965b) found that stress decreased the tenderness of beef longissimus, but Lewis, Brown and Heck (1965a) revealed that stress by periodic electric shock significantly increased the tenderness of the quadriceps femoris and psoas major. Lewis, Brown and Heck (1959) also found that periodic electric shock caused an increase in the tenderness of fresh ham. Lewis, Heck and Brown (1962b)
reported that stress prior to slaughter had no detrimental effect on the eating quality of pork. These results agree with work by Hedrick et al. (1963), who found that chops from pigs injected with epinephrine pre-slaughter were as desirable in flavor and tenderness as chops from non-stressed pigs. However, chops from stressed pigs had a longer shelf life. Anglemier et al. (1961) reported that epinephrine injected barrows were more tender and juicier than controls. Bramblett, Judge and Vail (1963), working with lambs, found that epinephrine injections and electric shock treatments caused a reduction in overall tenderness while Hedrick et al. (1961) found that lambs injected with epinephrine were darker in color than non-injected controls.

Hedrick et al. (1959) stated that dark cutting beef was caused by cattle being subjected to prolonged stress which arouses the sympathetic nervous system and stimulates the release of epinephrine and subsequent glycogen depletion. The severity of the condition will be determined by the intensity and duration of stress as well as individual cattle susceptibility and the efficiency of the stress defense mechanism. Hedrick et al. (1959) and Munns and Burrell (1966) agree that dark cutting beef arises when glycogen supplies are abnormally low in the muscle tissues prior to slaughter. Since glycogen is converted to lactic acid after death, the tissues of dark cutting beef are less acidic than normal beef muscles. Ashmore et al. (1971) showed that dark cutting beef results from an acceleration of glycolysis and stated that the best cure was prevention of the rapid glycolytic rate. Munns and
Burrell (1966) reported an 8% incidence of dark cutting beef from 1958 to 1961 at a Toronto, Canada, packing plant and higher occurrences in poorer quality cattle. Loeffel (1942) found that dark cutting beef was more tender than normal, bright, cherry red colored beef, although bright cutting beef was more desirable in flavor. However, the U.S.D.A. (1965) and Hedrick et al. (1959) reported no difference in palatability between dark cutting and normal beef.

Anglemier et al. (1961), Lewis, Heck and Brown (1961) and Lewis, Brown and Heck (1965b) reported that pre-slaughter stress raised the muscle pH in swine. A similar effect has been noted in beef (Hedrick et al., 1959; Lewis, Brown and Heck, 1962a; Lewis, Brown and Heck, 1965a) and in lambs (Hedrick et al., 1961).

Bouton, Harris and Shorthose (1971), working with lambs, observed a positive correlation of ultimate pH with water-holding capacity and juiciness but a negative relationship with Instron reading. In addition, the authors noted that lamb was in its least tender state at pH 6.0. McClain and Mullins (1969) also found a higher water binding capacity to be associated with higher pH.

Khan and Lentz (1973) designed an experiment to differentiate and characterize both high and low postmortem pH beef muscle in terms of dephosphorylation and glycolytic rate. They observed that in muscle with high postmortem pH, most of the dephosphorylation and glycolysis occurred after the death of the animal, whereas in muscle with low postmortem pH, the largest proportion
of both of these changes occurred either before or during slaughter. These same workers found a highly significant \((r=0.55)\) correlation between postmortem pH and seven day WBS value for all muscles studied. Based on this finding, the authors suggested that postmortem pH would offer an excellent means of segregating carcasses with respect to the aging time required to insure satisfactory tenderness. Ramsbottom and Strandine (1949) reported that the pH of beef dropped from about 6.4 at two hours after slaughter to about 5.5 at 24 hours postmortem. They also reported that the ultimate pH of Utility beef loins was consistently 0.2 of a pH unit higher than that of Good loins.

Huffman et al. (1969), studying the effects of ante-mortem injected phosphate and dietary calcium and phosphorus on muscle pH and tenderness, found no significant correlation between tenderness and muscle pH, although animals fed a ration with a low calcium to phosphorus ratio were significantly \((P<.05)\) more tender than control animals.

Fields et al. (1970) compared a tender line of cattle to a lean line and noted that the only significant difference between the two lines other than tenderness was that the tender line had a lower pH value of 0.25 at one hour postmortem.

**Breed Effects on Tenderness**

Carpenter et al. (1955), Burns, Koger and Kincaid (1958), Cole, Kincaid and Hobbs (1958), Damon et al. (1960),
Temple et al. (1960), Huffman et al. (1962), Kincaid (1962), Palmer (1963), Carroll, Rollins and Kunse (1964), Huffman et al. (1967), Goodner (1969) and Turner (1971) reported that tenderness differences exist due to breed and that Brahman and Brahman cross cattle were the least tender of any breed studied.

Burns, Koger and Kincaid (1958) found that Angus and Hereford steers were more tender than Brahman steers while Brahman crossbred steers were intermediate in tenderness. Palmer (1963) reported that Angus, Hereford and Shorthorn progeny were significantly more tender than progeny of Brahman and Brahman times (X) Shorthorn sires. He found that 86.7% of the Angus progeny were average or better in tenderness whereas 36.3, 84.7 and 56.8% of the Brahman, Hereford and Shorthorn progeny, respectively, were average or better in tenderness. Goodner (1969) compared Angus sired steers to Brahman, Brangus, Charolais and Hereford sired steers. Angus sired steers had the lowest mean shear value and Brahman sired steers had the highest mean shear values.

Dikeman et al. (1972) and Sharrah, Kunze and Pangborn (1965) found that the longissimus muscle of Angus was more tender than the same muscle in Herefords. However, the latter study reported that round roasts from Herefords were more tender than roasts from Angus or Charbray.

Temple (1965) reported in his review of Charolais research that in one study Charolais carcasses were about equal in tenderness to Hereford which is in agreement with experiments
conducted by Klosterman, Cahill and Kunkle (1961). However, in another experiment, Charolais crosses were more tender than the British breeds and crosses of British breeds.

Huffman et al. (1962) and Huffman et al. (1967) reported that 3/4 Angus, 1/4 Hereford cattle were more tender than other breed groups while Brahman were the least tender.

Ramsey et al. (1963) compared steaks from cattle of British and dairy breeding and found no difference in tenderness, juiciness or flavor scores, although loin steaks from cattle with Brahman breeding had the greatest cooking losses while steaks from dairy cattle had the least cooking losses. The steaks from Jersey cattle ranked the highest in tenderness, juiciness and flavor.

Cole, Kincaid and Hobbs (1958) found British breeds to be more tender than Brahman and Brahman cross cattle, while dairy breeds were intermediate between the two groups.

Alsmeyer et al. (1959) partitioned components of variance in an effort to see which variables accounted for the greatest amount of variability in tenderness by taste panel. The percentage of Brahman breeding and carcass grade accounted for the largest percentage of variation explaining 12.1 and 9.2, respectively.

Huffman et al. (1967) showed a positive relationship between length of time on full feed and tenderness. This effect was more evident in certain breed groups as suggested by a significant breed group X feed level interaction. Tests conducted by
Epley et al. (1968) demonstrated that tenderness increases as the length of time on feed increases. Furthermore, Epley et al. (1968) and Palmer (1963) showed that sire effects on tenderness were at least as great as breed effects, suggesting that tenderness can be improved by selection within and between breeds. Studies by Warwick (1958) and Christians et al. (1961) showed that tenderness is a highly heritable trait. Warwick in his review reported that the average heritability estimate for tenderness was 61% while the latter study reported heritability estimates ranging from 62 to 69%.
MATERIALS AND METHODS

A total of 260 straightbred and crossbred steers from the Louisiana 605 Crossbreeding Project were slaughtered at Thompson Packing Company, Satsuma, Louisiana, in 1971 and 1972. This included 124 steers in 1971 and 136 steers in 1972. Each year, approximately half of the steers were randomly selected and slaughtered at one time and the remaining steers were slaughtered one or two weeks later. The four slaughter dates involved in the study were June 4, 1971, June 18, 1971, June 6, 1972, and June 13, 1972.

Experimental steers were either straightbred Angus (A), Hereford (H), Brahman (B) and Charolais (C) or backcrosses or three-breed crosses from the aforementioned breeds. The steers of each year were sired by 15 performance tested bulls consisting of four Angus, two Brahman, five Charolais and four Herefords. In some instances, different sires within a breed were used from year to year while in other cases, the same sires were used over the 2 year period of the study.

The experimental steers were weaned at 228 days and pastured on rye grass for 140 days with supplemental grain as dictated by winter pasture conditions. The steers were placed directly into the feedlot and full-fed for 100 to 114 days, at which time they were moved directly to slaughter. The feedlot ration is shown in table 1.
### TABLE 1. COMPOSITION OF RATION

<table>
<thead>
<tr>
<th>Item</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (ground) or corn chops</td>
<td>648.07</td>
</tr>
<tr>
<td>Urea (28%)</td>
<td>6.80</td>
</tr>
<tr>
<td>Cottonseed meal (41%)</td>
<td>40.82</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>136.05</td>
</tr>
<tr>
<td>Oyster shell flour</td>
<td>6.80</td>
</tr>
<tr>
<td>Molasses</td>
<td>63.49</td>
</tr>
<tr>
<td>Salt</td>
<td>4.54</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>TM-10</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>907.07</td>
</tr>
</tbody>
</table>

<sup>a</sup>22.05 g terramycin/kg of premix
For the 124 steers slaughtered in 1971, carcass information and tenderometer values were obtained at 48 hours after slaughter. The twelfth rib section was removed at the packing plant and transported to the meat laboratory for WBS determinations. Carcass data were collected according to Schoonover (1972) and included hot carcass weight, animal age, marbling score, fat thickness opposite the twelfth rib, estimated percent kidney and pelvic fat, conformation score, U.S.D.A. quality and yield grade and rib-eye area at the twelfth rib (a compensating polar planimeter was utilized to measure the traced outline of the \text{longissimus} muscle).

Texture of the \text{longissimus} muscle was also measured, based on a scale of 1 to 6 with 1 representing very coarse, 2—coarse, 3—slightly coarse, 4—slightly fine, 5—fine and 6—very fine.

Tenderometer values were obtained by inserting the tenderometer into the exposed rib-eye surface at the twelfth rib. At this time, the \text{longissimus} muscle temperature was under 4.44° C. as recommended by Armour and Company (L. J. Hansen, \text{personal communication}).

Grading of the steers in this study was conducted according to U.S.D.A. specifications by two faculty members of the Animal Science Department, Louisiana State University.

In addition to the data collected for the 1971 steers, the following variables were measured for the 136 steers slaughtered in 1972: zero and one hour carcass temperature, one hour and 6-day ultimate pH and sarcomere length. At 48 hours after
slaughter, the eleventh to twelfth rib section of the left side was removed and transported to the Louisiana State University meat laboratory for WBS, pH and sarcomere length determinations.

Temperature Determination

Zero hour temperature was measured with the aid of a YSI Tele-Thermometer (Model Number 43TF) and the accompanying temperature probe. The probe was inserted into the interior of the throat cavity following bleeding of the animal to record the core temperature at slaughter. One hour postmortem *longissimus* temperature was taken at the twelfth rib using either a standard dial meat thermometer or a Tele-Thermometer.

pH Measurement

One hour postmortem pH was measured on the diaphragm muscle using a Leeds and Northrup (Catalogue 7401) pH meter and Corning electrode (Number 330-56200). Surface pH of five areas in the muscle was measured and the pH readings were averaged to obtain the final one hour pH.

Approximate 6-day or ultimate pH was determined on the *longissimus* muscle originating from the eleventh rib. Twenty-five to 35 grams of lean muscle with an equal amount of distilled water were blended in a Waring blender at medium speed for one minute. The pH was measured using a Leeds and Northrup pH meter and Corning electrode.
Sarcomere Length Determination

The *longissimus* muscle from the eleventh rib was also utilized for sarcomere length studies. At 5 days postmortem, approximately 10 gram dorsal and lateral muscle samples were removed, wrapped in aluminum foil, placed into Whirl-Pak bags, identified, and placed directly into the blast freezer until subsequent sarcomere length determinations could be made. Each muscle section was removed so that the muscle fibers could be sliced on the long axis of the myofibrils to obtain longitudinal sections.

The procedure for sarcomere length determinations consisted of trimming each frozen muscle sample to a uniform size (approximately 2.5 x 2.0 cm) and placing them on Lab-Tek specimen blocks.

Optimal Cutting Temperature (O.C.T.) compound designed for temperatures of -15° to -30° C. was used to facilitate slicing and freezing of the muscle section onto the specimen block. Ten micron thick sections were sliced using a Lab-Tek cryostat Model D. A cover slip kept at room temperature (22 x 30 mm and Number 1 thinness) was used to pick up the thin sliced section. The sample and cover slip were placed on a standard microscope slide containing a drop of glycerine jelly. The slide was examined with a Zeiss microscope (Model Number 4285922) under phase 2 objective, (plan 25/0.45) optovar setting 2, diaphragm setting 2 and 12.5 X ocular. Five adjacent sarcomeres were measured at five separate areas of a slide with the aid of a Bausch and Lomb calibrated ocular micrometer. Two
slides were examined per muscle section resulting in a total of 50 sarcomeres per muscle section or 100 sarcomeres per steer. The average sarcomere length for each steer was obtained by averaging the values obtained for the dorsal and lateral muscle sections.

Calculation of sarcomere length involved first the calibration of the ocular micrometer by the use of a stage micrometer which was ruled in 0.01 mm. It was determined that an ocular micrometer reading of 58.57 equaled a distance of 0.01 mm. With this knowledge, ocular micrometer readings obtained when measuring the distance between five adjacent sarcomeres could be obtained on a per sarcomere basis and converted to microns.

Warner-Bratzler Shear Determination

At 7 days postmortem, 3.8 cm thick longissimus steaks from the twelfth rib were deep fat fried in vegetable oil using a Hotpoint Model HK3 fryer. Steaks were cooked for 12 minutes at 135° C. to an approximate internal temperature of 71° C. Following cooking and a 15 minute cooling period, three 2.54 cm cores were removed from each steak and two WBS values were determined per core. Thus, the final WBS value obtained for each steak was made up of six individual WBS readings.

Statistical Analyses

Simple correlation and factor analysis were obtained with the use of the Statistical Analysis System package compiled by Barr and Goodnight (1972).
A multiple regression analysis was performed on all 16
variables to determine the optimum set of variables for predicting
WBS value (LaMotte and Hocking, 1970). This regression procedure
differs from the conventional regression procedure in that it is
grounded toward minimizing the mean square for error rather than max­
imizing R².

A least-squares analysis of variance (Harvey, 1960) was
performed on selected variables to determine the influence of breed­
ing on these traits.

Orthogonal comparisons among breed types were performed
on selected variables which were shown by analyses of variance to be
significantly affected by breed type. The 10 degrees of freedom
for breed type (line) were divided into 10 comparisons. Overall
comparisons were:

(1) Straightbreds (A, B, C, H) vs. backcrosses (A x AB,
C x CB, H x HB) and three-breed crosses (C x AB,
A x HB, C x HB, H x AB),

(2) Backcrosses (A x AB, C x CB, H x HB) vs. three-breed
crosses (C x AB, A x HB, C x HB, H x AB).

Comparisons within straightbreds were:

(3) B vs. A, C, H,

(4) C vs. A, H,

(5) A vs. H.

Comparisons within backcrosses were:

(6) C x CB vs. A x AB, H x HB,

(7) A x AB vs. H x HB.
Comparisons within three-breed crosses were:

(8) CAB, CHB vs. AHB, HAB,

(9) CAB vs. CHB,

(10) AHB vs. HAB.
RESULTS AND DISCUSSION

Comparison of Warner-Bratzler Shear Values to Carcass Traits

The type of breeding and number of steers used in this study are shown in table 2. For the purpose of analyses, steers produced by reciprocal crossbred cows were grouped together giving a total of 86 straightbreds, 68 backcrosses and 106 three-breed crosses. All backcrosses and three-breed crosses contained 1/4 Brahman breeding.

The WBS was used as a standard of comparison for tenderness in this study. Warner-Bratzler shear values were correlated with carcass traits to determine if traits routinely measured on the carcass were related to the ultimate cooked tenderness as measured by the WBS. Table 3 shows the simple correlation coefficient obtained between WBS value and each of the carcass traits on all 260 steers in the study. There was a significant negative correlation between WBS value and hot carcass weight (-.25), age (-.14), quality grade (-.21), marbling score (-.13), rib-eye area (-.33) and conformation score (-.29). The negative relationship of WBS with weight and age disagrees with the idea that tenderness decreases with increasing animal age (Webb, Kahlenberg and Naumann, 1959; Tuma et al., 1962). However, these studies used cattle of similar breed types with widely differing ages and weights, whereas
<table>
<thead>
<tr>
<th>Straightbred</th>
<th>Number</th>
<th>Back-cross</th>
<th>Number</th>
<th>Three-breed cross</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angus (A)</td>
<td>32</td>
<td>A x AB</td>
<td>21</td>
<td>A x BH</td>
<td>30</td>
</tr>
<tr>
<td>Brahman (B)</td>
<td>16</td>
<td>C x CB</td>
<td>22</td>
<td>C x AB</td>
<td>25</td>
</tr>
<tr>
<td>Charolais (C)</td>
<td>21</td>
<td>H x BH</td>
<td>25</td>
<td>C x HB</td>
<td>22</td>
</tr>
<tr>
<td>Hereford (H)</td>
<td>17</td>
<td></td>
<td></td>
<td>H x AB</td>
<td>29</td>
</tr>
</tbody>
</table>

|      | 86     | 68             |        | 106/260           |        |

*a Backcross and three-breed cross steers are pooled together over reciprocal crossbred cows; for example, the A x AB backcross contain Angus backcross steers from A x B and B x A cows and the A x BH three-breed cross are derived from B x H and H x B cows.*
### TABLE 3. CORRELATION BETWEEN WARNER-BRATZLER SHEAR VALUES AND SOME CARCASS TRAITS

<table>
<thead>
<tr>
<th>Trait</th>
<th>Correlation coefficient</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot carcass wt., kg</td>
<td>-.25**</td>
<td>235.97</td>
<td>32.33</td>
</tr>
<tr>
<td>Age, days</td>
<td>-.14**</td>
<td>475.67</td>
<td>20.37</td>
</tr>
<tr>
<td>Quality grade&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.21**</td>
<td>9.06</td>
<td>1.23</td>
</tr>
<tr>
<td>Marbling score&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-.13*</td>
<td>4.63</td>
<td>2.35</td>
</tr>
<tr>
<td>Rib-eye area, cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-.33**</td>
<td>64.52</td>
<td>10.77</td>
</tr>
<tr>
<td>Yield grade</td>
<td>0.08</td>
<td>2.50</td>
<td>0.71</td>
</tr>
<tr>
<td>Fat thickness, cm</td>
<td>-.10</td>
<td>0.66</td>
<td>0.38</td>
</tr>
<tr>
<td>Conformation score&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.29**</td>
<td>12.31</td>
<td>1.47</td>
</tr>
<tr>
<td>Tenderometer, kg</td>
<td>0.08</td>
<td>6.23</td>
<td>1.05</td>
</tr>
<tr>
<td>WBS value, kg</td>
<td>----</td>
<td>9.55</td>
<td>2.36</td>
</tr>
</tbody>
</table>

* P < .05  
** P < .01

<sup>a</sup> 10=good, 13=choice; each unit represents one-third of a grade.

<sup>b</sup> 4=traces, 7=slight; each unit represents one-third of a marbling score.
steers in this experiment had a narrow weight and age range (table 3) and a wide range of breed types (British, French and Zebu cattle).

Since, within a given maturity group, marbling score exerts the greatest influence on final quality grade, the correlation of marbling score and WBS should be similar to the correlation of quality grade and WBS. The significant but low correlations of -.21 and -.13 of WBS with quality grade and marbling score are in agreement with the review article of Jeremiah et al. (1970) who reported that quality grade contributed 7% of the variation in tenderness as determined by mechanical tests. However, work by Dikeman et al. (1972) revealed no significant relationship of marbling score and quality grade with WBS value, although most of the cattle in the study were acceptable in tenderness.

The significant negative correlations of WBS with rib-eye area (-.33) and conformation score (-.29) may be a natural consequence of the negative relationship of WBS with age and weight. Older and heavier carcasses usually have larger rib-eye areas and tend to have higher conformation scores (table 4). The negative relationship of WBS with weight, rib-eye area and conformation score may also be a partial reflection of mean values of carcass traits that exist for the specific breeds. Data from table 4 reveal that Brahman cattle were the lightest breed having the smallest rib-eye area, lowest conformation score and highest WBS value. In contrast, Charolais cattle were the heaviest, having the largest
<table>
<thead>
<tr>
<th>Trait</th>
<th>Angus Mean</th>
<th>S.D.</th>
<th>Brahman Mean</th>
<th>S.D.</th>
<th>Charolais Mean</th>
<th>S.D.</th>
<th>Hereford Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot carcass wt., kg</td>
<td>211.06</td>
<td>24.83</td>
<td>196.73</td>
<td>34.81</td>
<td>263.38</td>
<td>20.61</td>
<td>202.97</td>
<td>25.71</td>
</tr>
<tr>
<td>Age, days</td>
<td>482.62</td>
<td>15.97</td>
<td>454.56</td>
<td>21.46</td>
<td>473.10</td>
<td>19.15</td>
<td>470.29</td>
<td>17.59</td>
</tr>
<tr>
<td>Quality grade&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.19</td>
<td>1.42</td>
<td>7.88</td>
<td>1.41</td>
<td>8.81</td>
<td>0.98</td>
<td>8.94</td>
<td>0.56</td>
</tr>
<tr>
<td>Marbling score&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.69</td>
<td>2.75</td>
<td>2.31</td>
<td>1.92</td>
<td>3.90</td>
<td>1.70</td>
<td>4.71</td>
<td>1.65</td>
</tr>
<tr>
<td>Rib-eye area, cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>56.78</td>
<td>5.36</td>
<td>50.65</td>
<td>6.26</td>
<td>77.49</td>
<td>8.52</td>
<td>57.68</td>
<td>7.23</td>
</tr>
<tr>
<td>Yield grade</td>
<td>2.91</td>
<td>0.57</td>
<td>2.38</td>
<td>0.64</td>
<td>1.68</td>
<td>0.48</td>
<td>2.49</td>
<td>0.39</td>
</tr>
<tr>
<td>Fat thickness, cm</td>
<td>0.91</td>
<td>0.30</td>
<td>0.33</td>
<td>0.30</td>
<td>0.33</td>
<td>0.15</td>
<td>0.74</td>
<td>0.23</td>
</tr>
<tr>
<td>Conformation score&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.97</td>
<td>0.97</td>
<td>10.81</td>
<td>2.20</td>
<td>13.10</td>
<td>1.34</td>
<td>12.23</td>
<td>1.15</td>
</tr>
<tr>
<td>Tenderometer, kg</td>
<td>6.57</td>
<td>1.38</td>
<td>6.45</td>
<td>0.73</td>
<td>6.09</td>
<td>0.84</td>
<td>6.75</td>
<td>1.26</td>
</tr>
<tr>
<td>WBS value, kg</td>
<td>8.45</td>
<td>1.63</td>
<td>13.38</td>
<td>4.78</td>
<td>8.87</td>
<td>1.79</td>
<td>10.09</td>
<td>2.20</td>
</tr>
</tbody>
</table>

<sup>a</sup> Standard deviation

<sup>b</sup> 10=good, 13=choice; each unit represents one-third of a grade.

<sup>c</sup> 4=traces, 5=traces plus, 7=slight; each unit represents one-third of a marbling score.
rib-eye area, highest conformation score and lowest WBS value. Table 5 shows the positive correlation among hot weight, rib-eye area and conformation score. All possible correlations among these variables were highly significant.

Warner-Bratzler shear values were not significantly correlated with yield grade ($r=0.08$) and fat thickness ($r=-.10$). These results are in agreement with the work of Martin et al. (1971).

Generally, steers in this study had high cutability values and low marbling scores. The high cutability is reflected in the low yield grade of 2.50, which corresponds to 51.2% of the carcass weight in boneless, closely trimmed, retail cuts from the round, loin, rib and chuck. The steers were very trim, average in muscling and had light carcasses which all contributed to the high cutability. The average marbling score was only 4.6 which is less than "traces plus" amount of marbling. Consequently, most of the steers in this study graded Good as suggested by a mean quality grade of 9.06. Thirteen of 260 steers or 5% were Choice or better while 53 steers or 20% graded Standard and 193 steers or 74% were Good.

**Comparison of Warner-Bratzler Shear Values to Tenderometer**

Warner-Bratzler shear values were compared to Armour Tenderometer values to determine if the tenderometer predicts the ultimate tenderness of beef. Since the tenderometer is a
TABLE 5. CORRELATIONS AMONG HOT WEIGHT, RIB-EYE AREA AND CONFORMATION SCORE

<table>
<thead>
<tr>
<th>Traits</th>
<th>Rib-eye area</th>
<th>Conformation score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot weight</td>
<td>0.56**</td>
<td>0.37**</td>
</tr>
<tr>
<td>Rib-eye area</td>
<td></td>
<td>0.35**</td>
</tr>
</tbody>
</table>

** P < .01
nondestructive instrument used on the intact beef carcass and is simple to operate, it would be valuable to the beef industry if it could accurately predict tenderness.

An important finding of this study was that WBS values were not significantly (P > .05) correlated with Armour Tenderometer values, as indicated by the correlation coefficient of 0.08. With this sample of data, tenderometer values do not predict carcass tenderness as measured by the WBS. This finding does not agree with research conducted by Carpenter et al. (1972) and Luckett et al. (1973), as these scientists found low but highly significant correlations between WBS and tenderometer of 0.25 and 0.48, respectively. Although Dikeman et al. (1972) found a significant 0.29 correlation between the two variables, they felt the correlation was too low to enable accurate prediction of tenderness. The correlation coefficient of 0.25 reported by Carpenter et al. (1972) was based on a combined population of Choice and Good carcasses. When only the Good carcasses were considered, a lower, nonsignificant correlation of 0.17 was found between the two variables. From these results the authors suggested that the tenderometer was more reliable for predicting tenderness of Choice than Good cattle. Hansen (1972) also found a highly significant correlation of 0.42 between WBS and tenderometer within the Choice grade but a nonsignificant 0.30 relationship between the two variables within the Good grade. In addition, higher correlations of tenderometer with a trained taste panel were found for the Choice grade (r=0.77) than
for the Good grade ($r=0.69$). Both of these coefficients were highly significant.

Hansen found highly significant correlations between tenderometer and a taste panel and between WBS and a taste panel. However, he found low and nonsignificant correlations between WBS and tenderometer within the Good grade. Because of this, he suggested that the tenderometer and the WBS are physically different and may not be measuring the same factors in the same way or to the same degree.

In order to more clearly determine the possible relationships that might exist especially between the tenderometer and WBS a factor analysis was performed. A principal objective of a factor analysis is to "attain a parsimonious description of observed data" (Harman, 1961). This analysis has the effect of reducing a number of variables to a fewer number of factors by utilizing correlations from which the factors are identified. A second property of the factor analysis conducted is that the factors are orthogonal. Thus, traits which are present in one factor and not weighing heavily on other factors are considered independent. The variables included in the factor analysis were: hot carcass weight, age, quality grade, marbling score, rib-eye area, yield grade, fat thickness, conformation score, WBS value, tenderometer value, average sarcomere length, ultimate pH and one hour temperature. These 13 variables were reduced to four factors. Those traits found in factor one, in order of importance, were quality grade, marbling score, conformation score, fat thickness and yield grade while factor two
contained rib-eye area, yield grade, carcass weight and fat thickness. Factor three was bipolar with tenderometer value and yield grade being weighed positively while fat thickness, age and carcass weight were weighed negatively. Factor four was also bipolar and contained average sarcomere length and WBS value on the positive side and ultimate pH on the negative side.

Since factor one weighed heavily quality grade and marbling score and factor two emphasized rib-eye area, these two factors were arbitrarily designated as measures of "quality" and "cut-ability." Tenderometer value was the most important variable in factor three while factor four was influenced mostly by average sarcomere length and WBS value. Both factors three and four measured traits associated with tenderness. However, efforts to incorporate these two factors into one factor resulted in failure. This result along with the low correlation coefficient between WBS and tenderometer suggest that WBS and tenderometer are measuring different carcass characteristics which is in agreement with the earlier suggestion by Hansen (1972). However, this experiment does not show if the tenderometer is measuring any trait or traits that are directly related to tenderness.

Comparison of Armour Tenderometer Values to Carcass Traits

It has been previously shown that tenderometer values were not significantly correlated with WBS values indicating that tenderometer values do not enable the prediction of carcass
tenderness. It is of interest to examine tenderometer values in relation to other carcass traits. Table 6 depicts the simple correlation coefficients obtained between tenderometer and carcass traits. Tenderometer values were significantly (P< .01) positively correlated with U.S.D.A. quality grade (r=0.19) and marbling score (r=0.16). Higher tenderometer values were associated with higher quality grades and marbling scores. These results agree with the theory that higher marbling scores increase penetration resistance (Martin et al., 1971; Dikeman et al., 1972; L. J. Hansen, personal communication).

Tenderometer values were significantly negatively related to weight (r= -.18) and rib-eye area (r= -.12). Steers with higher tenderometer values were lighter in weight and had smaller rib-eyes which agrees with the previous work of Luckett et al. (1973). The explanation of this finding does not appear to be linked to differences in marbling score between lighter and heavier steers since marbling score was not significantly (P >.05) related to rib-eye area and weight (P> .05).

Tenderometer values were negatively but not significantly correlated with age, yield grade, fat thickness and conformation score.

Comparison of Warner-Bratzler Shear Value to Temperature, pH and Sarcomere Length

Table 7 denotes the type of breeding and number of steers used in this phase of the study. There were 49
<table>
<thead>
<tr>
<th>Trait</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot carcass wt., kg</td>
<td>-.18**</td>
</tr>
<tr>
<td>Age, days</td>
<td>-.06</td>
</tr>
<tr>
<td>Quality grade&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.19**</td>
</tr>
<tr>
<td>Marbling score&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.16**</td>
</tr>
<tr>
<td>Rib-eye area, cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-.12*</td>
</tr>
<tr>
<td>Yield grade</td>
<td>-.04</td>
</tr>
<tr>
<td>Fat thickness, cm</td>
<td>-.09</td>
</tr>
<tr>
<td>Conformation score&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.09</td>
</tr>
</tbody>
</table>

* P < .05

** P < .01

<sup>a</sup> 10 = good, 13 = choice; each unit represents one-third of a grade.

<sup>b</sup> 4 = traces, 7 = slight; each unit represents one-third of a marbling score.
### TABLE 7. BREEDS AND NUMBERS OF STEERS

<table>
<thead>
<tr>
<th>Straightbred</th>
<th>Number</th>
<th>Backcross Number</th>
<th>Three-breed cross Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angus (A)</td>
<td>21</td>
<td>A x AB 11</td>
<td>A x BH 15</td>
</tr>
<tr>
<td>Brahman (B)</td>
<td>11</td>
<td>C x CB 10</td>
<td>C x AB 16</td>
</tr>
<tr>
<td>Charolais (C)</td>
<td>9</td>
<td>H x BH 13</td>
<td>C x BH 10</td>
</tr>
<tr>
<td>Hereford (H)</td>
<td>8</td>
<td></td>
<td>H x AB 12</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>34</td>
<td>53/136</td>
</tr>
</tbody>
</table>

*Backcrosses and three-breed cross steers are pooled together over reciprocal crossbred cows; for example, the A x AB backcross contain Angus backcross steers from A x B and B x A cows. The A x BH three-breed cross are derived from B x H and H x B cows.*
straightbreds, 34 backcrosses and 53 three-breed crosses with all backcrosses and three-breed crosses containing 1/4 Brahman breeding.

In conjunction with the objective of relating beef tenderness to sarcomere length, pH and temperature, the correlation coefficients of these variables with WBS as well as means and standard deviations are shown in table 8.

**Correlation of Warner-Bratzler Shear Values with Carcass Temperature**

It is well established that stress conditions prior to slaughter elevate body temperature (Goodell, Graham and Wolff, 1950; Weldy et al., 1964; Diez, 1970). If it could be shown that animal or carcass temperature at the time of slaughter was related to tenderness, measurement of temperature would offer a simple and practical way to segregate carcasses based on their expected tenderness. However, table 8 shows there was no significant correlation between WBS and zero hour temperature (r= -.08) suggesting that zero hour temperature contributes little to tenderness.

Warner-Bratzler shear value was significantly negatively related to 1 hour temperature (r= -.20) indicating that steers with higher shear values have lower 1 hour temperatures. The explanation of this relationship is not apparent since 1 hour temperature should be affected by fat thickness, muscling, hot carcass weight and glycolytic rate. There was a significant (P<.01) relationship of 1 hour temperature with fat thickness (r=0.24)
TABLE 8. CORRELATIONS BETWEEN WARNER-BRATZLER SHEAR VALUES AND TEMPERATURE, pH, SARCOMERE LENGTH AND TEXTURE

<table>
<thead>
<tr>
<th>Trait</th>
<th>Correlation coefficient</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero hour temp., °C</td>
<td>-.08</td>
<td>40.21</td>
<td>0.72</td>
</tr>
<tr>
<td>One hour temp., °C</td>
<td>-.20*</td>
<td>39.02</td>
<td>1.28</td>
</tr>
<tr>
<td>One hour pH</td>
<td>-.03</td>
<td>6.64</td>
<td>0.17</td>
</tr>
<tr>
<td>Six-day pH</td>
<td>0.53**</td>
<td>5.43</td>
<td>0.10</td>
</tr>
<tr>
<td>Dorsal sarcomere length, μ</td>
<td>-.25**</td>
<td>1.66</td>
<td>0.10</td>
</tr>
<tr>
<td>Lateral sarcomere length, μ</td>
<td>-.36**</td>
<td>1.67</td>
<td>0.08</td>
</tr>
<tr>
<td>Average sarcomere length, μ</td>
<td>-.37**</td>
<td>1.66</td>
<td>0.07</td>
</tr>
<tr>
<td>Texture</td>
<td>0.06</td>
<td>3.57</td>
<td>0.74</td>
</tr>
<tr>
<td>WBS value</td>
<td>---</td>
<td>9.72</td>
<td>2.72</td>
</tr>
</tbody>
</table>

* P < .05  
** P < .01
indicating that steers with more fat have higher 1 hour tempera-
tures which can be explained by the insulating properties of fat.
One hour temperature was also significantly (P < .01) related to
conformation score (r = 0.24) but not to rib-eye area (r = 0.09) or
carcass weight (r = 0.04). One hour temperature was negatively re-
lated to pH at 1 hour (r = -.13) and after 6 days (r = -.20, P < .05).
The latter two variables are measures of glycolytic rate.

The negative relationship of WBS and 1 hour tempera-
ture can be partly explained by the influence of breed (table 9).
The Brahman breed had a lower 1 hour temperature than the Angus,
Charolais or Hereford breed. Since the Brahman steers also had
the highest WBS value, the negative association of WBS with 1 hour
temperature was partially due to the Brahman breed.

Relationship of Warner-Bratzler Shear to pH

Postmortem muscle pH is related to the rate of glycoly-
sis and degree of stress of the animal (Ashmore et al., 1971; Khan
and Lentz, 1973). Pale, soft and exudative (PSE) muscle in swine
is associated with a rapid glycolytic rate. Some workers have
shown a rapid glycolytic rate to be associated with less tender
pork (Breidenstein, 1963; Dildey et al., 1970), while Deethhardt and
Tuma (1971) found PSE muscle to be more tender than muscle under-
going normal glycolysis. Consequently, in this study it was of
interest to determine the relationship which existed between ten-
derness and pH in beef muscle.

Warner-Bratzler shear value was not significantly
### TABLE 9. TEMPERATURE, pH, SARCOMERE LENGTH AND TEXTURE COMPARISONS WITHIN BREED

<table>
<thead>
<tr>
<th>Trait</th>
<th>Angus Mean</th>
<th>S.D.</th>
<th>Brahman Mean</th>
<th>S.D.</th>
<th>Charolais Mean</th>
<th>S.D.</th>
<th>Hereford Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero hour temp., °C</td>
<td>40.46</td>
<td>0.73</td>
<td>39.79</td>
<td>0.58</td>
<td>40.83</td>
<td>0.80</td>
<td>40.09</td>
<td>0.96</td>
</tr>
<tr>
<td>One hour temp., °C</td>
<td>39.84</td>
<td>1.16</td>
<td>37.78</td>
<td>1.06</td>
<td>39.22</td>
<td>1.59</td>
<td>39.34</td>
<td>1.13</td>
</tr>
<tr>
<td>One hour pH</td>
<td>6.58</td>
<td>0.12</td>
<td>6.65</td>
<td>0.22</td>
<td>6.64</td>
<td>0.13</td>
<td>6.49</td>
<td>0.18</td>
</tr>
<tr>
<td>Six-day pH</td>
<td>5.41</td>
<td>0.09</td>
<td>5.48</td>
<td>0.14</td>
<td>5.39</td>
<td>0.05</td>
<td>5.49</td>
<td>0.17</td>
</tr>
<tr>
<td>Dorsal sarcomere length, μ</td>
<td>1.68</td>
<td>0.12</td>
<td>1.65</td>
<td>0.07</td>
<td>1.67</td>
<td>0.16</td>
<td>1.63</td>
<td>0.11</td>
</tr>
<tr>
<td>Lateral sarcomere length, μ</td>
<td>1.71</td>
<td>0.09</td>
<td>1.63</td>
<td>0.10</td>
<td>1.68</td>
<td>0.05</td>
<td>1.66</td>
<td>0.08</td>
</tr>
<tr>
<td>Average sarcomere length, μ</td>
<td>1.70</td>
<td>0.09</td>
<td>1.64</td>
<td>0.07</td>
<td>1.68</td>
<td>0.08</td>
<td>1.64</td>
<td>0.09</td>
</tr>
<tr>
<td>Texture</td>
<td>4.02</td>
<td>0.54</td>
<td>3.95</td>
<td>0.91</td>
<td>3.06</td>
<td>0.63</td>
<td>3.62</td>
<td>0.44</td>
</tr>
<tr>
<td>Warner-Bratzler shear, kg</td>
<td>8.54</td>
<td>1.67</td>
<td>13.89</td>
<td>5.17</td>
<td>8.27</td>
<td>2.01</td>
<td>9.60</td>
<td>2.16</td>
</tr>
</tbody>
</table>

*a Standard deviation
correlated with 1 hour pH, indicating little or no relationship of 1 hour pH to tenderness. However, an important finding of this study was that there was a highly significant correlation (r=0.53) of WBS with 6-day pH. This result indicated that more tender steers have a lower pH than less tender steers. Lawrie (1966) also reported that as pH increases from 5.5 to 6.0 tenderness decreased and at pH values of 6.0 and above tenderness tends to increase again. Although the pH values in this study were not as high as those reported by Lawrie, both experiments found that at pH values below 6.0, tenderness decreases as pH increases. Khan and Lentz (1973) also found a significant correlation between 7 day WBS value and postmortem pH (r=0.55). Furthermore, they suggested that measurement of postmortem pH would offer an excellent means of segregating carcasses for required aging time and ultimate tenderness.

Relationship of Warner-Bratzler Shear to Sarcomere Length

The degree of muscle contraction can be estimated from the sarcomere length of the myofibril and has been shown by several workers to be related to tenderness (Locker, 1960; Mullins et al., 1969; Smith, Arrango and Carpenter, 1971). However, Covington and Tuma (1970) did not find a significant relationship between sarcomere length and WBS values.

In this study, WBS values were significantly correlated with dorsal sarcomere length (r= -.25), lateral sarcomere length (r= -.36) and average sarcomere length (r= -.37). These results
showed that the more tender steaks had longer sarcomeres and that sarcomere length contributes to tenderness which agrees with the studies of Dikeman, Tuma and Beecher (1971) and Hostetler et al. (1972). In the latter study, the authors utilized WBS values as the measure of tenderness and found that sarcomere length accounted for 12% of the variation in WBS value.

Relationship of Warner-Bratzler Shear to Texture

Warner-Bratzler shear values were not significantly associated with texture scores (r=0.06). Dikeman, Tuma and Beecher (1971) also found a similar correlation of 0.02 when beef ribs from A, C and E maturity groups were considered. Since C and E maturity carcasses are of less retail economic importance than A maturity carcasses, another trial was conducted involving only A maturity ribs. A negative relationship (r= -0.57) was found between WBS and texture score. The authors attributed the disagreement between the two trials as being due to the wide variation in texture of C and E maturity ribs utilized in trial 1.

The relationship of temperature, pH, sarcomere length and texture with each other are depicted in table 10. Zero hour temperature was not significantly correlated with any other variable except 1 hour temperature (r=0.61). One hour temperature was significantly negatively associated with 6-day pH (r= -0.20) and positively related (r=0.17) to lateral sarcomere length. Steers with higher 1 hour temperatures have lower 6-day pH measurements, longer sarcomere lengths at the lateral position and are more
## TABLE 10. CORRELATIONS AMONG TEMPERATURE, pH, SARCOMERE LENGTH AND TEXTURE

<table>
<thead>
<tr>
<th>Trait</th>
<th>One hour temp., C</th>
<th>One hour pH</th>
<th>Six-day pH</th>
<th>Dorsal sarcomere length, μ</th>
<th>Lateral sarcomere length, μ</th>
<th>Average sarcomere length, μ</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero hour temp., C</td>
<td>0.61**</td>
<td>-.12</td>
<td>-.16</td>
<td>-.06</td>
<td>0.14</td>
<td>0.04</td>
<td>-.04</td>
</tr>
<tr>
<td>One hour temp., C</td>
<td>-.13</td>
<td>-.20*</td>
<td>-.08</td>
<td>0.17*</td>
<td>0.04</td>
<td>-.07</td>
<td></td>
</tr>
<tr>
<td>One hour pH</td>
<td>0.03</td>
<td>0.08</td>
<td>-.11</td>
<td>0.01</td>
<td>-1.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Six-day pH</td>
<td>-.30**</td>
<td>-.38**</td>
<td>-.41**</td>
<td>-.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal sarcomere length, μ</td>
<td></td>
<td></td>
<td></td>
<td>0.32**</td>
<td>0.86**</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Lateral sarcomere length, μ</td>
<td></td>
<td></td>
<td></td>
<td>0.76**</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average sarcomere length, μ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* P < .05

** P < .01
tender. Increased tenderness is shown in table 8 by the negative relationship of WBS with 1 hour temperature and lateral sarcomere length and the positive relationship of WBS to 6-day pH.

One hour pH was not correlated with any other variable in the study. However, 6-day pH was significantly correlated with 1 hour temperature and all sarcomere length measurements. These results suggest that all these variables contribute to the ultimate tenderness.

Texture was not significantly correlated with any other variable. This result does not agree with the work of Dike-man, Tuma and Beecher (1971) since they found a highly significant positive relationship of texture with sarcomere length (r=0.77). Their results indicated that fine textured meat had longer sarcomeres.

Multiple Regression Analysis to Predict Warner-Bratzler Shear

Variables have been defined in terms of their correlation with WBS. However, some of the variables do not relate to WBS in an independent manner. For example, quality grade and marbling score are not independent, since marbling score is the primary determinant of quality grade. A multiple regression analysis (LaMotte and Hocking, 1970) was performed to find an optimum equation to describe WBS and to maximize the efficiency of the regression line by minimizing the sum of squares for error. The 16 independent variables included in the model were hot carcass weight, age,
U.S.D.A. quality grade, marbling score, rib-eye area, U.S.D.A.
yield grade, fat thickness, conformation score, Armour Tenderometer,
dorsal and lateral sarcomere length, 1 hour and 6-day pH, zero and
1 hour temperature and texture.

The optimum equation for predicting WBS was: WBS = 
98.91 + 26.29 (6-day pH) - .81 (quality grade) - 5.28 (fat thick-
ness, in) - 1.48 (rib-eye area, sq in). The coefficient of deter-
mination ($R^2$) associated with this four variable model is 45.66%,
whereas the original 16 variable model explained 48.83% of the vari-
ation in WBS. Decreasing the model from 16 to 4 variables only re-
duced the $R^2$ by 2.72%. The first variables to be eliminated from
the model are more related to other variables in the model than to
WBS. The order of variable disappearance from the model was mar-
bling score, weight, yield grade, tenderometer, dorsal sarcomere
length, texture and age. The order of elimination for the remain-
ing variables was less important due to their higher correlation
with WBS and lower correlation with other variables.

A separate analysis was performed to determine if line
effects (breed type) had any additive contribution to the source of
variation in WBS. Since the $R^2$ was practically unchanged (46.52%)
and the line effects were not significant, it was concluded that
most of the variation due to breed type was accounted for by the
variables included in this model as covariables. Most of the dif-
ferences among lines were accounted for by 6-day pH, quality grade,
fat thickness and rib-eye area.
Breed Differences for Tenderness Related Traits

Since tenderness differences exist between breed types, selected traits directly or indirectly related to tenderness were considered on a within line or breed basis. As shown in table 11, there was a significant line effect for quality grade, fat thickness, rib-eye area, 1 hour temperature and WBS value. No significant differences between lines were found for sarcomere length or 6-day pH.

Sire effects were not considered in these analyses. It is emphasized in the discussion to follow that some of the differences ascribed to lines may be due to or strongly influenced by sire.

Table 12 depicts the least-square means and standard errors of each of the selected variables while table 13 shows the correlation coefficients of WBS values with the same variables within line. Lines 5 through 7 and lines 8 through 11 were considered together and shown under the column headings of backcross and three-breed cross.

Quality Grade

Quality grade is an important economic trait since it determines the market value. Higher grading beef is also more tender as revealed by Jeremiah et al. (1970) and substantiated by this study.

There was a significant line effect on quality grade as shown in table 11. Linear comparisons show that straightbreds
TABLE 11. ANALYSES OF VARIANCE FOR SELECTED TRAITS

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Quality grade</th>
<th>Fat thickness</th>
<th>Rib-eye area</th>
<th>One hour temp.</th>
<th>Average sarcomere length</th>
<th>Six-day pH</th>
<th>Warner-Bratzler shear value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines</td>
<td>10</td>
<td>6.15*</td>
<td>1.15**</td>
<td>615.66**</td>
<td>4.45*</td>
<td>0.00514</td>
<td>0.011</td>
<td>25.99*</td>
</tr>
<tr>
<td>Error</td>
<td>125</td>
<td>1.59</td>
<td>0.074</td>
<td>53.16</td>
<td>1.42</td>
<td>0.00506</td>
<td>0.009</td>
<td>5.90</td>
</tr>
<tr>
<td>Total</td>
<td>135</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* P < .05

** P < .01
<table>
<thead>
<tr>
<th>Line</th>
<th>Number</th>
<th>Quality grade</th>
<th>Fat thickness, cm</th>
<th>Rib-eye area, cm²</th>
<th>One hour temp., C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>S.E.ᵃ</td>
<td>Mean</td>
<td>S.E.</td>
</tr>
<tr>
<td>A (1)</td>
<td>21</td>
<td>10.05</td>
<td>0.27</td>
<td>0.92</td>
<td>0.06</td>
</tr>
<tr>
<td>B (2)</td>
<td>11</td>
<td>7.73</td>
<td>0.38</td>
<td>0.24</td>
<td>0.08</td>
</tr>
<tr>
<td>C (3)</td>
<td>9</td>
<td>8.44</td>
<td>0.42</td>
<td>0.28</td>
<td>0.09</td>
</tr>
<tr>
<td>H (4)</td>
<td>8</td>
<td>8.62</td>
<td>0.45</td>
<td>0.55</td>
<td>0.10</td>
</tr>
<tr>
<td>A x AB (5)</td>
<td>11</td>
<td>9.82</td>
<td>0.38</td>
<td>0.85</td>
<td>0.08</td>
</tr>
<tr>
<td>C x CB (6)</td>
<td>10</td>
<td>8.80</td>
<td>0.40</td>
<td>0.34</td>
<td>0.09</td>
</tr>
<tr>
<td>H x HB (7)</td>
<td>13</td>
<td>8.69</td>
<td>0.35</td>
<td>0.88</td>
<td>0.08</td>
</tr>
<tr>
<td>C x AB (8)</td>
<td>16</td>
<td>9.06</td>
<td>0.31</td>
<td>0.57</td>
<td>0.07</td>
</tr>
<tr>
<td>A x HB (9)</td>
<td>15</td>
<td>9.20</td>
<td>0.33</td>
<td>1.09</td>
<td>0.07</td>
</tr>
<tr>
<td>C x HB (10)</td>
<td>10</td>
<td>8.20</td>
<td>0.40</td>
<td>0.36</td>
<td>0.09</td>
</tr>
<tr>
<td>H x AB (11)</td>
<td>12/136</td>
<td>9.25</td>
<td>0.36</td>
<td>0.95</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.90</td>
<td>0.11</td>
<td>0.64</td>
<td>0.02</td>
</tr>
</tbody>
</table>

ᵃ Standard error of means
TABLE 12. Continued

<table>
<thead>
<tr>
<th>Line</th>
<th>Number</th>
<th>Average sarcomere length, μ( \mu )</th>
<th>Six-day pH Mean</th>
<th>Six-day pH S.E.</th>
<th>Warner-Bratzler shear value, kg Mean</th>
<th>Warner-Bratzler shear value, kg S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (1)</td>
<td>21</td>
<td>1.70 0.02</td>
<td>5.41 0.02</td>
<td>8.52 0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B (2)</td>
<td>11</td>
<td>1.64 0.02</td>
<td>5.48 0.03</td>
<td>13.85 0.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (3)</td>
<td>9</td>
<td>1.68 0.02</td>
<td>5.39 0.03</td>
<td>8.25 0.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H (4)</td>
<td>8</td>
<td>1.64 0.03</td>
<td>5.49 0.03</td>
<td>9.58 0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A x AB (5)</td>
<td>11</td>
<td>1.66 0.02</td>
<td>5.47 0.03</td>
<td>9.94 0.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C x CB (6)</td>
<td>10</td>
<td>1.68 0.02</td>
<td>5.41 0.03</td>
<td>8.57 0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H x HB (7)</td>
<td>13</td>
<td>1.66 0.02</td>
<td>5.43 0.03</td>
<td>10.28 0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C x AB (8)</td>
<td>16</td>
<td>1.66 0.02</td>
<td>5.42 0.02</td>
<td>9.30 0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A x HB (9)</td>
<td>15</td>
<td>1.68 0.02</td>
<td>5.41 0.02</td>
<td>9.51 0.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C x HB (10)</td>
<td>10</td>
<td>1.65 0.02</td>
<td>5.44 0.03</td>
<td>9.67 0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H x AB (11)</td>
<td>12/136</td>
<td>1.64 0.02</td>
<td>5.41 0.03</td>
<td>10.03 0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>1.66 0.01</td>
<td>5.43 0.01</td>
<td>9.77 0.22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 13. CORRELATION OF WARNER-BRATZLER SHEAR VALUES WITH SELECTED VARIABLES WITHIN LINES

<table>
<thead>
<tr>
<th>Trait</th>
<th>Angus</th>
<th>Brahman</th>
<th>Charolais</th>
<th>Hereford</th>
<th>Backcross</th>
<th>Three-breed cross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality grade</td>
<td>-.20</td>
<td>-.41</td>
<td>0.02</td>
<td>-.21</td>
<td>-.21</td>
<td>0.12</td>
</tr>
<tr>
<td>Fat thickness, cm</td>
<td>-.19</td>
<td>-.59</td>
<td>0.12</td>
<td>-.51</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Rib-eye area, cm²</td>
<td>-.37</td>
<td>-.79**</td>
<td>-.42</td>
<td>0.15</td>
<td>-.46**</td>
<td>-.25</td>
</tr>
<tr>
<td>One hour temp., C</td>
<td>0.20</td>
<td>*-.58</td>
<td>-.09</td>
<td>-.57</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>Average sarcomere length, μ</td>
<td>-.10</td>
<td>-.72*</td>
<td>-.13</td>
<td>-.48</td>
<td>-.46**</td>
<td>-.24</td>
</tr>
<tr>
<td>Six-day pH</td>
<td>0.45*</td>
<td>0.71*</td>
<td>0.83**</td>
<td>0.33</td>
<td>0.64**</td>
<td>0.36**</td>
</tr>
</tbody>
</table>

* P < .05
** P < .01
graded significantly lower than the average of backcrosses and three-breed crosses. Observation of least-square means in table 12 shows that Brahman had the lowest quality grade (7.73) while the Angus had the highest grade (10.05). The individual values for backcrosses and three-breed crosses (lines 5 through 11) tended to be intermediate between the lower grading Brahmans and the higher grading Angus. These results are in general agreement with the studies of Goodner (1969).

The Brahman breed graded significantly lower than the average of the Angus, Hereford and Charolais but of the straight-bred cattle, only the Angus exhibited a carcass grade above the overall mean. Angus did not grade significantly higher than Herefords although the difference was approaching significance. All other comparisons involving grade within backcrosses or three-breed crosses were not significant. Table 13 shows that the correlations of WBS with quality grade were not significant for any of the lines. This may be due to chance as there were small numbers of steers within each line.

Fat Thickness

Although fat thickness was not significantly related to WBS values, the fat thickness was included in the multiple regression equation as one of the four variables to predict WBS value.

Line effects for fat thickness were highly significant as indicated by a significant mean square of 1.15 (table 11). Straightbreds had a significantly lower mean fat thickness than the
average of the backcrosses and three-breed crosses. The difference in fat thickness was attributed to heterosis.

No significant difference for fat thickness was found for any of the remaining orthogonal comparisons. No significant correlations of WBS with fat thickness were found for any of the breed types (table 13).

Rib-Eye Area

The rib-eye area indicates the amount of lean meat found within a carcass and is a primary determinator of retail value.

There was a highly significant correlation (r = -0.79) between WBS and rib-eye area within the Brahman breed (table 13). This finding substantiates the belief that Brahmans were strongly influencing the overall correlation (r = -0.33) between the two variables.

Line effects on rib-eye area were highly significant as shown in table 11. Straightbreds had significantly smaller rib-eyes than the average of the 7 remaining lines (backcrosses and three-breed crosses). This difference is probably a reflection of heterosis. Inspection of table 12 reveals that the Brahmans had the smallest rib-eye (50.00 cm²) and Charolais, the largest (75.49 cm²), in agreement with research reported by Damon et al. (1960) and Goodner (1969).

The Brahmans had significantly (P < .01) smaller rib-eyes than the average of the Angus, Charolais and Hereford while
only the Charolais breed had larger rib-eyes than the overall mean (60.39 cm²). Charolais had larger (P < .01) rib-eyes than the average of the two British breeds, Angus and Herefords. Similarly, C x CB backcrosses exhibited significantly (P < .01) larger rib-eyes than the average of A x AB and H x HB backcrosses. Comparisons of Charolais three-breed crosses (CHB and CAB) with the average of all other three-breed crosses approached significance and tended to substantiate that Charolais (the largest breed studied) had larger rib-eyes than any other breed type.

One Hour Temperature

The lower 1 hour temperature of the Brahman may partially account for their higher WBS value. Table 13 shows a negative relationship of WBS with 1 hour temperature for the Brahman (r = -.58) and for the Hereford (r = -.57). Since the Hereford ranked second to the Brahman in WBS, the aforementioned correlations may suggest that 1 hour temperature is an important consideration in those animals found to be less tender. Locker and Hagyard (1963) and Fields, Carpenter and Smith (1971) also found that rate of chill affects beef tenderness.

Line effects for 1 hour temperature were significant (P < .05) as shown in table 11. Brahman had significantly (P < .01) lower 1 hour temperatures (37.78° C.) than the average of the Angus, Charolais and Herefords. These three breeds had mean 1 hour temperatures above the overall average of 38.96° C. No significant difference in 1 hour temperature was found for any of the remaining
comparisons.

Average Sarcomere Length

Line effects for average sarcomere length were not significant (table 11). The correlation coefficient of -0.37 reported between WBS value and average sarcomere length may be influenced equally by all the lines represented in the study. A negative relationship of WBS with sarcomere length was found for all the lines (table 13). The lack of variation in sarcomere length is apparent from inspection of the least-square means in table 12.

Six-Day pH

Six-day pH measurements were not affected by line (table 11) and suggest that the correlation coefficient of 0.55 between WBS and 6-day pH was not influenced by line. The nonsignificant line effect on ultimate pH indicates that 6-day muscle pH measurements are useful for predicting tenderness in a variety of breed types. Data from table 13 support this idea since all correlations of WBS with 6-day pH were significant except for the Hereford breed.

Warner-Bratzler Shear Value

A significant (P < .05) line effect existed for WBS value (table 11). Straightbreds had significantly (P < .01) higher WBS values than the average of the backcrosses and three-breed crosses indicating that straightbreds were less tender. Examination
of table 12 reveals this result was due to the high WBS value of the Brahman (13.85 kg) since shear values of Angus, Charolais and Herefords were under the overall mean of 9.77 kg.

Brahman steers had significantly (P < .01) higher WBS values than the average of all other straightbreds. This finding agrees with results reported by Alsmeyer et al. (1959) and Damon et al. (1960).

Although WBS values of Charolais were not significantly lower than the average of the Angus and Herefords, Charolais backcrosses (C x CB) had significantly lower WBS values than the average of the Angus and Hereford backcrosses (A x AB and H x HB), indicating that Charolais backcrosses are more tender than Angus and Hereford backcrosses. These results disagree with Damon et al. (1960) who found that Hereford, Angus and Charolais did not differ significantly in WBS value.
SUMMARY

Two-hundred sixty purebred and crossbred steers of Angus, Brahman, Hereford and Charolais breeding were slaughtered and utilized for tenderness studies. Eighteen variables were studied in relation to their effect on tenderness. These variables were hot carcass weight, age, quality grade, marbling score, rib-eye area, yield grade, fat thickness, conformation score, tenderometer values, Warner-Bratzler shear values, zero and 1 hour temperature, 1 hour and 6-day pH, dorsal, lateral and average sarcomere length and texture.

There was a significant negative correlation between WBS value and hot carcass weight (-.25), age (-.14), quality grade (-.21), marbling score (-.13), rib-eye area (-.33) and conformation score (-.29). These coefficients indicate that less tender meat was from younger, lighter and lower grading carcasses with smaller rib-eyes and lower marbling and conformation scores.

Warner-Bratzler shear values were not significantly (P > .05) correlated with Armour Tenderometer values indicating that tenderometer values do not predict carcass tenderness as measured by the WBS. A factor analysis tended to substantiate the theory that WBS and tenderometer are measuring different carcass characteristics. Tenderometer values were significantly (P < .01) positively correlated with U.S.D.A. quality grade (r=0.20) and marbling score.
(r=0.16) showing that higher marbling scores increase penetration resistance.

Warner-Bratzler shear values were significantly correlated with 1 hour carcass temperature (-.20), 6-day pH (0.53) and average sarcomere length (-.37). These values show that less tender muscle had lower 1 hour temperatures, higher 6-day pH measurements and shorter sarcomere lengths than more tender muscle. The results suggest that measurement of postmortem pH would offer a practical means of segregating carcasses into tenderness groups.

A multiple regression analysis to predict WBS revealed that the optimum equation was: WBS = 98.91 + 26.29 (6-day pH) - 0.81 (quality grade) - 5.28 (fat thickness, in) - 1.48 (rib-eye area, sq in). The coefficient of determination (R²) associated with this model was 45.66%, whereas the original model including all the variables explained 48.38% of the variation in WBS. Line (breed type) effects were nonsignificant. Consequently, most of the differences among lines were accounted for by 6-day pH, quality grade, fat thickness and rib-eye area.

Line comparisons revealed that Brahman steers were significantly (P< .01) tougher than the average of the Angus, Charolais and Hereford while Charolais backcrosses (C x CB) were more tender than the average of the Angus and Hereford backcrosses (A x AB + H x HB).
LITERATURE CITED


VITA

Ronald Louis Luckett, son of William L. and Magdalen C. Luckett, was born in Evansville, Indiana, January 19, 1941. He received his elementary and secondary education at St. Vincent Academy, Morganfield, Kentucky. A Bachelor of Science degree in Agriculture was granted in January 1964 from the University of Kentucky. He entered graduate school at the same university and received a Master of Science degree in Meat Science in January 1966. He then accepted a position as food technologist at the Food Research Division of Armour and Company, Oak Brook, Illinois. He relinquished this position and accepted a position as Research Associate at Louisiana State University in July 1969. Since that time, he has pursued the Doctor of Philosophy degree with a major in Animal Science and a minor in Biochemistry.

The author was married to Nancy Shaw Holt of Sturgis, Kentucky, on August 17, 1963.
Candidate: Ronald Louis Luckett

Major Field: Animal Science

Title of Thesis: Correlation studies of tenderness parameters in straightbred and crossbred cattle

Approved:

Signature: Thomas ridgen
Major Professor and Chairman

Signature: James E. Thompson
Dean of the Graduate School

EXAMINING COMMITTEE:

Signature: George Heid carried

Signature: J. L. Lee

Signature: Jack E. Krish

Signature: Prentiss Schilling

Date of Examination:
August 31, 1973