INFLUENCE OF PRE-SLAUGHTER HOLDING TIME, GROWTH PATH AND CASTRATION ON MEAT QUALITY CHARACTERISTICS OF BEEF *M. LONGISSIMUS THORACIS*

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ABSTRACT

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The New Zealand Beef Industry has included among its research goals the need to enhance product consistency and consumer satisfaction. Identifying on-farm and post-slaughter techniques for producing quality meat will permit the delivery of a more consistent product.. The objectives of this study were to examine the influence of castration, pre-slaughter holding time, and growth path on meat quality characteristics with emphasis on meat tenderness. Sixty male Hereford x Angus cattle were used, half of which were castrated at weaning. They were then ranked within their castration groups on their growth performance during a 100-day pre-trial period. Of the 40 faster-growing animals, 20 were randomly selected to be slaughtered at 16-18 months of age at approximately 550 kg liveweight (the fast group; F) and the remaining 20 were managed in such a way that they reached the same liveweight as the slower-growing 20 animals (S) at 25 months of age (restricted group; R). Once at the abattoir half the animals were randomly selected within castration and growth path groups to be held for either 4 or 28 hours pre-slaughter. Measures of meat quality characteristics were made on a sample of the *M. longissimus thoracis*, of each animal that was removed soon after slaughter. The bulls produced meat with higher ultimate pH values (5.64 vs 5.46, $P<0.001$) and meat that was significantly tougher than steers as evaluated by MIRINZ peak force (6.6 vs 4.6 kg, $P<0.001$), and sensory toughness (6.10 vs 4.50, $P<0.001$), both before and after adjustment for differences in pH. Animals held for 4h pre-slaughter had tougher meat as measured by Instron compression maximum load (92.8 vs 82.0, $P<0.05$). Cattle in Group F produced meat that had a higher ultimate pH ($P<0.001$), however, meat from animals in Group F was significantly more tender as measured by sensory analysis ($P<0.001$). There were few differences between cattle in Groups R and S suggesting that differences in tenderness in this and other studies between animals on fast and slow growth rates were a result of differences in animal age rather than in inherent growth potential of the animals. Results suggest that holding cattle under appropriate welfare standards and allowing them enough time to recover from trucking and environmental stress should result in acceptable meat. Results from this trial have practical implications for producers and processors, and for the production of beef for the New Zealand Quality Mark. In this trial beef was tougher when it was from bulls or from older groups of cattle, with these two effects appearing to be additive. It is therefore suggested that cattle age and gender criteria should be considered for inclusion in the Quality Mark system.

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ERRATA

Page	Paragraph	Line	Correct item	Item to be replaced
27	2	7	(Purchas & Grant 1995)	(Purchas & Grant 1997)
42	1	1	Figure 3.2	Figure 3.1
46	3	2	Figures 3.3 and 3.4	Figures 3.2 and 3.3
47	1	2	Figure 3.3	Figure 3.2
48	1	4	Figure 3.4	Figure 3.3
49	1	7	Purchas & Grant (1995)	Purchas & Grant (1997)
50	4	3	Purchas & Grant 1995	Purchas & Grant 1997
51	1	1	Purchas & Grant (1995)	Purchas & Grant (1997)
52	4	1	Purchas & Grant (1995)	Purchas & Grant (1997)
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References:
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Hood, D.E.; Tarrant, P.V. 1981: The problem of dark cutting in beef. Martinus Nijhoff, The Hague.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

*	P<0.05
**	P<0.01
***	P<0.001
+	P<0.1
NS	P>0.1
%	percent
°C	degrees Celsius
µm	micrometre
c/kg	cents per kilogram
cm^2	centimetre squared
cm^2/g	centimetre squared per gram
g	gram
g/kg	gram per kilogram
kg	kilogram
kg/day	kilogram per day
kgf	kilogram force
kPa	kiloPascals
mg	milligram
ml	millilitre
mm	millimetre
mm/min	millimetre per minute
mm^3	millimetre cubed
mW	milli Watts
nm	nanometres
&	and
28h	28 hour pre-slaughter holding period
3Cut Wt	joint weight of 3 muscle cuts – knuckle, outside and inside
4h	4 hour pre-slaughter holding period
c.	about
CC Length	carcass length
CL	cooking loss
Cohes	cohesiveness
Cwt	carcass weight
Dchew	deviations from mean for chewiness
Dcohes	deviations from mean for cohesiveness
Dhardness	deviations from mean for hardness
Dinijuic	deviations from mean for initial juiciness
Dovjuice	deviations from mean for overall juiciness
Dr%	dressing-out percentage
Dtoughness	deviations from mean for toughness
EMA	eye muscle area
EXJ	expressed juice
F group	fast growth path group
FD	fibre diameter
hr	hour
Inijuic	initial juiciness

IY	initial yield
KCl	potassium chloride
KP Fat	kidney and pelvic fat
LD	*longissimus dorsi*
LD2	load at 20 mm
LD8	load at 80 mm
LSMeans	least square means
Lwt	liveweight
Max	maximum
MFI	myofibrillar fragmentation index
mo	months of age
NaCl	sodium chloride
n	number
Ovjuice	overall juiciness
PF	peak force
PF-IY	peak force minus initial yield
pH_u	ultimate pH
R group	restricted growth path group
r	correlation coefficient
R^2%	coefficient of determination
RMSE	residual means standard error
RSD	residual standard deviation
S group	slow growth path group
Sarco	sarcomere length
SE	standard error
Sig	significance
TotalWD	total work done
vs	versus
WB	Warner-Bratzler
Wt	weight

CHAPTER ONE

INTRODUCTION

New Zealand's meat industry vision for the future is "to be the preferred source of quality meat products in major markets" (Meat New Zealand 1998). In order to achieve this vision Meat New Zealand has included amongst its research goals the need for product differentiation and the need to enhance product consistency and consumer satisfaction, including the improvement of tenderness of prime beef cuts through production and processing. The establishment of quality standards through the beef quality mark has enabled Meat New Zealand to issue guidelines pertaining to acceptable levels of meat quality for all areas of beef production and processing. Identifying on-farm and post-slaughter techniques of producing quality meat will allow for the delivery of a more consistent product, which will aid in strengthening New Zealand's market position in the target markets.

Of the attributes of the eating quality of beef, tenderness has most often been ranked first (Baron 1984). Detecting factors that determine tenderness of beef and identifying on-farm or pre-slaughter management methods that can alter tenderness in beef will allow the farmers to more readily produce meat that fulfils beef quality and consumer standards. Quality of beef and especially tenderness is determined by many factors via intrinsic determinants such as activity of proteolytic enzymes, ultimate pH, rate of glycolysis or state of muscle contraction. These intrinsic determinants are linked to the biological factors that are known to affect tenderness such as animal age, sex, nutritional status or stress levels pre-slaughter.

Objectives of the trial reported here were to examine the influence of castration, pre-slaughter holding time and growth path on meat quality generally and especially on tenderness of beef from *M. longissimus thoracis.*

Following this introduction (Chapter 1) the thesis includes a review of literature relating to the subject of beef quality (Chapter 2), a self-contained scientific paper giving the results of the experimental work and containing an introduction to the trial, discussion and conclusion (Chapter 3), and finally a general discussion and conclusions (Chapter 4).

CHAPTER TWO

REVIEW OF LITERATURE REGARDING FACTORS AFFECTING MEAT QUALITY

2.1 INTRODUCTION

Animal age, growth path of the animal, pre-slaughter holding time and castration may all have a significant influence on important beef quality parameters.

This literature review will look at the influence of these on-farm and pre-slaughter factors on meat quality determinants such as fat levels, collagen content, meat pH, muscle fibre type and rate of proteolysis. It will also cover the effect of meat quality determinants on quality parameters including juiciness, meat colour and especially tenderness.

2.2 EFFECT OF ANIMAL AGE ON MEAT QUALITY

2.2.1 Introduction

The effect of animal age on beef tenderness has been the subject of considerable research and when differences exist most results suggest that the meat from older animals is less likely to be tender than that from younger animals (Wulf et al. 1996; Purchas et al. 1997). However, some studies have shown little or no change in tenderness with increasing animal age (Ritchey & Hostetler 1964; Bond et al. 1982) and others have noted an increase in tenderness with animal age (Bouton et al. 1978a; Powell 1991). Reasons for the alternative results include the differences in connective tissue content between different muscles in the same animal, a corresponding increase in animal condition with age, and cooking conditions of the cut of meat in question. A summary of a sample of findings on effects of animal age is presented in Table 2.1. The influence of animal age on beef tenderness and the factors that cause the differences in reported results are discussed below.

Table 2.1 A summary of results from a sample of selected trials showing the effect of animal age on beef tenderness.

Reference	Outline	Results and Conclusion
Jacobson & Fenton (1956)	The *longissimus dorsi*, *psoas major* and *semimembranosis* muscles were collected from 24 heifers in 4 different age groups (8, 11, 16 and 20 months of age) and evaluated using the Warner-Bratzler shear device and a sensory panel.	Tenderness scores for the sensory panel decreased with increasing age (scores of 7.6, 8.1, 6.7, 6.4 for the animals at 8, 11, 16 and 20 months of age, respectively, for the *longissimus* muscle) while Warner-Bratzler values increased (12, 15, 18 and 22 kg). Similar results were found for the other muscles. Levels of significance were not reported.
Arthaud et al. (1977)	Two Hundred and fifty six Angus cattle were slaughtered in one of four age groups: 12, 15, 18 or 24 months of age. Tenderness of the *longissimus* muscle was evaluated by Warner-Bratzler shear and a sensory panel.	There was no effect of animal age on tenderness in terms of either Warner-Bratzler shear or sensory score between all age groups.
Dikeman et al. (1986)	One hundred and forty four Angus cattle slaughtered at 12, 15, 18 and 24 months of age. Tenderness of the *longissimus* muscle was evaluated by Warner-Bratzler shear and a sensory panel.	There were no slaughter age differences in Warner-Bratzler shear or sensory panel scores.
Shorthose & Harris (1990)	Twelve selected muscles were used from 8 beef animals in each of 8 different age groups – 1, 10, 18, 24, 30 and 60 months of age. Tenderness was evaluated by Warner-Bratzler shear and a sensory panel.	Increasing animal age had a large and highly significant ($P<0.001$) detrimental linear effect on tenderness in both Warner-Bratzler shear and sensory evaluation. This was particularly marked in those muscles with a higher connective tissue content.
Powell (1991)	Tenderness of the *longissimus dorsi* muscles from non-electrically stimulated beef cattle aged 18 or 54 months, which were chilled quickly, was evaluated using Warner-Bratzler shear force.	Warner-Bratzler shear force values were 14.5 vs 10.2 kg for the 18- and 54-month old animals, respectively ($P<0.05$) as a result of the influence of the older fatter carcasses chilling at a slower rate which resulted in less cold shortening than the younger, leaner and lighter animals.
Purchas & Grant (1995)	Warner-Bratzler shear measurements were made on samples of the *M. longissimus* taken from 40 Hereford bulls, 40 Hereford x Friesian bulls and 40 Friesian (Hereford x Angus) steers slaughtered at either 20- or 28-months of age.	Animals slaughtered at 28-months of age were significantly ($P<0.001$) tougher (13.80 kg) than those slaughtered at 20-months of age (9.85 kg). The higher shear values of the 28-month old animals were probably a reflection of less soluble collagen, although this was not measured in this study.

Reference	Outline	Results and Conclusion
Shackelford et al. (1995a)	The rib-eye rolls from 28 yearling heifers (19 mo) and 25 2 yr-old cows (31 mo) were used to evaluate tenderness using the Warner-Bratzler shear force and a trained sensory panel.	Differences between the two age groups for both Warner-Bratzler (6.0 kg vs 6.1 kg; 19 mo vs 31 mo) and the sensory panel (5.0 vs 4.6) were not significant.
Gullet et al. (1996)	*Longissimus dorsi* and *semitendinosis* muscles from one hundred and eight crossbred steers representing three age groups (12, 17 and 24 months) were used to evaluate tenderness both with a Warner-Bratzler shear device and with sensory analysis.	No significant age effects were obtained for shear measurements on *longissimus dorsi* samples. However, shear measurements on *semitendinosis* samples showed significant effects for age of animal. Significantly ($P<0.05$) lower shear values were obtained for samples from 12 month animals than from 17 and 24 month old animals.
Wulf et al. (1996)	The striploin, sirloin and round cuts were selected to measure the effect of animal age on tenderness of beef from Limousin steers aged from 15–18 months. Tenderness was evaluated by Warner-Bratzler shear and a sensory panel.	As Limousin steers matured over the narrow age range there were significant increases ($P<0.05$) in Warner-Bratzler shear and sensory panel scores especially in the high collagen cuts. The round cut was the toughest (4) followed by the sirloin (5) and then the striploin (5.5) when cooked medium-rare and as assessed by sensory panellists on a scale of 8 (extremely tender) to 1 (extremely tough). Similar results were found for Warner-Bratzler shear force.
Purchas et al. (1997)	Samples of the *M. longissimus thoracis* were collected from 158 mixed breed bulls aged either 20- or 28- months of age. Tenderness of the samples was measured using a Warner-Bratzler Shear device.	There was a significant ($P<0.01$) difference in Warner-Bratzler shear between the 20-month old group (12.14 kg) and the 28-month old group (14.52 kg), with the older animals being tougher.

2.2.2 Connective tissue

Older animals do not have greater concentrations of connective tissue in muscle in comparison with younger animals, but the extent of cross-linking increases with age and this may influence the tenderness of the meat. Changes in the connective tissue contribution to mechanical properties of cooked meat with increasing age depend upon a number of factors. It would be expected that the effects would be greatest in muscles with a greater abundance of connective tissue (Bouton et al. 1978a). Wulf et al. (1996) found decreases in tenderness with increasing age that were especially significant in high-collagen cuts. The high-collagen round cut was significantly tougher ($P<0.05$) than sirloin and strip loin (Figure 2.1), but especially so with increased animal age.

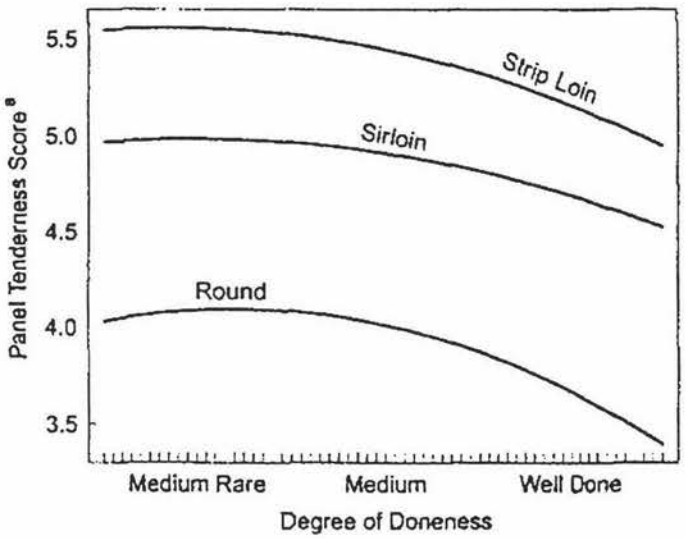

Figure 2.1 Effects of degree of doneness and cut on taste panel tenderness ratings of cooked steaks (RSD = 0.39). [a]8 = extremely tender; 1 = extremely tough (Wulf et al. 1996).

Collagen

Of the connective tissue components only collagen appears to be responsible for the differences in tenderness due to animal age. The contractile elements actin and myosin, which are in the non-connective tissue part of the muscle, cannot account for these changes since their metabolic turnover time is about 12 days (Bailey 1972). Therefore, even in an old animal the actin and myosin is not "old". In contrast collagen has a very long turnover time, thus giving time for the cross-links to accumulate and then stabilise themselves. The aggregation and cross-linking of collagen increases throughout life (Wenham et al. 1973). Maturation and aging also result in an increase in the force of contraction at the shrinkage temperature and a decrease in the rate of relaxation after shrinkage. Under normal cooking conditions, less

collagen is solubilised in meat from older animals. This situation results in a sensation of toughness when meat from older animals is consumed (Hill 1966).

Collagen is important in meat tenderness not only because of its concentration in muscle, but also because of its ability to undergo molecular changes during animal maturation (Cross et al. 1973). The physical properties of muscle collagen are determined by its specific composition resulting from a series of processes of synthesis and degradation of the protein during the preceding growth of the animal (Boccard et al. 1979). When meat is cooked collagen shrinks, swells, disintegrates and is solubilised. Analyses have shown that collagen is a strong inextensible fibre whose properties vary considerably with age of the animal (Bailey 1972). With increasing age the collagen becomes more thermally stable and much less soluble (Hill 1966). Dikeman & Tuma (1971) found that collagen solubility was highly related to the shear force and taste panel tenderness of steak.

Unruh et al. (1986) reported that total amount of collagen was lower in bulls at 12 and 13.8 months than 17.4 months. Between animals the age-associated increase in collagen cross-linking or decreased collagen solubility significantly affects muscle tenderness (Miller 1994). Cross et al. (1973) found that chronological age was significantly related to percentages of soluble collagen in muscle. Collagen solubility declines significantly with increasing age (Seideman 1986, Wulf et al. 1996), the number of intermolecular collagen cross-links increase (Cranwell et al. 1996) and collagen shrinkage temperatures for sheep leg muscles, loin and fillet increase in the same manner with increasing animal age (King 1989).

Dikeman et al. (1986) reported Warner Bratzler shear force values of 5.85 kg, 6.03 kg, 6.89 kg and 6.98 kg and tenderness scores of 7.06, 7.19, 7.35 and 7.01 for cattle aged 12 months, 15 months, 18 months and 24 months, respectively, for the *longissimus* muscle of bulls and steers combined. Although these values appeared to show a trend of decreasing tenderness with increasing age (except for tenderness score at 24 months) the shear force values were not significant. They did however find that the percentage of soluble collagen tended ($P< 0.05$) to be highest at 15 months and lowest at 24 months.

Therefore, increases in meat toughness with increasing animal age can be partly attributed to increases in the total amount of collagen and decreases in soluble collagen.

2.2.3 Animal condition and age effects

It is generally believed that toughness of meat increases with the age of the animal. However Wenham et al. (1973) found that, in lamb, rapid chilling or early freezing of pre-rigor carcasses could have dramatic effects on tenderness, which could overshadow age as a factor.

Smith et al. (1976) suggested that fatter lambs produce more tender muscle than leaner lambs because of the insulatory effect of fat in reducing cold-shortening. This creates a confounding effect when judging the influence of animal age on tenderness as often older animals are also grown to a heavier carcass weight (Powell 1991). For this reason trials which are performed to measure the influence of animal age on tenderness of the meat often manipulate growth rates of the animals to ensure that they reach the same slaughter weight regardless of age, although under commercial conditions greater age of the animal is usually associated with greater weights.

In an experiment performed by Powell (1991) on the tenderness of beef *longissimus dorsi* muscles from cattle that were either 18 or 54 months old, the chilling conditions of the experiment were rapid. As a result the non-electrically stimulated *longissimus dorsi* muscles cold shortened and were tough, although those from older animals less so (14.5 vs 10.2 kg Warner Bratzler shear force ($P< 0.05$) for 18- and 54-months of age respectively). A reason for this age effect may have been the influence of the older, fatter carcasses, which would have chilled at a slower rate resulting in less cold shortening than the younger, leaner and lighter animals.

Zinn et al. (1970) reported an interaction between the length of feeding time and maturity which indicated that at some point, animal age exerts a negative effect on tenderness which is greater than the positive effect of further time on feed. The *longissimus* muscle of steers and heifers with an initial age of 250 (± 45) days was most tender ($P<0.05$) at 150, 180 and 210 days on feed but after this point increasing animal age exerted a negative effect on the tenderness (as measured by Warner-Bratzler shear). Animals slaughtered at the end of their economic lives or with poor nutrition have moderately high ultimate pH values and the resulting toughness of meat is often attributed to age of the animal (Devine et al. 1993).

In a trial it can be difficult to separate the effects of animal age on meat tenderness from the effects of animal condition. This has been attempted by including a group of animals that are slaughtered at the same weight (and hopefully the same condition) at a different age.

2.2.4 Muscle type

Powell (1991) found that upon cold shortening of the *longissimus dorsi* (LD) muscles from 18 month or 54 month old beef there was a uniform increase in toughness across the ages. The LD is also known to have a low connective tissue content in its muscle structure so that the major contributor to its toughness is likely to be the myofibrillar proteins (Ritchey & Hostetler 1964; Shorthose & Harris 1990). Other valuable muscles such as the *semimembranosis* and *biceps femoris* are regarded as tougher than the LD (even when the effects of cold shortening are minimised) which is the result of the increased connective tissue content.

The LD is the muscle most frequently studied for effects of different treatments on meat quality attributes of beef animals. The tenderness of this muscle is also very dependent on the rate of cooling of carcasses which is important as the rate of chilling in relatively exposed muscles such as the *longissimus dorsi* would be affected by factors such as carcass weight and fat cover. (Shorthose & Harris 1990). It has been shown that the Warner-Bratzler shear force values obtained from LD muscles from 9, 16, 27 and 42 month old beef animals decreased (ie. tenderness increased) with increase in age and increase in animal carcass weight (Bouton et al. 1978a). In contrast the results of muscles restrained from shortening and thus effectively independent of chilling rate indicated that tenderness decreased with an increase in animal age. This work demonstrates that some muscles are affected by animal age more than others which suggests that if muscles that remain uniformly tender from older animals are able to be identified they could be included in a different classification and the rest of the carcass downgraded (Bouton et al. 1978a).

Treatment effects can affect meat quality characteristics in different muscles to different extents, as a consequence, care has to be taken in extrapolating results from one muscle to another.

2.2.5 Sex condition

There are significant decreases in tenderness due to increasing animal age in all sex groups (Bouton et al. 1978a). However Field et al. (1966) illustrated that age-related declines in tenderness are significantly more pronounced for bulls than steers and heifers, particularly in muscles high in collagen. This is thought to be due to an increase in rate of formation of cross-linking in collagen in the bulls compared to the other sex groups (Cross et al. 1984). As

a result, age related trials on the tenderness of meat from bulls could have different results to those from heifers or steers.

2.2.6 Post-mortem conditions

Sarcomere length

Sarcomere length is often affected by post-mortem conditions such as cold shortening and hanging position. In extreme cold shortening conditions the toughness due to contracted sarcomeres can often override the effect of collagen. As a result, the contribution to toughness of the meat by connective tissue due to animal age is difficult to assess (Bailey 1972). Work by Bouton et al. (1978b) showed that tenderness decreased with age when the effects of pre-rigor shortening on the properties of the selected muscles were avoided by hanging the pre-rigor carcass from the pelvis within 1 hr of slaughter, when pre-rigor shortening occurred the results were not significant.

Cooking Conditions

Wenham et al. (1973) found that older sheep including rams compared well in palatability with younger animals. This could be a result of larger carcasses and slower cooling rates. They also attributed the comparable tenderness to the cooking method. All samples were roasted in their trial, but they noted that mutton cooked by frying pan or grilling might well be tougher, since there is little time for any softening of connective tissue. They concluded that with adequate control of time and temperature relations in the post-mortem period, mutton from quite old animals, including rams, could readily be upgraded.

Bouton & Harris (1972b) also found large differences in beef tenderness of different age groups as a result of different cooking temperatures (see Figure 2.2). They found that Warner-Bratzler shear force values on the deep pectoral muscle of veal were highest at 40°C (least tender) and lowest at 70°C, while for old cows shear values were lower than those for veal at 40°C and 50°C, but higher at cooking temperatures of 60°C and 70°C. The authors suggest that the high shear force values of veal at a low cooking temperature were indicative of the greater amount of collagen per unit weight due to the smaller fibres as compared to the larger fibres of the old cows. The decrease in toughness of veal from 50°C to 60°C was due to the rapid solubilisation of the cross links, while the increase in toughness of the old cows over these temperatures was a result of an increase in myofibrillar protein denaturation. Solubilisation of the connective tissue of the old cows would occur at higher temperatures.

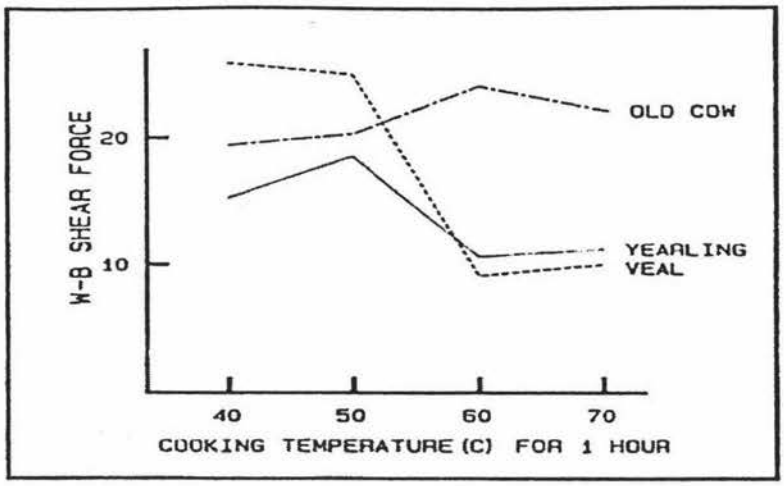

Figure 2.2 Cooking temperature effect on age-related tenderness changes (Based on results from Bouton & Harris 1972b).

2.2.7 Summary

Figure 2.3 shows a sample of the various pathways (both negative and positive) whereby increasing animal age may have an effect on the tenderness of meat from both sheep and beef cattle.

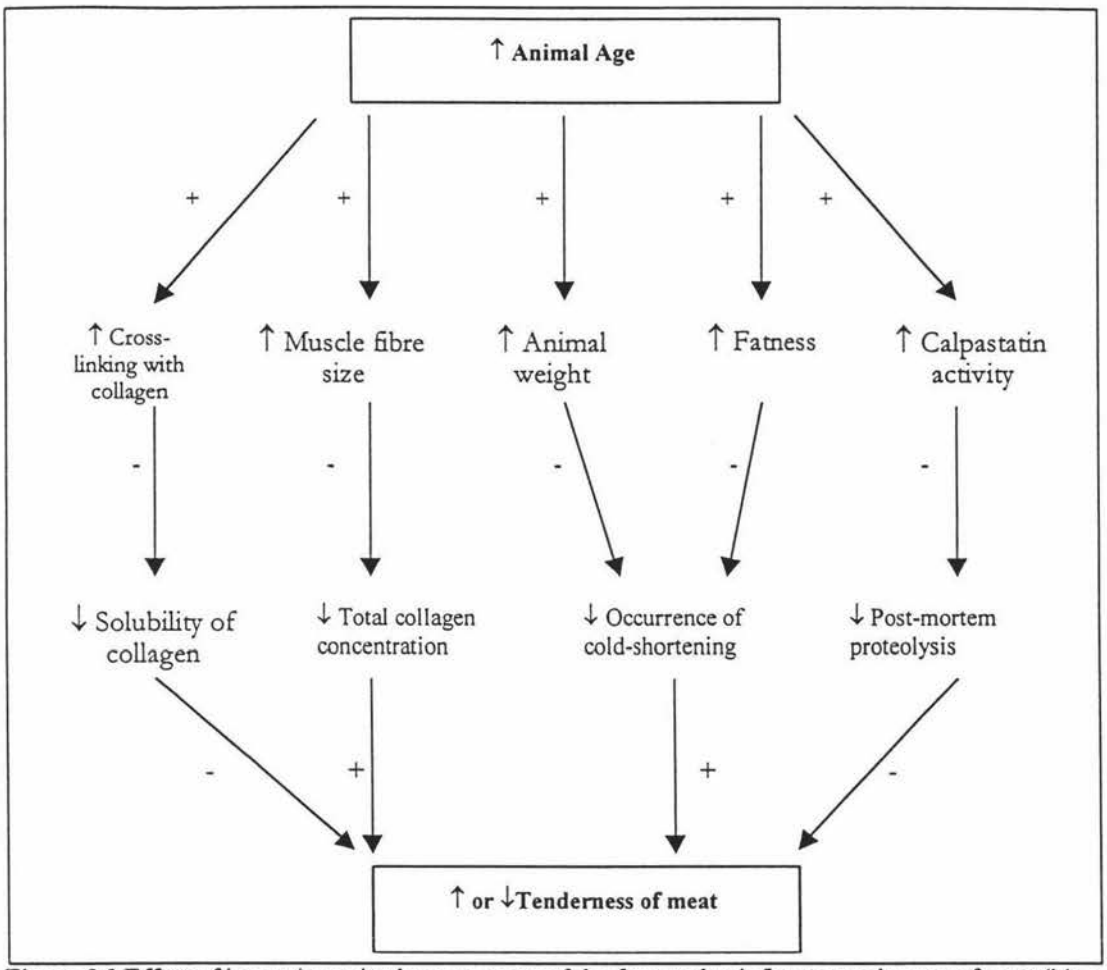

Figure 2.3 Effect of increasing animal age on some of the factors that influence tenderness of meat ('-' = decrease in tenderness; '+' = increase in tenderness).

2.3 EFFECT OF GROWTH PATH ON MEAT QUALITY

Nutritional influences on carcass composition and tenderness are usually a result of differences in growth rates of animals fed different quantities of the same quality of feed or differences due to alternative energy levels or qualities of the same quantities of feed. In the case of different growth rates decisions need to be made on whether composition and meat quality comparisons should be made at the same age (and therefore different weights and levels of fatness) or at the same slaughter weights (and therefore different ages). However even when animals are slaughtered at constant weights there is a tendency for cattle which are growing faster due to higher levels of nutrition to deposit a greater proportion of fat in their gain. It has been found in several trials that animals grown at higher growth rates due to better nutrition result in fatter carcasses (Morgan 1979; Wu et al. 1981; Keane et al. 1990), lower lean and bone content (Bond et al. 1982; Keane et al. 1990) and more tender meat (Purchas & Grant 1995; Purchas et al. 1997) than animals with lower growth rates.

The effects of forage- and grain-based feeding systems on beef quality have been extensively reviewed by Muir et al. (1998) and were not thought appropriate to include here. This review will focus mainly on the effect of growth path of the animal prior to slaughter on tenderness of beef.

Table 2.2 gives an outline of the findings from a selected sample of papers on the nutritional influences on change in carcass composition and/or meat tenderness for beef cattle

Table 2.2 Findings from selected papers on nutritional influences on changes in composition and tenderness during growth with particular reference to beef cattle

Reference	Methods	Results and Conclusion
Morgan (1979)	Three groups of weaned Hereford steers were grazed separately on pasture. Groups 1 and 2 maintained liveweight gains of 0.8 and 0.4 kg/day respectively with supplementation of hay and oats. Group 3 were not supplemented and gained at zero and 0.11 kg/day during corresponding periods (years 1 and 2). Group 1 was slaughtered at 420 and 450 kg liveweight in years 1 and 2 at 19 months of age. After this point Groups 2 and 3 were grazed together until they reached the same slaughter liveweight as group 1 at 25 and 27 months of age respectively.	Mean depth of fat cover over the eye muscle at the 10-11th rib in groups 1, 2 and 3 were 8, 6 and 4 mm in year 1, and 12, 5 and 6 mm in year 2, respectively (P=0.05). Group 1 carcasses also had shorter skeletal dimensions, contained more fat, and graded better than the carcasses of groups 2 and 3 (P=0.05). In year 1, group 1 *longissimus dorsi* muscles of the steers were also more tender (P=0.05) which could have been a result of their younger age but also the differences in fatness. However in year 2 there were no differences in tenderness between the three groups. Measurements were not adjusted for weight of the animals.
Wu et al. (1981)	18 Hereford steers were divided into three groups. Animals in group 1 were slaughtered at 18-19 months of age after being fed on grass for 120 days. Group 2 were fed a high energy diet for 120 days and slaughtered at the same age and group 3 were pastured for 120 days and then fed a high energy diet for a further 126 days and were slaughtered at c. 21-22 months of age.	Cattle fed the high energy diet (groups 2 and 3) had greater 12th rib fat thickness, higher percentages of kidney, pelvic and heart fat and had heavier carcass weights than cattle fed grass only (P<0.05). As measured by taste panel *longissimus dorsi* samples from group 3 had less (P<0.05) detectable connective tissue than samples from grass-fed cattle (group 1).
Bond et al. (1982)	78 Angus castrated calves were fed a feed mixture containing 70% concentrates in 3 different regimes: A) continuous *ad-libitum*, CA) restricted to gain about 0.45 kg daily, and C) restricted as in group B until 6 months before slaughter. They were serially slaughtered from 6 months until 6 years of age.	Growth rate of steers fed *ad-libitum* was greater than restricted steers only for the first 24 months. The daily gain in fat deposition was higher (P<0.01) in the A steers than in the other steers over the feeding period The A steers were also the most efficient in producing fat followed by the CA group. During the first period (0-6 months) steers fed *ad-libitum* were the most efficient converters of feed protein for tissue production and after that period the steers which had been restricted were the most efficient. Treatment A (P<0.01) had significantly greater height at withers, depth of chest and length of body than the other treatments up to about 30 months after which level of feed made no difference (adjusted for slaughter weight). Bond et al. (1982) concluded that growth rates and body composition for the steers were changed by level of feeding. There were no significant differences attributable to treatment as measured by either taste panel or Warner-Bratzler shear.

Reference	Methods	Results and Conclusion
Smith et al. (1989)	Sixty-four Angus bulls were allotted at 8 months of age to two energy management systems: a constant (C) energy (shelled corn plus corn silage) throughout the trial and a two-phase (2P) feeding system (corn silage to day 112 followed by a whole corn diet). Bulls were slaughtered as a lot when a 13th rib fat thickness of 7.6 mm was detected.	Carcasses were more youthful ($P<0.01$) and fatter, provided less ($P<0.05$) edible portion, with a smaller ($P<0.05$) and more ($P<0.05$) finely textured *longissimus* muscle under C than 2P. Meat from the *longissimus* muscle was most ($P<0.05$) tender in the C system (5.73 vs 4.96, as measured by taste panel where 4 = slightly tough and 6 = moderately tender). Tenderness measured by Instron shear force was not significantly different between the two treatments. The authors concluded that feeding bulls at a constant energy diet produced good quality beef that was quite palatable, although yield of edible product was reduced.
Purchas & Grant (1995)	One hundred and twenty cattle made up of 80 bulls and 40 steers were run together from 4 months on hill country until 20 months of age when the heaviest half were slaughtered. The remaining 60 animals were carried through until slaughter at 28 months of age.	After adjustment to a common carcass weight the group slaughtered at 20 months had less kidney and pelvic fat, but more intramuscular fat and slightly greater fat depths than the 28-month old group ($P<0.05$). Purchas & Grant (1995) suggested that kidney and pelvic fat is less affected than fat depth by a period of slow growth. *M. longissimus* samples from the younger animals were also more tender (9.85 vs 13.80 kg, $P<0.05$) when measured by Warner-Bratzler. However it was not possible to separate the effects of animal age at slaughter from effects of differences in growth to 20 months.
Steen & Kilpatrick (1995)	Two hundred and thirty six mixed-breed bulls, steers and heifers were fed a diet at 12 to 13 months of age (372 kg liveweight) consisting of grass silage and concentrates either *ad libitum* or at 80% of *ad libitum* intake. Bulls were slaughtered at 560, 610 and 660 kg, steers at 510, 560 and 610 kg and heifers at 460, 510 and 560 kg.	At a constant slaughter weight of 560 kg there was a significant ($P<0.001$) reduction in subcutaneous fat depth, total internal fats and fat trim and increase in lean and bone content when food intake was restricted.
Purchas et al (1997)	One hundred and fifty eight mixed-breed cattle consisting of 118 bulls and 40 steers were run together from 4 months on hill country until 20 months of age when the heaviest half were slaughtered. The remaining half were carried through until slaughter at 28 months of age.	Differences in carcass characteristics between treatments were similar to those reported by Purchas and Grant (1995). At the same weight the older group had longer carcasses and more kidney and pelvic fat ($P<0.05$). They also had lower fat depths and less intramuscular fat although these differences were not significant. After only 1 day of ageing *M. longissimus* muscles from the younger group were significantly more tender than the older group (12.14 kg vs 14.52 kg, $P<0.01$) but, like Purchas and Grant (1995) it was not possible to separate the effects of age at slaughter and differences in growth rates to 20 months on tenderness.

Fast rates of growth caused by a high plane of nutrition can lead to an earlier onset of the fattening phase of growth. Morgan (1979) concluded that steers slaughtered at 19 months of age produced fatter carcasses of more compact conformation than steers that had undergone one or more periods of slow growth or weight loss slaughtered at the same liveweight at 25-27 months of age. Purchas & Grant (1995) and Purchas et al. (1997) reported similar results for bulls and steers.

Effects of growth path of the animal on meat quality depend on their influence on one or more of the factors which determine the tenderness of meat and/or their interactions (Shorthose & Harris 1991). These factors include mature weight of the breed, pre-slaughter stress, rate of carcass cooling, ageing of meat, the cut of meat chosen and duration of cooking. Tenderness has a myofibrillar component and a connective tissue component. Meat tenderness is determined by the nature and state of the contractile protein and by the content and properties of connective tissue. Animal age and nutritional status of the animal influence the type and extent of crosslinking in intramuscular collagen. Nutritional effects influencing the myofibrillar component of toughness must act by affecting the extent of contraction of muscles post-mortem, the ultimate pH values of the muscles, their susceptibility to ageing and combinations of these (Shorthose & Harris 1991). The connective tissue component of toughness increases with animal age, due to an increase in heat stable collagen cross-links and a reduction in the amount of soluble collagen in the muscle.

Animals on lower planes of nutrition slaughtered at either the same weight, or the same subcutaneous fat depth, will be older than animals on higher planes of nutrition. As a result it is difficult to separate the effects of age at slaughter from the effect of nutritional regime on meat quality characteristics (Purchas & Grant 1995). It is therefore difficult to conclude that differences in tenderness of animals due to the connective tissue component of meat tenderness are a result of the nutritional regime and not simply the differences in age of the animals. Slaughtering animals at the same age usually results in differences in weights between the treatment groups and there is then difficulty in separating the effects of nutritional treatment from weight of the animal (Bennett et al. 1995).

Although carcass weight and fatness tend to increase together, subcutaneous fat exerts an effect on cooling rates of muscle over and above that due to the correlation between weight and fatness (Shorthose & Harris 1991). It has been proposed that an increase in the subcutaneous fat of the animal as a result of the nutritional regime results in a decrease in the

degree of post-mortem shortening and toughening of the muscle (Miller et al. 1987; Steen & Kilpatrick 1995) resulting in more tender meat.

Wu et al. (1981) found that, according to taste panels, animals fed grass for 120 days and then a high energy diet for a further 126 days before slaughter at c. 21-22 months of age had less ($P<0.05$) sensory-panel-perceived and Warner-Bratzler shear detectable connective tissue in the *longissimus dorsi* than animals that had simply been fed grass for 120 day and slaughtered at 18-19 months of age. Shear force values did not differ among *longissimus dorsi* steaks for the treatments.

Bruce et al. (1991) reported that the compensatory growth shown by animals finished on a high-energy diet following growth on diets of reduced protein did not affect tenderness. However steers fed the corn-silage diet (high energy) had lower ($P<0.05$) shear force values than steers fed a low energy diet of alfalfa/grass diets (3.59 vs 4.50 kg) and a higher fat deposition (286.8 vs 231.8 g/kg rib) suggesting that meat tenderness appeared to be affected primarily by dietary energy and its relationship to intramuscular fat deposition, rather than the rate of growth.

Aberle et al. (1981) suggested that rate of growth in steers is more important in determining tenderness than time on feed, attributing the benefits of rapid growth rates to enhanced collagen solubility. Crouse et al. (1985) avoided the effects of cold shortening by electrical stimulation and slow chilling and found that meat from cattle produced on a low energy diet was more tender and tended to possess less sensory-panel perceived and chemically extracted collagen than animals slaughtered at the same age and on a high energy diet. They concluded that high-energy diets enhanced collagen development. Dikeman et al. (1986) however, found no differences in collagen content for animals allotted to high energy or low energy diets.

It is concluded that animals with high growth rates due to better nutrition, will have heavier carcasses, greater subcutaneous fat levels and higher percentages of kidney, pelvic and heart fat. Animals with low growth rates have appeared to produce meat that is less tender than animals with high growth rates. This is probably due to the lower levels of subcutaneous or intramuscular fat of these animals as a result of their diet, which allows increased opportunities for cold-shortening and consequently tougher meat. However, by avoiding the effects of cold shortening through electrical stimulation or slow chilling there should be no effect of nutritional regime on tenderness as a result of fat depth.

Alternatively if animals on different nutritional regimes are slaughtered at the same fat depth there is normally an animal age effect involved. Animals with low growth paths slaughtered at the same fat depth as animals on higher nutritional regimes will be older and their meat may be tougher than the younger animals. This is a result of the increase in collagen crosslinks and a reduction in soluble collagen with increases in animal age. When animals on different energy levels are slaughtered at the same age and the same level of fatness there appears to be minimal differences in tenderness of the meat.

2.4 EFFECT OF PRE-SLAUGHTER HOLDING TIME ON MEAT QUALITY

2.4.1 Introduction

Long holding times of up to 28 hours are sometimes used at abattoirs as they provide more time to wash the cattle, allow cattle to empty their paunches and provide continuity of supply (Purchas 1992). Increasing the length of pre-slaughter holding time at the abattoir has been shown to result in beef, especially that from bulls, that has a high ultimate pH (Purchas 1992). Meat with a high ultimate pH of 5.8-6.0 is known to be tougher than an ultimate pH of 5.5 (Purchas et al. 1999). However, contrasting results have shown that resting at the abattoir appears to have an additive, beneficial effect on the ultimate pH of beef (Wythes et al. 1988a; Wythes et al. 1988b).

This section of the review will focus on the differences in tenderness of beef from animals held for either 4 hours or 28 hours pre-slaughter and possible explanations for these differences.

2.4.2 Effect of Pre-Slaughter Holding Time on Meat Quality Characteristics

Ultimate pH is expected to increase with increased holding time if conditions are conducive to glycogen depletion in muscle, and glycogen levels prior to slaughter fall below a threshold level of about 1% of muscle weight (Purchas 1992). It has been reported that the incidence of high pH meat will be somewhat lower with a few hours of holding than slaughtering within one hour of arrival at the abattoir (Fabiansson et al. 1984). However the reasons for this are

not clear, as the rates of muscle glycogen replenishment are very slow (Warriss et al. 1984). Shorthose (1988) found that cattle rested for 4 days after a 1300 km journey to slaughter yielded a lower proportion of *M. longissimus dorsi* muscles with ultimate pH values greater than 5.8 than animals rested for only 2 days. In studies where cattle (or water buffalo) had been held at an abattoir with water available, mean pH values have decreased with increasing time in lairage (Figure 2.4). Wythes et al. (1988b) found that cattle rested at an abattoir for one day before slaughter had more tender meat than those slaughtered within a few (2.5) hours of arrival.

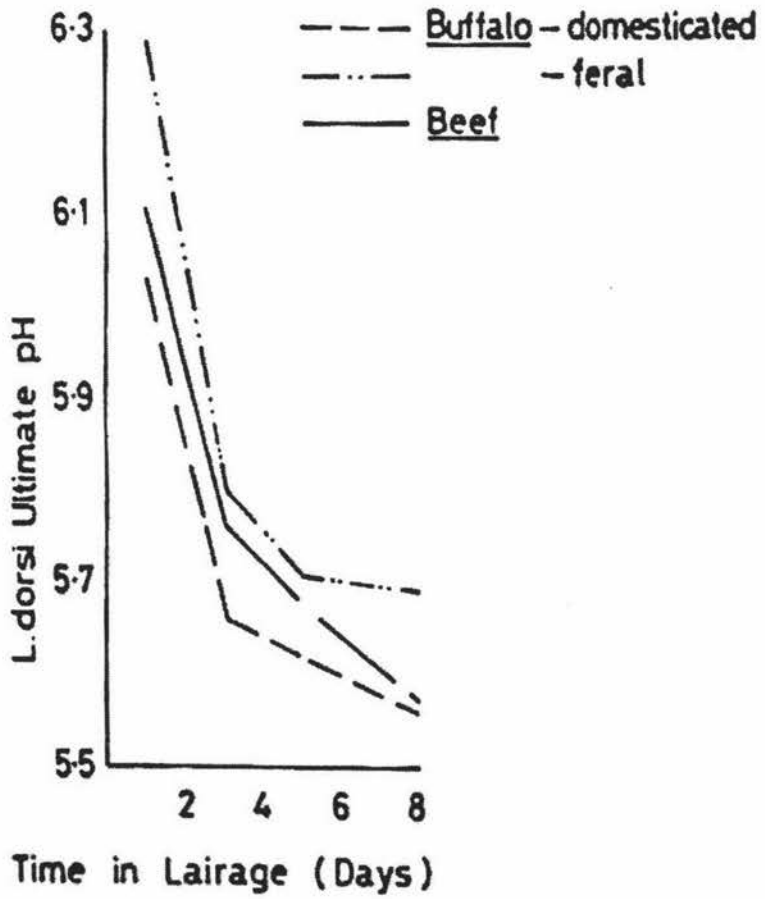

Figure 2.4 Effect of time in lairage, with feed and water, at an abattoir on the mean ultimate pH of the *M. longissimus dorsi* (Shorthose 1988).

Ultimate pH of beef is determined by glycogen in the muscle at the time of slaughter. A high muscle glycogen level will allow the muscle cells to metabolise after death, producing lactic acid and reducing muscle pH to around 5.5. Such meat will generally be tender. If the muscle contains less glycogen at slaughter there will be less lactic acid produced and ultimate pH will fall less (Carragher & Matthews 1996). An ultimate pH of 5.8 to 6.2 will tend to result in tougher meat (Purchas et al. 1999) (Figure 2.6).

Purchas (1992), when comparing the incidence of dark-cutting beef, found that cattle held for only 4 hours pre-slaughter had lower pH values than those held for 28 hours (5.64 vs 5.98 respectively, $P<0.001$). As Figure 2.5. shows, these increases in pH with increase in pre-slaughter holding time were more marked for bulls (5.69 vs 6.28). Steers showed a slight increase with the longer holding time (5.59 vs 5.75) and there was no difference in holding time with the heifers (5.59 for both groups).

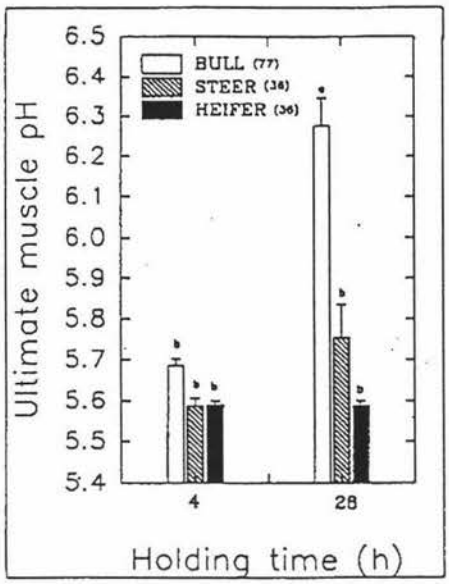

Figure 2.5 Average ultimate pH values of bulls, steers and heifers held for either 4 or 28 hours at the abattoir prior to slaughter. Bars with different letter above them differ significantly ($P<0.05$). The number of animals is shown in brackets (Purchas 1992).

Glycogen depletion occurs in muscles of animals which have not been fed and the rate of depletion is accelerated by strenuous muscle activity and/or by the action of the stress related hormone adrenaline (Purchas 1992). The depletion of glycogen and resultant decreased production of lactic acid post-slaughter is often prevalent in small pens of bulls, which are unable to avoid each other and as a result constantly violate individual distances aggressively, increasing muscular activity by mounting and fighting (Franc et al. 1988). The stress of new situations and environments such as trucking and holding in an abattoir may also result in an increase in ultimate pH, stress leads to the release of adrenal hormones including adrenaline which accelerates the rate of glycogen breakdown in muscle (Carragher & Matthews 1996). Starvation can also decrease glycogen reserves to below the critical point of 1% of muscle weight but starvation alone should not drop the glycogen level below the critical point within 28 hours. The greater ultimate pH values of bulls compared to steers are often a result of the bulls' greater susceptibility to pre-slaughter stress (Martin et al. 1971).

After 28 hours of muscular activity and/or stress, glycogen levels are likely to fall below the 1% critical point. As a result ultimate pH of animals (and especially bulls) increases with an increase in holding time to 28 hours as compared to a holding time of only 4 hours (Purchas 1992). A pre-slaughter holding period of 4 hours can result in depletion of glycogen through strenuous muscular activity or stress, although, the time may not be long enough for glycogen levels to decrease to below that critical point.

Other meat quality characteristics affected by increasing pre-slaughter time include decreased water-holding capacity and decreased cooking loss and increases in darkness of meat colour (Bartoš et al. 1988). These meat quality characteristics are all adversely affected by increasing ultimate pH (Bouton et al. 1971; Dutson 1983) which explains the effect of pre-slaughter holding time on them.

2.4.3 Effect of Ultimate pH on Tenderness of Beef

Providing cold shortening is avoided, the tenderness of beef tends to decrease with a rise in ultimate pH from 5.5 to 6.0 and then to improve with further increases up to 7.0 (Purchas et al. 1999, Figure 2.6).

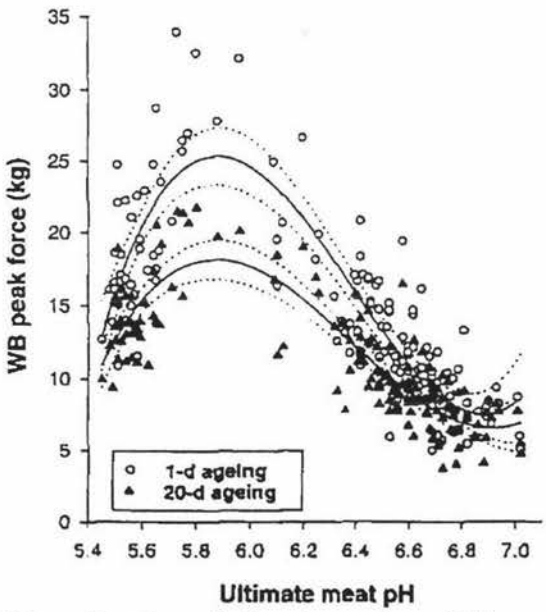

Figure 2.6 Changes in Warner-Bratzler peak shear-force values with increasing pH_u for samples of *M. longissimus thoracis* aged for either 1 or 20 days at 0-3°C. Polynomial regression lines with linear, quadratic, and cubic components are shown, along with 99% confidence intervals (Purchas et al. 1999).

The increase in tenderness as ultimate pH rises from 6 to 7 is attributed to the greater calpain activity, which is maximal at neutral pH. The increasing tenderness as pH falls below 6.0 has been attributed to enhanced protease activity (Yu & Lee 1986). An increase in sarcomere

length as pH decreases below about 6.2 is also thought to be involved in changes in tenderisation (Purchas 1990; Purchas & Aungsupakorn 1993, Purchas & Grant 1995).

Increases in ultimate pH to a value of 5.8 to 6.0 results in a decrease in tenderness of beef. Values above this peak result in beef that is more tender but increasing pH results in a meat quality defect known as dark cutting. Although dark-cutting meat (pH>6.0) is more tender than meat at a pH of about 5.8-6.0 it is of an unacceptable dark red colour and has a shorter shelf life than tender meat with a pH of 5.5-5.6 (Hood & Tarrant 1981). Ideal pH for acceptable, tender meat is therefore less than 5.8.

It is concluded that holding animals for more than four hours has the potential to result in meat that is high in pH and so there is a greater decrease in the tenderness of beef from animals over for longer periods than for animals held for only four hours (Purchas 1992). However, the degree of stress experienced by the animals can affect the rate of recovery of glycogen loss, this may be why some results (Wythes 1988a; Wythes 1988b) have shown that animals held for longer than a few hours have lower ultimate pH values and often an increase in tenderness than those held for a short period. Animals that are not subjected to stress at the abattoir or that don't stress easily may not have recovered from the transport stress within a few hours but are able to recover with longer periods of rest.

2.5 EFFECT OF CASTRATION ON MEAT QUALITY

2.5.1 Introduction

Bulls have a higher growth rate and are more efficient feed converters than steers and they produce a higher yielding carcass with more lean meat and less fat (Seideman et al. 1982). However meat from young bulls has been reported to be less tender in some studies and tenderness has been more variable than meat from steers (Arthaud et al. 1977; Crouse et al. 1985; Dikeman et al. 1986). The mechanism causing tenderness differences between bulls and steers is not well-defined (Morgan et al. 1993).

This review on the effect of castration on beef tenderness will look at some of the determinants of beef tenderness including fat thickness, ultimate pH and collagen content that may be affected by castration.

2.5.2 Fat Thickness

Decreased tenderness has been associated with cold shortening (Marsh et al. 1968) in response to rapid carcass chill rates. Bull carcasses have a thinner external fat cover than steer carcasses at equal carcass weights (Field 1971), Purchas et al. (1997) reported weight adjusted fat depths of 1.13 mm for Friesian bulls, 1.63 mm for Hereford x Friesian cross bulls and 3.32 mm for Charolais x Simmental cross steers ($P<0.05$). Because of the thinner fat covers bulls may be more subject to the cold shortening phenomenon after slaughter if processing conditions permit. Crouse et al. (1983) slaughtered bulls at a thinner fat cover than steers but found that the heavier carcass weights and thicker *longissmus* muscles resulted in a slower chill rate than steers. This suggests that bulls will only be tougher than steers as a result of cold shortening when they are slaughtered at equal carcass weights rather then the same age, as at the same age, carcass weights of bulls will be larger. Using slow cooling rates and/or the use of electrical stimulation of the carcass after slaughter should be effective in reducing the risk of increased toughness of bulls as there would be a reduced likelihood of cold shortening occurring (Riley et al. 1983).

Bulls are also known to have less intramuscular fat than steers, which may contribute to their increase in toughness (Bowling 1977). Purchas et al. (1997) reported age adjusted intramuscular fat percentages of 0.59% for Friesian bulls, 0.74% for Hereford x Friesian cross bulls and 1.76% for Charolais x Simmental cross steers ($P<0.05$), and Vanderwert et al. (1989) found that bulls had slightly less intramuscular fat than steers (3.02 vs 3.09%, $P<0.01$). In the latter study, intramuscular fat had a correlation coefficient of 0.34 for sensory panel overall tenderness and of –0.30 for Warner-Bratzler ($P<0.05$). Although significant, intramuscular fat was not as important as the relationship between fat thickness and the tenderness measurements ($r=0.69$ and $r=–0.49$, respectively, $P<0.01$).

2.5.3 Ultimate pH

A number of studies have reported that ultimate pH value is greater for beef from bulls than steers (Jones et al. 1986; Chrystall 1987; Purchas 1990) which is often a result of the bulls greater susceptibility to pre-slaughter stress (Martin et al. 1971) and the resultant depletion of muscle glycogen reserves (Watanabe et al. 1996). This difference in ultimate pH may account for some of the differences in tenderness between bull and steer beef (Purchas 1990). Purchas (1990) reported an average ultimate pH value of 6.35 for the bulls and 5.89 for the steers ($P<0.001$), but there were no significant differences in Warner-Bratzler shear. The author's

explanation for this was that the high pH values of the bulls were above the maximum shear value on the pH/shear force curve (Figure 2.5), and the ultimate pH for the steers was below. As a result of the shape of the relationship between shear force and pH, the markedly different pH values resulted in similar shear force values. Purchas (1990) concluded that the effects of ultimate pH on shear force values were similar for beef from the *M. longissimus dorsi* of bulls and steers, with a shear force maximum at a pH between 6.0 and 6.2.

Purchas & Aungsupakorn (1993) had similar ultimate pH results between *M. longissimus thoracis* from bulls and steers (6.21 vs 5.78, $P<0.001$) to Purchas (1990), and there were no significant differences in tenderness between the two groups. However after adjustment to a common pH, Warner-Bratzler shear force values for bull beef were significantly higher than the steers (13.2 vs 10.0 kg, $P<0.01$) suggesting that tenderness differences between bulls and steers are independent of ultimate pH values over this range. Jeremiah et al. (1991) reported ultimate pH differences between bulls and steers of 5.84 and 5.61 respectively ($P< 0.001$) with corresponding large differences in Warner-Bratzler shear force (7.20 vs 5.68 kg, $P<0.001$). It was concluded that for ultimate pH values under 6.0-6.2 there are large differences in tenderness between bulls and steers as a result of beef pH difference.

When excessive pre-slaughter stress is imposed on steers as well as bulls the increase in toughness of steer beef results in similar values of sensory panel tenderness for bull and steer beef (Jeremiah et al. 1988). These results suggest that differences in tenderness between bulls and steers as a result of ultimate pH can be minimised through the avoidance of pre-slaughter stress for bulls.

2.5.4 Collagen

Although not significant, Crouse et al. (1985) found that intact males tended to possess muscle with greater quantities of collagen, greater quantities of insoluble collagen and lower quantities of percentage soluble collagen over a constant percentage-of-rib-fat interval. Before adjustment to a constant percentage of rib fat, muscle from intact males possessed greater quantities ($P<0.01$) of collagen that was less soluble suggesting that variation in soluble collagen is associated with fat content and/or age. Cross et al. (1984), in contrast, reported that the *longissimus* muscle from bulls contained more soluble collagen (15.92 vs 14.76%, $P<0.01$) and Klastrup et al. (1984) also found that the proportion of heat soluble collagen was higher in bulls than both male castrates and heifers (21.0 vs 17.2 vs 16.7% respectively, $P<0.05$). Gerrard et al. (1987) also found that meat from bulls had more total collagen and

greater percentage of soluble collagen than meat from steers ($P<0.05$). They concluded that bulls have greater quantities of intramuscular collagen that matures more rapidly than that of steers. Vanderwert et al. (1989) reported significant ($P<0.05$) differences in total collagen of the *longissimus* muscle (6.02 vs 4.97 mg/g for bulls and steers, respectively) but gave low correlations coefficients of –0.17 and 0.14 (not significant) between total collagen and sensory panel overall tenderness and Warner-Bratzler shear force suggesting that total collagen differences do not adequately explain differences in tenderness between bulls and steers.

Gerrard et al. (1987) theorised that the great variability in tenderness observed in bulls may be attributed to rapid cyclic growth rates causing increased synthesis and degradation followed by maturation of collagen in a cyclic manner. As a result collagen could be extremely immature or undergoing an aging process at particular sampling times.

2.5.5 Calpastatin Activity

Morgan et al. (1993) found that there were increases ($P<0.05$) in 24 hour post-mortem calpastatin activity in the bulls compared to the steers (2.41 vs 1.33), and 24 hour post-mortem μ-calpain also tended to be higher in bulls (0.29 vs 0.21, $P<0.08$). They suggested that the greater calpastatin activity in bull *longissimus* muscle decreased the amount of myofibrillar protein proteolysis by μ-calpain resulting in less tender meat which was consistent with the higher shear force values of the bulls (4.9 vs 4.2 kg, $P<0.05$). Thomson et al. (1996) reported similar results to Morgan et al. (1993), in that, at one hour post slaughter steer samples tended to have lower calpastatin activities than bull samples and that the activity of μ-calpain was lower in the steer samples than the bull samples. However Thomson et al. (1996) found no significant differences after 24 hours post slaughter in shear force between the bulls and steers and that by 24 hours post slaughter approximately 15% of the activity of calpastatin in the bull beef was lost and as a result differences in calpastatin activity between bull and steers samples had disappeared. Therefore calpastatin activity results supported the data showing no differences in shear force from 24 to 120 hours post slaughter.

2.5.6 Muscle fibre types

Dreyer et al. (1977) reported that bulls had a higher ($P<0.05$) percentage of red (Type I) muscle fibres and a lower ($P<0.01$) percentage of white muscle fibres than steers in the *semitendinosis* muscle. Young & Bass (1984) found that the *longissimus dorsi* muscle of bulls had a high percentage of Type IIA fibre type than the steers and less Type IIB fibres ($P<0.001$) but

the difference in Type I was not significant. Bulls also had larger ($P<0.01$) mean fibre diameters in the *longissimus* muscle than steers (Ockerman et al. 1984). After adjusting for slaughter weight mean red fibre diameter was still larger ($P<0.05$) and white fibre diameter also tended to be larger although was not significantly so ($P=0.06$). Tenderness was correlated ($r = 0.53$, $P<0.05$) with percentage red fibres (but not percentage white fibres) which may explain the non-significant differences in tenderness between bull and steer beef in this trial.

2.2.7 Minimising Differences in Meat Tenderness between Bulls and Steers

The use of carcass electrical stimulation and less rapid cooling rates of the carcasses should avoid the risk of cold shortening of bull beef which often results in increased toughness due to the lower levels of fatness and smaller fat depths of the bull carcass (Riley et al. 1983). Intermediate levels of ultimate pH have been known to result in tougher meat. The avoidance of pre-slaughter stress should also reduce the risk of high ultimate pH levels in bulls, which are more susceptible to stress than steers (Martin et al. 1971). Ageing of meat has also been known to narrow the toughness differences between the sexes (Joseph & Connelly 1974).

CHAPTER THREE

INFLUENCE OF PRE-SLAUGHTER HOLDING TIME, GROWTH PATH AND CASTRATION ON MEAT QUALITY CHARACTERISTICS OF BEEF *M. LONGISSIMUS THORACIS*

3.1 INTRODUCTION

The tenderness of beef is known to be of importance to consumers, and in consumer surveys it has been identified as the quality characteristic that has most often caused dissatisfaction (Baron 1984). Four possible causes of variation in tenderness of meat include castration status of the animal, length of pre-slaughter holding period, growth path of the animal prior to slaughter and animal age.

Studies have indicated that the production of young bulls has resulted in advantages in rate of gain, leanness, yield of retail cuts and edible meat (Arthaud et al. 1977; Seideman et al. 1982). However, beef from bulls has been reported to sometimes have higher shear values and lower sensory panel tenderness ratings (Seideman et al. 1982; Gregory et al. 1983), although the average differences are inconsistent and often small (Seideman et al. 1982). Studies have indicated that bull beef may be tougher than meat from steers due to differences in the nature or concentration of muscle collagen (Boccard et al. 1979; Cross et al. 1984). However, it has also been suggested that many of the reported differences between beef from bulls and steers can be attributed to the higher proportion of high-pH beef from bulls (Purchas 1990; Purchas & Aungsupakorn 1993).

Cattle are commonly held at the abattoir for up to 28 hours pre-slaughter as it allows more time to wash the animals and enables them to empty their paunches (Purchas 1992). However, holding animals for longer periods of time pre-slaughter can result in an increased incidence of high-pH beef leading to tougher or dark-cutting meat, which may be avoided by holding cattle for only four hours pre-slaughter. Australian studies have found that cattle, which are rested at an abattoir for one day before slaughter, have more tender meat than those

slaughtered within a few hours of arrival (Wythes et al. 1988b). It is known, however, that bulls are more susceptible to stress than steers and as a result can produce tougher meat when held in a stressful environment pre-slaughter (Martin et al. 1971).

Beef from animals on growth paths involving higher levels of nutrition are generally more tender due to greater fat depths than beef from animals grown more slowly as there is less chance for the carcass to cold shorten (Miller et al. 1987; Steen & Kilpatrick 1995). In a series of trials conducted over recent years at Massey University it has been found that steaks from the cube roll were more tender from faster growing cattle in a mob that were heavy enough to be slaughtered at about 20 months of age, than similar steaks from slower growing members of the same initial mob that were grown through to about 28 months of age (Purchas & Grant 1997). It was not clear, however, whether this toughness was attributable to the greater age of the latter group or to the fact that they grew more slowly to 20 months.

The current trial attempted to distinguish between these two possibilities by including a third group of cattle from the faster growing section of the mob, but which were fed in such a way that they reached a similar final weight as the slower growing animals from the initial mob at an age of 25 months.

Specific primary objectives of this trial were therefore to evaluate differences in carcass characteristics and meat characteristics of beef *M. longissimus thoracis*:

1 between bulls compared to steers;

2 between cattle held for pre-slaughter holding times of either 4 hours or 28 hours, and

3 between cattle grown along fast, slow and restricted growth paths.

Information collected also permitted the following two secondary objectives to be addressed

4 to evaluate relationships between results from sensory assessments and from objective measures of tenderness, and

5 to further assess relationships between beef ultimate pH and the determinants and measures of beef tenderness and other meat quality characteristics.

3.2 MATERIALS AND METHODS

3.2.1 Experimental Design

The experiment was a 3 x 2 x 2 factorial design with three growth paths (fast, restricted and slow), two castration classes (bull and steer) and two pre-slaughter holding times (4 and 28 hours). The three growth paths included fast growing animals which reached the target slaughter weight at approximately 17 months of age, slower growing animals which reached the same target slaughter weight at approximately 25 months of age and a third group of cattle from the faster growing mob that were fed in such a way that they reached a similar final weight at the same age as the slower growing animals.

3.2.2 Animals and their management

The sixty Hereford-Angus cross weaners (30 bulls and 30 steers, castrated in November 1996) from a commercial Taihape herd were transferred to the Research Unit at Massey University in mid-March 1997. After a 9-day settling-in period they were run together with regular weighings for a period of 100 days. On the basis of their 100-day growth rate and within castration group the cattle were divided into a faster growing group (40 animals) and a slower growing group (S, 20 animals). The faster-growing animals were then randomly divided into a fast growing group (F, n=20, 10 animals of each castration class) and a restricted group (R, n=20, 10 animals of each castration class). All cattle were run together until 9 months of age and fed as much as possible within normal farm constraints.

The twenty animals from the faster-growing mob which were randomly selected to be in the fast growing group (Group F) were managed such that they reached a target slaughter weight of approximately 550 kg liveweight prior to slaughter before their second winter. The remaining twenty animals from the faster growing mob, which were designated as the restricted group (Group R), were managed such that they reached a similar slaughter weight at the same time as the slower growing mob (Group S). Bulls and steers from within the F, R and S groups were run together up to the time the bulls were slaughtered. Groups R and S were fed to achieve restricted liveweight gain (less than 0.5 kg/day) and were held on restricted rations for much of the period from 16 July 1997 until slaughter in November 1998. Group S was fed a restricted ration of pasture and hay (during winter, June 1998 – September 1998) in order to reach the target weight at 25 months of age. Restriction of liveweight gain

was achieved using rotational grazing on pastures that had previously been grazed by other groups of stock. Group F also reached the target weight of 550 kg liveweight at 25 months of age, but they had to be restricted to a greater extent over some periods to counter their greater growth potential.

Group F reached the target slaughter weight at 16-18 months of age with the 10 bulls being slaughtered on the 17 and 18 February 1998 and the 10 steers on the 21 and 22 April 1998. The bulls from the slower growing groups R and S were slaughtered after their second winter on the 16 and 17 of November, and the steers on the 23 and 24 of November (Figure 3.1). All animals were slaughtered following normal procedures at a commercial plant (Manawatu Beef Packers Ltd., Fielding).

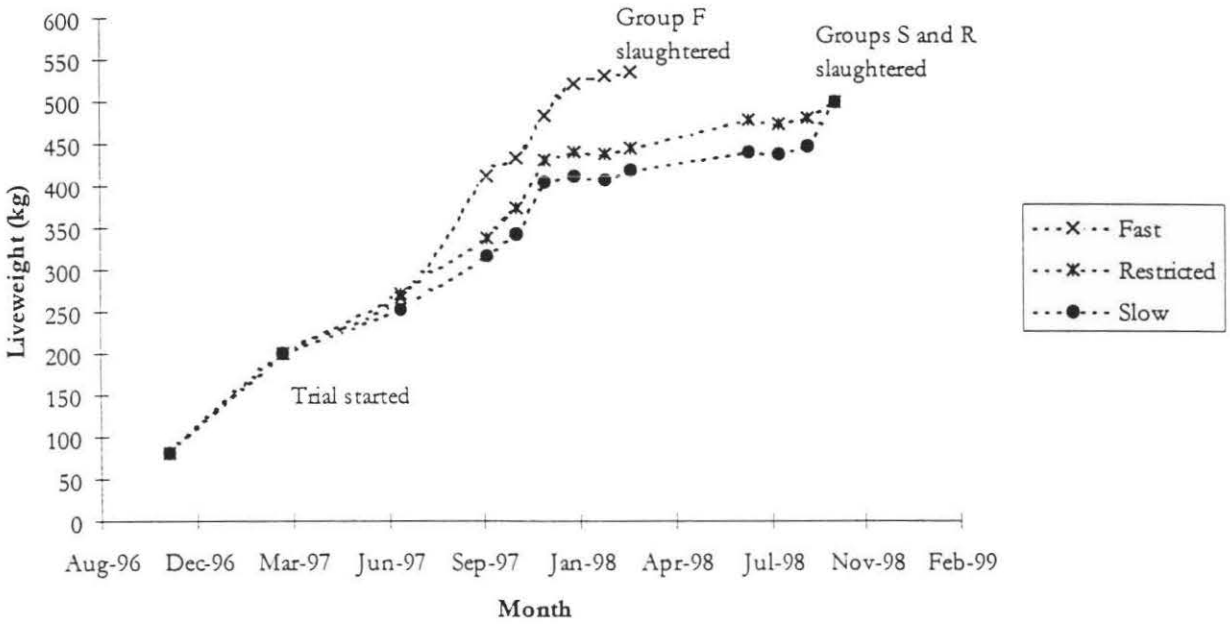

Figure 3.1 Increases in liveweight over time from birth till slaughter of the 60 animals in the three different growth path treatments.

3.2.3 On-farm measurements

Once the trial was under way, animal weights were recorded regularly at intervals of about four weeks to allow any required changes to feed allowances to be made. Measures of wither heights were made at intervals of about three months to enable frame-size scores to be calculated. Estimates of pasture intake were made on a subsample of cattle in July 1997, November 1997, January 1998 and October 1998 using the intra-ruminal slow-release chromium capsule technique (Parker et al. 1990), however, the results are not presented here.

3.2.4 Pre-slaughter Procedures

The cattle were weighed off-feed at about 0800 hours and trucked for approximately 20 km to Manawatu Beef Packers in Fielding. Prior to slaughter the groups were randomly divided within each castration and treatment group into either a 4-hour pre-slaughter-holding-period (4h) or a 28-hour pre-slaughter-holding-period (28h) group with access to water always available. Over this period the animals were kept under cover and not mixed with other groups. Handling and washing followed normal procedures. Animal behaviour was observed for 30 minute periods several times over the holding time with the frequency of the following events and their duration recorded; head butting, shouldering/pushing/relocation, fighting and mounting/attempted mounting, but these results will not be reported here.

3.2.5 Post-mortem Procedures

Carcass measurements

Immediately post slaughter samples of blood (during exsanguination) were taken from each animal. During dressing the number of permanent incisor teeth were recorded and the length of both sides of the carcass were measured from the distal end of the tarsals to the mid-point of the cranial edge of the first rib. Kidney and pelvic fat (KP Fat, from both sides) and the heart and liver were weighed. Muscling of the animals was assessed on a 9-point scale of 1+, 1, 1-, 2+, 2, 2-, 3+, 3, 3-. A sample of 1800-2000 g of *M. longissimus thoracis* from the cube roll region of each right side was removed after the carcass had entered the chiller within 90 minute post-mortem. Following overnight chilling at 1-3°C the eye-muscle area (LD muscle) was traced and fat depths were measured on the carcass between ribs 12 and 13. The eye-muscle area tracing was subsequently assessed using a Tamaya Planix-7 digital planimeter. In the boning room the inside, knuckle and outside cuts (3Cut Wt) from each hindquarter were weighed.

Muscle sampling

The *M. longissimus thoracis* sample was held at 12°C for 24 hours and then at 0-2°C until 7 days post-mortem. At that time approximately 800 g was removed from the sample, placed in a laminated oxygen impermeable plastic bag, vacuum packed and frozen at -30°C for use in the sensory analysis. The remaining sample was double bagged and frozen at -20°C for subsequent objective measures of meat quality.

Measurements of meat quality

Meat quality measurements were made after thawing the frozen samples for 24 hours at 3-5°C. A thin (5-10 mm) sliced was removed from the cranial end to square up the sample. A 10-15 mm thick slice was removed for sarcomere length assessment and colour tests. The middle portion of this slice was used for colour, and slithers from the medial and lateral portions were stored in test tubes for sarcomere length measurement.

Two 25 mm thick slices were cut and placed into plastic bags and thawed for a further six hours at 12°C before being cooked in a water bath for 90 mins at 70°C to be used for assessing tenderness with the Warner-Bratzler shear device and MIRINZ tenderometer. Another 25 mm slice was removed and also thawed at 12°C for 7 ½ hours before being cooked for 60 mins at 60°C to be assessed for tenderness with the Instron compression device.

A 30-40 mm slice was cut for ultimate pH, intramuscular fat content, water-holding capacity and MFI measurements. A 50-80 g portion was taken from the middle of the slice and stored in a plastic snap-top bag and refrozen at -15°C for determination of intramuscular fat content by the Soxhlet method at a later date.

Warner-Bratzler shear device and MIRINZ tenderometer

Two adjacent 25 mm steaks were used for the Warner-Bratzler and MIRINZ tenderometer measurements. Six 13 x 13 mm cores were cut from the centre of each steak after it had been cooked in a water bath at 70°C for 90 minutes, drained and then left to chill for at least eight hours. Cores were prepared to ensure that shears were made across the fibres rather than parallel to them (Purchas 1990).

Measurements, made at about one third the distance along each core with the Warner-Bratzler shear device (fitted with a square blade) included the initial yield force (the force at which the samples begins to yield), peak shear force (maximum force registered) and the average of all measurements taken (about 460 force values) as a measure of work done (Purchas & Aungsupakorn 1993). The remaining two thirds of each core was then trimmed to a 10 x 10 mm cross section and assessed with the MIRINZ tenderometer (Macfarlane & Marer 1966) which was used to determine tenderness of the cooked meat sample used the same cores as the Warner-Bratzler. The twelve pressure readings from the tenderometer were then averaged and converted into peak shear force using $y = 1.439x - 6.9287$ ($R^2 = 0.95$, where y = peak

force and x = force measured). Results measured in kPa were then converted to kgf using the following equation: kgf = 0.2108kPa – 3.6592.

Compression

An 'Instron compression device' was used which measures hardness (Harris 1976) as the force (in N) required to drive a 10 x 10 mm square diameter flat-ended plunger 8 mm into a 10-mm thick sample of cooked meat arranged so that the meat fibres are parallel to the plunger surface and perpendicular to the direction of plunger travel. This arrangement was based on the device described by Kamoun & Culioli (1988). The plunger is driven into the meat once at a crosshead speed of 100 mm/min and the work done determined. The parameters measured were the peak in force required which is a measure of myofibrillar resistance, the load at 2 mm and 8 mm which are the forces required to compress the sample by 20% and 80%, respectively and the area under the curve of the graph which measures in joules the total work done for the Instron Compression Device to compress the sample by 80%. Cores of 10 mm x 10 mm were used from a 25 mm steak that had been cooked in a water bath at 60°C for one hour and then left to chill for more than 8 hours. Cooked meat rather than raw meat was used as it allowed samples to be cut more precisely and closer correlations to be set up between sensory panel and instrumental texture evaluation (Lepetit et al. 1986).

Sarcomere length

Sarcomere length of samples of raw meat was determined by a laser diffraction method, similar to that described by Cross et al. (1980-1981) as detailed in Appendix 1.1. Twelve measurements were taken of the distance between the first order bands for each sample. Six measurements were from the medial side of the muscle and six from the lateral.

Fibre diameter

Slides prepared for sarcomere length assessment were also used to measure fibre diameter of 26 muscle fibres at 125x magnification (Hooper & Hanrahan 1975). Thirteen measurements were of fibres from the medial side of the *longissimus thoracis* muscle and thirteen from the lateral side.

Myofibrillar fragmentation index

Myofibrillar fragmentation indexes of all samples were measured as described by Purchas et al. (1997) using a modification of the method described by Johnson et al. (1990). Details are given in Appendix 1.2. Duplicate values from each animal were recorded.

Colour

Meat colour was assessed on a cut surface of each sample that had been exposed to the atmosphere for c. 90 minutes at 0-3°C using a Minolta Chroma-meter (CR-200) to give L*, a* and b* values (Purchas & Grant 1995). L*, a* and b* values indicated the brightness, redness and yellowness respectively, of the meat.

Water-holding capacity

Water-holding capacity was calculated using the Filter Paper Press method (Hamm 1986). A cube of 500 ± 20 mg of meat from inside the steak was placed on the centre of Whatman No. 1 filter paper (11 cm diameter) and placed on a perspex plate. Another perspex plate was then placed on top and lightly pressed before placing a 10 kg weight on it for 5 minutes. The weight was then removed and the meat reweighed. The wetted area was measured by planimeter. Expressed Juice values were calculated in two ways:

1 Expressed Juice (%) = [(Meat wt – squashed meat wt)/meat wt] x 100/1 (EXJ1)

2 Expressed Juice (cm^2/g) = Area (cm^2)/meat wt (g) (EXJ2)

Duplicates measures of expressed juice were made for each animal.

Measurements of pH

Meat pH was measured by adding 10 ml of 5 mM Iodoacetate and 150 mM KCl (pH 7.0, Bendall 1973) to 2.0 – 2.5 g of diced internal sample and homogenising the mixture with an Ultra-Turrax on about ¼ speed with 3 x 5 second bursts. The pH of the homogenised sample was then measured by inserting the combined electrode from the pH meter together with a temperature probe (Jenway model 3020) into the mixture.

3.2.4 Sensory Evaluation

All training and testing was conducted in the Sensory Evaluation Facility, Institute of Food, Nutrition and Human Health, located the Albany Campus of Massey University.

Panel Selection and Training

Eleven panelists were selected to take part in the sensory trial based on their interest and availability. There were 3 males and 8 females, aged between 23 and 55, all of whom regularly consumed meat. None of the panelists had had previous experience with sensory evaluation of meat.

The main objectives of training a panel is to obtain "a set of instruments", all of whom respond alike (Powers 1984). Panel training is necessary to expose the panelists to a common set of experiences (Duizer 1992). Training consisted of 8 daily sessions of up to one and a half hours in length. Panelists were trained to evaluate 6 texture attributes in the steaks. These attributes were initial juiciness, hardness, cohesiveness, toughness, chewiness and overall juiciness as defined in Table 3.1.

Table 3.1 Definitions of the attributes and their references measured in the sensory analysis of steaks from *M. longissimus thoracis.*

Attribute	Definition	References	Anchor points
Initial juiciness	How much juice is expressed as you bite down on the sample when it is placed between back molars?	Carrot (2) Sealord Chunky Style Tuna (8)	Not juicy (1) Very juicy (10)
Hardness	How much force is required to break the sample as you press down with your back molars?	Anchor Edam Cheese (4) Pak'nSave Jelly Beans (6)	Soft (1) Hard (10)
Cohesiveness	How does the sample break on the third chew?	Carrot (1.5) Pak'nSave Jelly Beans (6) Pak'nSave Soft Jubes (10)	Not cohesive (falls apart) (1) Very cohesive (stays together) (10)
Toughness	An overall impression of the the breakdown of the product which includes a combination of cohesiveness, chewiness, hardness and juiciness	Vienna (tasty) Bierstick (6.5)	Tender (1) Tough (10)
Chewiness	How many chews does it take to prepare the sample for swallowing?	Anchor Edam Cheese (1.5) Pak'nSave Jellybean (6.5)	Not chewy (1) Very chewy (10)
Overall juiciness	How much juice is expressed from the sample over the entire chewing process?	Sealord Cunky Style Tun (2) Carrot (8)	Not juicy (1) Very juicy (10)

Initial training sessions involved introducing the panelists to the different attributes using references such as tuna and carrots and also allowing the panelists to familiarise themselves with line scales. Panelists were asked to input the data onto a 10 cm unstructured line scale, labelled with appropriate anchors at 1 and 10 for each attribute. Appendix 1.3 shows the line scales used in the evaluation with the references decided on by the panelists added. These references were available at each session to allow the panelists to check their results.

Meat used during the early training sessions were roasted scotch fillet, rump and bolar cooked to different end point temperatures and using different oven temperatures to allow the

panelists to establish the difference in tenderness, juiciness, softness, cohesiveness and chewiness as a result of the different cuts of meat and cooking methods. For the last 4 training sessions, the Silex cooker was used and the meat sampled was from the *psoas major* and *longissimus* muscle which were expected to be similar in tenderness and juiciness to the meat used in the trial from the *M. longissimus thoracis* (Shackelford et al. 1995b) and it allowed the panelists to pick up smaller differences in the attributes. The aim of training was to get the panelists to produce precise, consistent and reproducible sensory measurements, of the sort expected from a well-trained, sensitive panel (Civille & Szczesniak 1973). Therefore, during the last 3 training sessions a pre-test condition was set up where panelists evaluated the same samples each session This data was analysed and no differences were found suggesting that the panelists were reproducible and consistent (Table 3.2).

Table 3.2 Consistency of results from panelists during training using beef cuts of contrasting quality.

	BEEF CUT					
	Rump	Scotch fillet	Sirloin	RSD[c]	Replicate	Panelist[d]
Initial juiciness	4.59	4.31	4.17	2.24	NS	*
Hardness	5.36[b]	5.35[b]	4.12[a]	1.48	NS	NS
Cohesiveness	5.39[b]	3.73[a]	4.78[b]	1.44	NS	*
Toughness	5.10[b]	4.85[b]	3.27[a]	1.70	NS	NS
Chewiness	5.74[b]	5.21[b]	4.01[a]	1.60	NS	**
Overall juiciness	5.18[b]	4.45[a b]	4.14[a]	1.64	NS	NS

[a,b] means with the same letter within the same row are not significantly different $P<0.05$
[c]RSD= residual standard deviation
[d]Levels of significance:
**$P<0.01$, *$P<0.05$, NS $P>0.1$

Sample Preparation

Meat was obtained frozen (-12°C) in approximately 1 kg portions. The portions were placed in a 3-5°C fridge for 2 hours which softened the meat enough to cut into 25 mm steaks yet was still frozen. After cutting into steaks, the meat was replaced back into the freezer and a steak was removed and put into the fridge 3 hours prior to cooking on the appropriate testing day. Steaks, cut to 25 mm were cooked in a Silex Domestic Grill (model 610.80, Appendix 1.4) set at a temperature of 200°C to an internal temperature of 75°C monitored by a Fluke 80PK-5A Type K thermocouple piercing probe attached to a 52K/J Fluke® thermometer. After cooking, each steak was cut into 15 mm cubes and the cubes were placed into covered labelled containers and warmed in a Bain-Marie Cooker for 30 minutes at a constant temperature of

75°C. At testing, the cubes were placed in a 30 ml cup lidded and labelled with a three digit code and distributed in a random order (specified by the experimental design) to the panelists. Six different samples were evaluated at each sitting and presented to the panelists with the lidded cups set into wells made in styrofoam slabs (about 250 mm x 150 mm x 50 mm) to maintain heat. One cube from each steak was allocated to each panelist unless another was requested. Panelists were instructed to cleanse the palate between samples with a bite of an unsalted cracker and a sip of water. Testing took place in individual booths under white lighting.

3.2.5 Statistical Analysis

All analyses were performed using the Statistical Analysis System computer package (SAS 1996). Data for treatment differences using objectives methods of measurement were analysed using general least squares procedures to test effects of castration, pre-slaughter holding time and growth path using a 3 x 2 x 2 factorial model. Results from sensory evaluation were analysed also using general least-squares procedures.

Stage 1 involved analysing all 1980 values of each attribute (11 panelists*3 steaks*60 animals) to give the least-squares means for each attribute for each animal (Appendix 2, A2.1). A mixed model was used for this step which included fixed (order, session, bullsteer, longshort, frs, bullsteer*longshort, bullsteer*frs, longshort*frs and bullsteer*longshort*frs) and random effects (panelist, animal nested within (bullsteer*longshort*frs) and rep nested within (bullsteer*longshort*frs*animal)). Least-squares means for bulls versus steers, long versus short holding periods, fast versus restricted versus slow growth paths and their interactions were also produced. In addition to analysing the absolute values of sensory scores, the deviations of these values from the mean for each panelist by session combination were also analysed. These were calculated within the same SAS program (Appendix 2.1).

Stage 2 of the analysis of the sensory evaluation results were similar to the analysis of the objective measures of meat quality using the animal least-squares means produced in Stage 1 (Appendix 2.2). Results produced were the least-squares means of the treatment effects of each attribute.

3.3 RESULTS

3.3.1 Carcass Characteristics

Castration effects

Measures of liveweight were made immediately after the body was stunned and hoisted onto the rail and prior to bleeding. The average pre-slaughter liveweight (Lwt) of bulls was approximately 25 kg higher than that from steers (Table 3.3), and this was reflected in greater carcass weights (Cwt). After adjustment to a common carcass weight there was no difference in dressing-out percentage (Dr%), but the bulls had a greater mean EMA ($P<0.01$) and lower levels of kidney and pelvic fat (KP Fat, $P<0.001$) and lighter liver weights ($P<0.01$). Steers had fat depths that were over three times greater than those of the bulls ($P<0.001$).

Table 3.3 Least–squares means for pre-slaughter liveweight, carcass weight and carcass characteristics (adjusted for Cwt). Animal numbers are in brackets. Interactions between the main effects are explained in the text. Interactions between the main effects are explained in the text.

Effect[d]		Lwt (kg)	Cwt (kg)	Dr% (%)	Fat Depth (mm)	EMA (mm^2)	KP Fat (kg)	Carcass Length (mm)	3Cut Wt (kg)	Liver Wt (kg)
R^2%[e]		28	30	70	77	53	83	67	89	62
RSD[f]		45.5	26.7	1.2	1.32	6.1	1.07	38.3	0.79	0.50
Cwt[g]		-	-	***	NS	***	***	***	***	+
BSt	B (30)	514.4[b]	286.3[b]	55.4	1.71[a]	75.6[b]	2.41[a]	2072	20.91	6.26[a]
	St(30)	489.1[a]	268.2[a]	55.1	5.65[b]	70.2[a]	5.21[b]	2070	20.85	6.79[b]
LSh	28h(30)	484.1[a]	269.7[a]	55.9[b]	4.02[b]	72.7	4.02	2079	20.80	6.47
	4h(30)	589.3[b]	284.8[b]	54.6[a]	3.34[a]	73.1	3.60	2063	20.96	6.58
FRS	F(20)	511.8	290.5	56.4[c]	4.85[b]	73.4	5.90[b]	2028[a]	19.51[a]	5.87[a]
	R(20)	500.4	270.0	54.1[a]	3.04[a]	71.2	2.48[a]	2096[b]	21.57[b]	6.71[b]
	S(20)	493.0	271.3	55.1[b]	3.16[a]	74.1	3.07[a]	2090[b]	21.56[b]	7.00[b]

[abc] Means within a column and within an effect without a common subscript letter are significantly different ($P<0.05$).

[d] B=B, St=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path

[e] R^2%=Coefficient of determination

[f] RSD=Residual standard deviation

[g] Level of significance:

***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Pre-slaughter holding time effects

Animals assigned the 4h holding time had heavier liveweights and carcass weights of 35.2 kg ($P<0.01$) and 15.1 kg ($P<0.05$), respectively, than those held for 28h (Table 3.3). After adjustment to a constant carcass weight the animals held for 4h had a slightly lower dressing-out percentage than those held for 28h ($P<0.05$) and lower fat depths ($P<0.05$).

Growth path effects

There was no difference in pre-slaughter liveweight between animals slaughtered at 20 months of age in the F group and those slaughtered at 28 months of age in the S and R groups, but those in the F group had slightly higher carcass weights at slaughter. The animals in the F group also had greater dressing-out percentages, followed by the animals in the S group, and those in the R group had the lowest dressing-out percentages. Animals in the F group had greater fat depths, shorter lengths, more kidney and pelvic fat, lighter 3Cut weights and liver weights ($P<0.001$) compared to animals in the R or S groups. There were no significant differences in carcass characteristics between animals on the slow growth path and those on the restricted growth path.

Animals slaughtered at 17 months of age on the fast growth paths had no permanent incisors, compared to 22.5% of the animals slaughtered at 25 months of age in the slow and restricted growth paths. Results on the number of incisors erupted in the different age groups and castration groups are presented in Table 3.4.

Table 3.4 Number of permanent incisors erupted by slaughter in bulls and steers at different ages.

			Number of permanent incisors				
Date slaughtered	**Number of animals**	**Castration status**	**0**	**1**	**2**	**3**	**4**
17/2/98 (16 mo[1])	10	Bulls	10	-	-	-	-
22/4/98 (18 mo)	10	Steers	10	-	-	-	-
16/11/98 (25 mo)	20	Bulls	7	3	10	-	-
22/11/98 (25 mo)	20	Steers	2	4	14	-	-

[1] mo = months of age

Interactions for carcass quality characteristics between the main effects

There was a significant ($P<0.01$) interaction between castration group and pre-slaughter holding period for carcass length. Bulls had significantly longer carcass lengths (2094 mm) in the 28h holding group than the 4h group (2051 mm) but the steers did not. The reasons for this are not clear. Dressing-out percentages of animals in the S and R groups were similar across castration groups but steers in the F group had significantly ($P<0.01$) higher dressing-

out percentages (57.0%) than bulls (55.8%) to give a significant BSt by FRS interaction. No other significant interactions between treatments were found for carcass characteristics.

3.3.2 Meat Quality Characteristics

Castration effects

Bulls produced meat with higher ultimate pH values than steers (P<0.001) and lower MFI values, shorter sarcomere lengths and lower L*, a* and b* values both when adjusted (Table 3.5) and also without adjustment for pH (Table A3.1, Appendix 3). After adjusting for pH, meat from bulls had larger fibre diameters (FD), lower EXJ1 and greater cooking losses (CL) at both 70°C and 60°C, although these differences were not significant without adjustment for pH.

Table 3.5 Least-squares means for measures of meat quality of the *M. longissimus thoracis* (adjusted for pH). Interactions between the main effects are explained in the text.

Effectd		pH	MFI	Sarcomere length	Fibre diameter	Expressed juice EXJ1	Expressed juice EXJ2	Cooking loss CL, 70°C	Cooking loss CL, 60°C	Meat colour L*	Meat colour a*	Meat colour b*
			(%)	(µm)	(µm)	(%)	(cm2/g)	(%)	(%)			
R [2%][e]		48	76	57	57	65	76	69	45	49	34	67
RSD[f]		0.2	3.2	0.07	5.1	1.9	2.0	2.5	3.4	1.5	4.6	0.9
pH[g]		-	NS	*	***	***	***	***	*	***	*	***
pH[2]		-	**	***	**	NS	***	*	*	*	NS	*
BSt	B	5.64[b]	86.2[a]	1.71[a]	58.8[a]	42.8[b]	40.8	25.9[b]	12.4[b]	35.8[a]	13.9[a]	4.9[a]
	St	5.46[a]	93.5[b]	1.77[b]	60.0[b]	41.8[a]	39.5	24.8[a]	11.7[a]	36.7[b]	15.5[b]	5.8[b]
LSh	28h	5.59	90.8[b]	1.74	60.4	41.1[a]	39.1[a]	24.7	11.6	36.0	14.1	5.4
	4h	5.50	88.9[a]	1.73	58.4	43.5[b]	41.2[b]	25.9	12.6	36.3	15.2	5.3
FRS	F	5.71[a]	92.7[a]	1.79[b]	63.7[b]	41.7	41.3[b]	23.5	10.0	36.6	17.4[b]	5.8
	R	5.48[b]	88.2[a]	1.73[ab]	56.4[a]	43.2	40.3[a]	26.3	13.0	35.9	13.7[ab]	5.2
	S	5.46[b]	88.6[b]	1.69[a]	58.1[a]	42.1	38.9[a]	26.1	13.3	36.0	12.8[a]	5.0

[abcdef] See Table 3.3

[g]Levels of significance:

***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Samples from the *M. longissimus thoracis* of bulls also required a larger maximum load (Max, P<0.001), more energy (P<0.001) and needed more force to compress meat to 80 mm (LD8, P<0.001) with the Instron compression device than the steers, both before (Table A3.2, Appendix 3) and after adjustment for pH (Table 3.6). Before adjustment for pH they also required more force to compress meat by 20 mm (LD2, P<0.05). With the Warner-Bratzler shear force device, meat from bulls required more work (TotWD, P<0.01), had a great initial

yield (IY, P<0.01) and a higher peak force (PF, P<0.001) both before and after adjustment for pH. Bulls also produced meat with higher MIRINZ peak force values than steers (P<0.001).

Table 3.6 Least-squares means of measures of tenderness performed on *M. longissimus thoracis* of the 60 animals (adjusted for pH). Interactions between the main effects are explained in the text.

Effect[d]		INSTRON				WARNER-BRATZLER				MIRINZ
		Max (Ncm^{-2})	LD2 (Ncm^{-2})	LD8 (Ncm^{-2})	Energy (J)	TotWD	IY (kg)	PF (kg)	PF-IY (kg)	PF (kg)
R²%[e]		63	49	57	59	61	56	60	54	55
RSD[f]		18.1	6.0	20.0	0.35	0.7	2.25	2.59	0.66	2.0
pH[g]		NS	NS	+	**	NS	NS	NS	NS	NS
pH²		**	**	***	*	***	***	***	***	***
BSt	B	104.4[b]	16.4	94.5[b]	0.41[b]	3.6[b]	9.1[b]	11.2[b]	2.1[b]	6.6[b]
	St	70.4[a]	12.9	66.0[a]	0.29[a]	2.9[a]	6.9[a]	8.6[a]	1.7[a]	4.6[a]
LSh	28h	82.0[a]	12.0[a]	75.5	0.32[a]	3.1	7.7	9.5	1.9	5.2
	4h	92.8[b]	17.3[b]	85.0	0.38[b]	3.4	8.3	10.3	1.9	6.0
FRS	F	79.1	19.3[b]	68.2[a]	0.35	3.0	7.4	8.6	1.3	4.6
	R	91.8	13.4[a]	86.2[b]	0.36	3.2	7.9	10.1	2.2	5.7
	S	91.2	11.2[a]	86.3[b]	0.34	3.5	8.8	11.0	2.2	6.4

[abcdef] See Table 3.3

[g]Levels of significance:

***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Pre-slaughter holding time effects

Animals held for 28h tended to produce meat with higher ultimate pH values than those held for 4h but these differences were not significant (P<0.1, Table 3.6). Adjusted for pH, the only difference in measures of meat quality between the 4h and 28h groups were for EXJ1 and EXJ2. Animals in the 4h group produced meat with higher expressed juice values than those in the 28h group (P<0.001). Without adjustment for pH, however, the meat from the 4h group also had lower MFI values (P<0.05), smaller fibre diameters (P<0.01) and greater cooking losses at 70°C (P<0.01) (Table A3.1, Appendix 3). Results from the Instron compression device showed that meat from animals held for only 4h required a greater maximum load, a greater load at 20 mm and more energy than those held for 28h (P<0.05). There were no significant differences between the two holding times for any Warner-Bratzler measurements or for MIRINZ peak force. Adjusting for pH did not affect these results.

Growth path effects

The F group produced meat with higher ultimate pH values than those in groups R or S (P<0.001). Without adjustment for pH samples from group F had greater MFI values (P<0.001), greater fibre diameters (P<0.001), smaller EXJ1 (P<0.001) and lower cooking

losses at 70°C ($P<0.001$). Meat from the fast group also required a lower maximum force for Instron compression but a higher load at 20 mm than the slow and restricted groups. When adjusted for pH there were no EXJ1 or cooking loss differences between the three groups but an increase in EXJ2 for group F ($P<0.05$). Group F also produced meat with greater sarcomere lengths and higher a* values than the S group ($P<0.01$), but they were the same as the R group. Maximum force required for Instron compression, load at 80 mm, total work done on the Warner-Bratzler shear device, peak force required, and MIRINZ peak force tended ($P<0.1$) to be lower for meat from the F group but these differences were not significant at the 5% level. Samples from the F group required a significantly higher load at 20 mm. There were no differences between groups R and S for any of the measurements shown in Table 3.5.

The effect of panelist on all attributes, and order on all but hardness, were highly significant ($P<0.05$, Table A4.1, Appendix 4). For deviations of attribute scores from the means within a panelist by session combination, the panelist effect was not significant (Table A4.2, Appendix 4) as expected because the procedure for calculating the deviations was designed to minimise the variation between panelists with respect to the part of the scale they used for a particular session. There were only slight changes in the size of treatment differences when absolute values or deviations were analysed. Sensory results based on an analysis of least-squares means for each of the sixty animals (Table 3.7, adjusted for pH) showed that meat from bulls was less juicy, harder, more cohesive, tougher and chewier ($P<0.001$) than meat from steers. Animals held for 4h produced meat tended to be tougher than meat from animals held for 28h, but these differences were not significant. Meat from animals on a slow or restricted growth path when slaughtered was harder, more cohesive, tougher and chewier than meat from animals on the fast growth path ($P<0.001$). Values unadjusted for pH showed similar results (Table A4.3, Appendix 4).

Table 3.7 Least-squares means of sensory panel-tested attributes of the *M. longissimus thoracis* (pH adjusted). Interactions between the main effects are explained in the text.

Effect[d]		Initial juiciness	Hardness	Cohesiveness	Toughness	Chewiness	Overall juiciness
R^2%[e]		47	75	74	70	77	21
RSD[f]		0.46	0.72	0.54	0.77	0.69	0.35
pH[g]		*	NS	*	NS	NS	NS
pH^2		**	***	***	***	***	NS
BSt	B	3.81 [a]	5.77[b]	5.90[b]	6.10[b]	6.54[b]	4.27
	St	4.41 [b]	4.04[a]	4.81[a]	4.50[a]	4.88[a]	4.40
LSh	28h	4.09	4.73	5.28	5.10	5.54	4.36
	4h	4.08	5.07	5.51	5.51	5.87	4.32
FRS	F	4.25	4.34[a]	4.96[a]	4.72[a]	5.16[a]	4.47
	R	4.03	5.13[b]	5.56[b]	5.52[b]	5.90[b]	4.29
	S	3.98	5.23[b]	5.68[b]	5.68[b]	6.07[b]	4.25

[abcdef] See Table 3.3

[g]Levels of significance:

***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Figure 3.1 shows the comparison of mean values for sensory toughness, MIRINZ peak force and Warner-Bratzler peak force over the treatments. The trend between groups is very similar which is consistent with the high correlations between these three measures of meat tenderness.

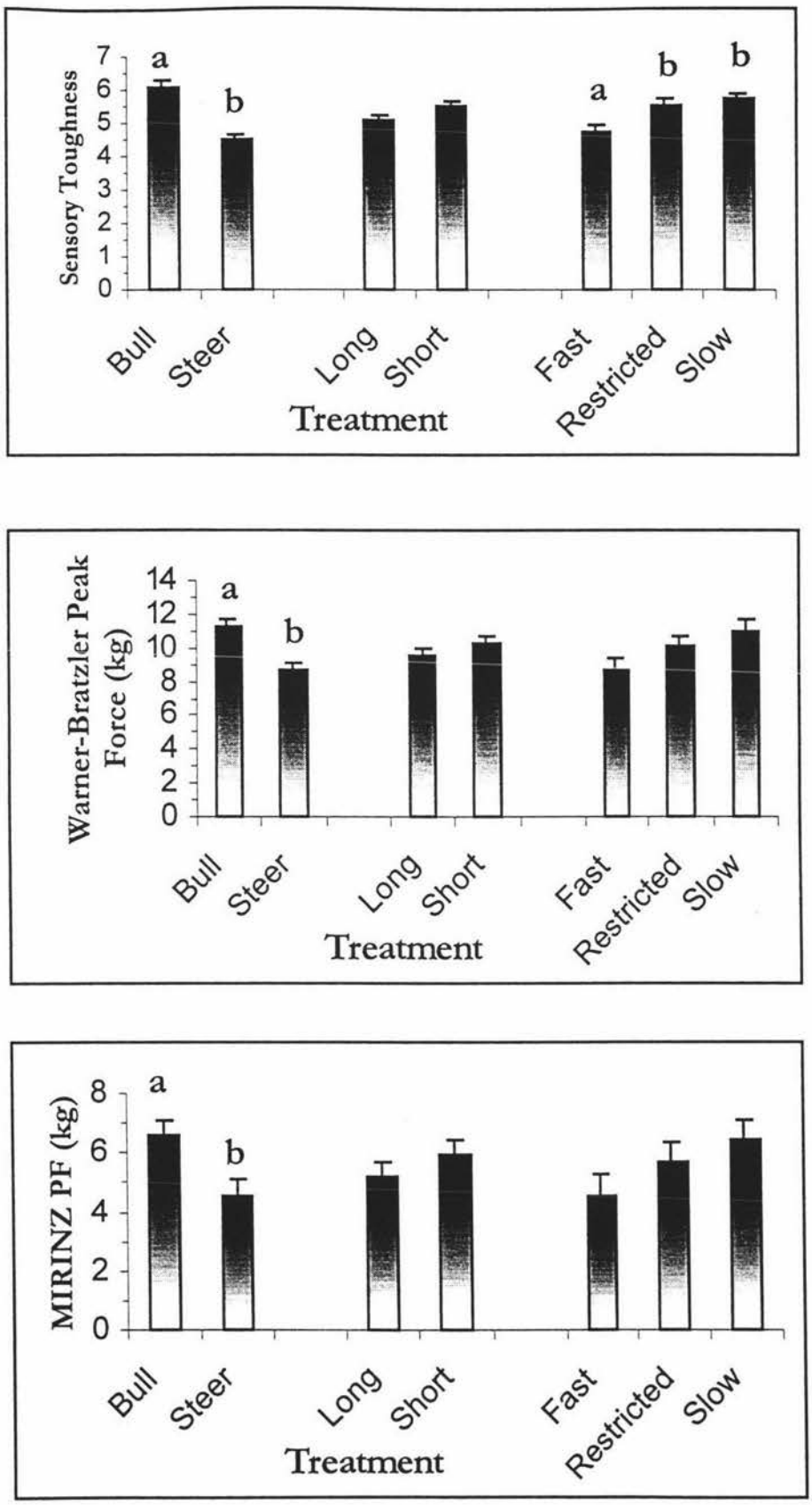

Figure 3.2 Mean (±SE) sensory toughness (upper graph), Warner-Bratzler peak force (middle graph) and MIRINZ peak force (lower graph) values for *M. longissimus thoracis* samples from cattle assigned different treatments ([ab]Columns within a treatment without a common letter are significantly different ($P<0.05$)).

Interactions between treatments for meat quality measurements

Interactions between treatments for measures of meat quality were similar both when results were unadjusted for pH (Table A3.1, Appendix 3) and adjusted for pH (Table 3.5). Interactions between castration and holding time and castration and growth for measures of MFI were significant ($P<0.01$), but the MFI of bulls was always less than steers. There were no differences in MFI between treatments within the bull group, but steers in Group F and in the 28h holding group had significantly larger MFI values than the other steer groups. Bulls had higher pH values than steers, but this effect was greater for animals in Group F than Groups S and R giving rise to a significant BSt by FRS interaction for ultimate pH. Interactions between pre-slaughter holding time and growth path were not significant.

Steers had higher sarcomere lengths when compared to bulls, as did animals in Group F relative to animals in Group R and S. The interaction between castration group and growth path reflected this as steers in all growth path groups and bulls in Group F had sarcomere lengths that were significantly greater than bulls in Groups R and S. Bulls in Group F had significantly ($P<0.05$) lower EXJ1 percentages than bulls in Group R but there were no differences in EXJ1 for the remaining groups. This led to a significant interaction between castration and growth path for expressed juice 1 values. For both cooking loss at 70°C and at 60°C there was a significant interaction between BSt and LSh because bulls in Group F had significantly ($P<0.05$) lower cooking loss values than bulls in Group R and S, but steers had similar cooking losses to the bulls across all growth paths.

Interactions were found between pre-slaughter holding time and growth path for peak force – initial yield (PF-IY, $P<0.05$) although there are no differences between treatments for the main effects (Table 3.6). Animals in the F group held for 28h pre-slaughter had significantly lower PF-IY values than the other groups except for animals in the F group held for 4h although there was no difference between this group and the others. Steers in all growth path groups had significantly lower Instron maximum force values than bulls ($P<0.05$) which was especially so for steers in the F Group, this resulted in a significant interaction between castration and growth path for Instron maximum force.

Interactions between treatments were not significant for sensory measured values unadjusted for pH. After adjustment for pH the interaction between pre-slaughter holding time and growth path was significant for sensory measured chewiness. Animals in all growth paths were significantly less chewy ($P<0.05$) when held for 4h pre-slaughter compared to those held for

28h pre-slaughter which was especially so for animals in the fast growth path group. There were no other significant interactions between treatments for other measures of sensory meat quality.

Despite significant interactions, means for main effects are still shown in Tables 3.3, 3.5, 3.6 and 3.7 as interactions did not affect the ranking of the treatment means for any of the measurements of carcass and meat quality characteristics.

3.3.3 Relationships between measures of meat quality

Correlations between measurements of meat quality

Table 3.8 shows the correlations between objective measures of meat quality. Correlations were made across all groups despite significant group effects and so values may be inflated. As expected the Warner-Bratzler parameters were all highly correlated with each other (P<0.001) and with MIRINZ peak force (P<0.001), and Warner-Bratzler peak force was especially highly correlated with MIRINZ peak force (0.96).

Table 3.8 Correlations between objective methods of measuring tenderness in *M. longissimus thoracis*

	Instron Compression				Warner-Bratzler		
	MAX	LD2	LD8	ENERGY	TotWD	IY	PF
LD2	0.32*[a]						
LD8	0.84***	0.31*					
ENERGY	0.78***	0.70***	0.82***				
TotWD	0.62***	0.37**	0.83***	0.67***			
IY	0.69***	0.31*	0.86***	0.65***	0.95***		
PF	0.69***	0.31*	0.86***	0.67***	0.97***	0.98***	
MIRINZ	0.71***	0.28*	0.87***	0.68***	0.91***	0.94***	0.96***

[a]Level of significance:
*** P<0.001; **P<0.01; *P<0.05

Sensory measures of hardness, cohesiveness, chewiness and toughness were all highly correlated with each other (P<0.001, Table 3.8), so only toughness will be used here to compare sensory analysis with objective measures of meat tenderness.

Table 3.9 Correlations between the sensory measures of meat quality of *M. longissimus thoracis.*

	INIJUIC	HARDNESS	COHES	TOUGHNESS	CHEWINESS
HARDNESS	-0.65***[a]				
COHES	-0.60***	0.98***			
TOUGHNESS	-0.60***	0.97***	0.94***		
CHEWINESS	-0.65***	0.94***	0.98***	0.97***	
OVJUIC	0.63***	-0.44***	-0.38**	-0.38**	-0.40**

[a]Level of significance:
*** P<0.001; **P<0.01; *P<0.05

Increased sensory toughness was closely (P<0.001) associated with shorter sarcomere lengths (r=-0.56), lower a* values (-0.52) and b* values (-0.52) and lower MFI values (-0.77). Toughness was also highly correlated with direct objective measures of tenderness including maximum force required for the Instron (0.76), peak force of the Warner-Bratzler (0.65) and MIRINZ peak force (0.71) (Table 3.10).

Table 3.10 Correlations between sensory and objective measurements of meat quality of the *M. longissimus thoracis.*

	Instron Compression				Warner-Bratzler			MIRINZ
	MAX	LD2	LD8	ENERGY	TotWD	IY	PF	PF
INIJUIC	-0.47***[a]	-0.02	-0.43**	-0.35**	-0.45***	-0.43**	-0.46***	-0.51***
HARDNESS	0.77***	0.12	0.70***	0.56***	0.59**	0.64***	0.66***	0.70***
COHES	0.78***	0.13	0.69***	0.56***	0.59**	0.63***	0.66***	0.70***
TOUGHNESS	0.76***	0.09	0.72***	0.54***	0.56***	0.64***	0.65***	0.71***
CHEWINESS	0.78***	0.14	0.72***	0.58***	0.61***	0.66***	0.68***	0.71***
OVJUIC	-0.17	-0.02	-0.22	-0.17	-0.27*	-0.26*	-0.28*	-0.33*

[a]Level of significance:
*** P<0.001; **P<0.01; *P<0.05

Relationships between quality characteristics and ultimate pH

Linear and quadratic regression coefficients were obtained from the same models used to produce results in Tables 3.5, 3.6, 3.7 and 3.8. Relationships between ultimate pH and several meat quality characteristics are given in Table 3.11. For direct measures of *M. longissimus thoracis* tenderness (Warner-Bratzler shear parameters, Instron compression parameters and MIRINZ peak force) only the quadratic components of the regression equations were significant with maximum pH values at 6.05, 5.69 and 6.11 respectively. Maximum and minimum values were calculated by differentiation of the regression equations. Similar quadratic relationships were found between sensory measures of tenderness, MFI, sarcomere length and pH. For other measures of meat quality such as cooking loss at 70°C and the colour parameters L* and b* the linear component was more significant (Table 3.11).

Relationships between ultimate pH and Warner-Bratzler peak force and ultimate pH and sarcomere length are shown in Figures 3.2 and 3.3 respectively.

Table 3.11 Regression relationships between measures of meat quality characteristics of the *M. longissimus thoracis* and ultimate pH.

Dependent variable (y)	Regression coefficient for pH		Max or Min	R^2%[a]	RSD[b]
	Linear	Quadratic			
Warner-Bratzler peak force	+169.3	-14.0***[c]	6.05 (max)	60	2.59
Instron max load	+505.1	-44.4**	5.69 (max)	63	18.1
MIRINZ peak force	+107.6	-8.8***	6.11 (max)	55	2.0
Cooking loss 70°C (%)	+88.8***	-8.0*	5.55 (max)	69	2.5
MFI (%)	-102.4	+8.9**	5.75 (min)	76	3.2
Sarcomere length (μm)	-3.5*	+0.3***	5.83 (min)	57	0.1
L*	-38.0***	+2.8*	6.79 (min)	49	1.5
a*	-85.9*	+6.7	6.41 (min)	34	4.6
b*	-28.9***	+2.1*	6.88 (min)	67	0.9
Hardness	+39.0	-3.3***	5.91 (max)	75	0.72
Cohesiveness	+28.5*	-2.5**	5.70 (max)	74	0.53
Toughness	+32.6	-2.8***	5.82 (max)	70	0.77
Chewiness	+41.9	-3.6***	5.82 (max)	77	0.69

[a] R^2% = Coefficient of determination
[b]RSD= Residual standard deviation
[c]Level of significance:
***P<0.001, **P<0.01,*P<0.05

The relationship between ultimate pH and Warner-Bratzler peak force as a quadratic regression was significant (R^2=0.31, P<0.01, Figure 3.2). There was a similar quadratic relationship between MIRINZ peak force and ultimate pH (R^2=0.26, P<0.05).

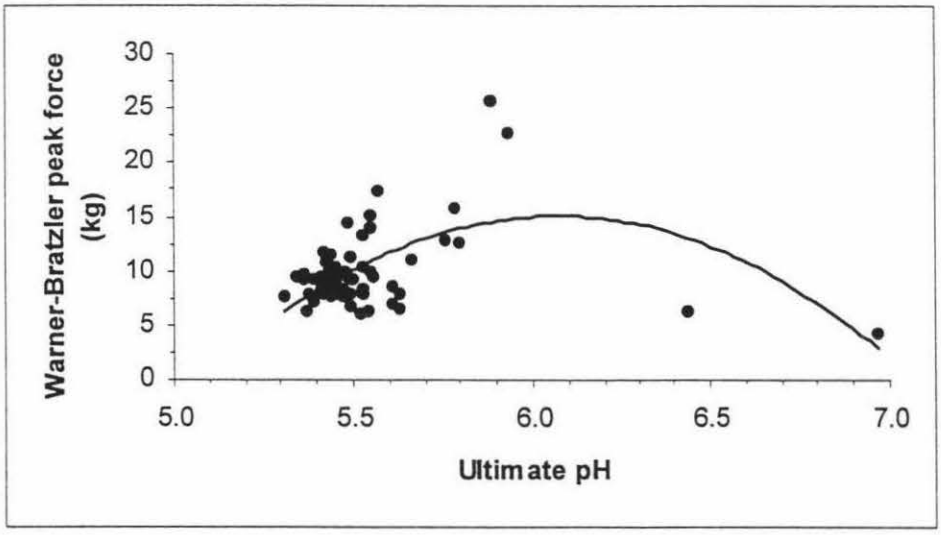

Figure 3.3 Changes in Warner-Bratzler peak shear force with increasing ultimate pH for samples of the *M. longissimus thoracis*.

There was a relatively weak relationship between sarcomere length and the linear component of ultimate pH (R^2=0.21, P<0.05), but the relationship between sarcomere length and the quadratic component of ultimate pH was highly significant (P<0.001). This relationship is shown in Figure 3.3.

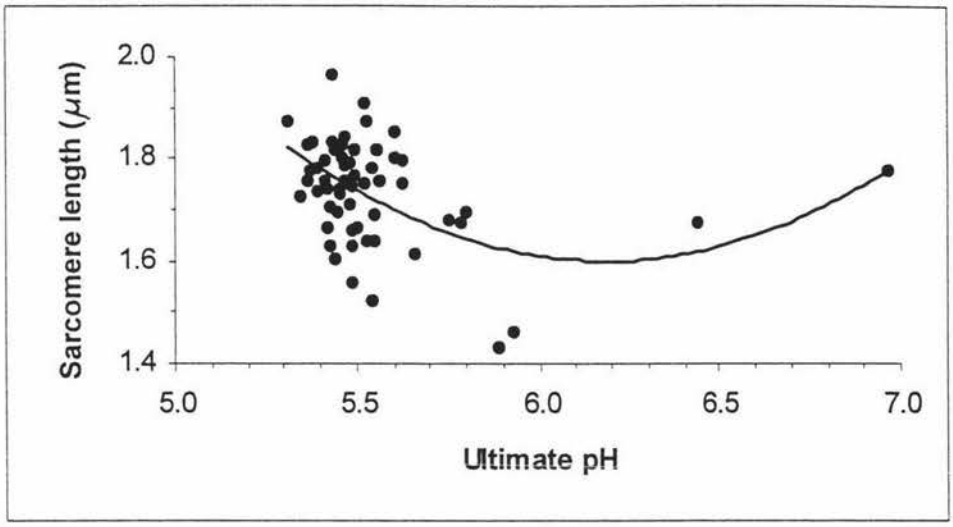

Figure 3.4 Changes in sarcomere length with increasing ultimate pH for samples of the *M. longissimus thoracis*.

3.4 DISCUSSION

The objectives of this trial were to evaluate the effect of castration, pre-slaughter holding time and growth path on carcass and meat quality characteristics, with emphasis on meat tenderness.

3.4.1 Castration

Carcass quality characteristics

The differences in carcass characteristics between bulls and steers (Table 3.3) appear consistent with other published comparisons. The greater pre-slaughter liveweight and carcass weight of the bulls over the steers, despite the fact that they had been slaughtered earlier, has also been reported by many studies including Ockerman et al. (1984) (difference of 48 kg liveweight and 28 kg carcass weight; P<0.01), Gerrard et al. (1987) (45 kg liveweight, 30 kg carcass weight) and Purchas (1990) (16 kg liveweight, 13 kg carcass weight, P<0.001). Further research on this topic was reviewed by Field (1971) and Seideman et al. (1982).

Because dressing-out percentage increases with increasing weight (Purchas et al. 1997) the values were adjusted to a common carcass weight. Purchas (1990) reported no differences in dressing-out percentage after adjustment for carcass weight between bulls and steers, a similar result to that found in this trial. However, previous studies have reported that bulls have higher dressing-out percentages than steers (Mickan et al. 1976, 55.8 vs 52.4, $P<0.01$; Gerrard et al. 1987, 58.2 vs 56.8) although these results were not adjusted for carcass weight. Purchas & Aungsupakorn (1993) and Purchas & Grant (1997) did adjust results for carcass weight and also found that bulls had higher dressing-out percentages than steers (51.5 vs 49.8, $P<0.001$ and 50.0 vs 49.2, $P<0.05$, respectively). However, it must be noted that the latter trial used Hereford x Friesian bulls and Friesian x (Hereford x Angus) steers, so the different dressing-out percentages when adjusted for carcass weight may have been a breed difference.

Measures of fatness, adjusted for carcass weight, were greater for the steers than the bulls as expected, and bulls had a greater EMA than steers. Klastrup et al. (1984) reported similar results (difference of 14.1 cm^2 rib-eye area, $P<0.05$) as did Purchas & Grant (1995) (difference of 2.3 mm fat depth and 6.5 cm^2 rib-eye area, $P<0.05$, between Hereford x Friesian bulls and Friesian x (Hereford x Angus) steers).

Meat quality characteristics

Sensory results showed that bulls were tougher than steers, but there was no difference in juiciness (Table 3.7). Similar results from sensory work were reported by Crouse et al. (1983), Jeremiah et al (1988) and Wulf et al. (1997), all of whom reported that bulls produced meat which was significantly ($P<0.05$) tougher than steers when measured by sensory panel. In keeping with the current results, Jeremiah et al. (1988) also found that bulls produced significantly ($P<0.05$) chewier meat than steers.

The greater incidence of high-pH beef from bulls compared to steers reported here is consistent with many results in many other studies (Chrystall 1987, 6.3 vs 5.9, $P<0.01$; Purchas 1990, 6.3 vs 5.8, $P<0.05$), as is the pattern of higher MFI values for muscle from steers than bulls (Purchas et al. 1997, 82.0% for Hereford x Friesian bulls, vs 83.2% for crossbred steers, $P<05$). However, other studies have found no difference in meat pH between bulls and steers (Jones et al. 1986). Purchas & Grant (1995) and Purchas (1990) reported that steers had greater sarcomere lengths, as in this study, but the differences disappeared when values were adjusted for differences in ultimate meat pH. Purchas & Aungsupakorn (1993) also found no differences in sarcomere length between bulls and steers after adjustment for pH. The results

of Klastrup et al. (1984) and Purchas & Aungsupakorn (1993) were consistent with those given here showing no differences in expressed juice (EXJ2) between beef from bulls and steers. Purchas & Aungsupakorn (1993) and Purchas & Grant (1995) reported that meat from the *M. longissimus thoracis* of bulls had higher cooking losses than steers after adjustment for pH, which is consistent with the results of this study (Table 3.5). However Purchas (1990) and Pietersen et al. (1992) reported no differences in cooking loss, although they did not adjust results for ultimate pH.

Shackelford et al. (1992) found differences in the colour parameters L* and b*, of the rib eye, between bulls and steers with steers having higher L* and b* values. This is similar to the current results (Table 3.5). Purchas & Grant (1995) reported that steers had greater L*, a* and b* than bulls, but these differences disappeared when the values were adjusted for differences in ultimate meat pH. It must be noted though that these comparisons were made on bulls and steers of differing breeds.

Present results showed that castration had a large effect on Instron maximum force, Warner-Bratzler peak force and MIRINZ peak force ($P<0.001$) both before and after adjustment to a constant pH. Similar results have been found in many other studies including those of Gregory et al. (1983), Dikeman et al. (1986) and Jeremiah et al. (1991). Reviews by both Field (1971) and Seideman et al. (1982) also concluded that meat from bulls has higher shear values than steers. Pietersen et al. (1992) evaluated tenderness of meat from the *M. longissimus thoracis* of bulls and steers using the Instron testing device fitted with a Warner-Bratzler measuring apparatus and found no significant differences but their results were not adjusted for pH. Meat from steers was significantly more tender than meat from bulls when measured by the Warner-Bratzler shear force device (4.63 kg vs 3.71 kg, $P<0.05$) in a trial performed by Klastrup et al. (1984), a result which is consistent with the current results (Table 3.6). Landon et al. (1978) found no differences in Warner-Bratzler shear of meat from bulls and steers slaughtered at the same weight at less than 18 months of age, and concluded that tenderness of meat from young bulls up to approximately 18 months did not differ from that for meat of steers of a comparable chronological age.

Most New Zealand trials mentioned already reported no significant differences in meat toughness as measured by Warner-Bratzler peak force between bulls and steers, possibly as a result of the pH effect on toughness (Purchas 1990; Purchas & Grant 1997) although bull beef tended to be tougher than that from steers ($P<0.1$). As shown in Table 2.6, ultimate pH values below 5.8 and above 6.2 resulted in more tender meat, as was the case in the studies of

Purchas (1990) and Purchas & Grant (1997) where an average ultimate pH for steers of below 5.8 and for bulls of above 6.2 resulted in similar tenderness levels between the two gender groups. Purchas & Aungsupakorn (1993) reported significant pH differences between bulls and steers (5.78 vs 6.21 ($P<0.001$)) and also that pH-adjusted peak force differences were significantly ($P<0.02$) higher for beef from bulls as was the case in the present trial. Woodham & Trower (1965) and Thomson et al. (1996) also reported no differences in tenderness between bulls and steers but both studies compared only a few animals (11 bulls vs 11 steers and 8 bulls vs 8 steers, respectively) which may have resulted in the low levels of significance.

3.4.2 Pre-slaughter holding time effect

Carcass quality characteristics

This study found that animals held for 4h pre-slaughter had higher live weights and carcass weights and lower dressing-out percentages and fat depths. Purchas (1992) also reported that animals held for only four hours had higher carcass weights (251.5 vs 240.9 kg, $P<0.001$). However, that study also reported no significant differences in liveweight and an increase in dressing-out percent (based on farm weights) and fat depth for animals held for only four hours compared to 28 hours pre-slaughter in contrast to our results. The difference in results between Purchas (1992) and the present results (Table 3.3) could be because in the current study carcass characteristic values were adjusted for carcass weight, but this was not done by Purchas (1992). Purchas & Keohane (1997) found that animals held for 3h pre-slaughter had higher carcass weights and tended to have lower dressing-out percentages compared with animals held for 27h pre-slaughter, and that there were no differences in fat depth, although their animals were not from a controlled experiment.

Meat quality characteristics

Current results show no difference in ultimate pH between the animals held for 4h and those held for 28h and the only significant differences for objective measures of meat quality were for expressed juice, where, like Purchas (1992), the animals held for 4h produced meat with greater expressed juice values (Table 3.5). The animals held for 28h also had meat with significantly lower Instron max force, load at 20 mm, and energy values than those held for only 4h. Purchas (1992) reported large differences in ultimate pH of meat from animals held for 4 hours pre-slaughter compared to animals held for 28 hours, particularly in the case of bulls. These pH differences were reflected in the greater values of expressed juice, cooking loss and sarcomere length of the meat from animals held for 4h. Purchas & Keohane (1997)

reported non-significant differences in pH between steers held for 3h or 27h. Animals held for 27h tended to have higher pH values of the *M. longissimus thoracis* ($P<0.10$). Wythes et al. (1988b) found that as the total resting period pre-slaughter increased, ultimate pH decreased as did IY and PF shear values. Purchas (1992) found no differences in WB shear force between the two groups, which agrees with the current results. However, Wythes et al. (1988b) reported that animals held for 1 day gave more tender beef than those held for only 2.5h pre-slaughter, although environmental conditions in which the animals were held pre-slaughter were uncertain.

The animals in the present trial were extremely quiet and showed little signs of stress or aggression during regular monitoring over the holding period. The results show that animals held for 4 hours were tougher as measured by Instron compression than animals held for 28 hours which conflicts with previous New Zealand trials (Purchas 1992) performed under similar conditions although animal behaviour in that trial was not reported. A possible explanation for this is that the animals held for only 4h pre-slaughter may not have had time to recover from transport stress and adjustment to a new environment compared to the animals held for 28h The conflict in results between this study and Purchas (1992) may also have been a result of breed differences. This study used Hereford x Angus cross cattle which may have been less prone to stress when held for longer periods of time than the Friesian cross steers used by Purchas (1992)

3.4.3 Growth path effect

Carcass quality characteristics

Current results showed that animals on a fast growth path slaughtered at 17 months of age had significantly more kidney and pelvic fat and a greater fat depth with higher dressing-out percentages than animals slaughtered on slow or restricted growth paths at the same liveweight at 25 months of age (Table 3.3). Similar results were reported by Allingham et al. (1998) who found that Brahman cross steers grown on a fast growth path for 257 days had greater unadjusted dressing-out percentages and fat depths than animals grown slowly for 100 days and then rapidly for the remaining 157 days to allow them to catch up to the fast group.

Purchas & Grant (1997) compared the carcass characteristics of a group of animals at 28 months of age after growing on a slow growth path, with a group of animals on a fast growth path slaughtered at 20 months of age. They found that, after adjustment to a common carcass weight, animals grown fast had higher dressing-out percentages (50.0 vs 48.7), greater fat

depths (2.60 mm vs 2.02 mm) and also shorter carcass lengths (2110 mm vs 2142 mm) ($P<0.05$) but they reported that the animals also had lower levels of kidney fat (2771 g vs 3639 g). Morgan (1979) found that Hereford steers which had grown slowly to the same final weight had lower fat depths and similar weights of kidney and channel fat. Further results of carcass characteristics of cattle grown along different growth paths were reviewed in Section 2.3.

Meat quality characteristics

The current results show that cattle grown on fast growth paths slaughtered at 17 months of age produced meat with a slightly higher ultimate pH than cattle slaughtered at 25 months of age on slow or restricted growth paths. They also had greater MFI values, sarcomere lengths, and higher expressed juice values and lower sensory measured toughness values. These results are, in part, similar to Purchas & Grant (1995) but no differences between growth path for any of the Warner-Bratzler measurements or for MIRINZ peak force were found, although animals in Groups S and R tended ($P<0.1$) to have higher values than the fast-growth-path group. Purchas & Grant (1995) reported that animals slaughtered at 20 months of age produced meat with greater sarcomere lengths and lower a* and b* values when adjusted for ultimate pH than animals slaughtered at the same weight after growing more slowly to 28 months of age, although ultimate pH differences were not significant. Animals grown faster also had lower WB-WI, WB-PF, WB-IY and WB (PF-IY) both with and without pH adjustment, but no differences in L* or cooking loss when compared to animals on a slow growth path slaughtered at 28 months of age. These results are consistent with studies on the effect of animal age on tenderness of beef over this age range (Wulf et al. 1996; Purchas et al. 1997, Table 2.1).

The fact that there were few differences between animals in Group S and Group R, but significant differences between animals in those two groups, and animals in Group F, suggests that differences in meat quality characteristics between animals on the different growth paths were a result of the difference in age of the animals when slaughtered (17 vs 25 months of age) rather than the different growth paths.

3.4.4 Correlations between measures of meat quality

The high correlations between the Warner-Bratzler parameters and MIRINZ peak force shown here (Table 3.8) have been reported in other studies (Bouton & Harris 1972a), and especially the correlation between Warner-Bratzler peak force and MIRINZ peak force.

Bouton & Harris (1972a) reported a correlation coefficient between these two measurements of 0.94 ($P<0.001$) which is only slightly lower than the correlation reported in this trial (Table 3.8). They concluded that both instruments were probably measuring the same property (the myofibrillar contribution to tenderness). The very strong correlation between Warner-Bratzler and MIRINZ shear force measured in this trial could be because each individual core was sheared by both instruments. The correlations between maximum Instron compression and Warner-Bratzler and MIRINZ peak force were slightly lower which may be the result of Instron compression measurements being influenced more by the connective tissue content of the samples rather than the myofibrillar components (Bouton & Harris 1972a). Samples used for measuring Instron compression were also cooked at a lower temperature and for a shorter period compared to samples used for the Warner-Bratzler and MIRINZ assessments, which could explain the lower correlations. Cooking the samples for Instron compression allowed the samples to be cut more accurately which was difficult to do with raw meat, but the samples were cooked at a lower temperature and for less time than samples prepared for the Warner-Bratzler and MIRINZ devices in order to minimise collagen breakdown.

Gregory et al. (1983) and Ockerman et al. (1984) both reported high correlation coefficients between sensory tenderness and juiciness of 0.54 ($P<0.01$). In this trial sensory toughness was also correlated with overall juiciness (-0.38, $P<0.01$) but was more closely correlated with the other sensory measures (Table 3.9). The strong correlations between the sensory characteristics of cohesiveness, chewiness, hardness and tenderness indicate that the parameters are measuring either the same element of tenderness or ones that are strongly related. Gregory et al. (1983) also reported high negative correlations between sensory measures of tenderness and Warner-Bratzler shear values (-0.55, $P<0.01$) as did Crouse et al. (1985) (-0.58, $P<0.01$). These were similar to the correlation between sensory toughness and Warner-Bratzler shear peak force as reported in the present trial (0.65, $P<0.001$). Warner-Bratzler peak force, Instron maximum compression and MIRINZ peak force were all highly correlated with sensory toughness (Table 3.10), suggesting that they were all monitoring changes in mechanical properties which could be detected subjectively.

The relationship between ultimate pH and Warner-Bratzler shear force showed the expected bell-shape (Figure 3.3) with a peak in shear force at a pH value of approximately 6.0 which is similar to that reported by Purchas & Aungsupakorn (1993), although this trial had very few pH values above this peak. It is known that myofibrillar contraction to sarcomere lengths below 1.8 – 2.0 μm increases toughness in the cooked post-rigor meat (Harris 1976). As

sarcomere length decreases Warner-Bratzler peak force increases (r=-0.70). Correspondingly as ultimate pH increases, Warner-Bratzler toughness increases to a pH of approximately 6.0 and then decreases (Figure 3.3) and sarcomere length decreases to a pH of approximately 6.0 and then increases (Figure 3.4). This relationship supports studies by Purchas (1990) and Purchas & Aungsupakorn (1993) where it was suggested that changes in sarcomere length as pH decreases may be involved in changes in tenderisation. Adjusting for pH reduced variation for those meat quality measurements that were affected by pH, as indicated by the size of the decrease in RSD values and increase in R^2% after pH and pH^2 was added to the statistical model (Tables 3.5, 3.6, 3.7, A3.1, A3.2, A4.3)

3.5 CONCLUSION

In this study steers produced fatter carcasses than bulls but tended to have lower dressing-out percentages with smaller eye muscle areas when adjusted for carcass weight. Bulls produced meat that is markedly tougher than steers as measured instrumentally and with sensory analysis. Cattle held for only 4h pre-slaughter had lower dressing-out percentages and fat depths than cattle held for 28h and produced tougher meat as identified by sensory analysis and Instron compression but not by Warner-Bratzler or MIRINZ peak force measures. Cattle which grew faster under standard conditions, and which were slaughtered at approximately 17 months of age after being on a fast growth path, had higher dressing-out percentages and higher fat levels as well as shorter carcass lengths and lighter 3Cut weights than cattle slaughtered at 25 months of age on slow and restricted growth paths and they produced more tender meat. There were few differences between animals on slow and restricted growth paths. Results from this trial suggest that differences in carcass and meat characteristics between the growth path groups were a result of animal age rather than inherent growth rates of the animals. Nutritional regime may also have caused the differences, as animals slaughtered at 25 months of age may have had tougher meat due to the feed restrictions imposed on them over the winter period.

CHAPTER FOUR

GENERAL DISCUSSION AND CONCLUSIONS

4.1 GENERAL DISCUSSION

The primary export markets targeted by the New Zealand beef industry are North America, South Asia, Japan, South Korea and the domestic market (New Zealand Meat Board 1998). The quality of meat being supplied is of vital importance to retaining and expanding these markets. The introduction of the Beef Quality Mark by Meat New Zealand has enabled meat quality standards to be established for the domestic market and as a result producers are able to identify cattle that fulfil the criteria for the Quality Mark. These standards include a maximum ultimate pH of 5.8 and a maximum MIRINZ tenderometer mean peak force score of 8 kg (New Zealand Beef and Lamb Marketing Bureau Inc. 1997). Identifying on-farm and post-slaughter techniques for producing quality meat that fit these criteria will allow the delivery of a more consistent product, which will aid in strengthening New Zealand's position in these targeted markets.

The main purposes of this study were to investigate the effects of castration, pre-slaughter holding time and growth path on meat quality characteristics, and especially tenderness, of the *M. longissimus thoracis* of beef cattle. Implications of the findings of the study are discussed below.

Effect of castration on meat quality

Results from this study show that bulls had a high yielding carcass with less fat than steers but they also produced meat that had a higher ultimate pH, was less tender and darker. These tenderness differences remained after adjusting for pH in contrast to some other studies (Purchas 1990; Purchas & Aungsupakorn 1993). Although both pH and toughness values for this study were within the national Beef Quality Mark guidelines, other studies suggest that bulls over the age of 18 months produce meat that is tougher and more variable than that from steers (Landon et al. 1978; Crouse et al. 1985; Dikeman et al. 1986) with pH values outside Quality Mark standards (Jeremiah et al. 1988; Purchas & Grant 1990; Purchas et al. 1997). These results suggest that meat from bulls over the age of 18 months should be

excluded from meat awarded the Quality Mark, as the quality of meat can not be guaranteed. The colour of meat is very important to most markets, as it is the appearance characteristic that is most likely to affect consumer acceptance of meat (Shackelford et al. 1992). Bulls produced meat that was significantly darker than steers, even after adjustments for pH differences, which is another reason to consider excluding shipments of prime cuts from bulls to some markets.

Effect of pre-slaughter holding time on meat quality

Beef from animals held for 4h pre-slaughter with water but no feed tended to be slightly tougher than that from animals held for 28h pre-slaughter when measured by the MIRINZ tenderometer, Warner-Bratzler shear and sensory evaluation but these differences were not significant. Results from the Instron compression device showed that meat from animals held 4h pre-slaughter was significantly tougher and required more energy to compress than meat from animals held for 28h pre-slaughter. Ultimate pH and MIRINZ tenderness values of meat from both treatments were within Quality Mark standards.

It has been reported that holding animals for longer periods at the abattoir results in tougher meat from animals which are subjected to strenuous muscular activity such as fighting and mounting (Purchas 1992) which is often a result of holding animals in small pens over long periods. However, animals in the current trial were extremely quiet and moved little during holding. This is probably the reason for the small differences in pH and meat quality between the animals as a result of pre-slaughter holding time. These results make it difficult to suggest an ideal length of time to hold animals pre-slaughter for the production of high quality beef. It is suggested that the Instron-measured toughness of animals held for only 4h pre-slaughter is a result of insufficient time to recover from trucking stress and the stress of a new environment.

Implementation of adequate welfare standards from producer to processor and optimum holding times for recovery after trucking and environmental stress should result in the production of meat with lower ultimate pH values which is more tender and brighter in colour than animals which have been stressed pre-slaughter. Because results from this trial were inconclusive it is suggested that more work needs to be done on the effect of length of pre-slaughter holding period, and time of feed, on meat quality characteristics.

Effect of growth path of the animal on meat quality

Animals on the fast growth path tended to have more fat but also higher dressing-out percentages, however, they produced meat with slightly higher ultimate pH values although sensory, Instron, Warner-Bratzler and MIRINZ toughness values tended to be lower. All values were within Beef Quality Mark standards.

The differences in pH may have been the result of handling conditions in the abattoir prior to slaughter rather than growth path as it is difficult to standardise conditions with a ten-month difference in slaughter dates. Very few differences were found between cattle in the slow and restricted growth-path groups which suggests that differences in tenderness reported in previous studies (Purchas & Grant 1995; Purchas et al. 1997) were a result of animal age rather than the inherent growth rate of the animal. However, it s impossible to separate the effect of animal age from nutritional regime as the older animals also went through an extra winter prior to slaughter and feed restrictions as a result of seasonal grass growth may have impacted on meat and carcass quality characteristics for both the slow and restricted groups. As a result it is suggested that meat awarded a Quality Mark should be sourced from animals slaughtered before their second winter at approximately 18 months of age. This would avoid the problem of tougher meat produced by either older animals or from animals that have gone through their second winter and produced tougher meat as a result of the nutritional regime. In the abattoir it may be difficult to detect older animals, the present method of grading animals by age is by counting their teeth. However, approximately twenty three percent of the 40 animals that were slaughtered after their second winter at 25 months of age in this trial had no permanent incisors and if their age was not known it may have been difficult to identify them as older animals. Recording date of birth or at least year of birth on compulsory ear tags for individual identification may avoid this problem in the future.

Encouragement of farmers to produce tender meat

Farmers are currently rewarded for quantity of beef produced and unfortunately not for quality. In November 1998 farmers that produced manufacturing grade bulls of 270.5-295 kg carcass weight were paid 256 c/kg compared to prime steers which were paid only 250 c/kg (Brian Speirs, Chief Economist, Meat & Wool Economic Service of New Zealand, pers comm., 1999) which was in recognition of the higher yielding carcasses of the bulls. Because the slaughtering of animals under New Zealand's pastoral system is seasonal, at certain times of the year which are early or late in the season, such as November, the payments to the farmer are higher. Payments to farmers in the preceding March were only 192.2 and 216.4

c/kg for steers and bulls respectively (Meat & Wool Economic Service of New Zealand 1998). Table 4.1 shows the trend for payments from March 1998 to February 1999. The highest payments to farmers were for animals slaughtered in the August-September months, during which few animals were slaughtered. Payments decreased as the numbers of animals being slaughtered increased, so for example in March 1998 when over 30,000 bulls and 50,000 steers were slaughtered payments were low compared to November 1998 when only 25,000 bulls and 40,000 steers were slaughtered and payments were much higher (Brian Speirs Chief Economist, Meat and Wool Economic Service of New Zealand, pers comm. 1999).

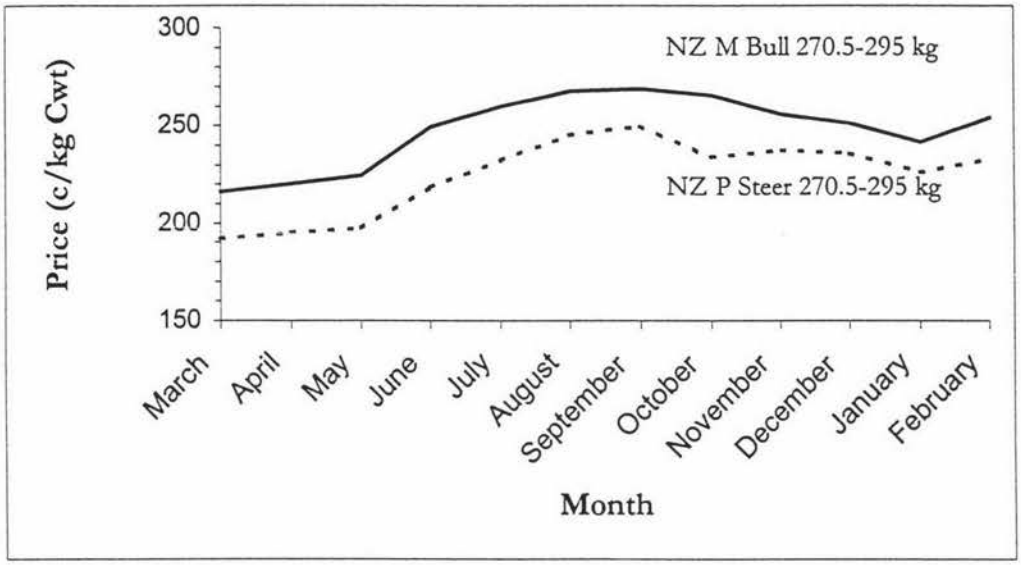

Figure 4.1 Mid-month price (c/kg carcass weight) quotations for manufacturing bulls and prime steers for 1998/99(Brian Speirs Chief Economist, Meat and Wool Economic Service of New Zealand, pers comm. 1999).

These prices encourage farmers to rear bulls rather than steers and under favourable weather conditions or grazing conditions they would find it more profitable to carry their cattle through their second winter for slaughtering earlier in the season, as not only are the animals heavier but the returns are higher. As a result methods of rewarding farmers for producing high quality meat must be implemented. Meat carrying the Quality Mark has the potential to fetch higher prices at market as quality of this meat can be assured. These higher prices could then be passed back to the farmer producing the meat. New Zealand exporters of beef could provide guarantees to target markets with respect to the quality and consistency of New Zealand meat and New Zealand farmers could be offered encouragement to continue producing good quality meat.

The initiation of a national animal identification system on the 1st July 1999 will enable the processor to trace carcasses back to the farmer, allowing farmers that produce cattle with good quality meat to be identified and rewarded (or penalised for bad quality) if satisfactory ways of routinely measuring meat quality, and especially tenderness, can be established. As a result the farmer could maintain (or improve) the management practises that were in place which resulted in good quality meat. In the event of the production of high pH or tough meat, animal identification would also allow processors to trace back to the handlers at the abattoir or truck drivers who did not maintain adequate welfare standards and stressed the animals, unnecessarily lowering their meat quality. Identification of individual animals from birth to slaughter will provide opportunity for the auditing or maintenance of meat quality standards for producers and processors. This is especially relevant for the findings of this study where older animals, which are not recommended for inclusion in meat for the beef Quality Mark, are easily able to be identified.

4.2 CONCLUSION

Bulls and animals slaughtered after their second winter (27 months of age) produced meat from the *M. longissimus thoracis* that was tougher than that of steers and animals slaughtered at approximately 15 months of age at the same liveweight. There were few differences between animals held for 4 hours and those held for 28 hours pre-slaughter. It is suggested, however, that animals held for only 4 hours pre-slaughter may not have had the chance to fully recover their glycogen levels which can be depleted as a result of trucking and the stress of a new environment at the abattoir.

It is concluded that in order to consistently produce meat from the *M. longissimus thoracis* with a guaranteed acceptable level of tenderness, management practises should avoid bulls slaughtered over the age of 15-18 months and animals slaughtered after their second winter. Standards avoiding unnecessary stress to animals prior to slaughter should also be maintained.

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APPENDIX 1

MEASURES OF MEAT QUALITY

A1.1 Measurements of sarcomere length

Sarcomere length was measured using a Spectra-Physics helium-neon laser, 2 mW 0.49 mm diameter beam, with a wavelength of 632.8 nm, which was mounted on a retort stand over a specimen holding device which had a fixed screen distance of 100 mm. The samples were viewed in a dimmed room to reduce outside light and make the diffraction bands clearer. In the sample preparation a muscle sample of approximately 1 x 1 x 4 mm was pressed out onto a microscope slide in 2-3 drops of distilled water with a cover slip. The pressing was done gently to keep the muscle fibres as parallel as possible. The slide was then placed horizontally in the path of a vertically orientated laser beam to give an array of diffraction bands on the screen. These bands were perpendicular to the long axis of the fibre. The average values were used to calculate the sarcomere lengths by use of the following formula:

$$\text{Sarcomere Length } (\mu m) = (632.8*10^{-3}*D[(T/D)^2+1]^{1/2})\ T^{-1}$$

Where D = distance from specimen holder to screen (constant 100 mm),

T = separation between first order maximum band and zero.

Cross et al. (1980-1981)

A1.2 Measurements of MFI

The myofibrillar fragmentation indexes (MFI) are a measure of the proportion of muscle fragments that pass through a 231 μm screen after the sample had been subjected to a standard homogenisation treatment. A 5 g (±0.5 g) sample of diced (c. 6 mm^3 pieces) partially thawed meat was added to 50 mL of physiological saline (0.85% NaCl) plus 5 drops of anti-foam A emulsion (Sigma Chemical) in a 100 ml graduated cylinder, and homogenised at c. ¼ speed using an 18 mm diameter shaft on an Ultra-Turrax homogeniser for two 30-second periods separated by a 20 second rest period. Homogenate remaining on the shaft was rinsed off into the cylinder using 20 ml of saline and the total was poured into a pre-weighed filter made from a 60 mm length of plastic pipe (52 mm internal diameter) with stainless steel mesh (231 x 231 μm holes) glued to one end. The filters typically finished dripping after 2-3 hours, at which time they were dried at 25-28°C in an incubator for 40 hours before being re-weighed.

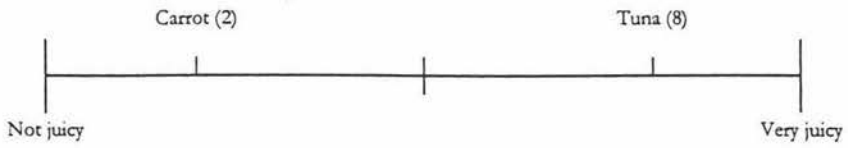
MFI values were calculated as 100 minus the percentage of the initial meat sample weight that remained on the filter. Values varied from about 78% (when nothing passes through the filter) to 100% when it all passed through. The high "zero" values of 78% reflects the extended drying time which was chosen because by that time the rate of decline in weight was low, and as a result the repeatability of the duplicates was better, compared to that from shorter drying times.

A1.3 Example of line scales used to evaluate sensory characteristics

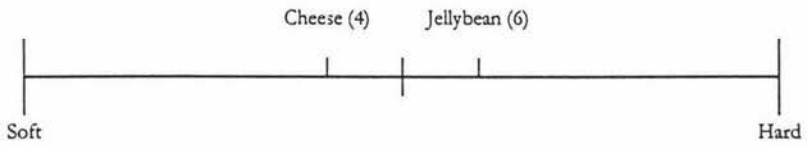
Definitions of the attributes are presented in Table 3.1.

SAMPLE _____

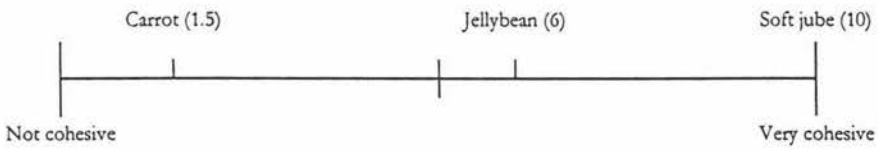
INITIAL JUICINESS



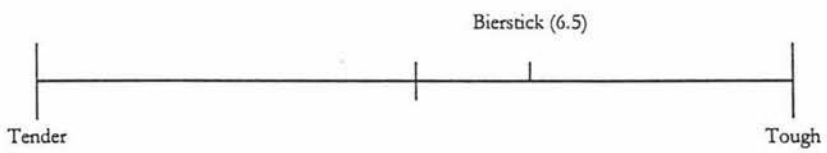
HARDNESS



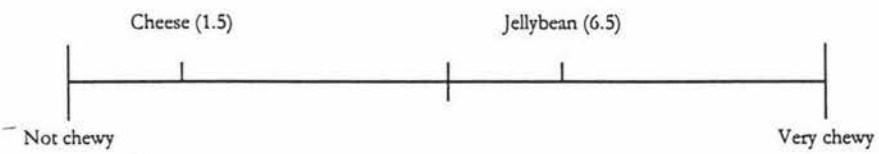
COHESIVENESS



TENDERNESS



CHEWINESS



OVERALL JUICINESS

A1.4 Preliminary Studies with the Silex Cooker

Introduction

The Silex cooker was chosen to prepare samples for sensory analysis work, as it was more representative of commercial and domestic cooking than the water bath method. The Silex has been used successfully in sensory work associated with the Australian Eating Quality Standards programme (Dr M.H. George, pers comm).

Prior to using the Silex in the main trial the consistency of the increase in internal temperature for steaks cooked at the same time had to be established. The importance of steak weight and thickness to the pattern of temperature increase was also evaluated. The overall aim of these preliminary trials was to determine whether the time of cooking alone could be used to get a uniform cooked product with respect to temperature reached and cooking loss when samples were cooked at a setting of 250°C to an internal temperature of 75°C. The differences in sensory attributes of the samples were also investigated at settings of 200°C and 175°C as well as 250°C

Materials & Methods

The Silex cooker

The Silex Kitchen Combination was purchased from Silex® Grills Aust. Pty Ltd. It is a 10-amp clam-type cooker with a sliding hinge arrangement that enables contents to be heated simultaneously from both top and bottom while the two cooking surfaces remain parallel to each other. The cooking surfaces are approximately 330 x 220 mm and comfortably allow up to six 105 mm x 105 mm steaks to be cooked at the same time.

Steaks

Steaks with a 30 mm thickness were used in calibrating the Silex. Four steaks were cooked simultaneously by the Silex and measurements of temperature increase were taken from all four. Cooking loss of the steaks was established by subtracting the final weight of the cooked steak (F) after it had chilled overnight from its initial weight before cooking (I) and dividing this value by I. Percentage cooking loss was then found by multiplying this final value by 100.

ie. %cooking loss = ((I –F)/I)*100 or (Weight loss with cooking/ Initial Weight) x 100/1

Temperature Measurements

Measurements of temperature increase and time taken was recorded using a Squirrel Datalogger. Two wire thermocouples were inserted into the centre of each steak allowing results to be recorded automatically on a computer.

Results

Importance of steak weight to the pattern of temperature

It was found that steaks had to be exactly the same weight and dimensions to allow them to cook at the same rate, otherwise there would be a large difference on the time it took the steaks to reach the desired internal temperatures. Figure A1.1 shows the time it took for four steaks of an average weight of 68.1 g to cook to an internal temperature of 75°C compared to four steaks with an average weight of 131.5 g (see Table A1.1 for more details).

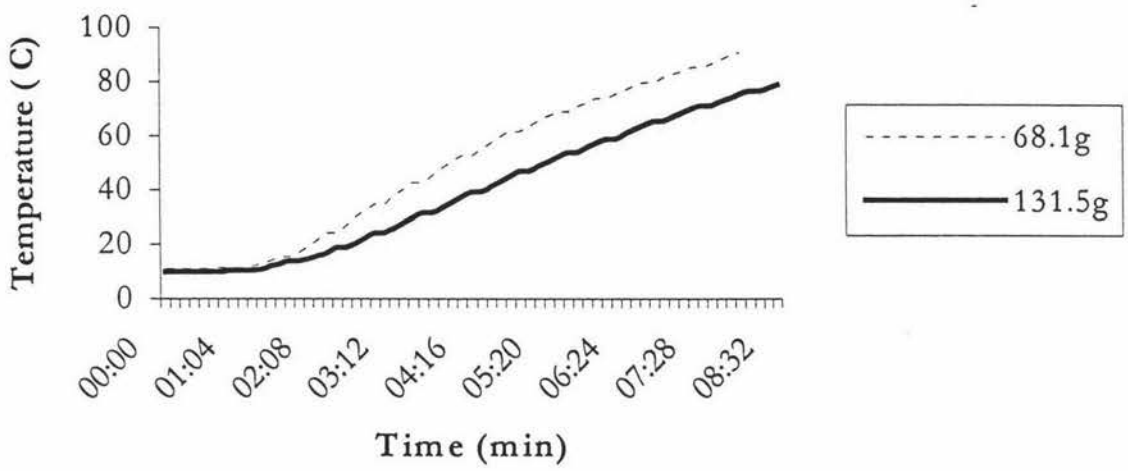


Figure A1.1 Effect of weight of steak from the beef eye of roll on pattern of temperature increase of steaks cooked on the Silex cooker.

Table A1.1 Time taken for the steaks to reach an internal temperature of 70°C and 75°C and the difference in cooking loss between the two different weights of the steaks.

Sample	Initial Weight (g)	Final Weight (g)	Cooking Loss (%)	Time to 70°C	Time to 75°C	Final Temp (°C)
1	72.7	44	39.48	5min 18	5min 12	95.09
2	62	36.4	41.29	4min 46	5min 50	100.62
3	65	38.7	40.46	7min	6min 39	79.99
4	72.5	41.1	43.31	6min 5	7min 43	87.99
1	130.1	82.6	36.51	7min 43	8min 13	77.14
2	131	79.9	39.01	7min 14	7min 32	80.71
3	131	82.2	37.25	7min 28	8min 3	79
4	134	83.1	37.99	7min 28	8min 3	79.09

Table A1.1 shows that the lighter steaks, which took less time to reach the same temperature, reached a greater final temperature than the larger steaks which may explain the increase in cooking loss for the lighter steaks.

Consistency of increase in internal temperature for steaks being cooked at the same time

Figure A1.2 shows the pattern of internal temperature increase of four steaks with nearly identical weights and dimensions cooked simultaneously on the Silex.

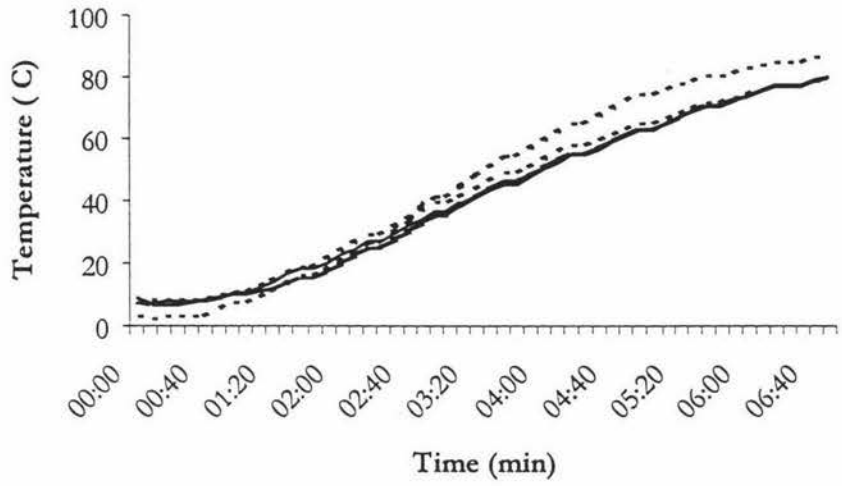


Figure A1.2 Pattern of internal temperature increase of four steaks from the beef eye of the round cooked on the Silex to reach an internal temperature of at least 75°C.

Three of the four steaks cooked at a similar rate reaching the desired internal temperature of 75°C in 6 minutes. However the other steak cooked a lot faster than the rest and reached 75°C in only 5 minutes and 24 seconds. Other trials showed even more unreliable results with the steaks all reaching 75°C at different times with cooking times varying by up to a minute. Although the difference in the pattern of internal temperature rise of the steaks may be caused by the Silex Cooker, it may also be a result of operator error as the thermocouples may not have been inserted into the centre of the steaks therefore causing a steak to appear to cook at a different rate than it actually was.

Differences in sensory analysis of the steaks cooked to the same internal temperature at different temperature settings on the Silex.

In order to allow the steaks take slightly longer to cook the Silex was trialed at settings of 180°C and 200°C as well as the 250°C that was used for earlier trials. Table A1.2 shows that

there were no differences between the sensory attributes of the samples cooked at different temperatures except between 180°C and the other two temperatures (200°C and 250°C) for softness and tenderness. There was no difference in sensory evaluation between 200°C and 250°C

Table A1.2 Sensory differences between samples cooked at either 180°C, 200°C or 250°C.

ATTRIBUTE	180°C	200°C	250°C	RSD [c]
Chewiness	4.63	5.26	5.53	1.54
Cohesiveness	4.31	4.48	4.79	1.82
Initial Juiciness	3.74	4.62	3.48	1.97
Overall Juiciness	3.99	5.10	4.42	1.69
Hardness	4.50[a]	5.57 [ab]	6.08[b]	1.17
Toughness	3.90 [a]	4.88 [ab]	5.97[b]	1.38

[a,b] means with the same letter within a row are not significantly different P<0.05
[c] RSD=Residual standard deviation

Conclusions

1 Temperature needs to be monitored, as time to a set temperature was too variable.

2 Use probe type thermocouples rather than wire type to enable more precise placement.

3 Standardising weight and thickness accurately would be essential if cooking was based entirely on time, but not to the same extent if internal temperature was monitored.

4 There was no difference in sensory analysis of the steaks when the cooker was set at either 200°C or 250°C and the steaks were cooked to an internal temperature of 75°C.

APPENDIX 2

STATISTICAL ANALYSIS OF RESULTS

A2.1 SAS program for stage 1 analysis of all data produced from sensory evaluation.

This program produced LSMeans of the means for all absolute values of the overall juiciness attribute from the 11 panelists and 3 steaks from each animal. It also gave the least-squares means attribute value for all 60 animals. The Bonferroni procedure was used for multiple comparisons as it guarantees that the probability of any false rejection among all comparisons made is no greater than 0.05. This is much stronger protection than controlling the probability of a false rejection at 0.05 for each separate comparison (Moore & McCabe 1989).

```
Filename tp 'sensory.dat';
data b;
infile tp lrecl=140;
input order session bullstee longshor frs trt panelist inijuic hardness cohes toughnes chew
ovjuic animal;
rep=1+int((session-1)/5;
run;

proc sort;
by panelist session;
run;

proc means data = b;
var ovjuic
class panelist session;
output out=means mean=movjuic;
run;

data b2;
     merge b means(where=(panelist>0 and session>0));
     by panelist session;
run;

data b2;
     set b2;
     dovjuic=ovjuic-movjuic;
run;

proc glm data = b2;
class order session bullstee longshor frs trt animal rep panelist;
```

```
model dovjuic=order panelist bullstee longshor frs bullstee*longshor bullstee*frs longshor*frs
bullstee*longshor*frs animal(bullstee*longshor*frs ) rep(bullstee*longshor*frs*animal)/ss1 e1;
random panelist animal(bullstee*longshor*frs ) rep(bullstee*longshor*frs*animal)/test;
lsmeans animal(bullstee*longshor*frs );
lsmeans bullstee longshor frs/stderr adjust=bon pdiff;
run;
```

Points to note about this program

1. The input data file contained 1980 lines corresponding to 11 panelists by 3 steaks sampled for each of 60 animals
2. Deviations were calculated for overall juiciness within a session by panelist combination to give the dovjuic variable
3. The model included order and panelist as well as the other treatment effects and their interactions
4. Output consisted of LSMeans for the:
   a) 60 animals
   b) bulls vs steers
   c) long vs short
   d) fast vs slow vs restricted

   as calculated from the 1980 values
5. Multiple comparisons within FRS were calculated using the bon procedure

A2.2 SAS program for stage 2 analysis of all data produced from sensory evaluation.

This program produced LSMeans of the means from each of the 60 animals of the overall juiciness attribute and was also used to produce LSMeans from the objective measures of meat quality.

```
Filename 'means.dat';
data means;
option ls=75;
infile tp lrecl=140;
input animal bullstee longshor frs inijuic hardness cohes toughnes chew ovjuic;

proc glm;
class bullstee longshor frs;
model inijuic hardness cohes  toughnes chew ovjuic = bullstee longshor frs longshor*bullstee
bullstee*frs longshor*frs/ss1 e1;
lsmeans bullstee longshor frs longshor*bullstee bullstee*frs longshor*frs/ stderr adjust=bon
pdiff;
run;
```

Points to note about this program

1) The input data file contains 60 lines corresponding to LSMeans of sensory results from each of the 60 animals, which were produced in Stage 1.
2) The model only included main effects and their interactions
3) Output consisted of LSMeans for the:
   a) bulls vs steers
   b) long vs short
   c) fast vs slow vs restricted

   as calculated from the 60 values
4) Multiple comparisons within FRS were calculated using the bon procedure.

APPENDIX 3

MEASURES OF MEAT QUALITY OF THE *M. LONGISSIMUS THORACIS* (UNADJUSTED FOR pH)

Table A3.1 Least-squares means of measures of meat quality of the *M. longissimus thoracis* of the 60 animals without adjustment for pH. Interactions between the main effects are explained in the text.

						Expressed juice		Cooking loss		Meat colour		
Effects [c]		pH	MFI (%)	Sarcomere length (µm)	Fibre diameter (µm)	EXJ1 (%)	EXJ2 (cm2/g)	CL, 70°C (%)	CL, 60°C (%)	L*	a*	b*
R^2% [d]		48	69	44	51	59	35	46	36	35	29	48
RSD [e]		0.2	3.54	0.08	5.3	2.0	3.3	3.3	3.6	1.6	4.7	1.1
BSt	B	5.64[b]	86.3[a]	1.68[a]	59.8	42.4	39.9	25.4	12.9	35.3[a]	13.0[a]	4.5[a]
	St	5.46[a]	93.4[b]	1.79[b]	59.0	42.2	40.4	25.2	11.4	37.1[b]	16.3[b]	6.2[b]
LSh	28h	5.59	91.0[b]	1.73	60.8[b]	40.9[a]	38.6[a]	24.4[a]	11.6	35.8	13.8	5.3
	4h	5.50	88.7[a]	1.74	57.9[a]	43.7[b]	41.7[b]	26.2[b]	12.6	36.6	15.5	5.5
FRS	F	5.71[b]	93.0[b]	1.75	65.4[b]	40.9[a]	39.7	22.7[a]	10.9	35.8	16.1	5.2
	R	5.48[a]	88.0[a]	1.74	55.7[a]	43.6[b]	41.1	26.8[b]	12.7	36.3	14.2	5.5
	S	5.46[a]	88.6[a]	1.72	57.1[a]	42.5[b]	39.8	26.8[b]	12.7	36.5	13.5	5.4

[ab] Means within a column and within an effect without a common subscript letter are significantly different ($P<0.05$).

[c] B=Bull, S=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path.

[d] R^2%= Coefficient of determination

[e] RSD=Residual standard deviation

Table A3.2 Least-squares means of the measures of meat tenderness performed on the *M. longissimus thoracis* of the 60 animals without adjustment for pH. Interactions between the main effects are explained in the text.

Effects [c]		INSTRON				WARNER-BRATZLER				MIRINZ
		Max (Ncm^{-2})	LD2 (Ncm^{-2})	LD8 (Ncm^{-2})	Energy (J)	TotalWD	IY (kg)	PF (kg)	PF-IY (kg)	PF (kgf)
$R^2\%$ [d]		0.53	0.48	0.52	0.59	41	38	42	42	42
RSD [e]		20.0	5.93	20.8	0.07	0.88	2.63	3.06	0.72	2.25
BSt	B	103.3[b]	16.5[b]	97.8[b]	0.41[b]	3.74[b]	9.50[b]	11.82[b]	2.31[b]	7.02[b]
	St	71.5[a]	12.7[a]	62.7[a]	0.28[a]	2.74[a]	6.49[a]	7.98[a]	1.50[a]	4.13[a]
LSh	28h	80.8[a]	12.0[a]	73.3	0.32[a]	3.16	7.72	9.64	1.93	5.27
	4h	94.0[b]	17.3[b]	84.2	0.38[b]	3.32	8.27	10.15	1.88	5.88
FRS	F	77.1[a]	19.6[b]	73.8	0.36	3.30	8.03	9.63	1.60	5.30
	R	93.2[b]	13.4[a]	84.4	0.35	3.10	7.67	9.77	2.10	5.48
	S	91.9[b]	11.0[a]	82.6	0.33	3.32	8.28	10.29	2.01	5.94

[ab] Means within a column and within an effect without a common subscript letter are significantly different ($P<0.05$).

[c]B=Bull, S=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path.

[d]$R^2\%$= Coefficient of determination

[e]RSD=Residual standard deviation

APPENDIX 4

RESULTS OF SENSORY EVALUATION ON SAMPLES OF *M. LONGISSIMUS THORACIS*

Table A4.1 Least-squares means for sensory-panel tested attributes of the *M. longissimus thoracis* for the absolute values. (adjusted for order and panelist).

Effect [e]		Inijuic	Hardness	Cohes	Tough	Chew	Ovjuice
R2 %[d]		43	54	46	60	60	49
RSD[e]		1.63	1.18	2.07	1.65	1.60	1.39
Order[f]		***	NS	+	***	+	***
Panelist		***	***	**	***	***	***
BSt	B	3.75[a]	5.98[b]	6.12[b]	5.77[b]	6.57[b]	4.22[a]
	St	4.42[b]	4.81[a]	4.49[a]	4.03[a]	4.85[a]	4.45[b]
LSh	28h	4.07	5.24[a]	5.06[a]	4.69[a]	5.51[a]	4.33
	4h	4.09	5.55[b]	5.54[b]	5.12[b]	5.91[b]	4.34
FRS	F	4.14	4.94[a]	4.73[a]	4.34[a]	5.20[a]	4.39
	R	4.07	5.60[b]	5.54[b]	5.17[b]	5.92[b]	4.32
	S	4.05	5.65[b]	5.64[b]	5.20[b]	6.01[b]	4.30

[ab] Means within a column and within an effect without a common subscript letter are significantly different (P<0.05).

[c]B=Bull, S=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path.

[d]R 2%= Coefficient of determination

[e]RSD=Residual standard deviation

[f]Level of signifcance:

***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Table A4.2 Least-squares means of the deviations from means for sensory-panel tested attributes of the *M. longissimus thoracis* for the absolute values (adjusted for order and panelist).

Effects [c]		Dinijuic	Dhardness	Dcohes	Dtough	Dchew	Dovjuice
R2%[d]		25	58	60	62	62	23
RSD[e]		1.40	1.11	1.77	1.25	1.22	1.19
Order[f]		***	NS	*	***	***	***
Panelist		NS	NS	NS	NS	NS	NS
BSt	B	-0.34[a]	0.58[b]	0.81[b]	0.87[b]	0.86[b]	-0.12[a]
	S	0.34[b]	-0.58[a]	-0.81[a]	-0.87[a]	-0.86[a]	0.11[b]
LSh	28h	0.1	-0.15	-0.24[a]	-0.22	-0.20	0.00
	4h	-0.1	0.15	0.24[b]	0.22	0.20	0.00
FRS	F	0.05	-0.46[a]	-0.57[a]	-0.56[a]	-0.50[a]	0.06
	R	-0.02	0.20[b]	0.23[b]	0.27[b]	0.21[b]	-0.02
	S	-0.04	0.26[b]	0.33[b]	-0.29[b]	0.30[b]	-0.04

[ab] Means within a column and within an effect without a common subscript letter are significantly different (P<0.05).
[c]B=Bull, S=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path.
[d]R 2%= Coefficient of determination
[e]RSD=Residual standard deviation
[f]Level of significance:
***P<0.001, **P<0.01, *P<0.05, +P<0.1, NS P>0.1

Table A4.3 Least-squares means of the sensory-panel tested attributes of *M. longissimus thoracis* for the 60 animals without adjustment for pH.

Effects [c]		Initial juiciness	Hardness	Cohesiveness	Toughness	Chewiness	Overall juiciness
R 2% [d]		42	51	60	60	61	17
RSD [e]		0.47	0.68	0.88	0.90	0.88	0.36
BSt	B	3.74[a]	5.98[b]	6.12[b]	5.77[b]	6.57[b]	4.22[a]
	St	4.42[b]	4.81[a]	4.49[a]	4.03[a]	4.85[a]	4.45[b]
LSh	28h	4.07	5.25	5.06[a]	4.69	5.51	4.33
	4h	4.09	5.55	5.54[b]	5.12	5.91	4.34
FRS	F	4.14	4.94[a]	4.73[a]	4.34[a]	5.20[a]	4.39
	R	4.06	5.60[b]	5.54[b]	5.17[b]	5.92[b]	4.32
	S	4.05	5.64[b]	5.64[b]	5.20[b]	6.00[b]	4.30

[ab] Means within a column and within an effect without a common subscript letter are significantly different (P<0.05).
[c]B=Bull, S=Steer; L=28h pre-slaughter holding period (28h), Sh=4h pre-slaughter holding period (4h); F=Fast growth path, R=Restricted growth path, S=Slow growth path.
[d]R 2%= Coefficient of determination
[e]RSD=Residual standard deviation