

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**A STUDY OF RELATIONSHIPS BETWEEN MUSCLE
ULTIMATE pH AND MEAT QUALITY CHARACTERISTICS
FOR M. LONGISSIMUS SAMPLES FROM FRIESIAN STEERS,
CHAROLAIS CROSS STEERS AND FRIESIAN BULLS**

**A thesis presented in partial fulfilment
of the requirements for the degree
of Master of Agricultural Science
in Animal Science
at Massey University
New Zealand**

RATANA AUNGSUPAKORN

1990

ABSTRACT

Comparisons of carcass and meat quality characteristics were made between forty Friesian bulls, twenty Friesian steers and nineteen Charolais x Angus cross steers which were grown on mixed pastures and slaughtered at a similar age of approximately 16 to 20 mo. Carcasses were evaluated and dressed under normal commercial conditions and samples of M. longissimus were taken from the right side of each carcass within 90 min of slaughter for meat quality assessments.

A comparison of the growth rates of Friesian and Charolais cross steers during the finishing period revealed no significant differences in initial liveweights, final liveweights or overall average daily liveweight gains ($p>0.05$). Differences in growth patterns indicated that the Friesians grew slightly faster initially while the Charolais cross steers exhibited higher average daily gains at later stages.

The Charolais cross steers had significantly greater dressing-out percentages ($p<0.001$), higher fat depths ($p<0.001$), shorter carcasses ($p<0.001$), larger rib-eye areas ($P<0.001$) and heavier steaks ($p<0.01$) than the Friesian steers when compared at a similar carcass weight. The Charolais cross steers had a greater mean meat yield than the Friesian steers of a similar carcass weight, as assessed by the sum of the six major hind-quarter cuts. There were no breed effects on ultimate meat pH, sarcomere length, meat tenderness, meat colour, cooking loss or expressed juice value for meat samples from the two steer groups.

Bulls produced leaner carcasses as evidenced by lower fat depth and intramuscular fat levels than steers. At a constant carcass weight, bulls had similar dressing-out percentages to Friesian steers, but the value was significantly lower than that of Charolais cross steers ($p<0.001$). The bulls possessed the longest carcasses and the largest rib-eye area after adjustments to the same carcass weight. Bull meat had significantly higher ultimate pH values ($p<0.01$) and a darker colour ($p<0.001$) than steer meat. Although there were no differences in sarcomere length, tenderness, cooking loss and expressed juice between meat from bulls and steers, bull meat appeared on the basis of shear-force deformation-curve parameters to contain more connective tissue.

However, when pH effects were adjusted for by covariance analysis bull meat had a lower WHC and was slightly tougher.

There was a significant curvilinear relationship between ultimate pH and meat tenderness with a minimum tenderness at a pH of approximately 6.1. The improved tenderness above this point was associated with improved WHC, while the decrease in meat tenderness from pH 5.4 to 6.1 appeared to be partly due to a significant decrease in sarcomere length. Meat colour darkened markedly with increases in pH values whereas WHC changed very little as pH values increased from 5.4 to 6.2, but was increased sharply with further increases in pH values above 6.2.

A comparison was made between the conventional vee-shaped Warner-Bratzler shear blade and a modified square-blade. The results were closely correlated, but the square-blade always provided clearer initial yield points on the shear deformation curves and higher peak shear force values. All shear parameters (PF, IY, PF-IY and WD) obtained from shear force deformation curves showed significant curvilinear relationships ($p < 0.001$) with ultimate pH.

It is concluded that differences in ultimate meat pH can lead to subsequent differences in several important meat quality characteristics. Nevertheless, the effects may sometimes be overshadowed by other factors such as cold-shortening conditions.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisors, Dr R.W. Purchas and Mr S.T. Morris for their guidance, help and advice during the experimental work and the preparation of this thesis. Special thanks and appreciation is due to Dr R.W. Purchas for his continued interest, encouragement and invaluable help given to me throughout my study.

Thanks are also extended to Waitaki International Limited for providing meat samples and to the staff for their excellent co-operation during carcass data and meat sample collection.

I also appreciate the help given to me by Mr A.Y. Abdullah during sample collection, Mr S. Phimsarn, Mr W. Chatupote and Mrs L. Phetpradap for advice with computer processing, and Mr W. Sereprasert for data analysis.

For help with chemical analysis, I would like to thank Ms R.A. Watson and Mr D.A. Hamilton of the nutrition laboratory.

I wish to thank Professor B.R. Watkin for encouraging me to come to study in New Zealand. Mrs G. Eustace for taking care of me and for her warm hospitality which made my stay an enjoyable and memorable one, and my family in Thailand for the care they gave my husband and children while I was away from them.

The financial support from the New Zealand government and the permission to come to study here from the Dairy Farming Promotion Organization of Thailand are gratefully acknowledged.

Finally, special appreciation is due to my mental supporters, Supachai, Wisarut and Wamarin Aungsupakorn for the love, understanding, patience and encouragement given to me during my time of study.

LIST OF TABLES

Table	Page
4.1	Initial and final liveweights and growth rates over nine periods for Charolais x Angus cross steers and Friesian steers.40
4.2	Least squares means of carcass characteristics for Friesian (F) bulls, Friesian steers and Charolais (C) x Angus cross steers.....43
4.3	Least squares means for the six major hind-quarter cuts of Friesian steers and Charolais x Angus steers.44
4.4	The significance of regression relationships between carcass weight (ccwt), rib-eye area (REA), carcass length (cc length), and fat depth (fat.d) and the sum of the last 3 cuts or the sum of all 6 cuts. Independent variables were fitted in the sequence shown.....45
4.5	Unadjusted means of several muscle characteristics of medium (M) and central (C) parts of <u>M. longissimus</u> from Friesian bulls, Friesian steers and Charolais x Angus cross steers.46
4.6	Least squares means of several muscle characteristics of medium (M) and central (C) parts of <u>M. longissimus</u> from Friesian bulls, Friesian steers and Charolais x Angus cross steers, after adjustment for ultimate pH.47

4.7	Regression relationships between sarcomere length and ultimate pH for samples of <u>M. longissimus</u> with an ultimate pH of less than 6.2 (n = 37).	48
4.8	Means for the work done and the peak shear force values of the conventional Warner-Bratzler shear blade (Vee-blade) and the modified Warner-Bratzler shear blade (Square-blade).	53
4.9	Least squares means for initial yield force (IY), peak shear force (PF), work done (WD) and peak-initial yield force (PF-IY) measured from shear force deformation curves for <u>M. longissimus</u> from Friesian bulls, Friesian steers and Charolais x Angus cross steers.	56
4.10	Means of shear force deformation curve parameters and some meat quality characteristics measured at different parts of <u>M. longissimus</u>	61
4.11	Least squares means of initial yield force (IY), peak shear force (PF), work done (WD) and peak-initial yield force (PF-IY) for <u>M. longissimus</u> from Friesian bulls, Friesian steers and Charolais x Angus cross steers. Values were adjusted for pH and sarcomere length (SCM). Independent variables were fitted in the sequence shown.	60
4.12	The significance of regression relationships between Warner-Bratzler peak shear force (PF), pH and sarcomere length (SCM) for samples of <u>M. longissimus</u> with ultimate pH of less than 6.2 (n = 37). Independent variables were fitted in the sequence shown.	62

LIST OF FIGURES

Figure	Page
4.1	Mean liveweights for Friesian and Charolais cross steers over the finishing period. Vertical bar show standard errors. 41
4.2	Mean average daily gains for Friesian and Charolais cross steers, plotted at the midpoint between each weighing time. Vertical bars show standard errors. 41
4.3	The relationship between ultimate pH and colour of <u>M. longissimus</u> as assessed by percent reflectance at 630 nm. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits. 49
4.4	The relationship between ultimate meat pH and sarcomere length of <u>M. longissimus</u> . Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits. 50
4.5	The relationship between ultimate meat pH and cooking loss of <u>M. longissimus</u> . Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits. 51

- 4.6 The relationship between ultimate meat pH and expressed juice of M. longissimus. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with quadratic regression line and 95 percent confidence limits.52
- 4.7 The relationship between the mean of 436 values per shear obtained using either square- or vee-blades in the Warner-Bratzler shear machine for M. longissimus samples from 14 animals. Standard error bars are shown for each variable within each animal, together with the overall regression equation based on the 96 individual shears. These mean shear force values are referred to as the work done (WD) in the text.....54
- 4.8 The relationship between peak shear force values obtained using either square or vee-blades in the Warner-Bratzler shear machine for M. longissimus samples from 14 animals. Standard error bars are shown for each variable within each animal, together with the overall regression equation based on th 96 individual shears.55
- 4.9 Four shear on 13 x 13 mm cores from M. longissimus of a 16 mo steer after cooking at 70 °C in a water bath for 90 min. Initial yield values are shown by the vertical arrows.57
- 4.10 The relationship between ultimate meat pH and peak shear force of M. longissimus. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits58

LIST OF ABBREVIATIONS

h	Hour
ml	Milliliter
mm	Millimeter
°C	Degree Celcius
mg	milligram
g	Gram
kg	kilogram
d	Day
mo	Month
min	Minute

TABLE OF CONTENTS

	Page
: ABSTRACT	i
: ACKNOWLEDGEMENTS	iii
: LIST OF TABLES	iv
: LIST OF FIGURES	vi
: LIST OF ABBREVIATIONS	viii
CHAPTER 1: INTRODUCTION	1
CHAPTER 2: REVIEW OF LITERATURE.....	4
2.1 INTRODUCTION	4
2.2 MEAT TENDERNESS	4
2.2.1 The measurement of meat tenderness.....	4
2.2.1.1 Subjective methods.....	5
2.2.1.2 Objective methods	6
2.2.2 Factors affecting meat tenderness.....	9
2.2.2.1 Myofibrillar proteins.....	9
2.2.2.1.1 Shortening effects	9
2.2.2.1.2 Proteolytic activity.....	10
2.2.2.1.3. Cooking effects.....	11
2.2.2.2 Connective tissue	12
2.2.2.2.1 Cooking effects.....	12
2.2.2.2.2 Aging effects.....	13
2.3 MEAT pH.....	13
2.3.1 Factors affecting the rate of pH change and ultimate meat pH.....	14
2.3.1.1 Pre-slaughter factors	14
2.3.1.1.1 Species effects	14
2.3.1.1.2 Variability between animals.....	14
2.3.1.1.3 Muscle fibre types.....	15

2.3.1.1.4 Pre-slaughter glycogen-depleting treatments	16
2.3.1.1.5 Pre-slaughter administration of drugs	17
2.3.1.2 Post-slaughter factors.....	17
2.3.1.2.1 Chilling procedures.....	17
2.3.1.2.2 Electrical stimulation	18
2.3.2. Meat quality characteristics affected by ultimate pH	19
2.3.2.1 Water holding capacity (WHC).....	19
2.3.2.2 Tenderness	20
2.3.2.2.1 Effects of pH through WHC	20
2.3.2.2.2 Effects of pH and proteolytic activity	22
2.3.2.3 Colour	23
2.3.2.4 Keeping quality.....	24
2.3.2.5 Flavour	25
2.4 BREED AND CASTRATION EFFECTS ON CARCASS AND MEAT QUALITY CHARACTERISTICS.	25
2.4.1 Carcass characteristics	25
2.4.1.1 Breed effects	25
2.4.1.2 Castration effects	27
2.4.2 Meat quality characteristics	28
2.4.2.1 Breed effects.	28
2.4.2.1.1 Tenderness	28
2.4.2.1.2 Juiciness.....	29
2.4.2.1.3 Flavour.....	29
2.4.2.1.4 Colour	30
2.4.2.2 Castration effects	31
2.4.2.2.1 Tenderness	31
2.4.2.2.2 Juiciness.....	32
2.4.2.2.3 Flavour.....	32
2.4.2.2.4 Colour	33

CHAPTER 3: MATERIALS AND METHODS	34
3.1 ANIMALS	34
3.2 CARCASS ASSESSMENT.....	35
3.3 MEAT QUALITY ASSESSMENTS	35
3.3.1 Sample preparation	35
3.3.2 Muscle pH.....	36
3.3.2.1 pH ₃ measurement	36
3.3.2.2 Ultimate pH	36
3.3.3 Sarcomere length	36
3.4.3 Meat colour (Reflectance Spectrophotometry).....	37
3.3.5 Warner-Bratzler shear force values	37
3.3.6 Water holding capacity (WHC)	38
3.3.7 Intramuscular fat.....	38
3.4. STATISTICAL METHODS.....	39
 CHAPTER 4: RESULTS	 40
4.1 GROWTH RATE	40
4.2 CARCASS CHARACTERISTICS.....	42
4.3 MUSCLE CHARACTERISTICS.....	45
4.4 MEAT TENDERNESS	53
4.5 RELATIONSHIPS BETWEEN SHEAR FORCE DEFORMATION CURVE PARAMETERS WITH ULTIMATE pH AND SARCOMERE LENGTH	59
 CHAPTER 5: DISCUSSION	 63
5.1 ULTIMATE pH AND MEAT QUALITY CHARACTERISTICS.....	63
5.2 MEAT TENDERNESS MEASUREMENT	65
5.3 BREED AND CASTRATION EFFECTS.....	67
5.3.1 Growth rate	67
5.3.2 Carcass characteristics	68
5.3.2.1 Dressing-out percent.....	68
5.3.2.2 Rib-eye area	69

5.3.2.3 Meat yield	70
5.3.3 Muscle characteristics.....	71
5.3.3.1 Muscle pH, colour and water-holding capacity (WHC)	71
5.3.3.2 Meat tenderness	73
CHAPTER 6: CONCLUSIONS	75
REFERENCES	78
APPENDICES.....	98

CHAPTER 1

INTRODUCTION

All forms of meat, regardless of species of animal, are good sources of essential amino acids, certain minerals and vitamins (Lawrie, 1985). Surveys conducted in Great Britain indicated that beef was usually more expensive than chicken, pork and lamb, but it was considered by the consumers to provide an excellent meal and to be a very appetizing, nourishing and tasty meat (Baron, 1984). Moreover, beef products were also ranked first on the usefulness factor, followed by chicken, while lamb and pork were considered poorly in this respect.

The acceptability of meat is related to its visual characteristics and its eating qualities, with the nature of these properties in the most acceptable meat varying considerably with cooking procedures. It is, therefore, difficult to compare organoleptic assessments of cooked meat between different taste panels. However, of the attributes of the eating quality of beef, tenderness has most often been ranked first, according to consumer attitudes and demand for meat (Baron, 1984). Meat tenderness was also shown to be the best predictor of overall acceptability of beef by taste panels from eight European countries (Dransfield *et al.*, 1982). The variation in meat tenderness may be the result of the collective effects of numerous traits, including the myofibrillar structure and its state of contraction, the connective tissue content and its degree of cross-linking, and the water holding capacity of the meat protein (Bouton *et al.*, 1973a). It is known that the prevention of cold-shortening can greatly diminish the contribution of myofibrillar structure to tenderness (Marsh & Leet, 1966; Davey *et al.*, 1967; Hostetler *et al.*, 1972). When cold-shortening conditions are avoided, an increase in muscle ultimate pH from 5.5 to 6.2 has been shown to lead to an increase in toughness of beef (Purchas *et al.*, 1988a). The increase in pH over this range has been reported to be associated with a significant decrease in sarcomere length (Purchas, 1988), although this association was not very close. The curvilinear relationships obtained between shear force value and ultimate pH showed the maximum shear force values at a pH of approximately 6.0 with further increases leading to lower shear force values, higher water-

holding capacity, darker colour and the phenomena of dark-cutting beef (Lawrie, 1985). Unfortunately, improvement in meat tenderness obtained by increasing pH above 6.0 are always accompanied by an undesirable dark colour, less flavour and poorer keeping quality. Consequently, more practical benefits will come from improvements in tenderness through an improved understanding of the negative relationship between tenderness and pH up to 6.0.

The main objective of this study was:

To examine the relationship between ultimate muscle pH and meat quality characteristics, with particular emphasis on its relationship with meat tenderness under conditions where cold-shortening is avoided.

One of the most widely used objective methods for assessing meat tenderness has been the Warner-Bratzler shear device which measures the force required to shear through a meat sample perpendicularly across the fibres (Bouton & Harris, 1972a). Although the peak shear force values from this device provide a good predictor of meat tenderness (Seideman & Theer, 1986), the correlations between peak shear force values and taste panel assessments are reported to be very variable (Szczeniak & Torgeson, 1965). Bouton & Harris (1972a) suggested that it might be difficult to acquire reliable predictive values when a single parameter is used to assess meat of widely differing structural properties. For example, the Warner-Bratzler shear device, peak shear force values mostly measure the strength of myofibrillar structures, whereas measures of compression strongly indicate the connective tissue strength. However, it has been suggested that these two components of meat tenderness could be measured effectively by the additional variables obtained from shear-force deformation curves, in which shear force values are plotted against the distance travelled by the shear blade (Bouton *et al.*, 1975c).

Therefore, a second objective of this study was:

To compare several variables derived from shear force deformation curves with regard to their relationships with ultimate pH and other meat characteristics.

The animals used in this study were Friesian steers, Charolais x Angus cross steers and Friesian bulls. Therefore, the opportunity existed to evaluate

differences in carcass and meat quality characteristics between these groups. Previous reports of comparisons between breed and sex groups of cattle have shown that, although differences in carcass and meat quality characteristics may sometimes exist, this is not always the case.

Thus, the third objective of this study was:

To determine the effects of breed and castration on carcass and meat quality characteristics.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

The sequences of material within this review will follow the objectives of the study as set out in chapter 1. Firstly, discussion will concentrate on the measurement of meat tenderness and factors that affect it. Secondly, the importance of meat pH as a determinant of the acceptability of meat and meat products will be considered. In this section factors affecting ultimate meat pH and the rate of pH decrease will be reviewed concomitantly with the characteristics that are affected by meat pH. Finally, the effects of castration and breed on carcass and meat quality characteristics will be reviewed. The Friesian, a dual purpose breed and the Charolais, a conventional late-maturing continental beef breed will be the main breeds considered in this review.

2.2 MEAT TENDERNESS

2.2.1 The measurement of meat tenderness

Meat tenderness can be assessed by either subjective or objective methods. The sensation of tenderness is a complicated physical process and is extremely difficult to measure (Pearson, 1963). It could be said that humans are the best instrument for evaluating meat tenderness as only human senses can perceive, analyse, integrate and interpret a large number of textural sensations at the same time (Larmond, 1976). However, sensory evaluation is always encumbered with many methodological, psychological, and physiological problems, resulting in different meanings in different places (Dransfield *et al.*, 1982). In addition it is time consuming and expensive to conduct properly (Harris, 1976). Therefore, objective methods have been developed to minimize these problems and to obtain the advantages of speed, reproducibility, and relative ease of standardisation.

2.2.1.1 Subjective methods

Meat is not a single component system, and the sensation of meat tenderness may be resolved into at least the following five components: the amount of resistance to initial chewing; the force required to tear the meat fibres apart; the amount of mastication required to reach a consistency for normal swallowing; the quantity of the residue left after mastication; and the texture of the residue after mastication (Hill, 1968).

Almost all sensory evaluations of meat tenderness, therefore, have involved some form of multicomponent analysis which has not been the case with instrumental techniques. Cover *et al.* (1962) subdivided tenderness in meat into six components: softness to tongue and cheek, softness to tooth pressure, ease of fragmentation of muscle fibres across the grain, mealiness, apparent adhesion between fibres and amount/firmness of connective tissue. These authors pointed out that "use of scores for the connective tissue component of meat tenderness has increased the precision of this phase of the attack on the multiple causes of tenderness". This multicomponent system has also been used in the work of Roger & Ritchey (1969) and Hostetler *et al.* (1973) and recently by Brandy & Hunecke (1985). The texture profile method described by Brandt *et al.* (1963) involves the evaluation of the mechanical, geometrical properties, and the fat and moisture content of meat. The analysis of properties is carried out, first, at the initial stage of ingestion, secondly, during mastication, and finally, on the residue. The texture profile method is applicable to meat but it has not been widely used in this way (Larmond, 1976). Harries *et al.* (1972) examined the interrelationships between the individual parts of a multicomponent scoring system (i.e. resistance to initial chewing, wetness, juiciness, cohesiveness, hardness, overall texture and chew count), and concluded that these characteristics were not independent and could be reduced to the two characteristics of toughness/tenderness, and juiciness. More elaborate subdivisions of sensations in the mouth did not add appreciably to the precision of the sensory assessment. These authors also demonstrated that "toughness and tenderness" could be evaluated well on hot or cold meat whereas juiciness was not. Dransfield *et al.* (1982) adopted these two characteristics to survey the acceptability of meat from eight European countries. Seideman & Theer (1986) indicated that only overall tenderness needed to be measured because the ease of

fragmentation, amount of detectable connective tissue and overall tenderness rating were all highly correlated ($r = 0.98 - 0.99$).

Sensory evaluation can generally be divided into two categories based on the end result desired (Szczesniak & Torgeson, 1965). First, an expression of consumer attitudes and preferences involves untrained, randomly selected panelists. A large panel size is necessary to obtain the higher confidence. At least 50-100 panelists are recommended, and a facial hedonic scale has been found to be more effective than a verbal scale which is limited by language barriers or by the age of the participants such as children (Abbott, 1972). Secondly, a panel to be used to describe the tenderness of the meat product, usually consists of 5-10 panelists (Cross *et al.*, 1986). Scoring systems have normally been used in the latter type. Rating scales may be unstructured (Harries *et al.*, 1972; Stone *et al.*, 1974) or structured (Dransfield *et al.*, 1982) where the terminology of points along the scale are variable and it is assumed that each word or phrase has the same meaning to each judge. It has been shown that open scales yield greater product differences than the structured ones (Stone *et al.*, 1974). The chew count method, which involves counting the number of chews required to masticate a meat sample to be ready for swallowing, may be quite objective and may relate well to instrumental techniques. However, it may not always adequately indicate tenderness differences, as wide variability in individual chew counts for similar samples have been reported (Harrington & Pearson, 1962; Szczesniak & Torgeson, 1965).

2.2.1.2 Objective methods

Szczesniak & Torgeson (1965) noted that the many types of instruments that have been developed to measure tenderness of meat operate by determining the behavior of the meat sample when forces are applied to it (Szczesniak, 1968). These forces may be either cutting, shearing, or pulling. Abbott (1972) pointed out that instrumental measurements were of little value unless they correlated well with the subjective evaluation sought. The most commonly used instrument is the Warner-Bratzler shear device (Ashgar & Pearson, 1980), even though correlations between results from this device and sensory assessments have been inconsistent (Szczesniak & Torgeson, 1965; Bouton *et al.*, 1975a; Taylor, 1982; Brady & Hunecke, 1985). The variability of these reported correlations is

to be expected as the instruments and taste panels may be measuring different structural properties of meat (Szczesniak, 1968) and meat toughness is not due solely to muscle fibre properties (Cover *et al.*, 1962). Bouton *et al.* (1973a) observed that shear force values correlated poorly with subjective assessments of tenderness when there were large differences in connective tissue strength. It is known that Warner-Bratzler peak shear force values are better correlated with the myofibrillar toughness than with connective tissue strength (Bouton & Harris, 1972a; Paul *et al.*, 1973; Cross *et al.*, 1973; Bouton *et al.*, 1975a; Harris, 1988). Similarly, compression/penetrometer measurements correlate best with connective tissue properties (Bouton & Harris, 1972b; Paul *et al.*, 1973; Bouton *et al.*, 1975a). However, both methods correlated well with taste panels (Bouton *et al.*, 1971).

The study of force deformation curves has been introduced to meat tenderness assessments in order to distinguish between the contributions to the structural strength of meat samples of myofibrillar and connective tissue components (Bouton *et al.*, 1975b). They suggested that the following five basic parameters could be obtained from the force deformation curves:

- (a) initial yield which is the force at which the material first begins to yield and which appears as the first major inflexion on the curve;
- (b) peak force which represents the maximum force recorded on any particular curve;
- (c) initial yield distance, defined as the distance from the first registering of force to the initial yield point;
- (d) final yield distance, defined as the distance between the first registering of force and the peak force;
- (e) the slope at yield, defined as the slope of the curve leading up to the initial yield point-measuring the rate of change of force at yield.

Bouton *et al.* (1975c) examined the possible relationships between shear, tensile and adhesion properties of meat and suggested that the initial effects of shear, compression or tensile force was to produce a yield in the myofibrillar structure. The force applied after this point was resisted mainly by the connective tissue structure.

Force deformation curves obtained due to different treatments known to affect myofibrillar fibres primarily reveal that the initial yield force values are mainly affected (Bouton *et al.*, 1975b). Similarly, force deformation curves obtained by using different machines, such as the volodkevich device, show that the myofibrils yield before the connective tissue (Rhodes *et al.*, 1972; Bailey, 1972). Consistent results have been obtained from force deformation curves produced by the effects of long term cooking (Bouton *et al.*, 1977). Recently, many of changes in the shear force deformation curves produced by different treatments, known to affect either myofibrillar or connective tissue structure, have been used to explain the differences in meat tenderness qualitatively. For example, pH effects (Bouton *et al.*, 1982a), species effects (Robertson *et al.*, 1984), chronological age, cooking and aging effects (Beilken *et al.*, 1986), and blade tenderization effects (Hayward *et al.*, 1980). The correlations between many parameters measured from shear force deformation curves and sensory tenderness measurements are significant, although wide variation exists in the values reported ($r = 0.3 - 0.8$) (Hayward *et al.*, 1980; Brady & Penfield, 1982; Moller, 1981; Seideman & Theer, 1986).

The conventional Warner-Bratzler shear measurements seem to offer greater interpretational difficulties, compared to the modified version with a straight-edged shear blade used with rectangular shaped samples (Bouton *et al.*, 1975c). However, the estimates of parameters measured from shear force deformation curves obtained from the two systems are highly correlated. Both systems show similar and significant responses to the treatments used to modify the structural components of meat (Moller *et al.*, 1982). These authors also noted that the parameters used to indicate the connective tissue strength such as the C-force (defined by Moller, 1981 as the yield point that occurred when the apex of the triangular shear blade was about to enter the slit) value and peak minus initial yield force value, obtained from both systems were not so well correlated. They indicated that the C-force value could give a better indication of the connective tissue contribution to subjectively determined tenderness, and it could be used instead of more elaborate measures such as adhesion (Bouton & Harris, 1972a). Moreover, Voisey (1971) stated that force and deformation can be recorded by electronic techniques in any textural test including puncture tests, tensile and compression tests, shear tests, and tests with consistometers and viscometers, but the interpretation of the result was a major problem.

2.2.2 Factors affecting meat tenderness

Factors affecting meat tenderness may be divided into pre-slaughter factors (e.g. species, age, breed, sex, and nutrition) and post-slaughter factors (e.g. postmortem glycolysis, conditioning, cooking, and processing) (Lawrie, 1985). These factors always exert their effects through the structural components in meat and Harris (1988) noted that the degree of tenderness can be related to: (a) the myofibrillar structure and its state of contraction, (b) the connective tissue content and the degree of collagen cross-linking, and (c) the water holding capacity of the meat proteins. In this section only the first two factors will be discussed. The last one will be covered in a subsequent section on muscle pH.

2.2.2.1 Myofibrillar proteins

2.2.2.1.1 Shortening effects

The loss of tenderness during the onset of rigor mortis is directly related to the degree of shortening of the sarcomeres and, therefore, the degree of interdigitation of actin and myosin filaments (Lawrie, 1985). Honikel *et al.* (1983) reported that shortening can take place in pre-rigor beef at temperatures between -1 and 38 °C. Locker & Hagyard (1963) observed that the shortening was minimal at 14-19 °C, and increased again at temperatures above 20 °C. They indicated that cold-shortening was more pronounced at low temperatures (<5 °C). Honikel *et al.* (1986) obtained a similar result that excised red bovine muscle (*M. sternomandibularis*) shortened less than 10 % at 6 °C and 18 °C. Below 6 °C the sarcomere contracted up to 70 %, while between 20 °C and 38 °C the sarcomere shortened up to 40 %. Toughness in cooked meat increased rapidly as the pre-rigor shortening increased from 20 to 40 percent of the initial length, but the toughness once more decreased as the degree of shortening increased from 40 to 60 percent due to progressive rupturing (Marsh & Leet, 1966). Stretching pre-rigor muscle effectively reduced adhesion between the meat fibres and hence reduced the contribution of the myofibrillar structure to tenderness (Locker & Wild, 1982). Reduction of muscle shortening and improved tenderness of major beef muscles have been obtained by suspending carcasses from the pelvic bone (Hostetler *et al.*, 1972; Smith *et al.*, 1971; Bouton *et al.*, 1973a). Also in pork, tenderness was improved by pelvic suspension

(Moller *et al.*, 1987). Post-mortem shortening can also be minimized by holding carcasses at 15-20 °C for at least the first 16 h after slaughter (Locker & Hagyard, 1963). The improvement of meat tenderness under high temperature (>9 °C) conditioning has been shown by Lochner *et al.* (1980), Marsh *et al.* (1981) and Paterson *et al.* (1988). However, the opposite results have also been reported (Elgasim *et al.*, 1981; Crouse *et al.*, 1983). The accelerated development of full rigor is easily achieved by electrical stimulation (Savell *et al.*, 1978; Dutson *et al.*, 1980; Pearson & Dutson, 1985). Dutson *et al.* (1980) emphasized that not all the problems of meat toughness were overcome by the prevention of cold-shortening. They pointed out some further tenderisation was due to the stimulation of proteolysis by activating lysosomal enzymes. Other authors have suggested that tissue disruption as a consequence of violent contraction during stimulation may also be responsible for increased tenderness (Savell *et al.*, 1978; Will *et al.*, 1980). Cold-shortening is not likely to affect muscle deep in a beef carcass (Bouton *et al.*, 1978), because its insulation allows rigor-mortis to be completed before the temperature decreases below 15 °C (Lawrie, 1985). Red muscles seem to be more susceptible to cold-shortening than white muscles (Davey & Gilbert, 1975), and the former muscles have been shown to respond less to electrical stimulation (Devine *et al.*, 1984).

2.2.2.1.2 Proteolytic activity

The physical properties of muscle fibres have been shown to be affected by aging which mainly weakens the myofibrils (Stromer & Goll, 1967; Davey & Dickson, 1970). Pearson (1986) noted that the weak point in the structure of myofibrils is the Z-line where degradation occurred first. There is evidence that breakage of the myofibrils at the Z-line is correlated with meat tenderness, and myofibrillar fragmentation has been shown to be a useful measure for meat tenderness (Olson *et al.*, 1976). Locker & Wild (1982) demonstrated that aging weakened both actin and the gap filaments, fracturing the I-band and thereby improving tenderness. The aging process can be affected by chilling rates as Elgasim *et al.* (1981) reported that there was little or no sign of sarcomere degradation in beef conditioned at 2 °C, but degradation was clear in meat conditioned at 16 °C for the first 12 h post-mortem. They found differences in tenderness and sarcomere length after 7 d post-mortem. Paterson *et al.* (1988) could not find any changes in sarcomere length under a similar treatment, but

meat conditioned at high temperature was more tender than meat conditioned conventionally, a result which is consistent with the reports of Lochner *et al.* (1980) and Marsh *et al.* (1981). Changes in myofibrillar proteins of bovine muscle during 14 d post-mortem storage at 2 °C, have been reported to be associated with the gradual disappearance of troponin-T which is known to be degraded by calcium-activated factor (CAF), resulting in improved tenderness during post-mortem storage (Koochmaraie *et al.*, 1984b). Bouton *et al.* (1975b, 1981) observed that the slope at yield and initial yield force values, obtained from meat aged at 0-1 °C for 3 wk, decreased significantly, indicating a weakened myofibrillar structure. Cold-shortened meat has been reported to show either negligible improvement in tenderness with aging (Davey *et al.*, 1967; Locker *et al.*, 1975) or significantly improved tenderness with aging (Goll *et al.*, 1964a; Newbold & Harris, 1972). However, it has recently been confirmed that myofibrillar proteins of cold-shortened muscles are affected by post-mortem aging in a manner similar to that of the normally chilled meat (Koochmaraie *et al.*, 1984a). In their review, Ashgar & Pearson (1980) concluded that the changes associated with post-mortem aging may be modified by sex of the animal, type of muscle, muscle composition and duration of aging.

2.2.2.1.3. Cooking effects

As meat is always cooked before eating, changes in meat structure when it is subjected to different cooking temperatures have been widely investigated. The first changes observed are the denaturation of myosin and actin which begins at 40-50 °C (Cross *et al.*, 1986). A decrease in shear and adhesion values obtained for samples cooked at 60 °C, compared to those of samples cooked at 50 °C (Machlik & Draudt, 1963; Bouton & Harris, 1972b) has indicated that the denaturation of the myofibrils at the lower temperature was accompanied by some collagen solubilisation increasing from 50 to 60 °C (Beilken *et al.*, 1986). Similarly, shear and compression values for samples cooked at 75 °C were greater than those for samples cooked at 60 °C (Machlik & Draudt, 1963; Purchas, 1972; Bouton & Harris, 1972b; Bouton *et al.*, 1975b) which has been attributed to a further increase in protein coagulation and a bunching up of the connective tissue not solubilized by heating. Higher cooking losses have been reported at higher temperatures (Bouton & Harris, 1972a; Bouton *et al.*, 1975b).

However, cooking at temperatures higher than 70 °C may lead to further coagulation of contractile proteins as well as further solubilisation of collagen (Paul *et al.*, 1973; Brady & Hunecke, 1985). Heating meat at 50-65 °C for an extended time, therefore, could be doubly beneficial by minimizing both the myofibrillar and the connective tissue contributions to toughness (Beilken *et al.*, 1986). Toughening effects caused by cold-shortening may be overcome by pressure-heat treatment rather than by prolonged cooking at 60 °C or 80 °C (Robertson *et al.*, 1984; Harris, 1988). The gap filament or T-filament (Locker, 1987) may contribute to cooked meat toughness, as it appears to be the last component to be degraded during cooking (Pearson, 1986).

2.2.2.2 Connective tissue

A strong relationship between toughness and animal age appears not to be associated with connective tissue content (Dransfield, 1977; Harris, 1988), but with the intermolecular cross-links which are the main factors responsible for the mechanical strength of collagen (Lawrie, 1985).

2.2.2.2.1 Cooking effects

During cooking of meat, collagen is denatured and it shrinks at about 60-75 °C (Cross *et al.*, 1986). Collagen solubilisation to form gelatin begins at about 50-70 °C and increases as the temperature increases (Paul *et al.*, 1973). However, the degree of collagen cross-linking, which increases with animal age (Lawrie, 1985), will influence the temperature at which it starts to solubilize (Goll *et al.*, 1964b). Bouton & Harris (1972b) demonstrated that the adhesion values of veal cooked at 90 °C decreased rapidly with cooking time and were almost zero at 3 h while in muscle from young steers there were no significant changes in the first hour and adhesion become negligible after 4 h. In muscles from aged cows cooked at the same temperature adhesion values increased initially and it was 8 h before they approached zero. Solubilisation of connective tissue from young animals may begin at temperatures above 50 °C, while it may occur at above 60 °C for older animals (Bouton *et al.*, 1981). The older the animal the higher the proportion of heat-stable cross-links (King, 1987).

In addition, the stress/strain properties of collagen fibres heated to above shrinkage temperature may increase due to the collagen fibres being hindered

from contracting by the presence of interstitial myofibrillar proteins such as in the stretched muscle restrained during cooking (Bouton *et al.*, 1982b).

2.2.2.2.2 Aging effects

The role of collagen in the tenderizing effect of conditioning may be small, compared to the effect of myofibrillar protein degradation. However, small changes in the structural and thermal stability of collagen do occur during conditioning. Judge & Aberle (1982) observed that a fall of thermal shrinkage temperature of bovine collagen after 7 d of conditioning at 7-8 °C was greater than that for samples held for 24 h at 3-5 °C. It has been found that some breakage of collagen cross-links occurred during high temperature conditioning and the collagen solubility was increased when compared with samples conditioned at 1 °C, although the differences were not significant (Wu *et al.*, 1982). As collagen structure can be degraded to soluble peptides by cathepsins (Stanton & Light, 1988), possibly the proteolytic cleavage could be maximized by electrical stimulation (Savell *et al.*, 1978) and the conditioning temperature. Maximal collagenolytic activity may be related to post-mortem pH as well (Stanton & Light, 1988).

2.3 MEAT pH

Once an animal dies its oxygen supply is cut off. ATP is, therefore, resynthesized only by anaerobic glycolysis, leading to the formation of lactic acid and consequently a lowering of muscle pH (Greaser, 1986). Most of the decline in pH occurs during the first 12-15 h post-mortem (Pearson, 1986), although the time needed to reach the ultimate pH varies, depending on the particular environment. The normal ultimate pH for many muscles is 5.5-5.7, but higher pH may occur if glycogen reserves are depleted before slaughter, if glycolytic enzymes are inactivated or if the glycogen is insensitive to enzymic attack (Lawrie, 1985).

2.3.1 Factors affecting the rate of pH change and ultimate meat pH

The pH obtained, either as a result of the lack of glycogen or from the inhibition of glycogen breakdown, is referred to as ultimate pH (Lawrie, 1985). The ultimate pH seems to be determined mainly by muscle glycogen concentration at slaughter as this is the major source of energy for post-mortem glycolysis (Pearson & Dutson, 1985). However, the relationship between ultimate pH and muscle concentration is non-linear, with the main effects on ultimate pH being at glycogen concentrations lower than 8 mg/g of muscle (Warris *et al.*, 1984). Enhancing the rate of glycogen breakdown could result in increasing the rate of pH fall, but not the extent of pH fall (Pearson & Dutson, 1985). Both the rate and the extent post-mortem pH fall are influenced by the following factors.

2.3.1.1 Pre-slaughter factors

2.3.1.1.1 Species effects

The pH decline rate is species dependent. Marsh & Thompson (1958) reported that at any temperature within the range 3-37 °C the rate of pH fall was faster in lamb than in beef. They also noted that in horse and rabbit muscle at 37 °C the pH fell at the same rate as beef. In the pig, Kastenschmidt (1970) indicated that glycogen concentration dropped by 30-50 % within 10 min post-mortem, reaching a final level at about 3-5 h after death. Lawrie (1985) pointed out that the PSE (pale, soft and exudative) condition in which the pH may fall to about 5.4 in 40 min, was moderately heritable, especially in pigs. In contrast, in beef *M. longissimus* glycogen content had dropped to final levels 24 h after death (Bodwell *et al.*, 1965). Recently, Lundberg *et al.* (1987) confirmed that the rate of post-mortem metabolism in pig muscle was higher than that of ovine muscle which in turn was higher than bovine muscle. They also noted that the ultimate pH in the pig and lamb muscle were significantly lower than that in beef.

2.3.1.1.2 Variability between animals

Considerable variability exists between different animals in the rate of glycolysis even within the same environmental conditions (Lawrie, 1985). Bendall (1978) found that the rate of pH fall in muscles from different animals varied by about

two fold in the high range of pH (7.0-6.7), and was slightly lower in the low pH range (6.6- 5.8). Marsh *et al.* (1981) also found a 1.3 unit range in pH at 3 h post-mortem among the M. longissimus of 40 beef sides. However, Tarrant & Mothersill (1977) found little variation in the rate of pH fall for the six major hindquarter muscles of beef between animals after correcting for the effects of differing cooling rates at different depths within the muscles. Carse & Locker (1974) observed that on lamb muscle surfaces pH varied only from pH 6.3 to 6.6 at 3 days, whereas for beef muscles it varied widely from pH 5.8 to 7.1.

2.3.1.1.3 Muscle fibre types

The differences in ultimate meat pH found in different animals and species seem to be related to differences in muscle fibre type components. Muscles can be classified according to their contractile activity (Bechtel, 1986) into slow-twitch oxidative fibres (alpha-red), fast-twitch oxidative-glycolytic fibres (beta-red), and fast-twitch glycolytic fibres (alpha-white). Lawrie (1977) stated that white muscle fibres have a highly developed sarcoplasmic reticulum which regulates the intracellular calcium concentration in living fibres. In contrast, red muscle fibres have a less developed sarcoplasmic reticulum and more mitochondria (Lawrie, 1977). In addition, Whiting (1980) indicated that anaerobic calcium uptake of mitochondria declined post-mortem before that of sarcoplasmic reticulum, so that white fibres tended to have higher glycolytic potential, higher glycogen concentration and showed lower ultimate pH (Monin *et al.*, 1987). Dildvey *et al.* (1970) pointed out that PSE pork had a significantly greater proportion of anaerobic fibres than normal muscles, especially in M. longissimus and M. semi-membranosus (Lawrie, 1985; Fabiansson & Rentersward, 1985). Similarly, the double-muscled bovine possesses more fast-twitch fibres than control animals and produced higher blood lactate concentrations (Ashmore, 1974). Ma & Addis (1973) observed that pH declined faster in turkey pectoralis muscle than in the most severely PSE porcine muscle, probably because it was nearly totally fast-twitch glycolytic fibres (Wiskus *et al.*, 1976). Thus in most cases muscles with a high proportion of red fibres have higher ultimate pH values than those with a high proportion of white fibres.

2.3.1.1.4 Pre-slaughter glycogen-depleting treatments

Pre-slaughter handling and degree of struggling of animals is an important factor affecting ultimate meat pH, because the stresses may induce glycogen depletion in muscle due to the action of adrenalin (Tarrant *et al.*, 1988). Ashmore (1974) pointed out that the response of muscle to stress was directly related to the proportion of muscle fibre types adapted for glycolytic metabolism. He emphasized that this metabolism responded dramatically to epinephrine, which is a hormone released in proportion to the level of stress imposed upon the animals. Thus, stress imposed before slaughter can deplete glycogen reserves leading to an undesirable high ultimate pH (Ashmore, 1973a).

Wythes *et al.* (1981) postulated that the pH of beef *M. longissimus* 24 h post-mortem did not increase necessarily with distance travelled (460-2055 km). Warris *et al.* (1984) observed that animals killed after mixing or regrouping with unfamiliar animals produced carcasses with high ultimate pH, coupled with dark cutting meat. The glycogen concentration could be recovered by resting at least 48 h before being killed (Warris *et al.*, 1984). Kenny & Tarrant (1988) suggested that the single penning of an oestrus heifer to eliminate mounting activity would reduce the incidence of dark-cutting. In their study they found that loss of muscle glycogen was accounted for by the number of times an animal mounted ($r = -.85$). Jones *et al.* (1986) suggested that minimum pre-slaughter stress and lower ultimate muscle pH could be obtained by slaughtering cattle shipped directly from feedlot, with no mixing with unfamiliar animals overnight at the abattoir.

Resting with some food and water during the long journey in addition to resting time before slaughter decreased the incidence of high pH beef (Wythes *et al.*, 1988). Tarrant *et al.* (1988) reported that sexual and aggressive behaviours were inhibited at high stocking density during a journey with the exception of mounting and pushing, which increased infrequently with stocking density. They also noted that at a constant stocking density, stress increased with pen location toward the back of the truck. Kenny & Tarrant (1987) pointed out that confinement in a moving truck induced more stress than either loading/unloading via a tailgate ramp or confinement in a stationary truck.

Another abnormal condition arising mainly in pigs that can be caused by stress is PSE meat. The PSE condition results from an accelerated post-mortem glycolytic rate that lead to pH values below 6.0 at 45 min post-mortem while muscle temperature is still high (Pearson, 1986). Bendall *et al.* (1963) reported that pH decline rate was 1.04 unit/h in PSE meat, compared with 0.65 unit/h in normal muscle held at 37 °C. Dalrymple & Kelly (1969) stated that PSE pork was produced more frequently in pigs that had been subjected to greater temperature fluctuations during hauling and holding prior to slaughter.

2.3.1.1.5 Pre-slaughter administration of drugs

The prevention of high ultimate pH meat can be achieved by epinephrine inhibitors such as propranolol, a beta blocking agent (Ashmore *et al.*, 1973a, 1973b). They showed that sheep injected with epinephrine and propranolol exhibited normal 48 h post-mortem pH values averaging 5.6-5.8, and normal muscle glycogen content at slaughter. McVeigh & Tarrant (1983) postulated that muscle glycogen depletion during social regrouping of cattle was not mediated predominantly by propranolol, although their results showed the rate of glycogen breakdown in propranolol-treated animals was reduced significantly during the first hour of mixing. Tranquilizers have also been used to reduce the incidence of PSE in pigs before transportation resulting in improvement in carcass temperature, colour, pH, and WHC, compared with untreated pigs (Cassens *et al.*, 1975). Moreover, the intravenous administration of relaxing doses of magnesium sulphate before slaughter also decreased the subsequent rate of post-mortem glycolysis, but injection of calcium salts and of adrenaline and noradrenaline enhanced the rate (Lawrie, 1985).

2.3.1.2 Post-slaughter factors

Post-slaughter factors affecting either ultimate meat pH or rate of pH fall mostly involve the modification of time-temperature relationships for the onset of rigor (Cassen *et al.*, 1975).

2.3.1.2.1 Chilling procedures

Scopes (1974) pointed out that the glycolytic rate increased in direct proportion to the amount of ATPase activity in the system, and the rate of ATP turnover

was highly correlated ($r = 0.97$) to muscle temperature (Tarrant & Mothersill, 1977). Thus pre-rigor muscles subjected to different cooling temperatures could result in different rates of pH fall. Marsh (1954) showed that beef longissimus reached pH 5.8 in 20 h at 7 °C and 16 h at 17 °C (ultimate pH c 5.6). Rigor has been achieved in 1.5 to 2 h in lamb conditioned at 45 °C (Davey & Gilbert, 1973). However, at low temperatures Cassen & Newbold (1967) indicated that pH fall was faster at 1 °C than 5 °C during the first few hours post-mortem. Similarly, in pig muscles cooled at 3 °C took on average 7 h to reach pH 6.0, while those cooled at 20 °C or -1 °C reached pH 6.0 at about 4 and 5.5 h respectively (Dransfield & Locker, 1985). In addition, a relatively rapid rate of glycolysis has been observed in the deep part of beef M. semimembranosus during chilling, reflecting the effects of high temperature in this region (Follett *et al.*, 1974). Tarrant (1977) showed that hot boning reduced the temperature differences within the muscle so that ultimate pH of hot boned beef was reached in 24 h, while in the carcass it was reached in 6, 12, and 24-48 h at 8, 5, and 1.5 cm depths respectively. The time required for pH to fall to 6.0 at several locations in intact beef sides varied from 2.2 to 13.6 h, depending on muscle types and depth in the carcass (Tarrant & Mothersill, 1977). Whiting (1980) found that anaerobic calcium uptake activity in mitochondria and sarcoplasmic reticulum increased with increasing temperature. However, he also noted that this activity declined with decreasing pH and when the temperature was above 25 °C for mitochondria and above 40 °C for the sarcoplasmic reticulum. Dutson, (1983) agreed that elevated temperature in post-mortem muscle increased the rate of pH decline. Crouse & Seideman (1984) confirmed that the pH at 3 h post-mortem was significantly lower for muscle conditioned at 26 °C than that of conditioned at 1 and 12 °C. There have been many other reports indicating that rate of post-mortem glycolysis is highly dependent on the cooling rate (Unruh *et al.*, 1986a; Buts *et al.*, 1986; Lee & Ashmore, 1985; Marsh *et al.*, 1987).

2.3.1.2.2 Electrical stimulation

The application of electrical stimulation (ES) to hot carcasses also hastens rigor mortis. In principle, ES will greatly accelerate glycolysis and speed up the pH drop (Carse, 1973) in two stages involving an initial rapid fall in pH during stimulation and a subsequent slower rate of pH fall which is still faster than in

unstimulated muscles (Newbold & Small, 1985). Houlier *et al.* (1984) observed that slow twitch muscles reacted least to stimulation and that stimulation was particularly effective for fast twitch muscles. The differences in rate of pH change between electrically-stimulated and unstimulated carcass have been widely reported. For example, Bendall (1976) reported that stimulated carcass reached pH 5.7 in about 3 h, accompanied by rigor onset, whereas the unstimulated carcass needed at least 10 h in lamb, and about 16-17 h in beef (Pearson & Dutson, 1985). Smulders *et al.* (1986) observed that stimulated beef carcasses reached pH below 6.0 within 2 h post-mortem, while the control carcasses needed approximately 6 h. But in veal the stimulated carcasses were already below 6.0 at about 45 min, compared with 6 h in the control sides (Eikelenboom & Smulders, 1986). Buts *et al.* (1986) found differences of 0.93-0.94 pH units 2 h post-mortem between control and ES carcasses. However, glycolytic rate of ES carcasses was affected by the subsequent cooling as well. Marsh *et al.* (1987) showed that the change in pH from initial to 3 h was 0.81 for the fastest cooling rate, compared with 1.32 for that of the slowest chilling rate. Furthermore, Newbold & Small (1985) indicated that the fall in pH during stimulation depended on pH of the muscle at the time of stimulation, the lower the pH, the smaller the acceleration in rate of pH fall.

2.3.2. Meat quality characteristics affected by ultimate pH

2.3.2.1 Water holding capacity (WHC)

Water is held in muscle by capillary force, mostly in the interfilamental spaces within the myofibrils, but a substantial part is also found in the spaces between the myofibrils and in the extracellular space (Offer & Trinick, 1983). Changes in the WHC of meat, which are the result of changes in the spaces occupied by the intrafibre water (Currie & Wolfe, 1980), are largely determined by ultimate pH and myofibrillar contraction state (Bouton *et al.*, 1971; Bouton & Harris, 1972a, 1972b; Honikel *et al.*, 1986). Thus changes in WHC are of interest and are a very sensitive indicator of changes in the charges and the structure of myofibrillar proteins (Hamm, 1960, 1975).

There have been many reports concerned with the relationship between WHC and pH. In the early work of Hamm (1960) and Penny *et al.* (1963), the

curvilinear relationship obtained indicated that a minimal WHC occurred at the average isoelectric point of the major proteins in muscle (pH 5.0 - 5.5) and then increased markedly with changing pH on both sides of this. Bouton *et al.*(1971, 1973b) and Bouton & Harris (1972a) obtained similar results, but the curvilinear relationship was most clear for meat cooked at 80 - 90 °C, and very little change in WHC was shown over the pH range 5.4 - 6.0. This agrees with Hamm (1975) that WHC increased with rising pH provided that the pH variation was larger than the range of 5.5 to 5.8. Gault (1985) measured WHC by the swelling ratio in both raw and cooked meat and confirmed that minimal swelling occurred between the pH of 4.5 - 5.6 and then markedly increased below pH 4.5 to reach the maximum value at pH 3.2 - 3.4.

Moreover, cooking loss is known to increase with increasing final cooked temperature (Bouton *et al.*,1973b; Bouton & Harris, 1972a), and the loss is more pronounced for rigor meat than for pre-rigor meat (Cia & Marsh, 1976; Cross & Tennet, 1980). Addition of salt (NaCl) to muscle homogenates causes an increase in WHC (Honikel *et al.*, 1981; Bernthal *et al.*, 1989). However, this effect is dependent on the pH of the tissue as well. That is salt increases the WHC at pH greater than the isoelectric point (IP), decreases it at pH <IP, while around the IP, no significant effect appears (Hamm, 1986).

2.3.2.2 Tenderness

2.3.2.2.1 Effects of pH through WHC

Increases in ultimate meat above pH of 6 generally increase tenderness whether it is assessed by objective or subjective methods. This increase in tenderness is consistent with increasing WHC which is highly correlated with pH (Bouton *et al.*, 1971, 1973b, 1982a, 1982b, Currie & Wolfe, 1980). However, the correlation between tenderness and pH is not always positive, especially when ultimate pH is less than 6.0. A curvilinear relationship between tenderness and pH with a maximum toughness at a pH of about 5.8 - 6.0, was obtained by Bouton *et al.* (1973b) for beef. They suggested that increasing fibre toughness in the 5.4 - 6.0 pH range is affected more by fibre contraction state than by the increased WHC over this pH range. This finding is confirmed by Purchas *et al.* (1988a) who observed that toughness of beef M. longissimus did increase over

the 5.5 - 6.0 pH range, and was accompanied by a significant decrease in sarcomere length. Bouton *et al.* (1982b) however, showed that the sarcomere lengths of meat samples were not significantly dependent on pH. This may be due to the stretching treatment applied to meat before cooking. Fjelkner-Modig & Ruderus (1983) classified beef M. semimembranosus and M. longissimus into three ultimate pH ranges (i.e. <5.8, 5.8-6.19, and >6.2) and observed that meat with medium pH was least tender, while there were no obvious differences in tenderness between the low- and high-pH meat. They also indicated that the greater improvement in tenderness after aging was recorded for the low-pH meat than DFD (dark, firm and dry) meat. Yu & Lee (1986) agreed that high pH beef longissimus muscle (>6.3) was significantly more tender than low pH beef (<5.8) which in turn was more tender than intermediate pH beef (5.8-6.3). They also pointed out that the low pH group had the longest sarcomere length whereas there was no difference between the high and intermediate groups. However, their results showed a significant correlation ($r = -0.76$) between shear force and sarcomere length thereby confirming earlier studies (Marsh & Leet, 1966; Smith *et al.*, 1971; Bouton & Harris, 1972b).

In most situations cooking losses were significantly lower for high pH meat than for normal pH meat (Fjelkner-Modig & Ruderus, 1983). It has been shown that PSE meat had higher cooking losses and lower total moisture content than normal meat (Kauffman *et al.*, 1964; Scarcy *et al.*, 1969; Fox *et al.*, 1980). This meat had also been rated lower than normal meat for juiciness and tenderness (Kemp *et al.*, 1976; Topel *et al.*, 1976). In some reports, however, PSE pork has been shown to be more tender (Deethardt & Tuma, 1971), and to have a similar juiciness to normal pork (Scarcy *et al.*, 1969). However, DFD meat has been rated highest in pH, tenderness, and lowest in cooking loss or expressible juice, compared with normal and PSE meat (Scarcy *et al.*, 1969; Topel *et al.*, 1976). Smith & Lesser (1982) demonstrated that drip loss from fresh PSE meat (pH 5.4-5.8) was more than double (17.0 vs 7.0 g/kg trimmed carcass weight), that of normal pork (pH 6.2-6.5).

In addition, the toughness which occurred due to cold-shortened muscle of normal pH (5.76 -6.08) and which was attributable to the denaturation of myosin as cooking temperature increased above 60 °C, was effectively eliminated by increasing ultimate pH (Bouton *et al.*, 1982a). Connective tissue seems to be

unaffected by pH (Bouton *et al.*, 1973b). This finding is supported by the increase in peak shear force values of stretched muscle, restrained during cooking at 80 °C, relative to free muscles at all ultimate pH values from 5.5 to 7.0 (Bouton, *et al.*, 1982b). However, increases in adhesion properties post mortem as pH dropped to 5.85 - 5.95 was demonstrated by Currie & Wolfe (1980), who also showed that the adhesion strength of the meat sample then dropped as the pH continued to fall to the point of rigor maximum.

2.3.2.2.2 Effects of pH and proteolytic activity

The evidence from the literature has indicated that post-mortem pH and temperature have a significant effect on muscle properties such as final meat tenderness. Dutson (1983) pointed out that the increased rate of pH decline at elevated temperatures was accompanied by increased activity of enzymes which caused the disruption of myofibrillar proteins. He also indicated that high pH enhanced CAF (calcium activated factor) activity, while low pH accelerated lysosomal activity. Yu & Lee (1986) reported that tenderness of high pH beef derived from an extensive degradation of Z-lines, whereas that of low pH muscles was caused mainly by a degradation of M-line and myosin heavy chains. Intermediate pH muscles did not show much degradation of muscle proteins, thereby resulting in tougher meat. The combined effects of high temperature and low pH as in the electrically-stimulated muscles has been reported by Yates *et al.* (1983) to increase myosin degradation. This was higher at 37 °C and pH 5.4 than at 4 °C and pH 7. This finding is supported by the fact that enzyme systems most responsible for degradation of myofibrillar proteins were more active at the higher temperature (37 °C) and lower pH (Dutson, 1983). Thus, it would seem that any treatment producing a low pH with muscle temperature still high should result in more tender meat (Crouse *et al.*, 1983; Smulders *et al.*, 1986; Eikelenboom & Smulders, 1986). However, Lee (1986) stated that further accelerating the aging process at higher temperatures of 30 to 40 °C could result in tougher meat than control muscle chilled conventionally. For instance, well finished heavy beef carcasses (293 kg) held at 35 °C for 3 h after slaughter showed greater toughness and shorter sarcomere lengths than the conventionally chilled carcasses (Lee & Ashmore, 1985), although, delayed-chilling at moderate temperatures from 10-13 °C improved meat tenderness in sheep and light weight beef carcasses (236 kg) (Lee, 1986). Similarly, delayed-

chilling may sometimes accelerate the already high rate of pH fall obtained from ES (electrical stimulation) treatment, resulting in significantly tougher meat (Buts *et al.*, 1986; Unruh *et al.*, 1986a; Marsh *et al.*, 1987). Marsh *et al.* (1987) presented evidence showing that tenderness of beef was highest when glycolysis had proceeded at an intermediate rate (corresponding to the attainment of a 3-h pH of about 6.1). In addition, Lochner *et al.* (1980) and Marsh *et al.* (1981) reported that high pH and high temperature enhanced meat tenderness greatly within 2-3 h post-mortem, presumably due to the rapid disruption of the Z-line by enzymes such as CAF (Dutson, 1983; Lee, 1986). In pigs, Moller & Vestergaard (1987) reported that tenderness of high pH excised muscles (6.1-6.5) was improved significantly by a 4 h delay before entering the chilling tunnel (operating at -28 to -22 °C). Their results showed a highly significant negative relationship ($r = -0.57$) between shear force and sarcomere length but only for the high pH group.

2.3.2.3 Colour

O'Keeffe & Hood (1982) stated that when the cut surface of meat is exposed to air, the reduced myoglobin combines with oxygen to form oxymyoglobin, but that the brightness and saturation of the red colour developed depended on the depth of oxygen penetration into the tissue. Cross *et al.* (1986) pointed out that oxidation of myoglobin to the undesirable metmyoglobin could occur at low pH (<5.4), and at low oxygen tension. Low pH causes denaturation of the protein moiety of myoglobin that protects the haem group. This dissociates the oxygen and also oxidises the iron molecule. This process is illustrated by the pale colour of PSE meat, which is the result of the low pH causing muscle structure to open and scatter light (Walters, 1975). Similarly, the lighter, brighter-red colour in displayed steaks from ES carcasses has been attributed to the faster rate of pH fall and tissue disruption (Sleper *et al.*, 1983; Unruh *et al.*, 1986a). These authors also indicated that ES muscle was more susceptible to metmyoglobin formation and had less anaerobic metmyoglobin reducing activity (MRA), leading to greater discoloration at 5-6 days display than control steaks. In contrast to PSE, DFD meat occurs as a result of high ultimate pH meat. Walters (1975) reported that muscles of DFD meat were swollen and tightly packed together, forming a barrier to the diffusion of oxygen, and light adsorption. Locker (1989) stated that the adsorption of light by dark red pigments increased

steadily as the pH moved from 5.6 to 7.0. Ashmore *et al.* (1973a) pointed out that mitochondria in high pH muscle remained active and as a result myoglobin would be deoxygenated, resulting in dark red meat. In cooked meat, Mendenhall (1989) reported that high pH (>6.2) inhibited the formation of brown cooked meat colour. That is the higher the pH the longer the cooking time and/or higher the final temperature required for denaturation of muscle pigments to form the grey globin ferrihemeochrome of cooked meat. Trout (1989) also showed that high ultimate pH markedly decreased the percentage myoglobin denaturation in beef, pork and turkey meat resulting in obvious colour differences in cooked meat. Moore & Gill (1987) found that the colour stability of displayed lamb declined with prolonged storage. They postulated that the increase in pH values observed might be related to the decline in colour stability.

2.3.2.4 Keeping quality

Kraff (1986) noted that meat provides favourable conditions for microbial growth, but the ultimate pH of fresh meat will frequently fall in the range 5.5-6.0 and most bacteria have an optimum growth pH near 7.0. He also pointed out that the aerobic growth of food poisoning staphylococci was limited at pH 5.3 and that anaerobic growth was almost completely prevented at this pH. Hence a lower pH value for meat products is desirable for delaying microbial spoilage. Rey *et al.* (1976) and Fox *et al.* (1980) reported that in general DFD pork was more susceptible to bacterial spoilage than normal meat, which in turn was more susceptible than PSE meat. Newton & Gill (1980-81) pointed out that high-pH DFD meat (>6.0) allowed growth of potent spoilage organisms which were inhibited at normal ultimate pH values. Additionally, they showed that early aerobic spoilage can be prevented by the addition of glucose because the presence of glucose prevented bacteria producing spoilage odours by attacking amino acids. In order to reduce anaerobic spoilage the surface pH must be reduced and a carbohydrate substrate is required. Visser *et al.* (1988) showed that decontamination of veal tongues by centrifugation with lactic acid before vacuum packing increased storage life. In contrast Dickson (1988) suggested that bacteria from both fat and lean beef were effectively reduced by washing with NaOH or KOH. Although packaging systems using a carbon dioxide atmosphere can extend the storage life of chilled lamb to at least 16 weeks (Gill, 1986), the display life may be reduced due to the increase in pH during storage

(Moore & Gill, 1987). Moreover, the growth of microorganisms that predominate on fresh meat has been inhibited to a greater extent by the combined effects of salt and acidified pH than the effect of either of the two alone (Kraff, 1986).

2.3.2.5 Flavour

Ultimate pH is one of the major biochemical variables which affects muscle flavour. Lawrie (1985) stated that flavour intensity decreased with increasing ultimate pH. He also noted that bacon of relatively high pH was less salty to the palate than that of low pH. Ford & Park (1980) noted that meat flavour intensity ratings and hedonic scaling of acceptability both showed significant negative correlations with ultimate pH. The differences in flavour volatiles of cooked meat from high pH (6.3-6.7) and normal meat has been found to occur in the qualitative and quantitative composition of the flavour volatile fraction (Ford & Park, 1980). It has been shown that high pH beef had an insipid flavour, but no flavour changes appear to arise in PSE pork (Meat research institute, 1973-74). However, Fox *et al.* (1980) showed that PSE pork had a significantly less desirable flavour than normal pork. Devol *et al.* (1988) showed that for 120 pork carcasses flavour strength was significantly correlated with ultimate pH, but the correlation obtained was very low ($r = -0.21$). In contrast Purchas *et al.* (1986) reported a high correlation ($r = 0.9$) between beef flavour strength and ultimate pH.

2.4 BREED AND CASTRATION EFFECTS ON CARCASS AND MEAT QUALITY CHARACTERISTICS.

2.4.1 Carcass characteristics

2.4.1.1 Breed effects

The use of bulls from beef breeds can improve the beef output from the dairy herd by increasing the growth rate and potential slaughter weight of the crossbred calves (More O'Ferrall *et al.*, 1989).

At the same age, Charolais x Friesian cross steers have been shown to be heavier in final liveweight and to have greater dressing-out percentages than straight-

bred Friesians (Jury *et al.*, 1980; Everitt *et al.*, 1980). The latter authors also indicated that carcass weight was significantly affected by the growth rate before weaning. Taylor (1982) stated that carcass conformation, size and maturity type were important differences in carcass characteristics between beef and dairy breeds. Many reports have indicated that purebred Friesians showed poorer beef conformation and dressing-out percentages when compared at the same age (Andersen *et al.*, 1977; Taylor, 1982; More O'Ferrall *et al.*, 1989) or at the same fat level (Kempster *et al.*, 1982a; 1988). Differences in dressing-out percentage between these two breeds, favouring Charolais, were found at the same conformation score (Bailey *et al.*, 1984). Moreover, Friesian cattle have been shown to produce longer carcasses (Morgan *et al.*, 1978b; Taylor, 1982) and smaller eye-muscle areas (Andersen *et al.*, 1977; Morgan *et al.*, 1978b; Taylor, 1982; Kempster *et al.*, 1982a; 1988) than Charolais cattle. However, More O'Ferrall and his co-workers found nonsignificant differences in carcass length and fat score between these breeds. In contrast, Morgan *et al.* (1978b) found much greater fat depths for Friesian carcasses, compared with the Charolais crosses, at the same weight.

Andersen *et al.* (1977) indicated that early maturing crosses produced a relatively lower muscle gain and a high fat gain at 300-575 kg liveweight. At this weight the Charolais had a higher muscle, and a lower fat and bone percentage than the Friesian (Andersen *et al.*, 1977; Taylor, 1982). Bass *et al.* (1981) found that at a constant age or weight, Friesian cross carcasses had higher percentages of trimmed fat and lower percentages of trimmed meat than the Charolais crosses. Everitt *et al.* (1980) agreed with these findings and indicated that the Charolais crosses had higher edible meat to bone ratios and high-priced cuts as a percentage of edible meat. However, the differences in high-priced cuts was small (41.5 vs 40.6 %). Similarly, at a fixed level of fatness, Kempster *et al.* (1982a, 1988) demonstrated that Charolais crosses were superior to Friesians in terms of conformation score, meat:bone ratios, total saleable meat and high-priced joints. Kempster *et al.* (1988) pointed out that breed crosses with larger adult body size such as the Charolais tended to have higher lean tissue growth rates, and this rate was lower for the Friesians or Holsteins in relation to their body size.

2.4.1.2 Castration effects

Entire males have carcasses of a different shape than castrated males and are also more muscular, particularly in the neck region (Kirton & Morris, 1989). These authors also pointed out that male conformation was not considered desirable by the meat trade. Seideman *et al.* (1982) stated that bulls gained faster and more efficiently, and produced leaner carcasses than steers. After reviewing numerous studies Field (1971) noted that bulls have an advantage over steers for average daily liveweight gain of 14-17 %, and that they also have a 13 % greater efficiency in converting feed to liveweight than steers. Bulls produce heavier carcasses and lower fat thickness over the M. longissimus than steers, but the dressing-out percentage has been similar for bulls and steers (Field, 1971). These effects of castration on carcass traits were supported by Ockerman *et al.* (1984) and Paterson *et al.* (1988). They reported that bull carcasses were longer, had heavier rounds, larger rib eye areas, and less subcutaneous fat than carcasses from steers at same age.

With regard to carcass composition, Berg & Butterfield (1968) indicated that steers fattened at lighter weights than intact males, so at a common weight bull carcasses tended to have lower percentage of dissectible fat and higher muscle:bone ratios than those of steers. Since the differences in percentage bone are small (i.e. 15.8 % for bulls and 15.6 % for steers, Field 1971), therefore, bulls tend to have the advantage in boneless chuck, rib, loin and round over steers. A difference of 4.8 percentage points using actual cutout figures of bulls and steers at similar age, has been reported by Champagne *et al.* (1969). Similarly, Jacobs *et al.* (1977a) reported that at the same age, bulls provided 9.2 % more actual cutable meat and 10.1 % less fat trim than steers. In addition, their results also showed that bulls gave 7.6 % more total retail cuts than steers. Landon *et al.* (1978) found greater total retail cuts for bulls than for steers, when compared at the same weights.

2.4.2 Meat quality characteristics

2.4.2.1 Breed effects.

2.4.2.1.1 Tenderness

Koch *et al.* (1976) and Taylor (1982) reported that meat tenderness differences among groups of beef breeds, including Charolais and Friesian, were small with all breed groups well above minimum levels of acceptance. In the report of More O'Ferrall *et al.* (1989) tenderness of M. longissimus from these two breeds were not significantly different, but Charolais beef had a slightly lower tenderness score than that of Friesians. However, Liboriussen *et al.* (1977) reported that all sires, including Charolais, gave tender meat for M. longissimus, as measured by either taste panel scores or shear force values. However, they found significant differences in tenderness between sire breeds for M. semitendinosus, which corresponded to differences in adhesion values, collagen content and solubility of collagen. Cross *et al.* (1984) obtained a similar result indicating that breed differences in tenderness were greater for infraspinatus and semimembranosus than for longissimus muscle. Their results supported those of other studies showing that Charolais and Friesian steers provide beef with similar tenderness for M. longissimus (Ziegler *et al.*, 1971; Johnson *et al.*, 1984). Martin *et al.* (1965) showed that meat from the Charolais breed was less tender and more fibrous than that of Hereford cattle. Bramblett *et al.* (1971) also found steaks from Hereford cattle had slightly lower shear values than those from Charolais. This implies that Charolais beef may be less tender than that of Friesian, because most of the reports mentioned above have indicated that Friesian and Hereford beef are similar in tenderness. Breed differences in tenderness after aging may be derived from differences in fibre types. Purchas (1989b) suggested that an increase in the proportion of red fibres may lead to less tenderness improvement with aging. Clancy *et al.* (1986) found that Friesians showed a greater percentage of red fibres and a lesser proportion of white fibres than the Charolais crosses. But the percentage of red fibres has been shown to decrease with age (Spindler *et al.*, 1980) and joints of Friesian cattle have been found to be more tender at a heavy weight (635 kg) than at a light weight (454 kg) (Lalande *et al.*, 1982). Nevertheless, the differences reported among breeds in meat tenderness are not large enough to cause concern (Koch *et al.*, 1976; Cross *et al.*, 1984).

2.4.2.1.2 Juiciness

As in the case of tenderness, juiciness has not been reported to differ significantly between beef from Charolais and Friesian cattle (Zeigler *et al.*, 1971; Everitt, 1972; Liboriussen *et al.*, 1977; Koch *et al.*, 1976; Taylor, 1982; More O'Ferrall *et al.*, 1989). More O'Ferrall *et al.* (1989) demonstrated that Charolais progeny had significantly higher drip loss percentage than those of Friesian and Hereford sires which were equal in this respect. Although Bramblett *et al.* (1971) found that press fluids and bound water percentage were similar between meat from the Charolais crosses and the Hereford breed, higher drip losses (2.6 vs 1.9 %) and cooking losses (12 vs 11 %) were found for Hereford meat. Conversely, Berry *et al.* (1977) obtained higher cooking loss percentages for Charolais meat (30.5 %) than for Hereford (28.7 %), whereas Johnson *et al.* (1988) found no differences in cooking loss between British and Continental breeds. Moreover, it has been reported that marbling score was not different between Charolais and Holstein breeds (Ziegler *et al.*, 1971), but greater scores may be found in Hereford carcasses than those of the previous two breeds. However, Purchas & Davies (1974a) found little change in juiciness with increased intramuscular fat percentage.

2.4.2.1.3 Flavour

Within the same species, breed differences in beef flavour may also be derived from fat which contains important flavour precursors (Moody, 1983). In the review of Smith *et al.* (1983) it was stated that only 7-11 % of the observed variability in sensory panel ratings for flavour was associated with differences in USDA (United States Department Of Agriculture) marbling score or intramuscular fatness. They also indicated that flavour desirability of loin steaks differed significantly when ranges in intramuscular fat percentage were 3.0-5.9 vs 2.0-2.9 and 2.0-2.9 vs 1.9 or less. At a similar age, it has been shown that there was no difference in marbling score between Friesian and Charolais carcasses (Hidioglou *et al.*, 1964; Zeigler *et al.*, 1971; Fredeen *et al.*, 1972), while intramuscular fat percentage ranged from 3.42 to 3.79 (Fredeen *et al.*, 1972). Thus this finding supports the result of Zeigler *et al.*, (1971) who found

no difference in flavour acceptability between beef from these two breeds. Berry *et al.* (1977) selected only carcasses with a typical small to moderate degree of marbling from several breeds and crosses. They found that all breeds were rated similarly in flavour score. Regardless of marbling score, many reports have been shown that flavour from Charolais and Friesian beef is similar in both intensity and desirability (Bramblett *et al.*, 1971; Everitt, 1972; Koch *et al.*, 1976; Liboriussen *et al.*, 1977; Taylor, 1982; Riley *et al.*, 1986; More O'Ferrall *et al.*, 1989), although significant breed effects on flavour have been reported (Ockerman *et al.* 1984). Nevertheless, flavour acceptability may be more influenced by the effects of nutrition than breed (Purchas & Davies, 1974b; Moody, 1983).

2.4.2.1.4 Colour

In a comparison of several pig breeds, Fjelkner-Modig & Pearson, (1986) showed that higher intramuscular fat level contributed to lighter-coloured meat. This is not always true for beef colour. For example, Damon *et al.* (1960) and Cross *et al.* (1984) found significant differences in marbling score between Charolais and Hereford beef, whereas Hidioglou *et al.* (1964) and Fredeen *et al.* (1972) found no differences in marbling score between these breeds. Meat colour in all these reports was similar for the two breeds. However, Damon *et al.* (1960) pointed out that scores received by breed groups showed a tendency for the Charolais breed to rank low in comparison to the British cattle for the colour of lean. Johnson *et al.* (1984; 1988) reported that carcasses from British breeds had greater marbling and higher USDA quality grades than did carcasses from Continental breeds. Likewise, Riley *et al.* (1986) considered that Holstein and British beef breeds were similar in both marbling score and USDA quality grade, but the former type tended to be rated lower than the latter. In addition, Purchas (1989b) pointed out that a darker colour may be associated with an increase in the proportion of red fibres. The proportion of red muscle fibres has been shown to be higher in Friesian longissimus muscle than that of Charolais (Clancy *et al.*, 1986). Thus, meat from the Friesian might be expected to be a darker colour.

2.4.2.2 Castration effects

2.4.2.2.1 Tenderness

Based on the reviews of consumer acceptance reported by Field (1971) and Seideman *et al.* (1982) it may be concluded that bull meat has an acceptable tenderness rating, but that the rating is slightly lower than that for steer meat of the same age. Hunsley *et al.* (1971) concluded that sex and age have a more adverse effect on tenderness in bull beef than in steer beef. They found that longissimus steaks from steers were more tender than those from bulls, either measured by taste panel or shear values. However, Reagan *et al.* (1971) reported that steaks from bulls 385 d of age were less tender than steaks from steers of the same age, but the difference was not apparent when compared at 484 d of age. Vanderwert *et al.* (1986) did not find differences in overall tenderness and connective tissue amount in five major muscle groups from bulls and steers. However, they indicated that steers were generally more acceptable, but most scores for bulls were in the acceptable range. Boccard *et al.* (1979) studied the influence of castration on the amount and solubility of collagen in various beef muscles. They found that the collagen content of muscle was higher in bulls than in steers, regardless of age, and collagen solubility decreased markedly between 12 and 16 mo in bulls. Dransfield *et al.* (1984) and Unruh *et al.* (1987) agreed that bull longissimus steaks contained more connective tissue and less soluble collagen than those of steers. On the other hand Seideman *et al.* (1984) found that a lower Zn content may be responsible for the greater tenderness of steer beef than that of bulls. Ockerman *et al.* (1984) and Seideman (1986) reported that bulls had less marbling and a higher percentage of red muscle fibres than steers, but that the response of muscles to aging did not differ (Calkins & Seideman, 1988; Seideman *et al.*, 1989). However, Paterson *et al.* (1988) showed that sensory panelists judged steers to be superior in tenderness and connective tissue residue, and that steers also possessed slightly longer M.longissimus sarcomeres after aging. They also pointed out that bulls tended to have higher 2 and 4 h pH values. This finding is consistent with that of Chrystall (1987) who found that over 50 % of ultimate pH values for bull beef were above 6.0, and over 20 % were above 7.0, whereas for steers less than 4 % were above pH 6.0. Although Martin & Fredeen (1974) agreed with this result, they indicated that bulls contributed virtually all of the carcasses with ultimate

pH values greater than 6.0 and these tended to be associated with lower shear values. Recently, Purchas (1989a) reported that mean Warner-Bratzler shear force values did not differ between bull and steer meat because the bull values were mainly above the peak of the pH/shear curve, while the steer values were mainly below it.

2.4.2.2.2 Juiciness

Inconsistent results have been reported regarding the juiciness of beef from bulls and steers. At the same age, Reagan *et al.* (1971), Dransfield *et al.* (1984) and Ockerman *et al.* (1984) postulated that steak from both bulls and steers were comparable in juiciness, whereas Forrest (1975), Unruh *et al.* (1987) and Paterson *et al.* (1988) reported that steak from bulls were rated less juicy than those of steers. Recently, Johnson *et al.* (1988) found no differences in juiciness and percentage cooking loss for steaks from bulls and steers at the same age. Although Vanderwert *et al.* (1986) obtained similar results in various muscles as those of the previous authors, they also found biceps femoris steaks from bulls were less juicy and had higher cooking losses than those of steers. However, Cross *et al.* (1984) compared *M longissimus* from bulls and steers at three different ages. They reported that bull beef samples were more juicy and had similar cooking losses to steer beef at 12 mo of age. At 18 mo of age bull beef was less juicy and had higher cooking losses than steer beef. The reverse trend at 18 mo of age is in agreement with Crouse *et al.* (1983) who reported higher cooking losses in bull meat because of lower marbling and thus more water in the muscle. However, Martin & Fredeen (1974) demonstrated that the highest values for water-holding capacity were obtained at a pH greater than 6.0, and all such carcasses were from bulls.

2.4.2.2.3 Flavour

Martin & Fredeen (1974) and Chrystall (1987) reported that most bull beef had ultimate pH values greater than 6.0. This beef will tend to show low flavour intensity due to negative relationship between pH and flavour (see 2.3.2.5). Although bulls generally have lower marbling than steers (Jacobs *et al.*, 1977b; Ockerman *et al.*, 1984; Seideman, 1986; Paterson *et al.*, 1988), the extent to which fat affects meat flavour is unclear (Moody, 1983). Jacobs *et al.* (1977b)

found no differences in beef flavour between bulls and steers, whereas Paterson *et al.* (1988) and Ockerman *et al.* (1984) found flavour scores were better for steer beef. Purchas & Davies (1974a) reported that flavour was improved with intramuscular fat, but they also noted that the closeness of relationship varied considerably. In addition, Cross *et al.* (1984) did not find any differences in flavour intensity between bulls and steers at three different ages. In contrast, Forrest (1975) reported that at an age of less than 15 mo, rib roasts from bulls were less flavourful than roasts from steers. Other examples have been reported that at similar ages bull beef is either comparable (Hunsley *et al.*, 1971; Dransfield *et al.*, 1984; Unruh *et al.*, 1987; Johnson *et al.*, 1988) or lower in flavour intensity (Reagan *et al.*, 1971; Crouse *et al.*, 1983; Paterson *et al.*, 1988). However, a sex effect on meat flavour appears to be a more serious concern in pork and lamb than in beef (Seideman *et al.*, 1982).

2.4.2.2.4 Colour

Bull meat tends to show darker colour than that of steers due to a higher ultimate meat pH (see 2.3.2.3). Seideman *et al.* (1982) stated that a higher incidence of dark cutter in bulls was due to their temperament and aggressive behaviour, leading to a higher ultimate pH of meat. Chrystall (1987) reported that both average and darkest colour readings were brighter for steers (pH 5.5 ± 0.4) than for bull (pH 6.3 ± 0.6), but the values were significantly different when measured on chilled sides only. Entire male carcasses are frequently rejected from boxed beef fabrication due to dark colour (Unruh *et al.*, 1986b). Jeremiah *et al.* (1988) found that when exposed to normal pre-slaughter stress, steer carcasses comprised about 90 % in the bright colour score group, 10 % in the medium/dark category and none in the dark score group, whereas bull carcasses comprised about 75 %, 15 % and 5 % in the bright, medium/dark and dark score group respectively. According to USDA quality grades, it has been shown that bull carcasses have significantly darker lean colour than that of steer carcasses (Jacobs *et al.*, 1977a; Cross *et al.*, 1984; Johnson *et al.*, 1988). Moreover, higher proportions of red muscle fibres which may contribute to darker meat colour (Purchas, 1989b) have been reported for bull meat (Clancy *et al.*, 1986).

CHAPTER 3

MATERIALS AND METHODS

3.1 ANIMALS

The Charolais x Angus cross steers used in this study were born in the spring of 1987. They were reared on their dams, castrated at approximately 3 mo, and weaned at 7 mo of age. These 19 steers came from the C Alma Baker Trust farm " Limestone Downs" located near Raglan in the North island. They were transferred to Bests Block at Massey university in March 1988 and were run on pasture together with a group of 20 similar aged artificially reared Friesian steers until slaughter at 16 to 20 mo of age. The management programme involved monthly weighings, drenching every six weeks and rotational grazing. Forty Friesian bulls (30 from Tuapaka farm and 10 from Keeble farm) were grown and finished on pasture using similar grazing management procedures to those used for the steers. They were selected for slaughter at a similar age to the steers so that each slaughter lot comprised 10 bulls and 9 or 10 steers.

Bulls and steers were weighed on the farm the day prior to slaughter. The weighing was performed within half an hour after they were taken off feed in the morning, and then they were transported (approximately 20 kilometers) to the Feilding meat processing plant of Waitaki International Limited. The bulls and steers were kept separately in the lairage overnight and slaughtered the following morning 24 - 30 h after removal from pasture. On each slaughter day, 10 bulls and 9 or 10 steers were slaughtered and dressed under normal commercial conditions. The M. longissimus from the 10th to 13th rib region (c. 900-1000 g) was removed from the right side of each carcass within 90 minutes post mortem. Each muscle sample was placed in a plastic bag and held at ambient temperature (15-20 °C) for 24 h and then transferred to a chiller (0-3 °C) and stored for 6 days. After chilling, the samples were kept frozen for 2-8 weeks (-15 to -20 °C), at which time each was processed and further measurements were made as outlined below.

3.2 CARCASS ASSESSMENT

The carcasses were weighed and evaluated for muscling and fat classes according to the New Zealand export beef carcass classification system (NZMPB, 1988). Carcass lengths, defined as a length from the distal end of the tarsal bones to the midpoint of the cranial edge of the first rib (Purchas, 1989a) were measured. After chilling overnight at 1-3 °C, the cross-sectional area of the M. longissimus was traced and the fat depth over the M. longissimus was measured between the 12th and 13th rib. The traced area of M. longissimus (cm²) was determined by using a digitising tablet attached to a computer. Fat thickness (mm) was measured at a point three-fourths the length of M. longissimus the chine bone end (American Meat Science Association, 1977), using a metal ruler.

At the time of boning, the carcasses were identified with a plastic tag on the hook and the hindquarters were released to the boning room intermittently (approximately every fifth carcass). This provided adequate time for collecting and weighing the six major hindquarter cuts from both sides of each carcass. These cuts were Tenderloin, striploin, rump, knuckle, topside and outside defined according to New Zealand beef and veal standard cuts (New Zealand Meat Producers Board, 1979).

3.3 MEAT QUALITY ASSESSMENTS

3.3.1 Sample preparation

The frozen sample after being thawed in the chiller (5-7 °C) for 20-22 h was removed from the plastic bag, weighed, and placed dorsal side down on a cutting board. Cutting started at the cranial end which was placed toward the right hand side and a thin slice (2-10 mm) was cut off to square it up. The subsamples were prepared as follow:

(a) a 15 mm thick slice was prepared for colour and sarcomere length measurement. The middle portion (30x30 mm) was used for colour. Medial and central slithers were taken from the remainders and stored in labeled test tubes for sarcomere length measurement.

(b) a steak of 25 mm was cut off for assessing cooking loss and Warner-Bratzler shear force values.

(c) a sample of at least 80 g was obtained from the middle part of a 40 mm thick slice and stored in a plastic bag ("snap-top") at -15°C for intramuscular fat analysis.

(d) the remaining parts from both ends of the 40 mm thick slice were used to obtain medial and central samples for pH and water-holding capacity assessments.

3.3.2 Muscle pH

3.3.2.1 pH₃ measurement.

The measurements of pH were carried out using a combination electrode (Schott Gerate N48; Jenway 3020 pH meter). Before measuring, it was calibrated against buffers of pH 7.0 and pH 4.0 at room temperature. The pH was measured by inserting the combination electrode in the chunk of muscle at 3 hours post-mortem. The temperature at the centre of this muscle was also determined at 3 h post-mortem by means of a digital probe thermometer (Huber, $-60..+400^{\circ}\text{C}$).

3.3.2.2 Ultimate pH

A 2-2.2 g sample of muscle excised from the inside of either the medial or the central region of the selected muscle was placed into approximately 10 ml of cold 5 mM sodium iodoacetate reagent and chopped with scissors (Bendall, 1973). It was then homogenized to a fine slurry using a homogenizer (Janke & Kunkel, Ultra Turrax Type TP 18/10). The pH was measured, using a Jenway 3020 pH meter with an Automatic Temperature Compensation probe that provided a continuous read-out of sample temperature. The combination electrode was dipped into the homogenate, shaken gently and read when the pH value and temperature display stabilized. The electrode was rinsed thoroughly with distilled water between measurements.

3.3.3 Sarcomere length

Sarcomere length was determined by a laser diffraction method, similar to that described by Cross *et al.* (1980-1981). The apparatus consisted of a helium-neon

laser generator (wavelength 632.8 nm; Spectra-Physics model 102.2 mW laser head model 212 power supply) which was mounted on a steel stand with a specimen holding device and screen. A small bundle of fibres was removed from the medial and central region of the selected muscle and then small groups of fibres were teased out on a microscope slide with 2-3 drops of buffered sucrose solution (0.05 M Tris, pH 7.6, 0.25M sucrose) (Stromer & Goll, 1967) and covered with a coverslip. The slide was placed horizontally in the path of a vertically-orientated laser beam to give an array of diffraction bands on the screen which was 100 mm from the sample. These bands were perpendicular to the long axis of the fibres. Twelve measurements were taken of the distance between first order bands for each sample and the average values were used to calculate the sarcomere length using a conversion table based on the formula given by Bouton *et al.* (1973a).

3.3.4 Meat colour (Reflectance Spectrophotometry)

Meat colour was measured as the percentage reflectance at a wavelength of 630 nm using a Bausch and Lomb Spectronic 20 fitted with a reflectance attachment (Ockerman & Cahill, 1969; Strange *et al.*, 1974). Samples for assessment were from approximately 15 mm-thick slices cut perpendicular to the fibres and trimmed of connective tissue and external fatty tissue. The measurement was conducted after the samples had been exposed to the atmosphere at 1-3 °C for 90 to 120 minutes. The instrument was zeroed between each sample using the reflectance standard supplied by the manufacturer.

3.3.5 Warner-Bratzler shear force values

For assessment of shear force values, 25 mm thick slices were cut from the M.longissimus. These steaks were weighed in plastic bags and cooked by immersing the bags in a water bath thermostatically controlled at 70 ± 0.5 °C for 90 minutes (Purchas, 1972). After cooking, liquids were poured off and the cooked meat was stored at 1 - 3 °C overnight. Cooking losses were determined by weighing the cooked samples after drying with paper towels to remove excess surface moisture, and then six cores (13x13 mm cross-section) were cut parallel to the orientation of the muscle fibres for each steak. Each core was sheared perpendicularly twice, using a modified version of the conventional

Warner-Bratzler shear device with a square-edged shear blade (Bouton *et al.*, 1975c, 1977) attached to a NEC multispeed microcomputer. Shearing was started when the microswitch was turned on, and this switch was automatically turned off when shearing was finished. For a single shear 872 ± 1 force values were transferred from the load cell to a data logger which displayed the peak force value. Pairs of adjacent values were averaged and the resulting 436 values were sent from the data logger to the computer. The latter set of data was used to plot a shear force deformation curve on the screen. The parameters measured from the shear force deformation curves were:

- (1) peak force (PF)- the maximum force recorded,
- (2) initial yield force (IY)- the force at which the sample first began to yield, i.e. the first major inflexion on the curve,
- (3) work done (WD)-the mean of the 436 shear force values,
- (4) the peak minus initial yield force (PF-IY) values were obtained by calculation.

A preliminary study was conducted in which the original vee-edged shear blade received with the Warner-Bratzler shear machine was compared with the square-edged blade. For 96 13 x 13 mm cores one shear was made with the vee blade and one was made with the square blade.

3.3.6 Water holding capacity (WHC)

Water holding capacity of muscle was measured in terms of expressible water using a filter paper press method for medial and central meat samples weighing between 500-600 mg. The sample was placed on a filter paper (Whatman No.1 11.0 cm diameter Qualitative, previously stored in a dessicator over saturated KCl) between plexiglass plates and then a 10 kg weight was applied to the top plate for 5 minutes (Matyniak & Ziolecki, 1983). The total wetted area of the filter paper was measured using a digitising tablet attached to a computer and the water holding capacity was calculated as expressed water in terms of the total area (cm^2) of wetted filter paper per unit weight of the sample (cm^2/g).

3.3.7 Intramuscular fat

Approximately 80 g of *M. longissimus* trimmed of subcutaneous fat, epimysium, and intermuscular fat, was finely chopped and mixed before three subsamples of 15-20 g were taken. These subsamples were freeze dried for 4 days and then fat extraction was carried out on two samples in a Soxhlet apparatus with petroleum ether (B.P. 40 to 60 °C) for 8 h (AOAC 1980). The third sample was extracted only when the difference between the first two replicates was greater than 0.5 percentage points.

3.4. STATISTICAL METHODS

Data was analysed using a general linear models programme (SAS, 1985). The parameters used in the various linear models were estimated by ordinary least squares procedures and tests of hypotheses about the parameters were carried out by analyses of variance for unadjusted means. Adjusted least-squares means for the variables measured were then computed after fitting the appropriate covariates in the analyses of covariance. Testing for heterogeneity of slope between the regression lines among the treatment groups was achieved by examining interactions between treatment groups and the covariates. Differences between individual means were tested by contrast statements (T-tests) within the SAS programme (SAS, 1985). Multiple regression was used to analyse relationships between carcass and meat quality characteristics.

Thus, the basic model used to describe carcass and meat quality data was :

$$Y_{ij} = u + T_i + b(x_{ij} - \bar{x}) + e_{ij}$$

where Y_{ij} = the j th observation in the i th treatment group,
 u = the overall mean,
 T_i = the effect of the i th treatment (either Friesian bulls, Charolais cross steers, or Friesian steers),
 b = the regression coefficient of y_{ij} on the covariate x_{ij} ,
 x_{ij} = the i th covariate in the i th treatment,
 \bar{x} = the overall mean of the covariate x_{ij} ,
 e_{ij} = a random error, assumed to be normally and independently distributed with zero mean and constant variance.

CHAPTER 4

RESULTS

4.1 GROWTH RATE

Average daily gains for the Friesian and Charolais steers were calculated over a period of 263 days from an age of approximately 8 months. The average daily gains were also calculated for each of the 9 periods between weighings through the finishing period (Table 4.1, Figures 4.1, 4.2).

Mean initial and final weights of the Friesian and Charolais cross steers were not significantly different, although the Friesian steers exhibited slightly higher values. This was reflected in the similar overall average daily gains calculated either from the first and last weights or from the regression of liveweight on time (Table 4.1). However, the growth patterns between these breeds differed in that the Friesians grew slightly faster up to 300 days while the Charolais crosses exhibited higher average daily gains from then on.

Table 4.1 Initial and final liveweights and growth rates over nine periods for Charolais x Angus cross steers and Friesian steers.

Item	Group		Pooled SD ^c	Significance of group effect ^a
	Charolais	Friesian		
Number	19	20		
Initial weight (kg)	198.2	205.3	18.6	ns
Final weight (kg)	410.5	412.8	22.6	ns
Average daily gain (kg/d)				
Period 1 (22d)	0.151	0.416	0.500	ns
Period 2 (54d)	0.655	0.788	0.149	**
Period 3 (29d)	0.269	0.300	0.554	ns
Period 4 (28d)	1.100	1.046	0.299	ns
Period 5 (29d)	0.376	0.264	0.286	ns
Period 6 (22d)	1.263	1.371	0.492	ns
Period 7 (34d)	1.134	1.006	0.219	ns
Period 8 (22d)	1.609	1.398	0.253	*
Period 9 (23d)	0.966	0.657	0.376	*
Overall (263d)	0.807	0.789	0.055	ns
Growth rate predicted by regression ^b	0.812	0.796	0.057	ns

a ns = $P > 0.05$, * = $P < 0.05$, ** = $P < 0.01$

b The regression of liveweight on time

c Standard deviation

Figure 4.1 Mean liveweights for Friesian and Charolais cross steers over the finishing period. Vertical bars show standard errors.

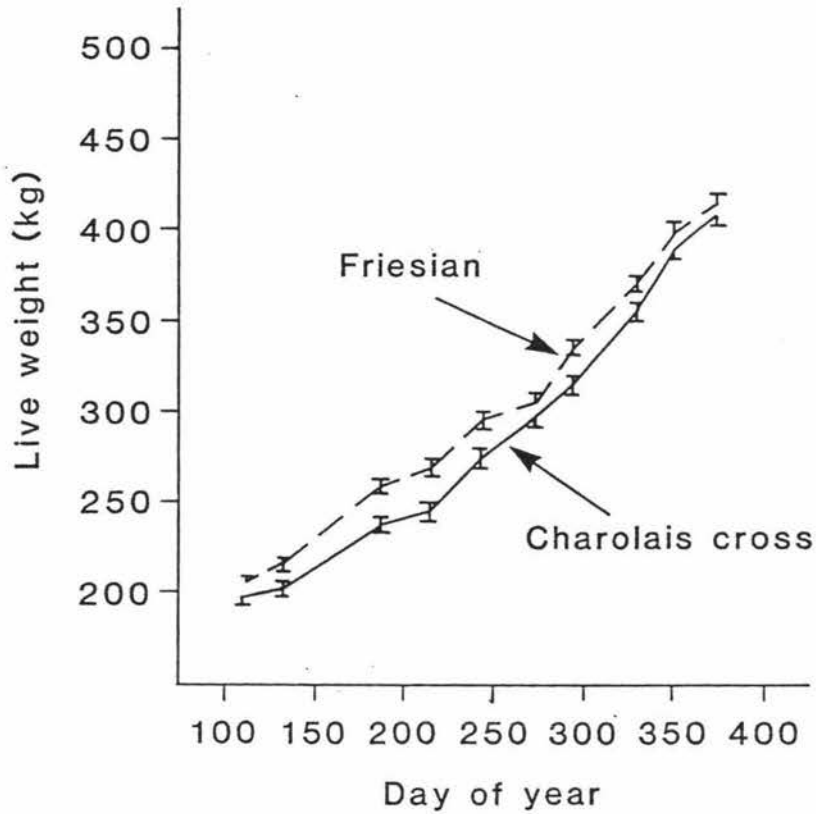
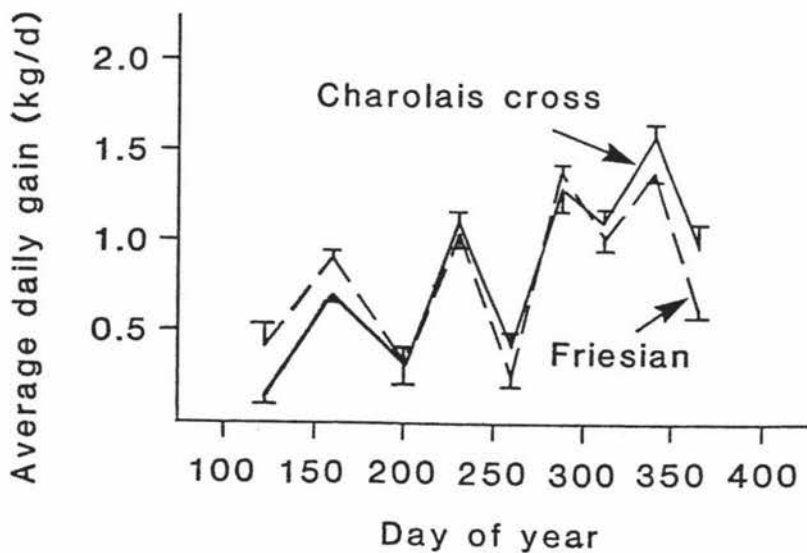


Figure 4.2 Mean average daily gains for Friesian and Charolais cross steers, plotted at the midpoint between each weighing time. Vertical bars show standard errors.



4.2 CARCASS CHARACTERISTICS

Means values for several carcass characteristics are summarized in Table 4.2. The significance of slaughter lot effects was tested in the statistical model but was excluded when found to be non-significant. The only exception was dressing-out percent which differed significantly between lots and there was a significant lot by group interaction (Appendix 1).

There were no significant differences in initial and final liveweights or carcass weights between bulls and steers or between Friesian and Charolais cross steers. Dressing-out percent was significantly greater for the Charolais cross steers than the Friesian bulls and steers, even after adjusting to the same carcass weight by covariance analysis. The Charolais cross steers possessed the highest fat depths and intramuscular fat levels and the Friesian steers had intermediate fat depths which were nearly twice those of the Friesian bulls. The level of intramuscular fat in *M. longissimus* was similar between the steer groups, but was about four times greater for steer samples than for bull samples. Group averages were not appreciably changed by the adjustment to a constant carcass weight.

Marked differences between groups in carcass length, rib-eye area and steak weights were evident. The Charolais cross steers had significantly shorter carcasses, larger rib-eye areas and heavier steaks than the Friesian steers. Carcass lengths did not differ between Friesian bulls and steers, but the bulls showed greater rib-eye areas and heavier steak weights. Rib-eye areas and steak weights did not differ between the Friesian bulls and Charolais cross steers but bull carcasses were longer. When compared at the same carcass weight, differences in carcass lengths and rib-eye areas were marked among all three groups, but steak weights were still similar between the bulls and Charolais cross steers both of which were higher than for Friesian steers.

Means of the six major hind-quarter cuts from both sides for the steers (Table 4.3) indicated that the Charolais crosses produced significantly greater weights of all cuts either with or without adjustment to the same carcass weight, except that carcass-weight-adjusted tenderloin weights were similar. However, significant relationships between carcass and joint weights did reduce the group differences to some extent after adjustment.

Table 4.2 Least squares means of carcass characteristics for Friesian (F) bulls, Friesian steers and Charolais (C) x Angus cross steers.

Item	Group			Group effect ⁴	Correlation with carcass wt.	Carcass wt effect	RSD ¹	R ² (%) ²
	F-bulls	F-steers	C-steers					
<u>Unadjusted values:</u>								
Number of animals	40	20	19					
Live weight (kg)	452.5	444.4	438.1	ns			22.3	7.02
Carcass weight (kg)	228.4	224.6	232.6	ns			13.2	4.56
Dressing-out (%)	50.47 ^a	50.54 ^a	53.12 ^b	***			1.79	28.82
Carcass length (mm)	2031 ^a	2013 ^a	1952 ^b	**			73	16.43
Rib eye area (cm ²)	71.15 ^a	60.61 ^b	66.42 ^b	***			9.01	19.57
Steak weight (g)	206.50 ^a	186.60 ^b	209.50 ^a	***			19.9	18.08
Fat depth (mm.)	0.93 ^a	1.82 ^b	3.36 ^c	***			0.96	51.74
Intramuscular fat (%)	0.59 ^a	2.42 ^b	2.04 ^b	***			0.64	63.11
<u>Values adjusted to a constant carcass weight:³</u>								
Dressing-out (%)	50.47 ^a	50.97 ^a	52.61 ^b	***	0.51	***	1.37	63.97
Carcass length (mm)	2031 ^a	2018 ^b	1947 ^c	***	0.25	**	65	37.76
Rib eye area (cm ²)	71.16 ^a	61.11 ^b	66.09 ^c	***	0.34	***	7.05	53.28
Steak weight (g)	206.6 ^a	189.3 ^b	206.0 ^a	**	0.43	***	17.7	38.78
Fat depth (mm)	0.93 ^a	1.83 ^b	3.34 ^c	***	0.13	ns	0.97	53.11
Intramuscular fat (%)	0.59 ^a	2.41 ^b	2.04 ^b	***	-0.01	ns	0.63	66.97

¹ Residual standard deviation

² Coefficient of determination for the model which included breed and sex effects, and carcass weight as a covariate where shown.

³ Adjusted to a constant carcass weight by covariance analysis

⁴ *** P<0.001, ** P<0.01, ns P>0.05

a,b,c Means within the same row bearing different superscripts are different (P<.05)

Table 4.3 Least squares means for the six major hind-quarter cuts of Friesian steers and Charolais x Angus cross steers.

Item	Group		Group ^d effect	R ^{2a}	RSD ^b (%)	Carcass wt ^d effect.
	F-steers	C-steers				
<u>Unadjusted values</u>						
Number of animals	20	19				
1 Tenderloin (kg)	1.72	1.84	**	48.45	0.12	
2 Striploin (kg)	2.55	2.94	***	64.98	0.23	
3 Rump (kg)	3.78	4.36	***	61.40	0.30	
4 Topside (kg)	6.15	6.74	***	54.95	0.39	
5 Knuckle (kg)	4.05	4.43	***	52.89	0.25	
6 Silverside (kg)	5.48	6.43	***	69.00	0.38	
7 Sum of 4, 5, 6 (kg)	31.37	35.22	***	62.52	1.89	
8 Sum of all 6 cuts (kg)	47.51	53.60	***	67.34	2.78	
<u>Values adjusted for carcass weight^c</u>						
1 Tenderloin (kg)	1.75	1.81	ns	63.89	0.09	***
2 Striploin (kg)	2.60	2.93	***	68.97	0.21	***
3 Rump (kg)	3.87	4.26	***	80.42	0.20	***
4 Topside (kg)	6.25	6.63	***	68.63	0.31	***
5 Knuckle (kg)	4.12	4.35	***	73.31	0.18	***
6 Silverside (kg)	5.60	6.29	***	83.65	0.26	***
7 Sum of 4, 5, 6 (kg)	32.03	34.53	***	84.69	1.22	***
8 Sum of all 6 cuts (kg)	48.53	52.53	***	89.20	1.62	***

a Coefficient of determination

b Residual standard deviation

c Adjusted to constant carcass weight by covariance analysis.

d ns P>0.05, ** P<0.01, *** P<0.001.

After adjustment to a constant carcass weight and correcting for group effects there were significant relationships between cut weights and carcass length (negative) and rib-eye area (positive), but no relationship with fat depth (Table 4.4). However, the significance of the last three variables did not change with the sequence in which they were fitted in the model except for carcass length which was significant only when fitted in the model before rib-eye area. The relationships between cut weights with rib-eye area and carcass length were more significant ($p<0.001$) when analysed without prior correction for group effects. The correlations between cut weights and carcass weight, rib-eye area, carcass length, and fat depth are presented in Appendix 2. The correlations between individual cut weights or percentages, and between cut weights from each side are shown in Appendix 3 and 4 respectively.

Table 4.4 The significance of regression relationships between carcass weight (ccwt), rib-eye area (REA), carcass length (cc length), and fat depth (fat.d) and the sum of the last 3 cuts or the sum of all 6 cuts. Independent variables were fitted in the sequence shown.

Dependent variable	Independent Variables		RSD ^a	R ^{2b} (%)
	Item	significance ^c		
3-cuts weight (kg)	Group	***	1.14	85.4
	ccwt	***		
	cc length	*		
	REA	***		
	fat.d	ns		
All 6-cuts weight (kg)	Group	***	1.33	91.9
	ccwt	***		
	cc length	**		
	REA	***		
	fat.d	ns		

^a Residual standard deviation

^b Coefficient of determination

^c ns P>0.05, * P<0.05, **P<0.01, ***P<0.001.

4.3 MUSCLE CHARACTERISTICS

The group means for muscle characteristics associated with meat quality, which are presented in Table 4.5, showed that bulls produced meat with a lower temperature and higher pH at 3 h post-mortem, and lower reflectance values. Sarcomere length, cooking loss and expressed juice did not differ significantly between bulls and steers. All characteristics except the temperature at 3 hr post-mortem were similar for Friesian and Charolais cross steers. The influence of pH on muscle characteristics (Table 4.6) indicated highly significant relationships with reflectance values, sarcomere length, cooking loss and expressed juice. After adjustment for pH by analyses of covariance, the differences in reflectance values for samples from bulls and steers disappeared. Mean sarcomere lengths were still similar among groups, but the pH-adjusted values were closer and the coefficient of determination was increased from 3.70 to 33.85 % when pH was used as an independent variable. At the same ultimate pH, cooking loss differed significantly among all groups. Bull meat exhibited the highest cooking loss, followed by meat from Charolais cross steers with meat from Friesian steers having the lowest cooking loss. Expressed juice was higher for bull samples but differences in expressed juice between groups were statistically significant at only the 11 % level.

Table 4.5 Unadjusted means of several muscle characteristics of medial (M) and central (C) parts of *M. longissimus* from Friesian bulls, Friesian steers and Charolais x Angus cross steers.

Item	Group			Group ^f effect	R ^{2d} (%)	RSD ^e
	F-bulls	F-steers	C-steers			
Number	40	20	19			
pH _{3g}	6.86 ^a	6.69 ^b	6.70 ^b	*	12.73	0.21
Temperature _{3g} (°C)	28.56 ^a	29.94 ^b	31.05 ^c	***	41.95	1.24
R630 (%)	12.53 ^a	17.27 ^b	17.07 ^b	***	21.23	4.55
Ultimate pH _M	6.43 ^a	6.00 ^b	6.07 ^b	***	17.23	0.45
Ultimate pH _C	6.30 ^a	5.92 ^b	5.97 ^b	**	14.24	0.45
Average pH	6.37 ^a	5.96 ^b	6.02 ^b	**	16.05	0.44
Sarcomere length M (µm)	1.47	1.56	1.55	ns	6.20	0.16
Sarcomere length C (µm)	1.58	1.61	1.59	ns	1.07	0.14
Average sarcomere length (µm)	1.52	1.59	1.57	ns	3.70	0.14
Cooking loss (%)	25.90	26.30	27.18	ns	1.20	4.77
Expressed juice M	39.00	41.22	39.44	ns	4.18	4.44
Expressed juice C	41.69	42.58	42.67	ns	0.18	4.80
Average expressed juice	40.34	41.90	41.17	ns	2.38	4.24

a,b,c Means within the same rows with different superscripts are different (P<0.05)

d Coefficient of determination

e Residual standard deviation

f ns P>0.05, * P < 0.05, ** P< 0.01, *** P<0.001.

g pH and temperature at 3 hr post-mortem.

Table 4.6 Least-squares means of several muscle characteristics of medial (M) and central (C) parts of *M. longissimus* from Friesian bulls, Friesian steers and Charolais x Angus cross steers, after adjustment for ultimate pH.

Item	Group			Group effect ^f	pH effect		R ² ^d (%)	RSD ^e	Correlation with pH.
	F-bulls	F-steers	C-steers		pH	(pH) ²			
Number	40	20	19						
R630 (%)	14.38	15.24	15.31	ns	***	***	82.55	2.21	-0.84
Sarcomere length M (μm)	1.51	1.53	1.51	ns	***	**	33.32	0.14	-0.41
Sarcomere length C (μm)	1.60	1.59	1.57	ns	***	*	24.61	0.13	-0.41
Ave. sarcomere length (μm)	1.55	1.55	1.54	ns	***	**	33.85	0.12	-0.45
Cooking loss (%)	27.59 ^a	24.22 ^b	25.84 ^c	***	***	***	88.03	1.71	-0.86
Expressed juicie M (cm ² /g)	40.35	39.63	38.53	ns	***	**	74.91	2.46	-0.77
Expressed juicie C (cm ² /g)	42.87	41.14	41.67	ns	***	**	56.79	3.28	-0.64
Ave. expressed juice (cm ² /g)	41.58	40.36	40.17	ns	***	***	68.78	2.48	-0.77

a,b,c means in the same row with different superscripts are different (P<0.05)

d coefficient of determination

e Residual standard deviation

f ns P>0.05, * P<0.05, ** P<0.01, *** P<0.001

The influences of $(\text{pH})^2$ on all characteristics shown in the Table 4.6 were statistically significant indicating curvilinear relationships. The nature of these relationships are shown in Figures 4.3, 4.4, 4.5, and 4.6. Percent reflectance (Figure 4.3) decreased with increasing pH. Sarcomere length also decreased with an increase in pH up to 6.4 and then increased slightly with further increase in pH (Figure 4.4). Cooking loss and expressed juice changed slightly with an increase in pH from 5.4 to 6.0, but both decreased steadily with further increases in pH (Figures 4.5 and 4.6). The changes in sarcomere length in relation to change in ultimate pH from 5.4 to 6.2 (Table 4.7) showed that sarcomere length decreased linearly with an increase in ultimate pH in this range.

Table 4.7 Regression relationships between sarcomere length and ultimate pH for samples of *M. longissimus* with an ultimate pH of less than 6.2 ($n = 37$).

Dependent variable (y)	Independent variable (x)	Significance ^a	RSD ^b	R ² ^c (%)
Sarcomere length M (μm)	(1) pH	**	0.13	27.17
	(2) $(\text{pH})^2$	ns		
Sarcomere length C (μm)	(1) pH	***	0.10	26.87
	(2) $(\text{pH})^2$	ns		
Ave. Sarcomere length (μm)	(1) pH	***	0.10	38.48
	(2) $(\text{pH})^2$	ns		

a ns $P > 0.05$, ** $P > 0.01$, *** $P < 0.001$

b Residual standard deviation

c Coefficient of determination

C Central part

M Medial part

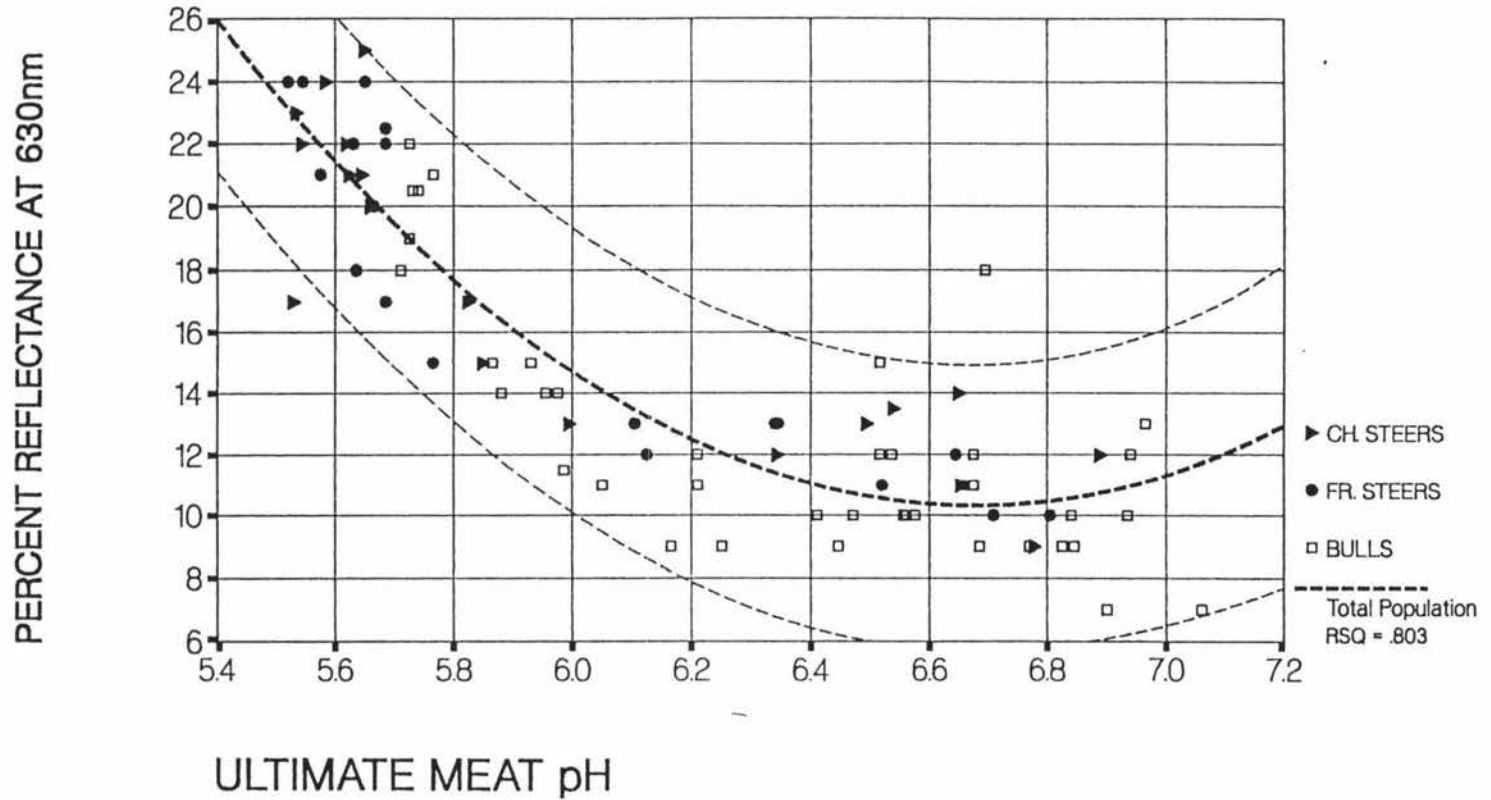


Figure 4.3 The relationship between ultimate meat pH and colour of *M. longissimus* as assessed by percent reflectance at 630 nm. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits.

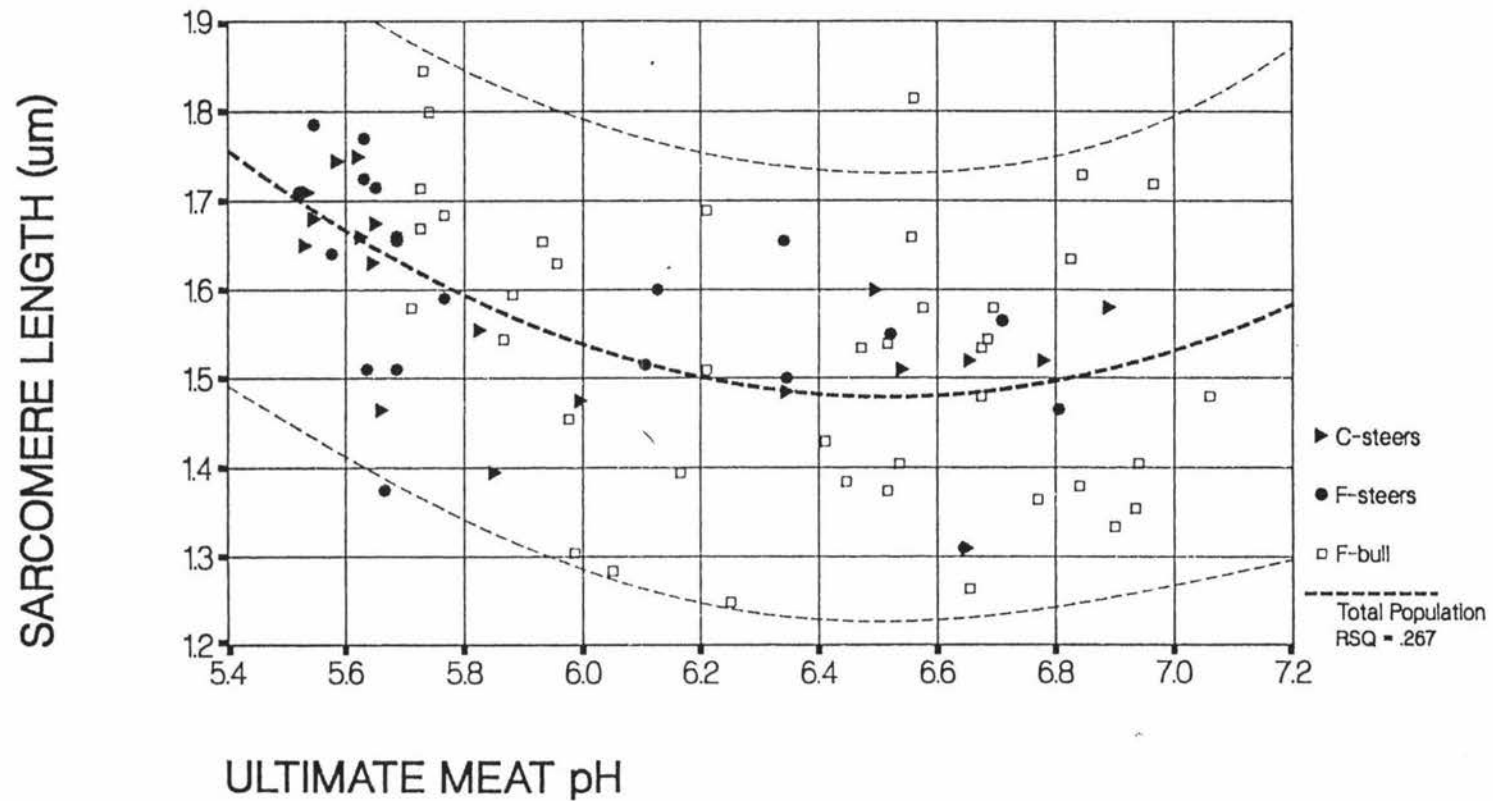


Figure 4.4 The relationship between ultimate meat pH and sarcomere length of *M. longissimus*. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits.

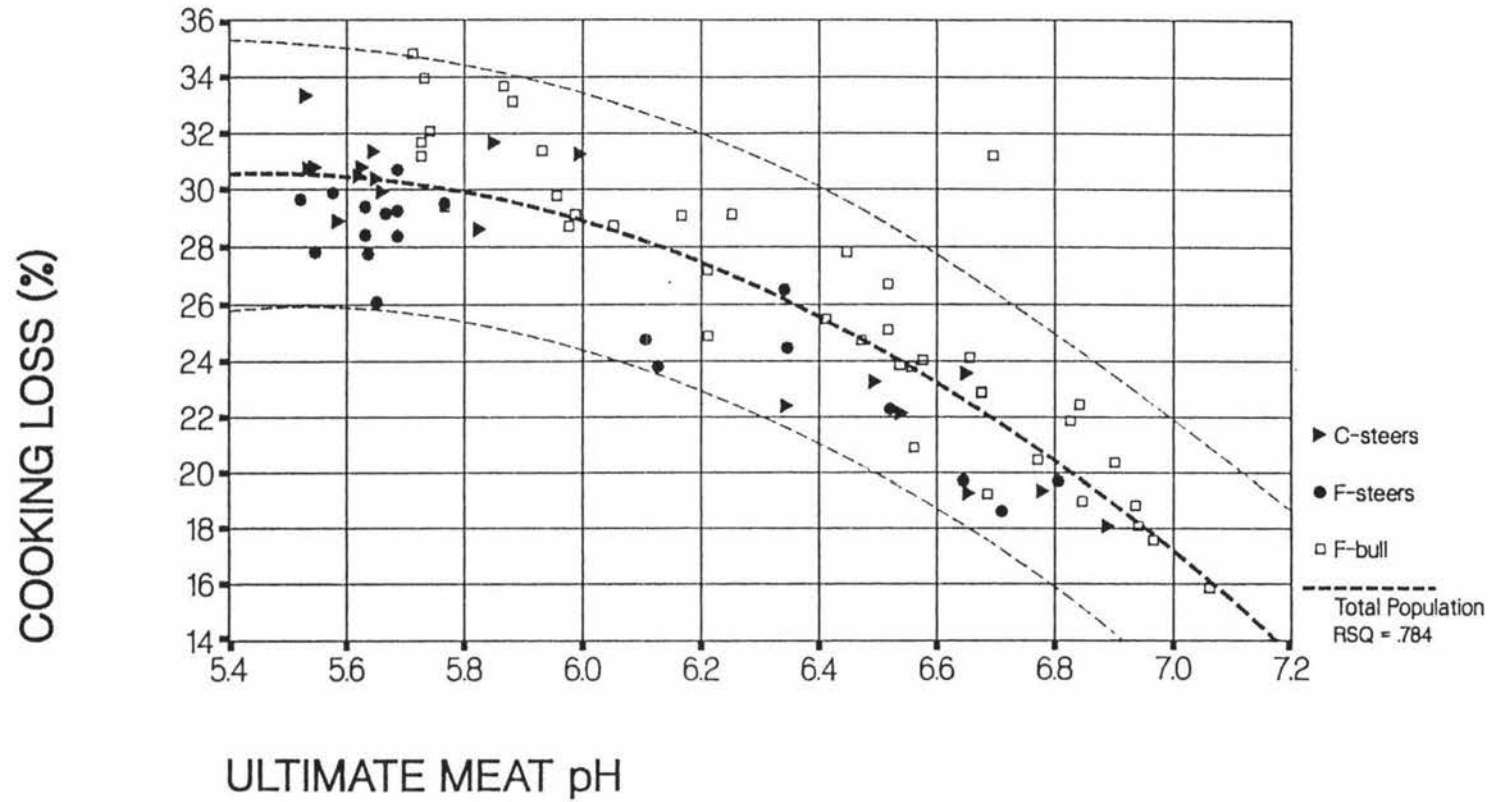


Figure 4.5 The relationship between ultimate meat pH and cooking loss of *M. longissimus*. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits.

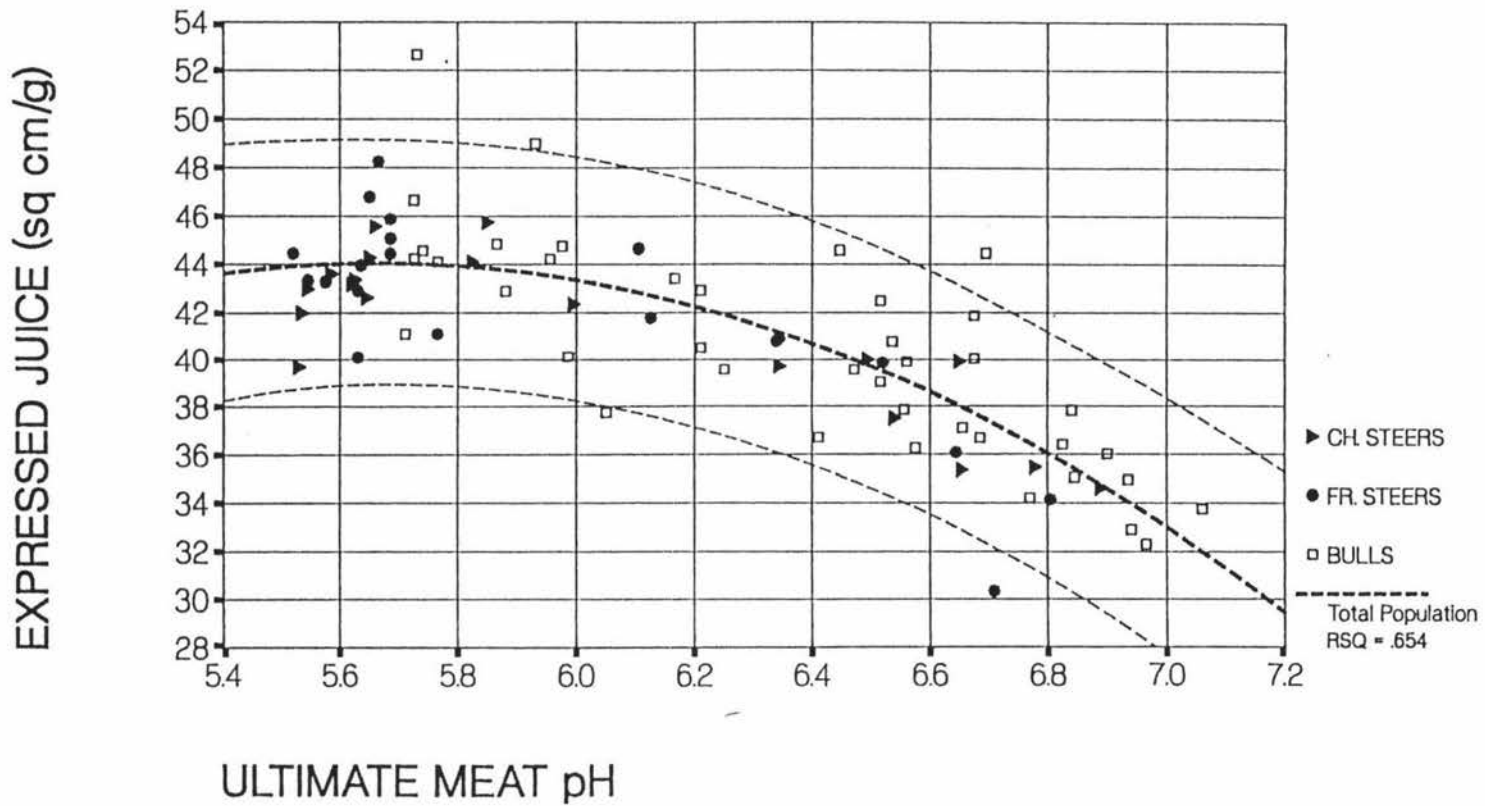


Figure 4.6 The relationship between ultimate meat pH and expressed juice of *M. longissimus*. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits.

4.4 MEAT TENDERNESS

Results of a comparison between two shear blades (i.e. square-blade and vee-blade) within a Warner-Bratzler shear device, are presented in Table 4.8. The work done by the two blades was similar, but the peak shear force values were significantly higher for the square-blade than the vee-blade. Regression equations in Figures 4.7 and 4.8 indicate that increases in work done for the vee-blade were approximately 84 percent of those of the square-blade, whereas increases in the peak shear force values for the vee-blade were only 52 percent of those for the square-blade. Typical shear force deformation curves obtained from these two blades are shown in Figure 4.9. The square-blade always produced curves with clearer initial yield points. Thus, only the square-blade was used to determine meat tenderness for samples in this study.

Table 4.8 Means for the work done and the peak shear force values of the conventional Warner-Bratzler shear blade (Vee-shape) and the modified Warner-Bratzler shear blade (Square-blade).

Item	Blade shape		Pooled Std. Dev.	Blade shape effect ¹	Correlation between vee and square blade
	Vee-blade	Square-blade			
Number of shears	96	96			
Work done ²	2.67	2.83	1.33	ns	0.95
Peak shear force values (kg)	6.36	10.82	5.32	***	0.96

¹ ns P>0.05, *** P<0.001

² Work done = mean of 436 shear values.

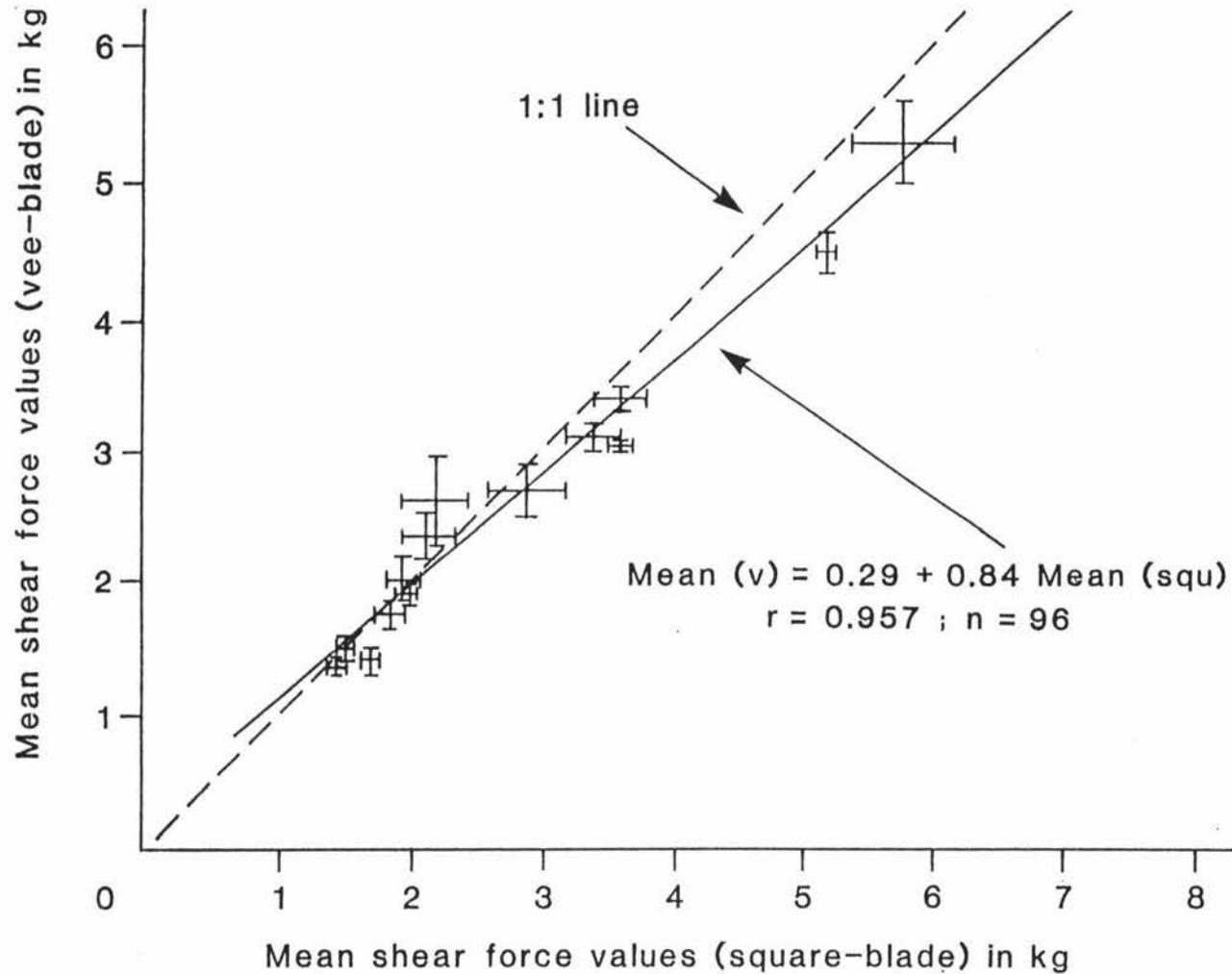


Figure 4.7 The relationship between the mean of 436 values per shear obtained using either square or vee-blades in the Warner-Bratzler shear machine for *M. longissimus* samples from 14 animals. Standard error bars are shown for each variable within each animal, together with the overall regression equation based on the 96 individual shears. These mean shear force values are referred to as the work done (WD) in the text.

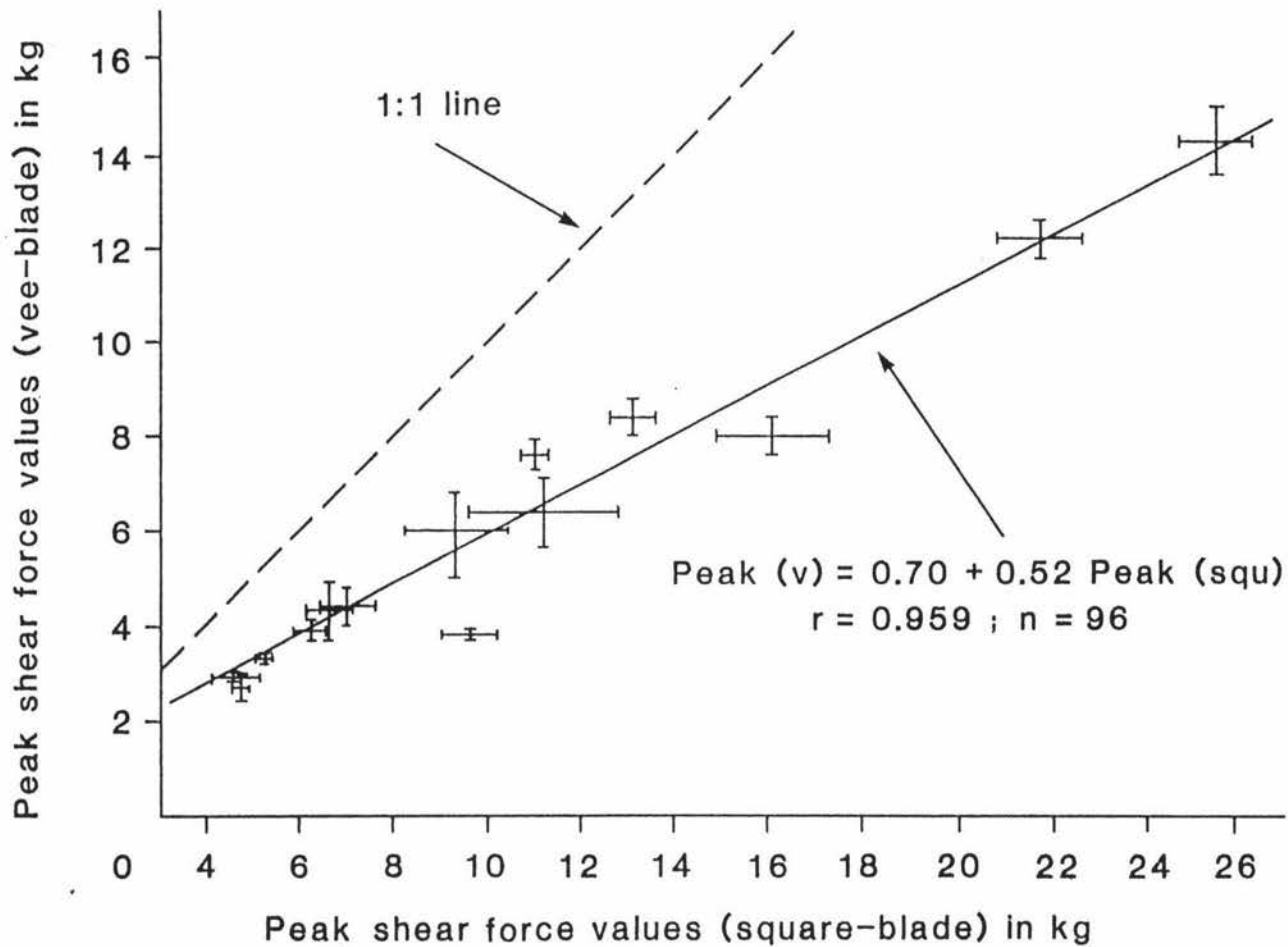


Figure 4.8

The relationship between peak shear force values obtained using either square or vee-blades in the Warner-Bratzler shear machine for *M. longissimus* samples from 14 animals. Standard error bars are shown for each variable within each animal, together with the overall regression equation based on the 96 individual shears.

Figure 4.9 Four shears on 13 x 13 mm cores from *M. longissimus* of a 16 mo steer after cooking at 70°C in a water bath for 90 min. Initial yield values are shown by the vertical arrows.

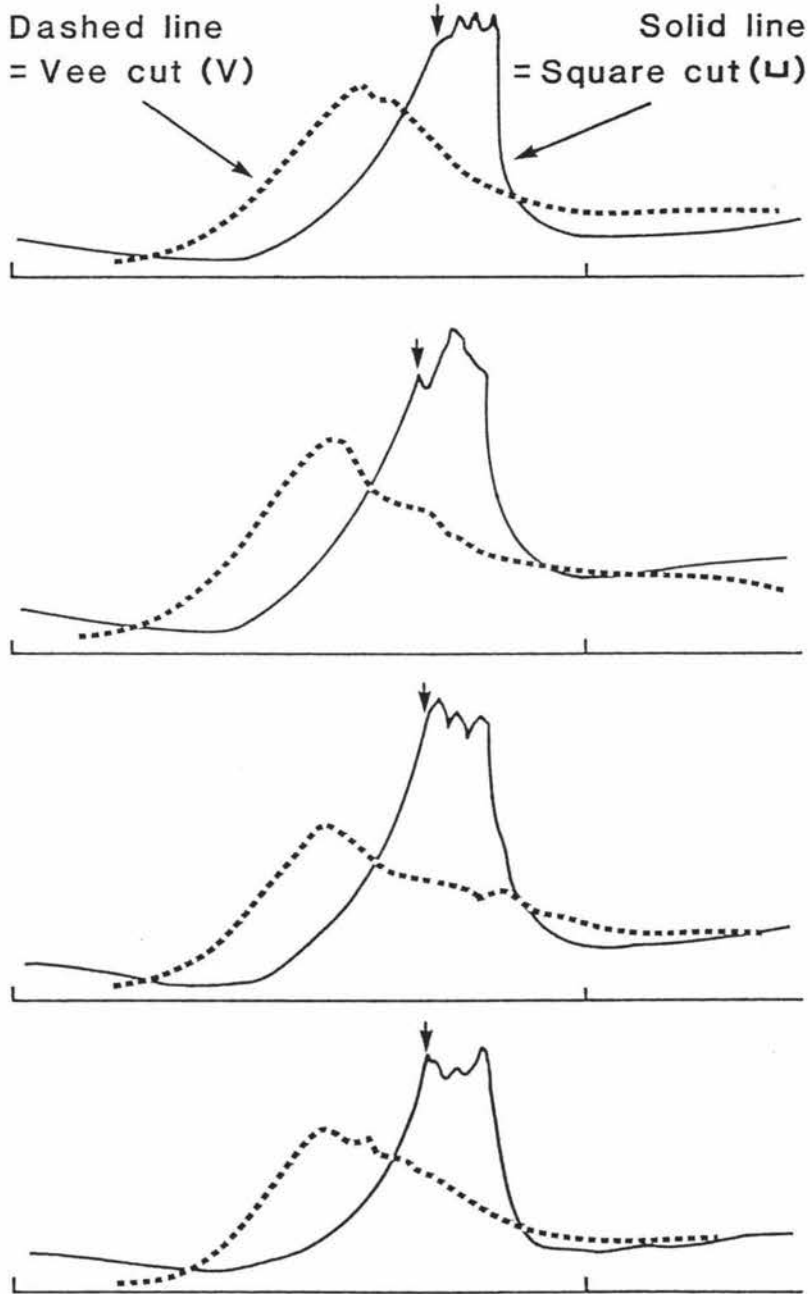


Table 4.9 Least squares means for initial yield force (IY), peak shear force (PF), work done (WD) and peak-initial yield force (PF-IY) measured from shear force deformation curves for M. longissimus from Friesian bulls, Friesian steers and Charolais x Angus cross steers.

Item	Group			Group ^c effect	R ² ^d (%)	RSD ^e	Correlation with		
	F-bulls	F-steers	C-steers				IY	PF	(PF-IY)
Number	40	20	19						
Medial IY (kg)	10.05	8.57	9.89	ns	4.55	5.00			
Central IY (kg)	9.90	8.47	9.54	ns	2.22	5.14			
Lateral IY (kg)	9.46	8.26	9.76	ns	3.05	4.98			
Overall IY (kg)	9.80	8.43	9.73	ns	2.67	4.82		0.994	
Medial PF (kg)	11.95	9.98	11.33	ns	4.87	5.62			
Central PF (kg)	11.91	10.09	11.00	ns	3.12	5.55			
Lateral PF (kg)	11.81	9.89	11.55	ns	3.92	5.42			
Overall PF (kg)	11.89	9.99	11.29	ns	3.50	5.30	0.994		
Medial (PF-IY) kg	1.89	1.47	1.45	ns (14.00)	5.04	1.03			
Central (PF-IY) kg	2.01	1.61	1.47	ns (8.98)	6.14	0.94			
Lateral (PF-IY) kg	2.31 ^a	1.62 ^a	1.79 ^b	**	1.35	0.84			
Overall (PF-IY) kg	2.08 ^a	1.55 ^b	1.57 ^b	**	1.26	0.70	0.624	0.707	
Medial WD	3.12	2.81	3.17	ns	6.78	1.22			
Central WD	3.19	2.93	3.15	ns	4.40	1.22			
Lateral WD	3.24	2.96	3.27	ns	3.63	1.22			
Overall WD	3.18	2.90	3.20	ns	4.45	1.17	0.974	0.977	0.675

a, b Means within the same rows with different superscripts are different (P<0.05)

c ns P>0.05, ** P<0.01

d Coefficient of determination

e Residual standard deviation

The group means for all parameters measured are given in Table 4.9. There were no significant differences in initial yield force (IY), peak shear force (PF) and work done (WD) among all groups, compared at either medial, central or lateral parts of the steaks, or in the overall means. In contrast (PF-IY) values for the lateral part and overall means were similar between Friesian and Charolais cross steers, but were significantly higher for Friesian bulls ($p < 0.01$). Although the (PF-IY) values for medial and central parts did not differ significantly among groups, these differences approached significance ($p = 14.0$ and 9.0 % respectively).

A comparison between means of shear parameters and some other quality characteristics measured at different regions across *M. longissimus* are shown in Table 4.10. Peak shear force, initial yield force and work done values did not differ significantly between regions, although all of these means showed similar trends with decreasing values from medial to lateral parts. Conversely, peak-initial yield force values (PF-IY) increased from medial toward lateral parts. The (PF-IY) values for medial and central region were similar, but both were significantly lower than that of the lateral part ($p < 0.05$). Ultimate pH was significantly lower for the central sample, whereas sarcomere length and expressed juice were significantly greater for central than medial samples.

Table 4.10 Means of shear force deformation curve parameters and some meat quality characteristics measured at different parts of *M. longissimus*.

Item	Muscle region			Region ¹ effect	Overall means
	Medial	Central	Lateral		
Peak shear force (kg)	11.33	11.25	11.28	ns	11.28
Initial yield force (kg)	9.66	9.97	9.24	ns	9.46
Peak-initial yield force (kg)	1.67 ^a	1.78 ^a	2.03 ^b	*	1.82
Work done	3.06	3.12	3.19	ns	3.12
Ultimate pH	6.24	6.12	-	***	-
Sarcomere length (μm)	1.51	1.59	-	***	-
Expressed juice (cm^2/g)	39.72	42.15	-	***	-

¹ ns $P > 0.05$, *** $P < 0.001$

a,b means in the same row with different superscripts are different ($P < 0.05$).

4.5 RELATIONSHIPS BETWEEN SHEAR FORCE DEFORMATION CURVE PARAMETERS WITH ULTIMATE pH AND SARCOMERE LENGTH.

Relationships between IY, PF, WD and (PF-IY) with ultimate pH and sarcomere length are shown in Table 4.11. Again highly significant curvilinear relationships between all shear parameters and pH were obtained. Sarcomere length also showed significant relationships with all shear parameters except (PF-IY). The relationships with shear force parameters were significant when sarcomere length was fitted in the models either before or after pH, although the significance of sarcomere length only approached the 10 % level for WD when sarcomere length was fitted before pH.

After adjustment for pH and sarcomere length, means of all parameters were significantly higher for bulls than steers, while those of Friesian and Charolais cross steers did not differ (Table 4.11). For all four variables the variation accounted for by the combined effect of pH and sarcomere length was greater than by the effect of pH alone, although the coefficient of determination was only slightly increased in the case of (PF-IY) by including sarcomere length.

Figure 4.10 shows the nature of the relationship between peak shear force and ultimate pH with the highest values at a pH of about 6.1 and with an increase in tenderness on either side of this. The relationship between peak shear force and ultimate pH in the range from 5.4 to 6.2 (Table 4.12) indicated that more of the variation in peak force over this pH range was accounted for by sarcomere length ($R^2 = 67.57 \%$) than by pH ($R^2 = 60.78 \%$). However, about 80 percent of the variation was accounted for by the combined effect of pH and sarcomere length which was greater than that of either of the two alone, but less than the sum of the individual effects.

Table 4.11 Least squares means of initial yield force (IY), peak shear force (PF) work done (WD) and peak-initial yield force (PF-IY) for *M. longissimus* from Friesian bulls, Friesian steers, and Charolais x Angus cross steers. Values were adjusted for pH and sarcomere length (SCM). Independent variables were fitted in the sequence shown.

Item	Group			Group effect	R ² ^c %	RSD ^d	Correlation with		Covariates	
	F-bulls	F-steers	C-steers				pH	SCM	variables	significance ^e
Overall IY (kg)	10.48 ^a	7.54 ^b	9.26 ^{ab}	**	61.14	3.11	-0.44	-0.21	(1) pH *** (2) (pH) ² *** (3) SCM ***	
Overall PF (kg)	12.67 ^a	8.97 ^b	10.76 ^{ab}	**	61.66	3.41	-0.43	-0.21	(1) pH *** (2) (pH) ² *** (3) SCM ***	
Overall (PF-IY) (kg)	2.18 ^a	1.43 ^b	1.49 ^b	**	39.26	0.61	-0.22	-0.14	(1) pH * (2) (pH) ² *** (3) SCM ns (5.3%)	
Overall WD	3.39 ^a	2.64 ^b	3.06 ^{ab}	**	61.07	0.76	-0.51	-0.12	(1) pH *** (2) (pH) ² *** (3) SCM ***	

a,b means in the same row with different superscripts are different (P<0.05)

c Coefficient of determination

d Residual standard deviation

e ns P>0.05, * P<0.05, ** P<0.01, ***P<0.001.

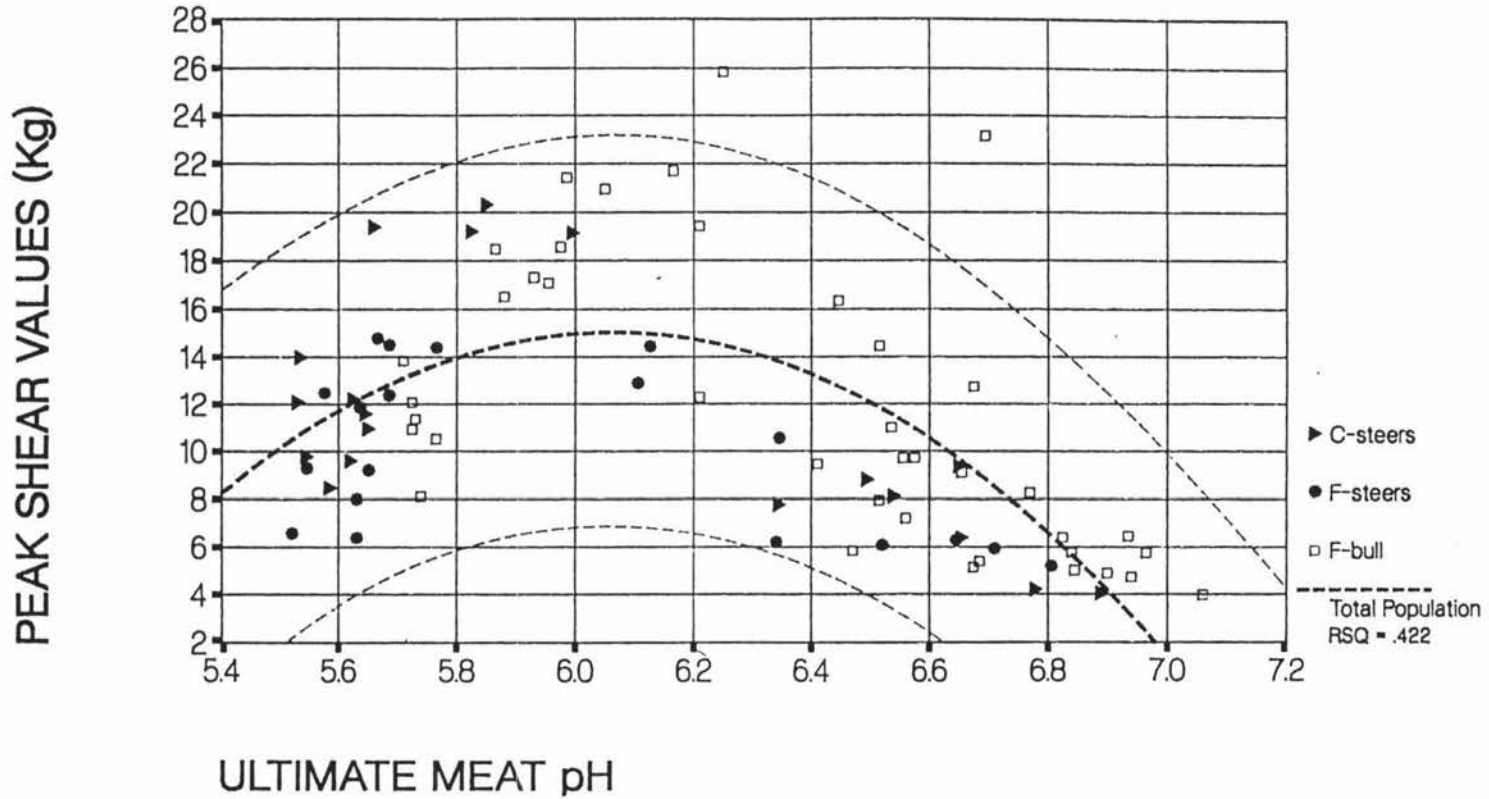


Figure 4.10 The relationship between ultimate meat pH and peak shear force of *M. longissimus*. Values are shown for Friesian bulls, Friesian steers and Charolais cross steers together with the quadratic regression line and 95 percent confidence limits.

Table 4.12 The significance of regression relationships between Warner-Bratzler peak shear force (PF), pH and sarcomere length (SCM) for samples of M. longissimus with an ultimate pH of less than 6.2 (n = 37). Independent variables were fitted in the sequence shown.

Dependent variable (Y)	Independent variables (X)	Significance ^c	RSD ^b	R ² ^a (%)
Overall PF	(1) pH	***	2.73	60.78
	(2) (pH) ²	ns		
	(1) SCM	***	2.44	67.57
	(1) pH	***	1.96	80.25
	(2) (pH) ²	ns		
	(3) SCM	***		
	(1) SCM	***	1.96	80.25
	(2) pH	***		
	(3) (pH) ²	ns		

a Coefficient of determination

b Residual standard deviation

c ns P>0.05, *** P<0.001.

CHAPTER 5

DISCUSSION

In this chapter the results will be discussed in the same sequence as the objectives of the study as listed in chapter 1. Thus, relationships between ultimate pH and meat quality characteristics will be discussed first, followed by a discussion of the meat tenderness measurement results, and finally the effects of breed and castration on carcass and meat quality will be considered.

5.1 ULTIMATE pH AND MEAT QUALITY CHARACTERISTICS

Ultimate pH values normally encountered in post-rigor meat can vary from 7.0 down to 5.4. Variability in cooked meat tenderness between different types of beef muscle has been shown to be influenced by differences in their ultimate pH, with improved tenderness generally being correlated with higher ultimate pH (Dransfield, 1977), particularly for ultimate pH values >6.0 (Fjelkner-Modig & Ruderus, 1983; Yu & Lee, 1986): The curvilinear relationship between meat tenderness and ultimate pH reported here is in good agreement with previous studies (Bouton *et al.*, 1973b; Martin & Fredeen, 1974; Purchas, 1989a). The minimum tenderness at a pH of approximately 6.1 is likely to be accompanied by lower WHC relative to meat with a higher pH. Meat pH has been clearly identified as a major factor influencing the WHC of meat, with a minimum WHC occurring at a pH of around 5.0 to 5.5 and with values increasing markedly with changing pH on either side of this point (Hamm, 1960; Penny *et al.*, 1963). Moreover, cooked meat tenderness has been demonstrated in some studies to increase concomitantly with a linear increase in WHC over the pH range 5.5 to 7.1 (Bouton *et al.*, 1971, 1973b). However, the WHC/pH relationship can be affected by cooking temperature as a quadratic component improved this relationship at higher temperatures (Bouton *et al.*, 1973b). Similarly, Gault (1985) found that increased WHC below the iso-electric point of the myofibrillar proteins markedly increased cooked meat tenderness. Although cooking losses can be severely increased with cooking temperature (Bouton *et al.*, 1971), greater values have been shown to be associated with lower levels of WHC in uncooked meat (Gault, 1985). Changes in mechanical

properties of uncooked beef muscle as it undergoes rigor mortis have been shown to be correlated with changes in the WHC of the muscle fibres as influenced by pH and the rate of pH fall (Currie & Wolfe, 1980). These may be because improved WHC will decrease cooking loss and consequently more water and less structural components appear in a given cross-sectional area of a meat sample (Purchas, 1989a).

On the other hand improvements in tenderness of high pH meat may be explained by differences in proteolytic activities. A degradation of Z-lines caused by calcium-activated proteases which have a pH optimum close to 7.0 (Dutson, 1983) may contribute to greater tenderness improvement of high pH meat than that of lower pH meat (Yu & Lee, 1986). Moreover, Marsh *et al.* (1987) reported that meat tenderness declined appreciably as pH at 3 h post-mortem decreased below 6.1, indicating a decreased activity of these enzymes as the favourable environment changed. However, the decrease in meat tenderness as pH at 3 h post-mortem increased above 6.1 in their study was not apparent in the present trial possibly due to the proportion of samples with a high ultimate pH. This may also have been because cold-shortening was avoided and muscle temperatures were in the range to cause large improvements in meat tenderness (Lochner *et al.*, 1980), but were not high enough to cause heat-shortening (Lee & Ashmore, 1985).

Lysosomal proteolytic enzyme activity may be responsible for tenderizing of low pH, high temperature meat (Dutson, 1983). The increase in shear force values as ultimate pH increase from about 5.5 to 6.2 may indicate a decrease in the activities of those enzymes. However, there may be other factors affecting tenderness of meat within this pH range as the lower pH meat is not always more tender (Marsh *et al.*, 1987). Although WHC can be improved with increasing ultimate pH, the increase in this pH range (5.5 -6.2) is very small and unlikely to have much effect on tenderness. Differences in fibre contraction state may be considered to be the predominant factor affecting tenderness of meat in this pH range when cold-shortening was avoided (Purchas, 1989a). Bouton *et al.* (1973b) showed that tenderness of meat with a pH lower than 6.0 was significantly improved by stretching but this effect did not appear at high pH values. It has also been shown by Honikel *et al.* (1986) that shortening of pre-rigor beef with pH values below 6.0 was greater than that of higher-pH beef

when cold-shortening did not occur. Similarly, increases in shear force values for beef samples when ultimate pH increases from 5.5 to 6.3 has been shown to be associated with shorter sarcomere length (Yu & Lee, 1986; Purchas *et al.*, 1988a). However, the effects of pH on shear force values were still significant after adjustment for variation in sarcomere length. This suggests that pH exerts its effects only partly through an effect on sarcomere length. The indirect effect of pH on shear force values was evident by the increase in percent variation accounted for when pH and sarcomere length were fitted together in the model (Table 4.12).

There is also some support for a decrease in sarcomere length over a range of pork samples ranging from PSE to DFD reported by Irving *et al.* (1989) and PSE pork has been rated less tender (Scarcy *et al.*, 1969; Topel *et al.*, 1976). Purchas *et al.* (1988b) showed that the paler portion of pork *M. semimembranosus* was more tender, had longer sarcomeres and lower pH values, relative to the darker part.

The reported influences of pH on WHC and colour are consistent with the results of Lawrie (1985) and Purchas (1989a). Hamm (1986) explained that the increase in tissue pH above the iso-electric point of myofibrillar proteins brings about an increase in negative net charge, and consequently increases electrostatic repulsion between similarly charged protein groups. Therefore, the protein network is enlarged and more water can be immobilized, and WHC is improved. High water retention in the meat may form a barrier to the penetration of oxygen and increases the absorption of light, resulting in darker meat colour (Walters, 1975; Locker, 1989).

5.2 MEAT TENDERNESS MEASUREMENT

Differences in typical shear force deformation curves obtained from the vee-blade and the square-blade support the suggestion that the conventional Warner-Bratzler shear blade offers greater interpretational difficulties than the modified straight-edged shear blade (Bouton *et al.*, 1975c). This was reflected in significantly higher peak shear force values and clearer initial yield points for the square-blade, although the values for work done in both systems were similar. However, high correlations for each of these parameters between the

two blade types indicated that both blades gave similar results, thereby confirming the report of Moller *et al.* (1982).

All shear parameters (PF, IY, PF-IY and WD) showed highly significant curvilinear relationships with ultimate pH. This implies that all aspects of structural strength measured were affected by changes in ultimate pH values. Rao *et al.* (1989) demonstrated that muscle swelling increased across and along the muscle fibre axis between pH 5.1 and pH 4.1. It should be expected to do so on the other side of the iso-electric point of myofibrillar proteins as well (Hamm, 1986), and hence reduced shear force values might be expected (Gault, 1985). However, this was not the case, therefore, factors such as discussed in the previous section must be involved. Bouton *et al.* (1982b) showed that initial yield and peak force values decreased significantly at similar rates with an increase in ultimate pH from 5.5 to 7.0. Their results were attributed to the linear reductions in cooking losses associated with increased pH. Sarcomere lengths of the meat samples did not show a significant relationship with ultimate pH due to stretching treatments. In contrast, sarcomere length in the present trial showed significant negative relationships with ultimate pH and all shear parameters measured except (PF-IY) values (Table 4.11). Thus, (PF-IY) values may be an indicator of connective tissue rather than myofibrillar strength as suggested by Bouton *et al.* (1975c). A significant increase in sarcomere length as ultimate pH declined significantly from medial to central parts (6.24 to 6.12) was associated with non-significant decrease in PF, IY and WD values suggesting that these parameters were mainly dependent on myofibrillar strength. The slight increase in (PF-IY) values from medial to central part of the same sample may be attributed to the increase in sarcomere length and hence the number of fibre and connective tissue sheaths presented in a given cross-sectional area (Bouton *et al.*, 1975c). The results in the present trial, therefore, support the finding of Bouton *et al.* (1977) that the shear force deformation curve parameters could be used to explain the strength of both myofibrillar and connective tissue components. However, the PF value which is the sum of the force deformation for these two structural components seems to be more influenced by myofibrillar strength (IY) than connective tissue strength (PF-IY) (Table 4.9). This may explain the variation in the relationships between shear force deformation curves and subjective measurements of meat tenderness when the connective tissue content of meat samples is different (Hayward *et al.*, 1980; Brady & Penfield, 1982; Seideman & Theer, 1986).

5.3 BREED AND CASTRATION EFFECTS

5.3.1 Growth rate

As the Friesian and Charolais cross steers had different pre-trial treatments which may have affected results on their growth performance during the early part of the trial, the growth rate during the first period may be considered as a pre-test adjustment period to alleviate variation in pre-test environment (Blair, 1989).

A number of reports have shown positive relationships between mature size of breed and growth rate (Andersen *et al.*, 1977; Blakely *et al.*, 1978; Southgate *et al.*, 1982; Kempster *et al.*, 1988). Thus, progeny of large European sire breeds such as the Charolais usually grow faster than progeny of sires of smaller British beef breeds. Straight-bred Friesians have an adult body size that is smaller than Charolais crosses, but similar to British beef breeds, as assessed by lean tissue growth rate (Kempster *et al.*, 1988). Breed groups in the present trial were different from the many reports in which breed comparisons have been made. Reports of direct comparisons between Charolais x Angus crosses and straight Friesians have not been found in the literature. With regard to breeds of sire, Charolais and Friesian sired steers tend to grow faster than British breeds of cattle, and Charolais cross steers tend to grow slightly faster than Friesian steers (Blakely *et al.*, 1978; Baker & Carter, 1980). Allen & Southgate (1978) showed that at 18 mo of age Charolais x Friesian cross steers grew 10.4 % faster than straight-bred Friesian steers, while Everitt *et al.* (1980) found only a 3.7 % higher growth rate for the Charolais x Friesian crosses over the age of 15 to 22 mo, compared to straight Friesian. Likewise, in a twenty-four month beef production system Southgate *et al.* (1982) found that average daily gain (ADG) was 4 to 14 % greater for Charolais crosses, compared with pure-bred Friesian steers. Comparisons between breeds of dams have shown that steers out of Holstein cows had higher postweaning ADG (Lusby *et al.*, 1975) and heavier yearling weights (Willham, 1973) than those from Hereford and Angus cows (Lusby *et al.*, 1975), although this would not account for greater postweaning gains (Fredeen *et al.*, 1972). Thus, the ADG for straight-bred Friesian and Charolais x Angus cross steers may be similar because the potential higher

growth rate of the Charolais breed may be offset by the slower growth rate of the Angus breed. In the present trial, the overall average growth rates of the steer groups did not differ significantly, although the mean value was approximately 2.5 % higher for the Charolais x Angus cross steers. Similar growth rates between Charolais x Hereford cross and pure-bred Friesian steers have also been reported by Morgan (1981). The higher growth rate for the Friesian steers during the earlier periods of this trial (period 2) may be due to pre-trial environmental effects, as animals grown on restricted diets may subsequently exhibit compensatory growth (Blair, 1989). However, the Charolais cross steers did show their higher potential growth rates in the later period. These results are supported by the finding of Jury *et al.* (1980) who reported an advantage in growth rate from 100 to 400 days for straight-bred Friesians over Charolais crosses, and vice versa from 400 to 600 days, leading to heavier final liveweights for the Charolais crosses. Morgan *et al.* (1978a) also found significantly higher average daily gains for Friesian-sired steers than those of the Charolais-sired steers at the age of 8 to 16 mo, but the difference disappeared for the period from 16 to 27 mo. Everitt *et al.* (1980) suggested that the realisation of the high genetic growth potential of the Charolais breed may require higher feeding levels than those available under pastoral farming.

5.3.2 Carcass characteristics

5.3.2.1 Dressing-out percent

Fatness and carcass conformation are factors known to affect dressing-out percentage of farm animals. Kirton & Morris (1989) pointed out that fatter animals or those with a blockier conformation, which is expected to indicate thicker muscle cross-sections (Kempster *et al.*, 1982b), tend to have higher dressing-out percents than other animals of similar weight. Differences in dressing-out percents between the two breed groups obtained in the present trial were consistent with those of Everitt *et al.* (1980), compared at a similar weight, and Kempster *et al.* (1982a, 1988), compared at the same fat level. Although this is not a direct comparison between the same breed groups as reported here, the Charolais breed of sire tends to produce greater dressing-out percent values than the Friesian (Kempster *et al.*, 1988; Morgan *et al.*, 1978b) and Angus dams also produce progeny with greater dressing-out percent values than

Friesian dams (Fredeen *et al.*, 1972). Beef breeds tend to show greater dressing-out percents than dairy breeds (Andersen *et al.*, 1977). Thus, higher values should be expected for beef breed crosses than for beef x dairy cross steers. Mean dressing-out percentage has been shown to increase with increasing carcass weight (Kempster *et al.*, 1982a). Although in the present trial mean carcass weights did not differ significantly between groups, the Charolais cross carcasses were 8 kg heavier than those of the Friesian steers. This was associated with a significantly greater fat depth for the Charolais cross carcasses when compared at a constant carcass weight (Table 4.2). This finding confirms the general rule that dressing-out percentage is an indicator of the degree of finish of the carcass (Pearson, 1966) with the better-finished Charolais crosses have higher dressing-out percentages. However, at a similar age Morgan *et al.* (1978b) and More O'Ferrall *et al.* (1989) found that Friesian sired-steers out of either Hereford or Friesian dams had lower dressing-out percentages than those of Charolais sired-steers despite similar or greater fat depths. This may have been partly due to significantly lower carcass weights for the Friesian steers in those studies or to superior levels of muscling of the Charolais crosses.

The differences in dressing-out percent in the present trial may also have been derived from the amount of internal fat which was excluded from the carcass weight during dressing. Berg & Butterfield (1976) pointed out that at any given age pure-bred Friesians produced greater amounts of kidney, cod and channel fats than Herefords, and Andersen *et al.* (1977) reported that Charolais cattle had less kidney fat and higher dressing-out percentages than Hereford cattle.

5.3.2.2 Rib-eye area

Rib-eye area will increase with increased carcass weight or with improved carcass conformation (Kempster *et al.*, 1982b). The most important factor influencing carcass conformation is breed, with beef breeds always showing better conformation than the dairy breeds (Kempster *et al.*, 1988). The greater weight-adjusted rib-eye area for the Charolais crosses in this study is in general agreement with previous findings (Morgan *et al.*, 1978b; Kempster *et al.*, 1982a, 1988), and is consistent with the heavier steak weights. The significantly shorter carcasses of the Charolais crosses may have contributed to the greater rib-eye areas. Garcia-de-Siles *et al.* (1977) pointed out that thickness of muscular tissue

had been achieved in cattle largely by shorter muscle lengths. However, differences in rib-eye area favouring Charolais crosses have also been found between breeds with similar carcass lengths (Morgan *et al.*, 1978b; More O'Ferral *et al.*, 1989). Taylor (1982) reported that at a similar liveweight Friesian carcasses were significantly longer and displayed a less desirable beef-type, as assessed objectively by the fleshing index, when compared with beef breeds such as the Hereford.

5.3.2.3 Meat yield

Better carcass conformation usually provides higher muscle to bone ratios, and higher yields of saleable meat (Kempster *et al.*, 1979; 1982b) when comparison are made at a similar weight or level of fatness. The differences in meat yield, as assessed by the total weight of six major hind-quarter cuts, between the two breed groups supported the general consensus that beef breeds, especially Charolais, are superior to the Friesian in the proportion of edible meat in the carcasses of their progeny, at a constant age or weight (Andersen *et al.*, 1977; Everitt *et al.*, 1980; Bass *et al.*, 1981). Kempster *et al.* (1982a) reported that pure-bred Friesians were less efficient than Charolais crosses in converting food into meat and had a lower proportion of saleable meat at the same level of fatness. This was due to the higher proportion of bone in the carcass of dairy cattle (Taylor, 1982; Everitt *et al.*, 1980; Kempster *et al.*, 1988). Moreover, the significant relationship between cut weights and carcass length (negative) and rib-eye area (positive) strongly support the suggestion that carcass length in relation to weight and rib-eye area might show a useful predictive relationship with carcass lean content among populations with variation in lean to bone ratios such as beef and dairy breeds (Kempster *et al.*, 1982b). In the present study fat depth showed a non-significant relationship with cut weights, supporting the statement by Kempster *et al.* (1982b) that fat thickness has been less accurate with beef and sheep carcasses than with pig carcasses in predicting carcass composition because their subcutaneous fat is less evenly distributed, less thick and forms a lower proportion of the total fat. The results in the current trial are not consistent with many studies where fat depth has proved to be a useful indicator of meat yield (Johnson & Ball, 1989; Ball & Johnson, 1989). In fact, fat thickness in most studies has been negatively associated with more of the variation in percent retail yield than rib-eye area (Hedrick, 1967). However, fat

depth at the 12th rib is frequently damaged by mechanical hide-pullers (Johnson & Ball, 1989), so a satisfactory measurement may not be achieved and the inconsistency of the degree of fat trim of commercially boned meat may also affect the close relationship between fat depth and meat yield (McIntyre, 1984). The contrasting breeds involved may have influenced the relationship between fat depth and yield of cuts as well (Ball & Johnson, 1989). Thus, with regard to saleable meat yield, based on the results in the present trial, the Charolais might be suitable as a sire breed to increase meat yield in dairy beef production.

Under the same condition, bulls generally grow faster and have a longer period of muscle growth than steers (Berg & Butterfield, 1976). Thus, bulls produce leaner carcasses and have more muscle than steers (Seideman *et al.*, 1982). The advantage of bulls in producing leaner carcasses is clearly evident by significantly lower fat depths and intramuscular fat levels. Similar results were reported by Seideman *et al.* (1989). However, the general conclusion that bulls have similar dressing-out percentage values to steers (Field, 1971) is true only when comparison was made within the same breed. In the present trial the Charolais cross steers had higher dressing-out percents than the Friesian bulls, but Friesian steers were similar to the bulls. Again this reflects the better finished carcasses of the Charolais cross steers (Pearson, 1966; Kirton & Morris, 1989). The greater rib-eye areas and the longer carcasses for bulls than for steers at the same weight were consistent with the results of Ockerman *et al.* (1984), Paterson *et al.* (1988) and Purchas (1989a). This may be attributed to the higher muscle growth rates and lower level of fatness for the bulls (Berg & Butterfield, 1976).

5.3.3 Muscle characteristics

5.3.3.1 Muscle pH, colour and water-holding capacity (WHC)

Group means of ultimate pH for Friesian and Charolais cross steers did not differ which is consistent with the results of More O'Ferrall *et al.* (1989), but the average pH values in the present trial were higher. This may have been due to the differences in pre-slaughter handling as animals penned overnight tend to produce meat with higher ultimate pH values than those animals slaughtered immediately after transportation (Jones *et al.*, 1986). Similar ultimate pH values

between the steers groups were reflected in the same meat colour, percent cooking loss, and expressed juice values. The results for meat colour between the steer groups is consistent with other reports (Koch *et al.*, 1976; Cross *et al.*, 1984), although the direct comparison has not been made between comparable groups. However, lower WHC values, as assessed by percent drip loss, for Charolais cross steers relative to Friesian steers has been reported by More O'Ferral *et al.* (1989). Bramblett *et al.* (1977) postulated that higher cooking losses could arise from higher fat contents, and lower moisture content. In the present trial steaks from these two breeds contained similar intramuscular fat percentages with no external fat so similar cooking losses could be expected. Johnson *et al.* (1988) also reported that steaks from British and continental breeds with similar marbling scores broiled to an internal temperature of 70 °C showed no differences in percent cooking loss. However, the average values of cooking loss and expressed juice in this study were higher than those reported by Purchas (1989a). This may have been caused by the period of frozen storage for the samples, as cooking loss for frozen meat has been shown to be greater than that of meat which has not been frozen (Bowles Axe *et al.*, 1983; Bhattacharya *et al.*, 1988).

The significantly higher mean ultimate pH value for bulls than for steers is consistent with the findings of Chrystall (1987), Jeremiah *et al.* (1988) and Purchas (1989a), and appears to have been responsible for the darker meat colour for the bulls, as colour differences disappeared when compared at a constant pH value. Jones *et al.* (1986) and Seideman *et al.* (1989) found no differences in meat colour between bulls and steers when their ultimate pH values were the same. Although cooking losses and expressed juice values in this study did not differ significantly between sex groups, bull meat showed higher values after pH adjustment, which is in agreement with the results of Purchas (1989a). Crouse *et al.* (1983) suggested that the lower marbling content of bull meat brought about higher cooking losses, but Johnson *et al.* (1988) did not find higher cooking losses for meat from bulls than steers.

It appears that pH differences could explain most of the differences in characteristic of muscle from bulls and steers in this study.

5.3.3.2 Meat tenderness

Breed differences in meat tenderness can be overshadowed by variation between sire groups within breeds, but there may be little reason to expect any differences in the tenderness of meat from different breeds of Bos taurus cattle (Purchas & Barton, 1976). The results reported here are in good agreement with the above statement, as there were no differences in tenderness of meat from Friesian and Charolais cross steers, as assessed by all the parameters obtained from shear force deformation curves. The results are consistent with many reports concerning the tenderness of these two breeds groups (Koch *et al.*, 1976; Cross *et al.*, 1984; More O'Ferral *et al.*, 1989). Although higher connective tissue and its lower solubility have been observed in some muscles of Charolais cross cattle (Martin *et al.*, 1965; Cross *et al.*, 1984), appreciable differences in tenderness have not been apparent. The similar (PF-IY) values obtained in the present trial support this finding.

Relatively small differences between meat from bulls and steers detected in the present study support the general consensus that bull meat is slightly less tender, but is rated in the acceptable range (Field, 1971; Seideman *et al.*, 1982). However, the higher (PF-IY) values for bull meat support the finding that bull meat contains more connective tissues than steer meat (Boccard *et al.*, 1979; Vanderwert *et al.*, 1986), assuming that this parameter is an indicator of connective tissue strength (Bouton *et al.*, 1975c). The similar sarcomere lengths for bull and steer meat corresponded to the results of Seideman *et al.* (1989), although Paterson *et al.* (1988) and Purchas (1989a) found that steers M.longissimus possessed slightly longer sarcomeres. None of these reports found differences in instrumental texture properties for bull and steer meat. The curvilinear relationship between pH and shear force values can be used to explain these results, since tenderness improved on either side of the maximum shear force value on the pH/shear force curve (Figure 4.10) and while the bull meat was mostly located above this point, most of the steer meat was below it. Similar results were reported by Purchas (1989a). In the current study bull meat produced significantly higher shear force values after adjustment has been made for pH differences. This implies that the improved tenderness of bull meat was associated with increases in pH values and WHC, as assessed either by cooking

losses (Figure 4.5) or expressed juice (Figure 4.6). Bull beef has been reported to be tougher, to be accompanied by higher cooking shrinkage, higher amounts of connective tissue and lower ease of fragmentation by Crouse *et al.* (1983), but differences in ultimate pH values were not reported in that study. The higher WHC of bull meat, therefore, may offset the other characteristics which could contribute to tougher meat, thereby leading sometimes to non-significant differences in meat tenderness of bulls and steers (Ockerman *et al.*, 1984; Dransfield *et al.*, 1984; Vanderwert *et al.*, 1986).

CHAPTER 6

CONCLUSIONS

Conclusions based on the results obtained in this thesis are arranged below in three categories which correspond to the three objectives set out in Chapter 1.

6.1 RELATIONSHIPS BETWEEN ULTIMATE pH AND MEAT QUALITY CHARACTERISTICS

(a) When cold-shortening conditions were avoided, ultimate meat pH seemed to be a major factor influencing meat tenderness, as evidenced by the significant curvilinear relationship between pH and meat tenderness.

(b) The minimum tenderness at a pH of approximately 6.1 was accompanied by a lower WHC relative to meat with a higher pH. The decrease in meat tenderness as pH values increased from 5.4 to 6.2 was partly associated with significant decreases in sarcomere lengths. Although the activity of proteolytic enzymes can contribute to meat tenderness improvement, the extent of this activity can be affected by changes in meat pH.

(c) The tenderness improvement as ultimate meat pH increased beyond 6.1 was accompanied by darker meat colour (lower reflectance values) and higher WHC (less expressed juice and lower cooking losses).

6.2 MEAT TENDERNESS MEASUREMENT

(a) The modified straight-edged Warner-Bratzler shear blade provided a typical shear-force deformation curve with a clearer initial yield point and a higher peak shear force value, compared to the conventional vee-shaped shear blade. However, both blades are likely to give similar results as indicated by similar values for total work done and high correlations for each of these parameters between the two blade types.

(b) The significant curvilinear relationships between several shear parameters and ultimate pH indicated that all aspects of structural strength measured were affected by changes in ultimate pH values.

(c) All shear parameters measured showed significant negative relationships with sarcomere length, except peak shear force-initial yield force values which are thought to be an indicator of connective tissue strength. However, the peak shear force value was more influenced by myofibrillar strength (initial yield force) than by connective tissue strength (peak shear force-initial yield force).

6.3 BREED AND CASTRATION EFFECTS

(a) No significant differences in overall average growth rate and final liveweight were found between pure-bred Friesian and Charolais x Angus cross steers, although the Charolais cross steers grew slightly faster in the later periods. Compensatory growth may have been responsible for the faster early growth rates in the Friesian steers if they had been on restricted diets during the pre-trial period.

(b) The Charolais cross steers had greater dressing-out percentages, greater rib-eye areas, but shorter carcasses than the pure-bred Friesian steers. This was reflected in significantly greater fat depths and superior levels of muscling of the Charolais cross carcasses, leading to heavier steak weights and higher meat yields.

(c) At a constant carcass weight, the bulls had greater rib-eye areas and longer carcasses than the steers. Bulls produced leaner carcasses, as reflected in lower fat depths and intramuscular fat levels. Dressing-out percent values for bulls and steers were similar when compared within the same breed.

(d) Breed differences in meat quality characteristics were not found in this study. Similar ultimate pH values for meat samples of Pure-bred Friesian and Charolais cross steers were consistent with similar mean values for meat tenderness, colour, percent cooking losses and expressed juice values.

(e) Conversely, higher ultimate pH values for meat from bulls than steers were responsible for a darker meat colour, but no differences in meat tenderness or WHC. However, bull meat seemed to have slightly greater connective tissue content, as indicated by higher peak shear force-initial yield force values. When pH effects were eliminated by covariance bull meat was slightly tougher and had lower WHC than steer meat.

REFERENCES

- Abbott, J.A. 1972: Sensory assessment of food texture. **Food technology**. **1**: 40-49.
- Allen, D.M., Southgate, J.R. 1977: The evaluation of breeds for beef production. **World review of animal production**. **13**: 29-36.
- American Meat Science Association 1977: Recommended procedures for beef carcass evaluation and carcass contests.
- Andersen, B.B., Liboriussen, T., Kousgaard, K., Buchter, L. 1977: Crossbreeding experiment with beef and dual-purpose sire breeds on Danish dairy cows. III. Daily gain, feed conversion and carcass quality of intensively fed young bulls. **Livestock production science**. **4**: 19-29.
- AOAC. 1980: Official methods of analysis, 13th ed. Association of official agricultural chemists, Washington, D.C., U.S.A.
- Ashgar, A., Pearson, A.M. 1980: Influence of ante- and post-mortem treatments upon muscle composition and meat quality. **Advances in food research**. **26**: 54-213.
- Ashmore, C.R., Carroll, F., Doerr, L., Tompkins, G., Stokes, H., Parker, W. 1973a: Experimental prevention of dark cutting meat. **Journal of animal science**. **36**: 33-36.
- Ashmore, C.R., Carroll, F., Doerr, L. 1973b: Effects of propranolol on characteristics of beef carcasses. **Journal of animal science**. **37**: 435-437.
- Ashmore, C.R. 1974: Phenotypic expression of muscle fibre types and some implications to meat quality. **Journal of animal science**. **38**: 1158-1164.
- Baker, R.L., Carter, A.H. 1980: Implications of experimental results with beef cattle in New Zealand. In: Proceedings of the world congress on sheep and beef cattle breeding. Barton, R.A., Smith, W.C. Eds. **1**: 87-99.
- Baron, P.J. 1984: Consumer attitudes and demand for meat. In: Matching production to the market for meat. Cuthbertson, A. and Gun, R.G. Eds. pp.1-6. D & J Croal Ltd, Haddington.
- Bailey, A.J. 1972: The basis of meat texture. **Journal of the science of food and agriculture**. **23**: 995-1007.
- Bailey, P.J., Cook, G.L., Kempster, A.J., Sains, A.G. 1984: The estimation of killing out in cattle from knowledge of breed, and visual appraisal of external fat cover and conformation. **Animal production**. **38**: 391-398.

- Ball, B., Johnson, E.R. 1989: The influence of breed and sex on saleable beef yield. **Australian journal of experimental agriculture**. **29**: 483-487.
- Bass, J.J., Carter, A.H., Johnson, D.L., Baker, R.L., Jones, K.K. 1981: Sire-breed comparison of carcass composition of steers from Angus dams. **Journal of agricultural science (Camb)**. **97**: 515-522.
- Bechtel, P.J. 1986: Muscle development and contractile proteins. In: Muscle as food. P.J.Bechtel Ed. pp. 1-35. Academic press, Inc.
- Berg, R.T., Butterfield, R.M. 1968: Growth patterns of bovine muscle, fat and bone. **Journal of animal science**. **27**: 611-619.
- Berg, R.T., Butterfield, R.M. 1976: New concepts of cattle growth. Sydney Univ Press.
- Berry, B.W., Wheel, M.R., Carpenter, Jr.J.A. 1977: Effects of muscle and cookery method on palatability of beef from several breeds and breed crosses. **Journal of food science**. **42**: 1322-1324.
- Bendall, J.R. 1973: Post-mortem changes in muscle. In: The structure and function of muscle. Bourne, G.H. Ed. 2nd ed. vol 2 pp. 243-309. Academic press, New York.
- Bendall, J.R. 1976: Electrical stimulation of rabbit and lamb carcasses. **Journal of the science of food and agriculture**. **27**: 817-826.
- Bendall, J.R. 1978: Variability in rates of pH fall and lactate production in the muscles on cooling beef carcasses. **Meat science**. **2**: 91-104.
- Bendall, J.R., Hallund, O., Wisner-Pederson, J. 1963: Post-mortem changes in the muscles of Landrace pigs. **Journal of food science**. **28**: 156-162.
- Beilken, S.L., Bouton, P.E., Harris, P.V. 1986: Some effects on the mechanical properties of meat produced by cooking at temperatures between 50 and 60 °C. **Journal of food science**. **51**: 791-796.
- Berenthal, P.H., Booren, A.M., Gray, J.I. 1989: Effect of sodium chloride concentration on pH, water-holding capacity and extractable protein of prerigor and postrigor ground beef. **Meat science**. **25**: 143-154.
- Bhattacharya, M., Hanna, M.A., Mandigo, R.W. 1988: Effect of frozen storage conditions on yields, shear strength and color of ground beef patties. **Journal of food science**. **53**: 696-700.
- Blair, H.T. 1989: Practical procedures for the genetic improvement of growth and carcass quality characteristics. In: Meat production and processing. Purchas, R.W., Butler-Hogg, B.W. and Davies, A.S. Eds. pp. 125-141. NZSAP Simon print, Palmerston north.
- Blakely, D.K., Wilton, J.W., Osborne, W.R., Burnside, E.B. 1978: The effect of breed of sire group on beef production and carcass characteristics. **Canadian journal of animal science**. **58**: 639-650.

- Boccard, R.L., Naude, E.T., Cronje, D.E., Smith, M.C., Venter, H.J., Rossouw, P.V. 1979: The influence of age sex and breed of cattle on their muscle characteristics. **Meat science**. **3**: 261-280.
- Bouton, P.E., Harris, P.V., Shorthose, W.R. 1971: Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. **Journal of food science**. **36**: 435-439.
- Bouton, P.E., Harris, P.V. 1972a: A comparison of some objective methods used to assess meat tenderness. **Journal of food science**. **37**: 218-221.
- Bouton, P.E., Harris, P.V. 1972b: The effects of cooking temperature and time on some mechanical properties of meat. **Journal of food science**. **37**: 140-144.
- Bouton, P.E., Fisher, A.L., Harris, P.E., Baxter, R.I. 1973a: A comparison of the effects of some post-slaughter treatments on the tenderness of beef. **Journal of food technology**. **8**: 39-49.
- Bouton, P.E., Carrol, F.D., Fisher, A.L., Harris, P.V., Shorthose, W.R. 1973b: Effect of altering ultimate pH on bovine muscle tenderness. **Journal of food science**. **38**: 816-820.
- Bouton, P.E., Ford, A.L., Harris, P.V., Ratcliff, D. 1975a: Objective-subjective assessment of meat tenderness. **Journal of texture studies**. **6**: 315-328
- Bouton, P.E. Harris, P.V., Shorthose, W.R. 1975b: Change in shear parameters of meat associated with structural changes produced by aging, cooking, and myofibrillar contraction. **Journal of food science**. **40**: 1122-1126.
- Bouton, P.E., Harris, P.V., Shorthose, W.R. 1975c: Possible relationships between shear, tensile, and adhesion properties of meat and meat structure. **Journal of texture studies**. **6**: 297-314.
- Bouton, P.E., Harris, P.V., Macfarlane, J.J., Snowden, J.M. 1977: The effects of long term cooking on shear force-deformation curves. **Journal of texture studies**. **8**: 297-310.
- Bouton, P.E., Ford, A.L. Harris, P.V., Shorthose, W.R., Ratcliff, D., Morgan, J.H.L. 1978: Influence of animal age on the tenderness of beef: Muscle differences. **Meat science**. **2**: 310-31.
- Bouton, P.E., Harris, P.V., Ratcliff, D. 1981: Effect of cooking temperature and time on the shear properties of meat. **Journal of food science**. **46**: 1082-1087.
- Bouton, P.E Harris, P.V., Macfarlane, J.J., Shorthose, W.R. 1982a: Influence of pH on the Warner-Bratzler shear properties of mutton. **Meat science**. **6**: 27-36.
- Bouton, P.E., Harris, P.V., Shorthose, W.R. 1982b: The effect of temperature and ultimate pH on the increase in meat toughness resulting from restraint during cooking. **Meat science**. **6**: 235-241.

- Bowles Axe, J.E., Kastner, C.L., Dikeman, M.E., Hunt, M.C., Kropf, D.H., Milliken, G.A. 1983: Effect of beef carcass electrical stimulation, hot boning, and aging on unfrozen and frozen longissimus dorsi and semimembranosus steaks. **Journal of food science.** **48:** 332-336.
- Bodwell, C.E., Pearson, A.M., Spooner, M.E. 1965: Post-mortem changes in muscle. I. Chemical changes in beef. **Journal of food science.** **30:** 766-772.
- Bramblett, V.D., Martin, T.G., Harrington, R.B., Evans, G.J. 1971: Breed, vitamin A supplementation and position effects on quality characteristics of beef short loin steaks. **Journal of animal science.** **33:** 349-354.
- Brady, P.L., Penfield, M.P. 1982: Effects of heating system, temperature and rate of heating on sensory characteristics of beef. **Journal of food science.** **47:** 1783-1792.
- Brady, P.L., Hunecke, M.E. 1985: Correlations of sensory and instrumental evaluations of roast beef texture. **Journal of food science.** **50:** 300-303.
- Brandt, M.A., Skinner, E.B., Coleman, J.A. 1963: Texture profile method. **Journal of food science.** **28:** 404-409.
- Buts, B., Casteels, M., Claeys, E., Demeyer, D. 1986: Effects of electrical stimulation, followed by moderate cooling, on meat quality characteristics of veal Longissimus dorsi. **Meat science.** **18:** 271-279.
- Calkins, C.R., Seideman, S.C. 1988: Relationships among calcium dependent protease, cathepsins B and H, meat tenderness and the response of muscle to aging. **Journal of animal science.** **66:** 1186-1193.
- Carse, W.A. 1973: Meat quality and the acceleration of post-mortem glycolysis by electrical stimulation. **Journal of food technology.** **8:** 163-166.
- Carse, W.A., Locker, R.H. 1974: A survey of pH values at the surface of beef and lamb carcasses, stored in a chiller. **Journal of the science of food and agriculture.** **25:** 1529-1535.
- Cassens, R.G., Newbold, R.P. 1967: Temperature dependence of pH changes in ox muscle post-mortem. **Journal of food science.** **32:** 13-14.
- Cassens, R.G., Marple, D.N., Eikelenboom, G. 1975: Animal physiology and meat quality. **Advances in food research.** **21:** 71-155.
- Champagne, J.R., Carpenter, J.W., Hentges, Jr. J.F., Palmer, A.Z., Koger, M. 1969: Feedlot performance and carcass characteristics of young bulls and steers castrated at four ages. **Journal of animal science.** **29:** 887-890.
- Chrystall, B.B. 1987: Detection of high pH meat with an optoelectronic probe. **New Zealand journal of agricultural research.** **30:** 443-448.

- Cia, G., Marsh, B.B. 1976: Properties of beef cooked before rigor onset. **Journal of food science.** **41:** 1259-1262.
- Clancy, M.J., Lester, J.M., Roche, J.F. 1986: The effects of anabolic agent and breed on the fibres of the longissimus muscle of male cattle. **Journal of animal science.** **63:** 83-91.
- Cover, S., Ritchey, S.L., Hostetler, R.L. 1962: Tenderness of beef. I: The connective tissue component of tenderness. **Journal of food science.** **27:** 469-475.
- Cross, H.R., Carpenter, Z.L., Smith, G.S. 1973: Effects of intramuscular collagen and elastic on bovine muscle tenderness. **Journal of food science.** **38:** 998-1003.
- Cross, H.R., Tennent, I. 1980: Accelerated processing system for USDA choice and good beef carcasses. **Journal of food science.** **45:** 765-768.
- Cross, H.R., West, R.L., Dutson, T.R. 1980-81: Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. **Meat science.** **5:** 261-266.
- Cross, H.R., Crouse, J.D., MacNeil, M.D., 1984: Influence of breed, sex, age and electrical stimulation on carcass and palatability traits of three bovine muscles. **Journal of animal science.** **58:** 1358-1365.
- Cross, H.R., Durland, R.R., Seideman, S.C. 1986: Sensory quality of meat. In: Muscle as food. P.J.Bechtel Ed. pp. 279-320. Academic press, Inc.
- Crouse, J.D., Seideman, S.C., Cross, H.R. 1983: The effects of carcass electrical stimulation and cooler temperature on the quality and palatability of bull and steer beef. **Journal of animal science.** **56:** 81-89.
- Crouse, J.D., Seideman, S.C. 1984: Effect of high temperature conditioning on beef from grass or grain fed cattle. **Journal of food science.** **49:** 157-160.
- Currie, R.W., Wolfe, F.H. 1980: Rigor related changes in mechanical properties (tensile and adhesive) and extracellular space in beef muscle. **Meat science.** **4:** 123-143.
- Dalrymple, R.h., Kelly, R.F. 1969: Influence of PSE pork in midwestern and southern hogs. **Journal of animal science.** **29:** 120 (Abstr.)
- Damon Jr, R.A., Crown, R.M., Singletary, C.B., McCraine, S.E. 1960: Carcass characteristics of purebred and crossbred beef steers in the gulf coast region. **Journal of animal science.** **19:** 820-844.
- Davey, C.L., Kuttel, H., Gilbert, R.V. 1967: Shortening as a factor in meat aging. **Journal of food technology.** **2:** 53-56.
- Davey, C.L., Dickson, M.R. 1970: Studies in meat tenderness. 8. Ultra-structure changes in meat during aging. **Journal of food science.** **35:** 56-60.

- Devey, C.L., Gilbert, K.V. 1973: The effect of carcass posture on cold, heat and thaw shortening in lamb. **Journal of food technology**. **8**: 445-451.
- Davey, C.L., Gilbert, K.V. 1975: Cold-shortening capacity and beef muscle growth. **Journal of the science of food and agriculture**. **26**: 755-760.
- Devine, C.E., Ellery, S., Averill, S. 1984: Responses of different types of ox muscle to electrical stimulation. **Meat science**. **10**: 35-51.
- Deethardt, D., Tuma, H.J. 1971: Effect of cooking method on various qualities of pork loin. **Journal of food science**. **36**: 626-628.
- Devol, D.L., McKeith, F.K., Bechtel, P.J., Novakofski, J., Shanks, R.D., Carr, T.R. 1988: Variation in composition and palatability traits and relationship between muscle characteristics and palatability in a random sample of pork carcasses. **Journal of animal science**. **66**: 385-395.
- Dildvey, D.D., Aberle, E.D., Forrest, J.C., Judge, M.D. 1970: Porcine muscularity and properties associated with pale, soft, exudative muscle. **Journal of animal science**. **31**: 681-685.
- Dickson, J.S. 1988: Reduction of bacteria attached to meat surfaces by washing with selected compounds. **Journal of food protection**. **51(11)**: 869-873.
- Dransfield, E. 1977: Intramuscular composition and texture of beef muscles. **Journal of the science of food & agriculture**. **28**: 833-842.
- Dransfield, E., Rhodes, D.N., Nute, G.R., Roberts, T.A., Boccard, R., Tourille, C., Buchter, L., Hood, D.E., Joseph, R.L., Schon, I., Casteels, M., Cosentino, E., Tinbergen, B.J. 1982: Eating quality of European beef assessed at five research institutes. **Meat science**. **6**: 163-184.
- Dransfield, E., Nute, G.R., Francombe, M.A. 1984: Comparison of eating quality of bull and steer beef. **Animal production**. **39**: 37-50.
- Dransfield, E., Locker, D.K. 1985: Cold-shortening toughness in excised pork *M. longissimus dorsi*. **Meat science**. **13**: 19-32.
- Dutson, T.R., Smith, G.C., Carpenter, Z.L. 1980: Lysosomal enzyme distribution in electrically stimulated ovine muscle. **Journal of food science**. **45**: 1097-1098.
- Dutson, T.R. 1983: Relation of pH and temperature to disruption of specific muscle proteins and activity of lysosomal proteases. **Journal of food biochemistry**. **7**: 223-245.
- Eikelenboom, G., Smulders, F.J.M. 1986: Effect of electrical stimulation on veal quality. **Meat science**. **16**: 103-112.
- Elgasim, E.A., Kennick, W.H., McGill, L.A., Roch, D.F., Soeldner, A. 1981: Effect of electrical stimulation and delayed chilling of beef carcasses on carcass and meat characteristics. **Journal of food science**. **46**: 340-343.

- Everitt, G.C. 1972: Lessons from the Charolais traits. Ruakura farmers' conference. pp. 77-99.
- Everitt, G.C., Jury, K.E., Dalton, D.C., Langridge, M. 1980: Beef production from the dairy herd IV. Growth and carcass composition of straight-bred and beef-cross Friesian steers in several environments. **New Zealand journal of agricultural research**. **23**: 11-20.
- Fabiansson, S., Rentersward, A.L. 1985: Low-voltage electrical stimulation and post-mortem energy metabolism in beef. **Meat science**. **12**: 205-223.
- Field, R.A. 1971: Effect of castration on meat quality and quantity. **Journal of animal science**. **32**: 849-858.
- Fjelkner-Modig, S., Ruderus, H. 1983: The influence of exhaustion and electrical stimulation of the meat quality of young bulls: Part 2-Physical and sensory properties. **Meat science**. **8**: 203-220.
- Fjelkner-Modig, S., Pearson, J. 1986: Carcass properties as related to sensory properties of pork. **Journal of animal science**. **63**: 102-113.
- Forrest, R.J. 1975: Effects of castration, sire and hormone treatments on the quality of rib roasts from Holstein-Friesian males. **Canadian journal of animal science**. **55**: 287-290.
- Follett, M.T., Norman, G.A., Ratchiff, P.W. 1974: The ante-rigor excision and air cooling of beef semimembranosus muscles at temperature between -5°C and $+15^{\circ}\text{C}$. **Journal of food technology**. **9**: 509-523.
- Ford, A.L., Park, R.J. 1980: Odours and flavours in meat. In: Development in meat science-1. Lawrie, R.A. Ed. pp.219-248. Applied science publisher, London.
- Fox, J.D., Wolfram, S.A., Kemp, J.D., Langlois, B.E. 1980: Physical, chemical, sensory, and microbiological properties and shelf life of PSE pork chops. **Journal of food science**. **45**: 786-790.
- Fredeen, T., Martin, A.H., Weiss, G.M., Slen, S.B., Sumption, L.J. 1972: Feedlot and carcass performance of young bulls representing several breeds and breed crosses. **Canadian journal of animal science**. **52**: 241-257.
- Garcia-de-siles, J.L., Ziegler, J.H., Wilson, L.L., Sink, J.D. 1977: Growth carcass and muscle characteristics of Hereford and Holstein steers. **Journal of animal science**. **44**: 973-984.
- Gault, N.F.S. 1985: The relationship between water-holding capacity and cooked meat tenderness in some beef muscles as influenced by acidic conditions below the ultimate condition. **Meat science**. **15**: 15-30.
- Gill, C.O. 1986: Chilled NZ lamb: a novel export product. **Food technology in New Zealand**. **21(1)**: 15-16.

- Goll, D.E., Henderson, D.W., Kline, E.A. 1964a: Post-mortem changes in physical and chemical properties of bovine muscles. **Journal of food science.** 29: 590-596.
- Goll, D.E., Bray, R.W., Hockstra, W.G 1964b: Age-associated changes in bovine muscle connective tissue. III. Rate of solubilization at 100 °C. **Journal of food science.** 29: 622-628.
- Greaser, M.L. 1986: Conversion of muscle to meat. In: Muscle as food. P.J.Bechtel Ed. pp. 37-102. Academic press, Inc.
- Hamm, R. 1960: Biochemistry of meat hydration. **Advances in food research.** 10: 355-463.
- Hamm, R. 1975: Water-holding capacity of meat. In: Meat. Cole, D.J.A., Lawrie, R.A. Eds. pp. 321-338. Butterworth, London.
- Hamm, R. 1986: Functional properties of the myofibrillar system and their measurements. In: Muscle as food. P.J.Bechtel Ed. pp.135-199. Academic press, Inc.
- Harris, P.V. 1976: Structural and other aspects of meat tenderness. **Journal of texture studies.** 7: 49-63.
- Harris, P.V. 1988: Meat tenderness. Proceedings of the 34th international congress of meat science and technology. Part A. pp. 169-172. Brisbane.
- Hayward, L.H., Hunt, M.C., Kastner, C.L., Kropf, D.H. 1980: Blade tenderization effects on beef longissimus sensory and instron textural measurements. **Journal of food science.** 45: 925-930 & 935.
- Harries, J.M., Rhodes, D.N., Chrystall, B.B. 1972: Meat texture. I Subjective assessment of the texture of cooked beef. **Journal of texture studies.** 3: 101-114.
- Harrington, G., Pearson, A.M. 1962: Chew count as a measure of tenderness of pork loins with various degrees of marbling. **Journal of food science.** 27: 106-110.
- Hedrick, H.B. 1967: Bovine growth and composition. Research bulletin 928. University of Missouri. Columbia, Missouri.
- Hidiroglou, M.M., Charette, L.A., Patterson, J.S. 1964: A comparison of growth and carcass characteristics of purebred Shorthorn and crossbred beef steers. **Canadian journal of animal science.** 44: 249-256.
- Hill, F. 1968: Quality in meat. Institute of meat bulletin 59: 6-16.
- Hostetler, R.L., Link, B.A., Landman, W.A., Fitzhugh, H.A. 1972: Effect of carcass suspension on sarcomere length and shear force of some major bovine muscles. **Journal of food science.** 37: 132-135.

- Hostetler, R.L., Link, B.A., Landman, W.A., Fitzhugh, H.A.Jr. 1973: Effect of carcass suspension method on sensory panel scores for some major bovine muscles. **Journal of food science.** **38:** 264-267.
- Honikel, K.O., Hamid, A., Fischer, C., Hamm, R. 1981: Influence of postmortem changes in bovine muscle on the water-holding capacity of beef. Postmortem storage of muscle at 20 °C. **Journal of food science.** **46:** 1-6.
- Honikel, K.O., Roncales, P., Hamm, R. 1983: The influence of temperature on shortening and rigor onset in beef muscle. **Meat science.** **8:** 221-241.
- Honikel, K.O., Kim, C.J., Hamm, R., Roncales, P. 1986: Sarcomere shortening of muscles and its influence on drip loss. **Meat science.** **16:** 267-282.
- Houlier, B., Valin, C., Monin, G., Sale, P. 1984: Effect of muscle type on electrical stimulation efficiency. **Science des aliments.** **4:** 167-175.
- Hunsley, R.E., Vetter, R.L., Kline, E.A., Burrougus, W. 1971: Effects of age and sex on quality tenderness and collagen content of bovine longissimus muscle. **Journal of animal science.** **33:** 933-938.
- Irving, T.C., Swatland, H.J., Millman, B.M. 1989: X-ray diffraction measurements of myofilament lattice spacing and optimal measurements of reflectance and sarcomere length in commercial pork loins. **Journal of animal science.** **67:** 152-156.
- Jacobs, J.A., Hurst, C.E., Miller, J.C., Howes, A.D., Gregory, T.L., Ringkob, T.P. 1977a: Bulls and steers. I. Carcass composition, wholesale yields and retail values. **Journal of animal science.** **46:** 695-698.
- Jacobs, J.A., Miller, J.C., Sauter, E.A., Avaji, F.A., Gregory, T.L., Hurst, C.E. 1977b: Bulls versus steers. Palatability and retail acceptance. **Journal of animal science.** **46:** 699-702.
- Jeremiah, L.E., Newman, J.A., Tong, A.K.W., Gibson, L.L. 1988: The effects of castration, preslaughter stress and zeranol implants on beef: Part I- The texture of loin steaks from bovine males. **Meat science.** **22:** 83-101.
- Johnson, E.R., Ball, B. 1989: Prediction of the commercial yield of beef from carcass destined for the Japanese market by using measurements from the carcass and non-carcass parts. **Australian journal of experimental agriculture.** **29:** 489-496.
- Johnson, D.D., Savell, J.W., Smith, G.C., Gill, D.R., Williams, D.E., Walters, L.E., Martin, J.J. 1984: Relationship of growth stimulants and breed groups on carcass characteristics and palatability of young bulls. **Journal of animal science.** **58:** 920-925.
- Johnson, D.D., Lunt, D.K., Savell, J.W., Smith, G.C. 1988: Factors affecting carcass characteristics and palatability of young bulls. **Journal of animal science.** **66:** 2568-2577.

- Jones, S.D.M., Newman, J.A., Tong, A.K.W., Martin, A.H., Robertson, W.M. 1986: The effects of two shipping treatments on the carcass characteristics of bulls implanted with zeranol and unimplanted steers. **Journal of animal science**. **62**: 1602-1608.
- Jury, K.E., Everitt, G.C. 1980: Beef production from the dairy herd. V. Growth of steers and heifers in different environments to 600 days of age. **New Zealand journal of agricultural research**. **23**: 21-25.
- Judge, M.D., Aberle, E.D. 1982: Effects of chronological age and postmortem aging on the shrinkage temperature of bovine intramuscular collagen. **Journal of animal science**. **54**: 68-71.
- Kastenschidt, L.L. 1970: The metabolism of muscle as food. In: The physiology and biochemistry of muscle as food. 2. E.J.Briskey., R.G. Cassens, and B.B. Marsh. (Eds) pp. 735-753. Univ of Wisconsin press, Madison.
- Kauffman, R.G., Carpenter, Z.L., Bray, R.W., Hoekstra, W.G. 1964: Biochemical properties of pork and their relationship to quality. I: pH of chilled, aged and cooked muscle tissue. **Journal of food science**. **29**: 65-69.
- Kenny, F.J., Tarrant, P.V. 1988: The effect of oestrus behaviour on muscle glycogen concentration and dark cutting in beef heifers. **Meat science**. **22**: 21-31.
- Kenny, F.J., Tarrant, P.V. 1987: The physiological and behavioural responses of crossbred Friesian steers to short-haul transport by road. **Livestock production science**. **17**: 63-75.
- Kempster, A.J., Cook, G.L., Southgate, J.R. 1979: Carcass characteristics of Friesian and beef breed x Friesian cattle at equal fatness. **Animal production**. **28**: 457. (Abs).
- Kempster, A.J., Cook, G.L., Southgate, J.R. 1982a: A comparison of the progeny of British Friesian dams and different sire breeds in 16- and 24-month beef production systems. **Animal production**. **34**: 167-178.
- Kempster, A.J., Cuthbertson, A., Harrington, G. 1982b: Carcass evaluation in livestock breeding, production and marketing. Granada, London. p 80.
- Kempster, A.J., Cook, G.L., Southgate, J.R. 1988: Evaluation of British Friesian, Canadian Holstein and Beef breed x British Friesian steers slaughtered over a commercial range of fatness from 16-month and 24-month beef production systems. **Animal production**. **46**: 365-378.
- Kemp, J.D., Montgomery, R.E., Fox, J.D. 1976: Chemical, palatability and cooking characteristics of normal and low quality pork loins as affected by freezer storage. **Journal of food science**. **41**: 1-3.

- Kirton, A.H., Morris, C.A. 1989: The effect of mature size, sex and breed on pattern of change during growth and development. In: Meat production and processing. Purchas, R.W., Butler-Hogg, B.W., Davies, A.S. Eds. pp. 73-85. NZSAP Simon print Ltd, Palmerston North.
- King, N.L. 1987: Thermal transition of collagen in ovine connective tissues. **Meat science**. **20**: 25-37.
- Koohmaraie, M., Kennick, W.H., Anglemier, A.F., Elgasim, E.A., Jones, T.K. 1984a: Effect of post-mortem storage on cold-shortened bovine muscle: Analysis by SDS-polyacrylamide gel electrophoresis. **Journal of food science**. **49**: 290-291.
- Koohmaraie, M., Kennick, W.H., Elgasim, E.A., Anglemier, A.F. 1984b: Effects of post-mortem storage on muscle protein degradation: Analysis by SDS-polyacrylamide gel electrophoresis. **Journal of food science**. **49**: 292-293.
- Koch, R.M., Dikeman, M.E., Allen, D.M., May, M., Crouse, J.D., Campion, D.R. 1976: Characterization of biological types of cattle. III. Carcass composition, quality and palatability. **Journal of animal science**. **43**: 48-62.
- Kraft, A.A. 1986: Meat microbiology. In: Muscle as food. P.J. Bechtel Ed. pp.239-278. Academic press, Inc.
- Landon, .E., Hedrick, H.B., Thompson, G.B. 1978: Live animal performance and carcass characteristics of beef bullocks and steers. **Journal of animal science**. **47**: 151-155.
- Lawrie, R.A. 1977: Meat: Current developments and future status. **Meat science**. **1**: 1-13.
- Lawrie, R.A. 1985: Meat science. 4th edition. Pergamon press, Oxford.
- Lalande, G., Larmond, E., Fahmy, M.H. 1982: Meat quality evaluation at three slaughter weights of steers from the Holstein-Friesian breed and its crosses with Main-Anjou, Limousin, Chainina and Blonde D'Aquitaine. **Canadian journal of animal science**. **62**: 363-369.
- Larmond, E. 1976: Texture measurement in meat by sensory evaluation. **Journal of texture studies**. **7**: 87-93.
- Lee, Y.B., Ashmore, C.R. 1985: Effect of early post-mortem temperature on beef tenderness. **Journal of animal science**. **60**: 1588-1596.
- Lee, Y.B. 1986: Early- postmortem measurements and conditioning in assessing and enhancing meat quality. **Journal of animal science**. **63**: 622-632.
- Liboriussen, T., Andersen, B.B., Buchter, L., Kousgaard, K., Moller, A.J. 1977: Crossbreeding experiment with beef and dual-purpose sire breeds on Danish dary cows. IV. Physical, chemical and palatability characteristics of longissimus dorsi and semitendinosus muscles

- from crossbred young bulls. **Livestock production science.** 4: 31-43.
- Locker, R.H., Hagyard, C.J. 1963: A cold-shortening effect in beef muscle. **Journal of the science of food and agriculture.** 14: 787-793
- Locker, R.H., Devey, C.L., Nottingham, P.M., Haughey, D.P., Low, L.H. 1975: New concepts in meat processing. **Advances in food research.** 21: 157-222.
- Locker, R.H., Wild, D.J.C. 1982: Yield point in raw beef muscle. The effect of aging, rigor temperature and stretch. **Meat science.** 7: 93-107.
- Locker, R.H. 1987: The non-sliding filaments of the sarcomere. **Meat science.** 20: 217-236.
- Locker, R.H. 1989: Muscle into meat. In: Meat production and processing. Purchas, R.W., Butler-Hogg, B.W., Davies, A.S. Eds. pp. 173-183. NZSAP Simon print Ltd, Palmerston North.
- Lochner, J.V., Kaufman, R.G., Marsh, B.B. 1980: Early-postmortem cooling rate and beef tenderness. **Meat science.** 4: 227-241.
- Lusby, K.S., Wyatt, R.D., Stephens, D.F., Totusek, R. 1975: Feedlot performance and carcass merit of the third calves from Hereford, Hereford x Holstein and Holstein cows. In: Animal science and industry. Research report pp. 36-40. Oklahoma State University and USDA.
- Lundberg, P., Vogel, H.J., Fabiansson, S., Ruderus, H. 1987: Post-mortem metabolism in fresh porcine, ovine, and frozen bovine muscle. **Meat science.** 19: 1-14.
- Ma, R.T-I., Addis, P.B. 1973: The association of struggle during exsanguination to glycolysis, protein solubility and shear in turkey pectoralis muscle. **Journal of food science.** 38: 995-997.
- Martin, T.G., Drake, M.K., Garrigus, R.R., Perry, T.W., Beeson, W.M. 1965: Carcass traits of Hereford and Charolais x Hereford heifers. **Journal of animal science.** 24: 866 (Abs)
- Martin, A.H., Fredeen, H.T. 1974: Postmortem pH change as related to tenderness and water-holding capacity of muscle from steer, bull and heifer carcasses. **Canadian journal of animal science.** 54: 127-135.
- Marsh, B.B. 1954: Rigor mortis in beef. **Journal of the science of food and agriculture.** 5: 70-75.
- Marsh, B.B., Thompson, J.F. 1958: Rigor mortis and thaw rigor in lamb. **Journal of the science of food and agriculture.** 9: 417-424.
- Marsh, B.B., Leet, N.G. 1966: Studies in meat tenderness. III. The effects of cold-shortening on tenderness. **Journal of food science.** 31: 450-459.

- Marsh, B.B., Lochner, J.V., Takahashi, G., Kragness, D.D. 1981: Effect of early-postmortem pH and temperature on beef tenderness. **Meat science**. **5**: 479-483.
- Marsh, B.B., Ringkob, T.P., Russel, R.L., Swartz, D.R., Pagel, L.A. 1987: Effects of early-postmortem glycolytic rate on beef tenderness. **Meat science**. **21**: 241-248.
- Matyniak, J., Ziiolecki, J. 1983: Changes in some biochemical and physical characteristics of duck meat kept under deep chilled storage. **Fleischwirtsch.** **63**: 597-598.
- Machlik, S.M., Draudt, H.N. 1963: The effect of heating time and temperature on the shear of beef semitendinosus muscle. **Journal of food science**. **28**: 711-718.
- McIntyre, B.L. 1984: Technical basis of objective measurement. Animal production in Australia. **Proceedings of the Australian Society of Animal Production**. **15**: 40-47.
- McVeigh, J.M., Tarrant, P.V. 1983: Effect of propranolol on muscle glycogen metabolism during social regrouping of young bulls. **Journal of animal science**. **56**: 71-80.
- Mendenhall, V.T. 1989: Effects of pH and total pigment concentration on the internal color of cooked ground beef patties. **Journal of food science**. **54**: 1-2.
- Meat research institute 1973-74: The flavour of meat. Annual report pp.15-22. Langford, Bristol, BS187DY.
- Morgan, J.H.L., McKeown, D.W., Saul, G.R. 1978a: Breed and crossing effects on post-weaning growth rate of steers. **Proceedings of The Australian society of animal production**. **12**: 182
- Morgan, J.H.L., Clark, A.J., McKeown, D.W., Saul, G.R. 1978b: Breed and crossing effects on carcass characteristics of steers. **Proceedings of Australian society of animal production**. **12**: 183.
- Morgan, J.H.L. 1981: A comparison of breeds and their crosses for beef - production. II: Growth and puberty of heifers. **Australian journal of agricultural research**. **32**: 839-844.
- Moody, W.G. 1983: Beef flavour-A review. **Food technology**. **37(5)**: 227-232 and 238.
- More O'Ferrall, G.J., Joseph, R.L., Tarrant, P.V., McGloughlin, P. 1989: Phenotypic and genetic parameters of carcass and meat-quality traits in cattle. **Livestock production science**. **21**: 35-47.
- Moller, A.J. 1981: Analysis of Warner-Bratzler shear pattern with regard to myofibrillar and connective tissue components of tenderness. **Meat science**. **5**: 247-260.

- Moller, A.J., Bouton, P.E., Harris, P.V., Jones, P.N. 1982: A comparison between two different shear systems used for measuring meat tenderness. **Journal of food science.** **47:** 1354-1357 and 1364.
- Moller, A.J., Vestergaard, T. 1987: Effect of delay time before chilling on toughness in pork with high or low initial pH. **Meat science.** **19:** 27-37.
- Moller, A.J., Kirkegaard, E., Vestergaard, T., 1987: Tenderness of pork muscles as influenced by chilling rate and altered carcass suspension. **Meat science.** **21:** 275-286.
- Monin, G., Mejenes-Quijiano, A., Talmant, A. Sellier, P. 1987: Influence of breed and muscle metabolic type on muscle glycolytic potential and meat pH in pigs. **Meat science.** **20:** 149-158.
- Moore, V.J., Gill, C.O. 1987: The pH and display life of chilled lamb after prolonged storage under vacuum or under CO₂. **New Zealand journal of agricultural research.** **30:** 449-452.
- Newbold, R.P., Harris, P.V. 1972: The effect of pre-rigor changes on meat tenderness. **Journal of food science.** **37:** 337-340.
- Newbold, B., Small, L.M. 1985: Electrical stimulation of post-mortem glycolysis in the semitendinosus muscle of sheep. **Meat science.** **12:** 1-16.
- Newton, K.G., Gill, C.O. 1980-81: The microbiology of DFD fresh meats: A review. **Meat science.** **5:** 223-232.
- New Zealand Meat Producers Board 1979: New Zealand Meat A Trade Guide. New Zealand Meat Producers Board, Wellington.
- New Zealand Meat Producers Board 1988: New Zealand beef export carcass classification. New Zealand Meat Producers Board, Wellington.
- Ockerman, H.W., Cahill, V.R. 1969: Reflectance as a measure of pork and beef muscle tissue colour. **Journal of animal science.** **28:** 750-754.
- Ockerman, H.W., Jaworek, D., VanStevern, B., Parret, N., Pierson, C.J. 1984: Castration and sire effects on carcass traits, meat palatability and muscle fibre characteristics in Angus cattle. **Journal of animal science.** **59:** 981-990.
- Offer, G., Trinick, J. 1983: On the mechanism of water-holding capacity in meat: The swelling and shrinking of myofibrils. **Meat science.** **8:** 245-281.
- O'Keeffe, M., Hood, D.E. 1982: Biochemical factors influencing metmyoglobin formation on beef from muscles of differing colour stability. **Meat science.** **7:** 209-228.
- Olson, D.G., Parrish Jr, F.C., Stromer, M.H. 1976: Myofibril fragmentation and shear resistance of three bovine muscles during post-mortem storage. **Journal of food science.** **41:** 1036-1041.

- Paul, P.C., McCrae, S.E., Hofferber, L.M. 1973: Heat-induced changes in extractability of beef muscle collagen. **Journal of food science**. **38**: 66-68.
- Patterson, B.C., Jones, K.W., Gee, D.H., Costello, W.J., Romances, J.R. 1988: Effects of carcass chilling temperature on loin steaks from bulls and steers. **Journal of food quality**. **11**: 43-52.
- Pearson, A.M. 1963: Objective and subjective measurements for meat tenderness. Proceeding meat tenderness symposium pp. 135-160.
- Pearson, A.M. 1966: Desirability of beef-its characteristics and their measurement. **Journal of animal science**. **25**: 853-854.
- Pearson, A.M., Dutson, T.R. 1985: Scientific basis of electrical stimulation. **Advances in meat research**. **1**: 185-218.
- Pearson, A.M. 1986: Physical and biochemical changes occurring in muscle during storage and preservation. In: Muscle as food. P.J. Bechtel Ed. pp.103-134. Academic press, Inc.
- Penny, I.F., Voyle, C.A., Lawrie, R.A. 1963: A comparison of freeze-dried beef muscle of high or low ultimate. **Journal of the science of food and agriculture**. **14**: 535-543.
- Purchas, R.W. 1972: The relative importance of some determinants of beef tenderness. **Journal of food science**. **37**: 341-345.
- Purchas, R.W., Davies, H.L. 1974a: Meat production of Friesian steers: The effect of intramuscular fat on palatability and the effect of growth rates on composition changes. **Australian journal of agricultural research**. **25**: 667-677.
- Purchas, R.W., Davies, H.L. 1974b: Carcass and meat quality of Friesian steers fed on either pasture or barley. **Australian journal of agricultural research**. **25**: 183-192.
- Purchas, R.W., Barton, R.A. 1976: The tenderness of meat of several breeds of cattle raised under New Zealand pastoral conditions. **New Zealand journal of agricultural research**. **19**: 421-428.
- Purchas, R.W., Johnson, C.B., Birch, E.J., Winger, R.J., Hagyard, C.J., Keogh, R.G. 1986: Flavour studies with beef and lamb. Massey University.
- Purchas, R.W., Barton, A.R., Andrew, W.G.K. 1988a: An investigation into nature of meat tenderness differences in genetic lines of beef Shorthorn cattle. Proceedings 3rd world congress on sheep and beef cattle breeding 1: 504-507.
- Purchas, R.W., Pearson, G., Carr, J.R. 1988b: Effect of sampling site within two muscles, body weight, sex, and feeding level on the quality of meat from pigs. **New Zealand journal of agricultural research**. **31**: 41-49.
- Purchas, R.W. 1988: The contribution of meat pH differences to the relative tenderness of meat from bulls and steers. Proceedings of the 34th

International congress of meat science and technology. Part A: 213-215. Brisbane.

- Purchas, R.W. 1989a: An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. **Meat science**.(in press).
- Purchas, R.W. 1989b: On-farm factors affecting meat quality characteristics. pattern of change during growth and development. In: Meat production and processing. Purchas, R.W., Butler-Hogg, B.W., Davies, A.S. Eds. pp. 159-171. NZSAP Simon print Ltd, Palmerston North.
- Rao, M.V., Gault, N.F.S., Kennedy, S. 1989: Variation in water-holding capacity due to changes in the fibre diameter, sarcomere length and connective tissue morphology of some beef muscles under acid conditions below the ultimate pH. **Meat science**. **26**: 19-37.
- Reiley, R.R., Smith, G.C., Cross, H.R., Savell, J.W., Long, C.R., Cartwright, T.C. 1986: Chronological age and breed-type effects on carcass characteristics and palatability of bull beef. **Meat science**. **17**: 187-198.
- Rey, C.R., Kraft, A.A., Topel, D.G., Parrish, F.C.Jr., Hotchkiss, D.K. 1976: Microbiology of pale, dark, and normal pork. **Journal of food science**. **41**: 111-116.
- Reagan, J.O., Carpenter, Z.L., Smith, G.C., King, G.T. 1971: Comparison of palatability traits of beef produced by young bulls and steers. **Journal of animal science**. **32**: 641-646.
- Rhodes, D.N., Jones, R.C.D., Chrystall, B.B., Harries, J.M. 1972: Meat texture. II: The relationship between subjective assessments and a compressive test on roast beef. **Journal of texture studies**. **3**: 298-309.
- Roger, P.J., Ritchey, S.J. 1969: Sensory differentiation of beef tenderness and juiciness components over short intervals of cooking time. **Journal of food science**. **34**: 434-435.
- Robertson, J., Bouton, P.E., Harris, P.V., Macfarlane, J.J., Shorthose, W.R. 1984: Pressure-heat treatment of meat : A comparison of beef and buffalo meat. **Meat science**. **10**: 285-292.
- SAS 1985: User's guide: Statistic version, 5th edition. SAS Institute Inc. Carry NC, USA.
- Savell, J.W., Dutson, T.R., Smith, G.C., Carpenter, Z.L. 1978; Structural changes in electrically stimulated beef muscle. **Journal of food science**. **43**: 1606-1607 and 1609.
- Scarcy, D.J., Harrison, D.L., Anderson, L.L. 1969: Palatability and selected related characteristics of three types of roasted porcine muscle. **Journal of food science**. **34**: 486-489.

- Scopes, R.K. 1974: Studies with a reconstituted muscle glycolytic system. The rate and extent of creatine phosphorylation by anaerobic glycolysis. **Biochemical journal**. **138**: 119-123.
- Seideman, S.C., Cross, H.R., Oltjen, R.R., Schanbacher, B.D. 1982: Utilization of the intact male for red meat production: A review. **Journal of animal science**. **55**: 626-838.
- Seideman, S.C., Cross, H.R., Crouse, J.D. 1984: The effect of sex and age on the textural properties and mineral content of beef steaks. **Journal of food quality**. **7**: 91-96.
- Seideman, S.C. 1986: Methods of expressing collagen characteristics and their relationship to meat tenderness and muscle fibre types. **Journal of food science**. **51**: 273-276.
- Seideman, S.C., Cross, H.R., Crouse, J.D. 1989: Variations in the sensory properties of beef as affected by sex condition, muscle and postmortem aging. **Journal of food quality**. **12**: 39-58.
- Seideman, S.C., Theer, L.K. 1986: Relationships of instrumental textural properties and muscle fiber types to the sensory properties of beef. **Journal of food quality**. **9**: 251-161.
- Sleper, P.S., Hunt, M.C., Kropf, D.H., Kastner, C.L., Dikeman, M.E. 1983: Electrical stimulation effects on myoglobin properties of bovine longissimus muscle. **Journal of food science**. **48**: 479-483.
- Smith, G.C., Arango, T.C., Carpenter, Z.L. 1971: Effects of physical and mechanical treatments on the tenderness of the beef longissimus. **Journal of food science**. **36**: 445-449.
- Smith, G.C., Savell, J.W., Cross, H.R., Carpenter, Z.L. 1983: The relationship of USDA quality grade to beef flavor. **Food technology**. **37(5)**: 233-238.
- Smith, W.C., Lesser, D. 1982: An economic assessment of pale, soft exudative musculature in the fresh and cured pig carcass. **Animal production**. **34**: 291-299.
- Smulders, F.J.M., Eikelenboom, G., Van logtestijn, J.G. 1986: The effect of electrical stimulation on the quality of three bovine muscles. **Meat science**. **16**: 91-101.
- Southgate, J.R., Cook, G.L., Kempster, A.J. 1982: A comparison of the progeny of British Friesian dams and different sire breeds in 16- and 24-month beef production systems. I. Live-weight gain and efficiency of food utilization. **Animal production**. **34**: 155-166.
- Spindler, A.A., Mathias, M.M., Cramer, D.A. 1980: Growth changes in bovine muscle fibre types as influenced by breed and sex. **Journal of food science**. **45**: 29-31.
- Stone, H., Sidel, J., Oliver, s., Woolsey, A., Singleton, R.C. 1974: Sensory evaluation by quantitative descriptive analysis. **Food technology**. **28(11)**: 24-34.

- Stromer, M.H., Goll, D.E. 1967: Molecular properties of post-mortem muscle. II. Phase microscopic of myofibrils from bovine muscle. **Journal of food science.** **32:** 329-331.
- Strange, E.D., Benedict, R.C., Gugger, R.E., Metzger, V.G., Swift, C.E. 1974: Simplified methodology for measuring meat colour. **Journal of food science.** **39:** 988-992.
- Stanton, C., Light, N.D. 1988: The effects of conditioning on meat collagen: Part 2. Direct biochemical evidence for proteolytic damage in insoluble perimysial collagen after conditioning. **Meat science.** **23:** 179-199.
- Szczesniak, A., Torgeson, K.W. 1965: Methods of texture measurement viewed from the background of factors affecting tenderness. **Advances in food research.** **14:** 33-165.
- Szczesniak, A.S. 1968: Correlations between objective & sensory texture measurements. **Food technology.** **22:** 979-987.
- Taylor, D.G. 1982: A comparative study of Hereford and Friesian steers. II Carcass characteristics and meat quality. **Australian journal of agricultural research** **33:** 157-163.
- Tarrant, P.V., Mothersill, C. 1977: Glycolysis and associated changes in beef carcasses. **Journal of the science of food and agriculture.** **28:** 739-749.
- Tarrant, P.V., Kenny, F.J., Harrington, D. 1988: The effect of stocking density during 4 hour transport to slaughter on behaviour, blood constituents and carcass bruising in Friesian steers. **Meat science.** **24:** 209-222.
- Tarrant, P.V. 1977: The effect of hot-boning on glycolysis in beef muscle. **Journal of the science of food and agriculture.** **28:** 927-930.
- Topel, D.G., Miller, J.A., Berger, P.J., Rust, R.E., Parrish, F.C.Jr., Ono, K. 1976: Palatability and visual acceptance of dark, normal, pale coloured porcine *M. longissimus*. **Journal of food science.** **41:** 628-630.
- Trout, G.R. 1989: Variation in myoglobin denaturation and colour of cooked beef, pork, and turkey meat as influenced by pH, sodium chloride, sodium triphosphate and cooking temperature. **Journal of food science.** **54:** 536-540.
- Unruh, .A., Kastner, C.L., Kropf, D.H., Dikeman, M.E., Hunt, M.C. 1986a: Effects of low-voltage electrical stimulation on meat quality and display colour stability. **Meat science.** **18:** 281-293.
- Unruh, J.A., Gray, D.G., Dikeman, M.E. 1986b: Implanting young bulls with zeranol from birth to four slaughter ages: I. Live measurements, behavior, muscularity and carcass characteristics. **Journal of animal science.** **62:** 279-289.
- Unruh, J.A., Pelton, C.D., Gray, D.G., Dikeman, M.E., Allen, D.M., Corah, L.R. 1987: Effects of zeranol-implantation periods on palatability of

- longissimus steaks from young bulls and steers. **Journal of animal science**. **65**: 165-172.
- Vanderwert, W., McKeith, F.K., Bechtel, P.J., Berger, L.L. 1986: Influence of zeranol implants and electrical stimulation on the palatability traits of five muscles in Angus and Limousin Bulls and steers. **Journal of animal science**. **63**: 114-120.
- Visser, I.J.R., Koolmees, P.A., Bijker, P.G.H. 1988: Microbiological conditions and keeping quality of veal tongues as affected by lactic acid decontamination and vacuum packaging. **Journal of food protection**. **51**(3): 208-213.
- Voisey, P.W. 1971: Review paper: Modernization of texture instrumentation. **Journal of texture studies**. **2**: 129-195.
- Warris, P.D., Kestin, S.C., Brown, S.N., Wilkins, L.J. 1984: The time required for recovery from mixing stress in young bulls and the prevention of dark cutting beef. **Meat science**. **10**: 53-68.
- Walters, C.L. 1975: In: Meat colour: The importance of haem chemistry. In: Meat. Cole, D.J.A., Lawrie, R.A. Eds. pp.385-401. Butterworth, London.
- Whiting, R.C. 1980: Calcium uptake by bovine muscle mitochondria and sarcoplasmic reticulum. **Journal of food science**. **49**: 157-160.
- Will, P.A., Ownby, C.L., Henrickson, R.L. 1980: Ultrastructural postmortem changes in electrically stimulated bovine muscle. **Journal of food science**. **45**: 21-25 and 34.
- Willham, R.L. 1973: Dairy beef crossbreeding for Cornbelt beef production: Single-cross steer performance. In: Crossbreeding beef cattle series2. Koger, M., Cunha, T.J., Warnick, A.C. Eds. pp. 194-201. University of Florida press. Gainesville.
- Wiskus, K.J., Addis, P.B., Ma, R.T-I. 1976: Distribution of **beta red, alpha red and alpha white** fibres in turkey muscles. **Poultry science**. **55**: 562-572.
- Wu, J.J., Dutson, T.R., Carpenter, Z.I. 1982: Effect of post-mortem time and temperature on bovine intramuscular collagen. **Meat science**. **7**: 161-168.
- Wythes, J.R., Arthur, R.J., Thompson, P.J.M., Williams, G.E., Bond, J.H. 1981: Effect of transporting cows various distances on liveweight, carcass traits and muscle pH. **Australian journal of experimental agriculture and animal husbandry**. **21**: 557-561.
- Wythes, J.R., Arthur, R.J., Dodt, R.M., Shorthose, W.R. 1988: Cattle handling at abattoirs. II The effects of rest in transit and duration of the resting period before slaughter on carcass weight, bruising and muscle properties. **Australian journal of agricultural research**. **39**: 97-107.

- Yates, L.D., Dutson, T.R., Caldwell, J., Carpenter, Z.L. 1983: Effect of temperature and pH on the post-mortem degradation of myofibrillar proteins. **Meat science**. **9**: 157-179.
- Yu., L.P., Lee, Y.B. 1986: Effects of postmortem pH and temperature on bovine muscle structure and meat tenderness. **Journal of food science**. **51**: 774-780.
- Ziegler, J.H., Wilson, L.L., Coble, D.S. 1971: Comparisons of certain carcass traits of several breeds and crosses of cattle. **Journal of animal science**. **32**: 446-450.

APPENDICES

Appendix 1 Least-squares means of dressing-out percentage for Friesian bulls, Friesian steers and Charolais x Angus cross steers within each slaughter lot. The interaction between Lot and Group was significant ($P < 0.05$).

Group	Lot				Overall means
	1	2	3	4	
Friesian-bulls	49.64 ^a	51.56 ^a	51.11 ^a	49.57 ^a	50.47 ^a
Friesian-steers	50.91 ^{ab}	51.71 ^{ab}	49.09 ^b	52.17 ^{bc}	50.97 ^a
Charolais-steers	51.91 ^b	53.28 ^b	51.44 ^a	53.88 ^c	52.61 ^b
Overall means	50.80 ^d	52.18 ^e	50.55 ^d	51.88 ^e	

a, b, c Means in the same column with different superscripts are different ($P < 0.05$)
d, e Means in the same row with different superscripts are different ($P < 0.05$).

Appendix 2 Simple correlation coefficients between cut weights and some carcass characteristics used as independent variables in regression equations.

Cuts	Correlation with			
	Carcass cut	Rib-eye area	Carcass length	Fat depth
1 Tenderloin	0.70	0.67	-0.30	-0.05
2 Striploin	0.66	0.67	-0.46	0.34
3 Rump	0.77	0.65	-0.41	0.28
4 Topside	0.68	0.71	-0.42	0.15
5 Knuckle	0.73	0.60	-0.43	0.20
6 Silverside	0.73	0.56	-0.56	0.30
7 Sum of 4, 5, 6	0.75	0.65	-0.51	0.24
8 Sum of all 6 cuts	0.78	0.70	-0.50	0.26

Appendix 3 Simple correlation coefficients between individual cuts calculated for actual cut weights (below the diagonal) and as percentages of carcass weight (above the diagonal). The number along the top of the table corresponds to the numbered variables listed on the left hand side.

Actual weight	Percent of carcass weight								
		1	2	3	4	5	6	7	8
1	Tenderloin		0.41	0.50	0.61	0.66	0.47	0.63	0.68
2	Striploin	0.67		0.50	0.55	0.51	0.60	0.62	0.74
3	Rump	0.75	0.70		0.53	0.57	0.65	0.66	0.78
4	Topside	0.82	0.72	0.79		0.78	0.70	0.88	0.84
5	Knuckle	0.80	0.75	0.78	0.88		0.67	0.90	0.86
6	Silverside	0.73	0.75	0.82	0.85	0.85		0.90	0.89
7	Sum of 5, 6, 7	0.83	0.78	0.84	0.94	0.94	0.95		0.96
8	Sum of all 6 cuts	0.84	0.84	0.90	0.93	0.93	0.94	0.98	

Appendix 4 Simple correlation coefficients between cut weights from each side, calculated for actual cut weights and as percentages of carcass weight.

Item	Correlation coefficients	
	wt vs wt	% vs %
Tenderloin	0.84	0.71
Striploin	0.74	0.62
Rump	0.89	0.79
Topside	0.85	0.75
Knuckle	0.79	0.60
Silverside	0.90	0.82
Sum 3-cuts	0.96	0.92
Sum 6-cuts	0.97	0.95