

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

**An investigation of on-farm factors that may affect lamb growth,  
carcass characteristics and meat quality.**

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in

Animal Science

at Massey University, Palmerston North,

New Zealand

Sara Nicole Elmes

2013



## Abstract

Animal growth and meat yield are important to farmers and meat processors, and market signals indicate meat quality traits are becoming increasingly important to consumers. Therefore, an understanding of the on-farm factors affecting growth performance, carcass characteristics and meat quality attributes is imperative for the industry to be able to meet the requirements of consumers and reward farmers for superior carcass types.

The two experiments were carried out on Pohuetai farms in Central Hawkes Bay, New Zealand. All on farm measurements and management were conducted by Pohuetai farm staff. Slaughter plant carcass measurements were assessed by Silverfern Farms and Rissington Breedline staff members (including the student). Meat quality assessments were conducted by AgResearch, Invermay in Mosgiel. The statistical analyses for the experiments in this thesis were performed by the student.

The aim of experiment one (Chapter three) was to compare alternative forage crops for lamb growth, carcass characteristics and meat quality. 1178 male and female Rissington Primera lambs were grown on one of five forages; Chicory, Lucerne, Ryegrass/white clover mix and two hybrid Rape x Kale cultivars Spitfire and Titan. Lambs were slaughtered at one of three slaughter dates with mean lamb age at slaughter being 181, 214 or 250 respectively. The comparison of forages showed that lambs grazed on brassica forage crop species displayed superior growth performance and carcass characteristics. Both male and female lambs fed rape cultivars, had higher carcass weights, GR, DO% and hind quarter circumference compared to lambs finished on other forages. Female lambs finished on Lucerne and Ryegrass had tougher meat than those lambs finished on Chicory and rape cultivars. Meat from female lambs finished on Spitfire, Titan and Ryegrass had lighter meat after one day of simulated retail conditions compared to meat from lambs fed other forages. Lamb meat from females fed Ryegrass was reddest after 1 day of simulated retail conditions. Lamb from Titan finished female lambs was lighter and yellower over the whole display period. Females finished on Ryegrass had redder meat and a slower decline of redness over the whole display time.

Male lambs fed Ryegrass, Spitfire and Titan had less tender meat than males grazed on Lucerne. Spitfire grazed male lambs had lighter, redder and yellower lamb after 1 day of simulated retail conditions compared to males fed other forages. Lucerne and Ryegrass fed lambs had meat with the lowest redness, lightness and yellowness. Over the whole display time period, lamb from Spitfire fed male lambs was lighter and yellower. Ryegrass and Titan fed male lambs had the reddest meat up to day 7 of air exposure. Titan finished lambs had greater lamb flavour

intensity than other forage fed males. Lamb from male lambs fed Lucerne were juicier than the brassicas and Chicory. Spitfire fed lambs had meat with the highest overall liking compared to males finished on other forages.

The objective of experiment two was to investigate the effects of different forage diets, lamb sex and sire-breed during the finishing period on lamb growth, carcass, eating quality attributes when slaughtered at three slaughter dates. 1459 weaned male and female Rissington Primera, Landcorp Supreme and Landcorp Texel breedlines were used. Male progeny were superior in growth performance, leading to larger carcass weights and superior muscularity suggesting males would have higher lean meat yields compared to female lambs. Female lambs were fatter at the same weight however, there was no effect of sex on dressing out percentage. Lamb meat from females was more tender, redder, lighter and juicier than meat from males, indicating that lamb from females would be liked by consumers more than that from males.

Lamb fed on Titan were superior in all growth performance and carcass aspects, indicating Titan produced lamb with high pre-slaughter and carcass weights, superior muscularity over the hind quarters and higher dressing out percentage. The eating quality of lambs fed Titan was more tender, lighter, juicier and had a better overall liking than the other forages. Ryegrass produced lambs were redder suggesting that Titan fed lambs could deteriorate quicker than ryegrass fed lamb when on retail display. Lamb flavour intensity was also lower for Titan fed lambs compared to Ryegrass and Lucerne.

Primera displayed heavy pre-slaughter weights, high dressing out percentages, and muscularity. However, increased levels of fatness were also displayed. These carcass quality attributes were further implicated by high lamb flavour intensity relative to the other breeds, but no difference between breeds for any of the other meat quality parameters. Texel sired lambs displayed low pre-slaughter and carcass weights, average fat depth. However, high dressing out percentages and alongside superiority in saleable meat productivity at a given carcass weight. Lamb supreme lambs tended to display rapid growth from docking to slaughter, low carcass fat and comparable carcass weights compared with the other genotypes.

This study established that on-farm management can have effects on lamb growth, and meat and carcass characteristics. By manipulating the diet lambs are finished on, the sire-breed of sheep used and the sex slaughtered, changes in product can be seen at the consumer level. Therefore, this study provides an insight into the management factors that could be implemented to grow efficient lambs on quality forage with the carcass and therefore meat parameters that meet the demands of consumers.

## Acknowledgements

I wish to thank my Massey supervisors Dr Nicola Schreurs and Prof Paul Kenyon for their time, patience and mentorship. I am particularly grateful to Nicola who has supported and encouraged me from the very beginning, and has made an enormous commitment of her time and energy. Your open door policy, prompt marking and constructive feedback was greatly appreciated. I'd like to also thank the lecturers that taught my postgraduate papers, in particular, A/Prof Roger Purchas, Prof Peter Wilson, Prof Tom Barry, Prof Peter Kemp and A/Prof Patrick Morel.

The research for this thesis could not have been possible without the generous financial support from Focus Genetics, FarmIQ, and Ovita. Focus Genetics carried out the Progeny Test which generated the lambs used in this study. Gratitude also needs to go to the staff at Bristol University and AgResearch, Mosgiel, for the laboratory work done to obtain the meat quality data used in this research project. In particular I would like to thank Graham Leech and Geoff Nicoll from Focus Genetics whom have provided me with the resources and support throughout this project. Thank you to Aimee Charteris for mentoring and organising the initial stages of this Masters degree. A big thank you to the staff at the Silver Fern Farms, Takapau plant, the farm staff at Pohuetai farm and the 30 + casual staff employed at each slaughter. Your time, patience and precision are what made this project possible.

I am extremely appreciative for the provision of funding in the form of the New Zealand Ministry of Innovation and Science postgraduate fellowship, the Leonard Condell Farming postgraduate scholarship and Grasslands New Zealand student travel scholarship.

To Nadia Mclean and Wendy Bain, you have been truly invaluable during the course of my Masters, thank you for providing me with surplus support, guidance and encouragement throughout the thesis process.

To my friends near and far, you have been amazing, giving me the opportunity to get out of the office and supplying a compulsory beverage of two for my sanity. In particular I would like to thank Nicole Andrews, Natalie Howes and Sara Ford for being the listening ears I needed through my 'highs' and 'lows' and for the wise suggestions and reality checks.

For the Hawkes Bay getaways, I would like to express gratitude to my extended family for the home brews, unconditional support and never ending food supply! You have all supported me in your own ways and every part of that was hugely beneficial and very much appreciated. To my parents, thank you for your love, understanding and support throughout my university endeavours. I could not have got through this last six years without your support.

## Table of Contents

Abstract .....	3
Acknowledgements .....	5
List of Figures.....	8
List of Tables.....	9
Chapter 1: General Introduction .....	<b>Error! Bookmark not defined.</b>
Chapter 2: Literature Review .....	13
2.1 Introduction.....	13
2.2 The importance of meat quality within the New Zealand red meat industry.....	13
2.2.1 Contribution of New Zealand sheep production to the NZ economy.....	13
2.2.2 Markets for NZ lamb.....	13
2.3 Carcass characteristics of lambs .....	17
2.3.1 Carcass weight and dressing out percent.....	17
2.3.2 Composition.....	18
2.3.3 Tissue distribution.....	21
2.3.4 Fat and soft tissue depths.....	21
2.3.5 Carcass shape and muscularity.....	21
2.3.6 The contribution of carcass characteristics to meat quality.....	21
2.4 Meat quality characteristics of lamb .....	<b>Error! Bookmark not defined.</b>
2.4.1 Flavour.....	23
2.4.2 Tenderness.....	28
2.4.3 Meat colour.....	34
2.4.4 Texture.....	37
2.4.5 Juiciness.....	41
2.5 Factors affecting lamb growth and subsequent carcass and meat quality characteristics.....	46
2.5.1 The effect of lamb growth rate on carcass characteristics and meat quality.....	46
2.5.2 Environmental factors affecting lamb growth and carcass attributes.....	47
2.5.3 The effect of type of animal on lamb growth and carcass composition.....	53
2.5.4 Environmental factors affecting lamb meat quality.....	54
2.6 Research objectives.....	58
Chapter 3: Material and Methods .....	59
3.1 Experimental design .....	59
3.2 On-farm management.....	60
3.3 Pre- and post-slaughter management .....	60
3.4 Carcass measurements and meat sampling .....	61
3.5 Meat Quality tests.....	61
3.6 Sensory panel assessment.....	62
3.7 Data and calculations.....	63
Chapter 4: Effect of different forage diets on growth, carcass and meat quality characteristics of Primera lambs.....	64
4.1 Introduction.....	64

4.2 Material and methods.....	64
4.3 Results.....	66
4.4 Discussion.....	75
Chapter 5: Growth, carcass and meat quality characteristics of male and female lambs of three breeds finished on different forage diets.....	81
5.1 Introduction.....	81
5.2 Material and methods.....	82
5.3 Results.....	84
5.4 Discussion.....	97
Chapter 6: Conclusions and recommendations .....	102
Chapter 7: References .....	106



## List of Figures

Figure 2.1: New Zealand sheep meat export destinations by volume and value for the year ended June 2012 .....	13
Figure 2.2: Adapted from Purchas et al (2012) showing characteristics and groups of characteristics contributing to the average value per unit of weight of a carcass.....	16
Figure 2.3: The relationship between saleable meat yield and carcass fat percentage at different M:B ratios.....	19
Figure 2.4: Major components of the muscle sarcomere.....	28
Figure 2.5: The effect of ultimate lamb meat pH levels on the texture scores as assessed by trained taste panellists.....	38
Figure 2.6: Representative graph of penetrometer test showing the measured parameters of hardness, brittleness, cohesiveness, springiness, adhesiveness and chewiness.....	42
Figure 4.1: Least square means $\pm$ standard errors of Lightness (L*) colour measurements of meat over a seven day blooming period following slaughter from female lambs finished one of five diets prior to slaughter.....	70
Figure 4.2: Least square means $\pm$ standard errors of Lightness (L*) colour measurements of meat over a seven day blooming period following slaughter from male lambs finished one of five diets prior to slaughter.....	70
Figure 4.3: Least square means $\pm$ standard errors of redness (a*) colour measurements of meat over a seven day period following slaughter from female lambs finished three five prior to slaughter.....	71
Figure 4.4: Least square means $\pm$ standard errors of redness (a*) colour measurements of meat over a seven day period following slaughter from male lambs finished three five prior to slaughter.....	71
Figure 4.3: Least square means $\pm$ standard errors of yellowness (b*) colour measurements of meat over a seven day period following slaughter from female lambs finished five diets prior to slaughter.....	72
Figure 4.3: Least square means $\pm$ standard errors of yellowness (b*) colour measurements of meat over a seven day period following slaughter from male lambs finished five diets prior to slaughter.....	72
Figure 5.1: Least square means $\pm$ standard errors of redness (a*) colour measurements of meat over a seven day period following slaughter from lambs fed three diets prior to slaughter.....	88
Figure 5.2: Least square means $\pm$ standard errors of redness (a*) colour measurements of meat over a seven day period following slaughter from ram and ewe lambs.....	89
Figure 5.3: Least square means $\pm$ standard errors of redness (a*) colour measurements of meat over a seven day period following slaughter from lambs of three composite breeds.....	90

## List of Tables

Table 2.1: New Zealand sheep meat export destinations by volume and value for the year ended June 2012 (Meat Industry Association of New Zealand, 2012).	
Table 2.2: Attributes of common flavour descriptors of meat from pasture and concentrate finished lambs.....	26
Table 2.3: Attributes of some common tenderness descriptors of meat from pasture finished lambs.....	32
Table 2.4: Attributes of some common texture descriptors of meat from pasture finished lambs.....	40
Table 2.5: Attributes of some common juiciness descriptors of meat from pasture finished lambs.....	43
Table 2.6: Lamb growth performance and carcass characteristics of lambs on different forage crops.....	51
Table 2.7: Summary of literature evaluating the quality of meat from lambs on different forage types.....	54
Table 3.1: Average lamb age and live weight for lambs in each experiment at one of three slaughter dates.....	58
Table 3.2: Eight point category scale used in the sensory assessment of grilled lamb loin steaks.....	61
Table 4.1: Number of male and female Primera lambs grazed on the dietary treatments Chicory, Lucerne, Ryegrass, Spitfire and Titan.....	65
Table 4.2: The effect of forage species on female Primera lamb carcass composition and lamb growth performance. Hindquarter circumference was adjusted for carcass.....	66
Table 4.3 The effect of forage species of male Primera lambs on carcass composition and lamb growth performance. Hindquarter circumference and GR depth are adjusted for carcass weight.....	68
Table 4.4: Average $\pm$ standard error of the difference between meat quality parameters from loin muscles of female lambs finished on Chicory, Lucerne, Ryegrass, Spitfire and Titan prior to slaughter. Adjusted for pH and GR.....	68
Table 4.5: Average $\pm$ standard error of the difference between meat quality parameters from loin muscles of male lambs finished on Chicory, Lucerne, Ryegrass, Spitfire and Titan prior to slaughter. Adjusted for pH and GR.....	69
Table 5.1: Number of male and female Lamb supreme, Primera and Texel lambs grazed on the dietary treatments of Lucerne, Ryegrass and Titan.....	80
Table 5.2: The effect of forage species on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).....	84

Table 5.3: The effect of lamb sex on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).....	85
Table 5.4: The effect breed on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).....	87
Table 5.5: The effect forage species, lamb breed and lamb sex interactions on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).....	91
Table 5.6: The effect of forage species of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH.....	92
Table 5.7: The effect of lamb sex of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH.....	93
Table 5.8: The effect of breed of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH.....	94
Table 5.9: The effect of forage species, lamb sex and breed interactions of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH.....	95

## Chapter 1: General Introduction

New Zealand is widely recognized as a world leader in pastoral agriculture (Morris, 2009). The majority of the industry's income is reliant on exports, therefore it is imperative that high quality products are supplied to maintain the market share. For sheep farmers, producing a consistently high-quality product from pastoral based production systems has presented many challenges. Climate and weather variability can have a significant impact on seasonality of production, feed supply and farmers' ability to plan ahead.

There has been significant innovation in the meat processing sector over the last 20 years including the upgrading of facilities to meet higher specifications and improvement in processing efficiencies. The industry has moved from concentrating on exporting frozen carcasses, to exporting an increasing variety of products (McDermott et al, 2008). While traditional cuts (such as legs) and primal cuts (for further processing) still dominate exports, there has been a shift towards more chilled cuts which can receive a premium price (Ministry for Primary Industries, 2012). The New Zealand meat producing sector faces a variety of international competitors and competition from other protein sources (Ministry of Agriculture and Forestry, 2009). In order for lamb to be received as a premium product in competitive overseas markets it needs to meet the visual and eating expectations of the consumers (Campbell et al, 2011). New Zealand lamb is presented to a number of diverse markets, and there are opportunities to increase the value of New Zealand's red meat by improving the link between customer quality requirements in the various markets and production at the farm level (Ministry for Primary Industries, 2012). Consequently, meat quality continues to be a factor of research interest in agro-food chains in New Zealand.

Substantial progress and technological advancement in the areas of carcass processing, chilling and storage procedures have improved meat quality and reduced the variability of meat quality attributes. Research has targeted fundamental information on the effects of temperature and pH fall and the interaction of electrical inputs and chilling rate on meat quality attributes. The results have been used to tailor processing scenarios or develop new and individualised processes that optimise meat quality for different markets, and in particular the niche markets for New Zealand meat (Simmons et al, 2000).

A number of pre-slaughter factors within the lamb finishing system can significantly contribute to variation in the quality and eating traits of lamb-meat. These include environmental factors such as stressors, feed type and quality and animal factors such as age, genetics and sex (Campbell et al, 2011). A greater understanding of how biological differences between lambs

and how the diet of the lamb, alters intrinsic characteristics of the meat, could potentially offer mechanisms to prepare the lamb prior to post-slaughter processing, for discrete retail markets. This mechanism could provide scope and opportunity to further improve the consistency of the meat and eating quality of the lamb-meat product. It is therefore important to study the impact of on-farm decisions on carcass composition and meat quality traits if further improvements in meat quality are to be obtained (Payne et al, 2009).

## Chapter 2: Literature Review

### 2.1 Introduction

New Zealand meat is presented to a number of diverse markets, and while the basic meat quality attributes required by the customers in these markets may be similar, the distance and time taken to reach them will be very different which has the potential to adversely affect meat quality. A number of factors within the lamb finishing system can significantly contribute to variation in meat quality traits and consequently the eating quality of lamb-meat product. These include environmental factors such as stressors, feed type and quality and animal factors such as age, genetics and sex (Campbell et al, 2011). There have been significant research efforts into understanding factors influencing meat quality in the meat processing plant and on farm (Geesink et al, 2000). However, there is currently no way of routinely collecting large numbers of objective meat quality measurements in a timely manner and incorporating them into sheep finishing programmes. It is therefore important to study the impact of selection decisions on meat quality traits if quality is not to be inadvertently affected (Campbell et al, 2009).

### 2.2 The importance of meat quality within the New Zealand red meat industry.

#### *2.2.1 Contribution of NZ sheep production to the NZ economy*

The New Zealand agricultural sector is an integral part of the New Zealand economy. It is currently the world's largest exporter of sheep meat with a total of 310,933 tonnes valued at NZ\$2.6 billion generated in export earnings from total sheep meat production for the year ended June 2012 (Statistics New Zealand, 2012). The majority of New Zealand's red meat is shipped overseas, leading to a highly developed and export focused sector (Prescott et al., 2001). In 2006, only 3.9% of lamb was sold in carcass form with 81.5% sold as primal or sub-primal cuts, and a further 14.6% in boneless form (McDermott et al, 2008). Approximately 91% of all sheep meat produced in New Zealand is available for export which contributes to 55% of the country's global export trade (Beef and Lamb NZ Economics Service, 2011). Therefore, the acceptance of sheep meat in international markets is an important economic issue (Morris, 2009).

#### *2.2.2 Markets for NZ lamb*

The largest of the international destinations for lamb meat is the European union (EU), which imported 42.8% of New Zealand lamb export volume for the year ended June 2012 (Ministry of Primary Industries, 2012). New Zealand currently has favourable market access to the EU

market (McDermott et al, 2008) which has been developed through the counter seasonal supply of lamb, complementing Europe’s own production systems. Chilled lamb made up 40% and frozen lamb 60% of the volume of shipments to the EU for the 2012 June year (Beef and Lamb New Zealand Limited, 2012).

North Asia, which includes China, is the next largest market taking 24.1% of lamb shipments, followed by the Middle East with 11.2% and North America with 10% of shipments in the year ended June 2012 (Figure 2.1.). Within North Asia, China accounted for almost 80% of lamb shipments to this region with the volumes up 33.7% on the previous June year. North America generated more than 2.6 times the price per tonne compared with North Asia and Middle East due to the high value product mix that includes chilled lamb (Beef and Lamb Economic Service, 2012). Sheep meat exports to the Pacific were relatively steady, with small decreases in both volume and value compared to the previous year. With pressure likely to remain on New Zealand’s traditional sheep meat export markets (Europe and North America), the importance of emerging markets such as China are being recognised (Meat Industry Association of New Zealand, 2011).

**Table 2.1:** New Zealand sheep meat export destinations by volume and value for the year ended June 2012 (Meat Industry Association of New Zealand, 2012).

<b>Export destination</b>	<b>Percentage of total lamb export volume (%)</b>	<b>Annual volume (tonnes)</b>	<b>Value (NZ \$ billions)</b>
Europe	42.8	125,08	1400.3
North America	10.0	27,202	356.3
North Asia	24.1	77,913	392.3
SE Asia	3.0	10,591	60.0
Middle East	11.2	32,283	185.7
Pacific	4.0	13,523	72.6
Other	4.9	24,342	172.5
<b>Total</b>	<b>100</b>	<b>310,933</b>	<b>2640</b>

#### *2.2.2.1 Role of meat quality for establishing and maintaining sheep meat export markets*

Meat quality is an integral part of establishing and maintaining meat export markets (Troy & Kerry, 2010). Establishing new markets can be difficult and gaining acceptance of products that are unfamiliar to consumers from that country becomes important to ensure repurchase. Chilled prime cuts attain higher prices than their frozen counterparts because the former is considered a higher quality product mainly through improved tenderness as a consequence of the aging processes (Resconi et al., 2010).

Consumers from different countries differ in what they expect in lamb meat as desirable qualities. An accepted attribute (e.g., pastoral flavour intensity or marbling level) in one culture or region may be perceived as less preferable or unacceptable in another (Prescott et al, 2001). Japan and China show significant opportunity for sheep meat exporters if the undesirable sensory qualities they associate with the meat from pasture based systems can be identified and modified.

#### *2.2.2.2 New Zealand lamb schedule and its role in value signalling*

The current payment system aims to reward lean meat yield and the return to the producer is based on a price which reflects consumer demand versus supply. An increase in supply with low demand in the market place, generates a low payment per carcass. There is seasonal variation in supply and demand alongside repercussions of varying exchange rate, climatic events and tariffs (Purchas, 2012).

Hot carcass weight and a soft tissue or fat depth combine in the New Zealand lamb schedule to give an indication of carcass value (Beef and Lamb New Zealand Economic Service, 2011) by indirectly considering the lean meat yield and meat quality (Figure 2.2). Greater value is placed on heavier carcasses because more meat is yielded with minimal change in processing cost. Given the signals from carcass price schedules, it is logical that the on-farm response is to try to achieve fast growth rates which benefits both the meat producer by supplying animals of ideal carcass weight and minimising the costs associated with feeding and maintaining an animal (Purchas, 2012).

Measurements of fat depth or soft-tissue depth such as GR are usually made subjectively due to high slaughter-chain speeds. The fat depth measurement is considered to be a proxy for the content of fat in the carcass. High fat depths will often gain a price penalty as higher fat in the carcass lowers the proportion of muscle in the carcass (Stanford et al, 1998).

The current signal to farmers is to produce the heaviest animals possible, in the smallest amount of time without the development of excessive fat (Stanford et al, 1998). Currently, carcass payment schedules provide no incentive for farmers to supply animals of higher meat quality. A classification system that incorporates meat quality characteristics could potentially increase consistency and quality of lamb products produced in New Zealand (Lambe et al, 2009). However, such an approach would require better understanding of how on-farm management alters meat quality.



### *2.2.2.3 Value chain approach*

The consumer eating experience is a key component of the value chain model as it determines the value of the meat and in particular defines if the consumer is willing to pay a premium price and is a key contributor for consumer decision making regarding repurchase (Troy & Kerry, 2010).

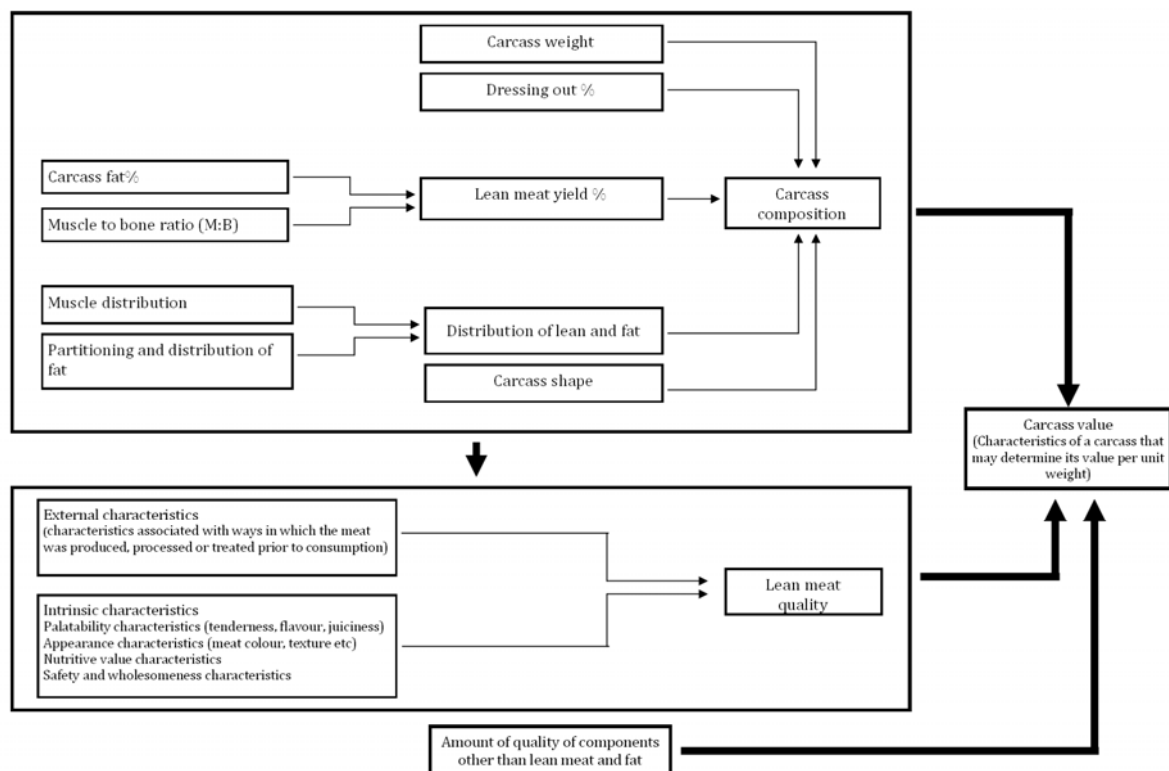
A third of consumers in a study conducted in Australia by Safari et al, (2002), faced difficulty in buying lamb of consistent and preferred quality. However, 75% of these consumers indicated that they would buy more lamb if they had access to a consistently tender and tasty product. This particular study indicates that consistent quality is of key importance to the consumer, and therefore is a crucial part of the value chain approach to ensure a reliable product is maintained in store.

In order for livestock industries to consistently produce high quality meat, there must be an understanding of the factors that cause quality to vary, and implementation of management systems to minimise quality variation (Warner et al, 2010). The influence of on-farm factors such as the animal's diet, breed or gender on meat quality is not well established. In order to understand the control points and mechanisms to reduce variability of meat quality and collaborate a value chain-approach, there needs to be further investigation at the farm level.

## 2.3 Carcass characteristics of lambs

Carcass characteristics such as dressing out percentage and carcass weight are linked to the growth and weight at slaughter of different animals while carcass characteristics such as the fat depths, soft tissue depths and carcass shape indirectly consider aspects of carcass composition. Carcass characteristics can also indirectly be linked to intrinsic determinants of meat quality (Purchas, 2012; Figure 2.2). There is potential for lambs which are fed different diets, or are of different breed or gender to have their meat quality modified via changes in carcass characteristics, in particular due to changes in the carcass composition (Kerr, 2000).

**Figure 2.1:** Adapted from Purchas, (2012) showing characteristics and groups of characteristics contributing to the average value per unit of weight of a carcass.



### 2.3.1 Carcass weight and Dressing out %

The carcass weight is directly related to the animal's live weight at slaughter by the dressing out percentage. The carcass weight therefore, reflects the growth achieved by the animal at the time of slaughter. The dressing out percentage is the ratio of the carcass weight to the live weight of the animal prior to slaughter. The dressing out percentage between animals can be influenced by differences in dressing procedures that may mean more tissue is removed or trimmed from

the carcass. Likewise, the live weight prior to slaughter can be subject to variation, usually due to differences in gut fill at the time of weighing (Purchas et al, 1989).

Differences in gut-fill can occur with animals fed on different diets as a consequence of differences in digestibility that allow for different rates of outflow from the rumen (Litherland et al, 2010). The sheep breed may alter the dressing out percentage due to breed differences in muscling, fatness or fleece weights (Johnson et al, 2005). Gender differences in dressing out are usually the result of differences in the tissues removed as part of the carcass preparation. Compared to castrate and female lambs, male lambs have been observed to have a lower dressing out percentage due to the testes making up a significant proportion of the live weight (Litherland et al, 2010).

### *2.3.2 Composition*

The carcass composition considers how muscle, fat and bone contribute to the overall carcass weight.

#### *2.3.2.1 Muscle % and Muscle to bone ratio*

The muscle to bone ratio (M:B) is an objective measurement which is often associated with superior muscularity (Purchas, Davies, & Abdullah, 1991). However, higher M:B ratio can be due to a lower bone weight per unit length rather than heavier muscles so that measures of muscularity may not differ even when quite large differences in M:B exist (Abdullah et al, 1993). Conversely, poorer M:B may result from heavier bone structure despite similar muscle depths, as seems to be the case for ram lambs relative to ewe lambs (Purchas et al, 1991). M:B ratio is often estimated from measures of carcass shape such as muscularity, which is defined as the thickness of muscle relative to skeletal dimensions (Johnson et al, 2005).

Lean-meat yield (LMY%) is equivalent to carcass muscle percent and is determined totally by carcass fat percent and the M:B (Figure 2.2). The saleable meat yield (SMY%) refers to the weight of saleable meat as a percentage of carcass weight. It is made up of entirely of lean meat with no bone and essentially no visible fat except marbling (Smeaton, 2003). Hot carcass weight which is routinely measured, together with GR, is used to predict saleable meat yield, to indicate the amount of trimming required and the likely yield of traditional or trim lamb cuts (Safari et al, 2002). SMY% decreases with increasing carcass fat percent, but at any given fat%, it will be higher when M:B is higher (Smeaton, 2003).

#### 2.3.4.1 Fat percent

The contribution of fat to meat palatability and other quality characteristics is a conflict between the positive contribution that intramuscular fat can provide to palatability against fat's negative contribution to lean meat yield (Kerr, 2000). Selection for very low fat cover can increase the likelihood of cold storage shrinking due to lack of insulation, as demonstrated by Smith et al, (1976). Fattier carcasses allow the muscle a slower cooling rate and therefore *rigor* is attained at higher temperatures. A slower cooling rate corresponds to a faster pH decline and could be responsible for differences in meat colour (Priolo et al, 2001). Sanudo et al, (2000b) in a light lamb carcass trial (10-11kg) also showed that low levels of fat cover were associated with tougher meat and also a lower intensity of flavour. On the other hand, for 1660 lamb carcass at heavier weights Jeremiah (1998) found very low relationships between measures of fatness and consumer ratings for overall palatability. Therefore, for very light carcass or under processing conditions that are conducive to cold shortening, a certain level of fatness is required for satisfactory palatability (Kerr, 2000).

Fat is laid down at different fat depots at different stages of lamb growth. Four major fat depots are: subcutaneous, perinephric, omental and that around and within muscles (intermuscular and intramuscular). Carcass meat yield is determined by trimmed fat percent and M:B (Abdullah et al, 1993). The effectiveness of fat depths and eye-muscle area measurements as predictors of carcass lean meat yield (LMY%), however, is not particularly good (Purchas, 2012). The value of a carcass of a given weight is largely determined by the LMY% which is a function of carcass fat percent (fat%) and M:B (Purchas, et al, 2002; Figure 2.2). This is illustrated by the equation:

$$LMY\% = (100 - fat\%) \times [(M:B) / ((M:B) + 1)]$$

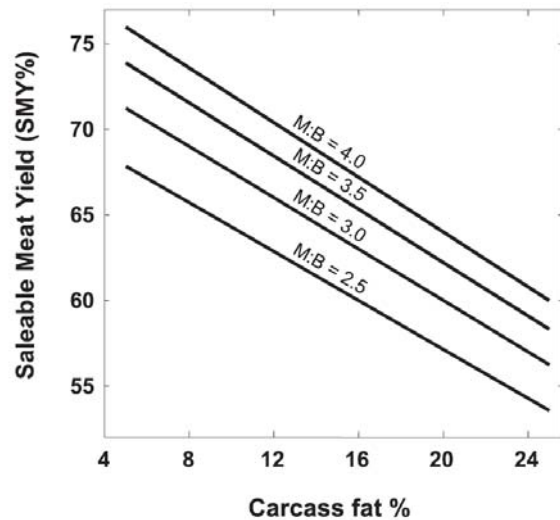
The equation shows that LMY% can be increased by either decreasing fat% or by increasing M:B. LMY% could also be shown as a function of fat% and bone%, but, because fat% is usually the most variable carcass component, it is usually expressed as the amount of bone in terms of M:B which, is independent of fat% (Purchas, 2012; Figure 2.3). Alternatively fat% can be viewed as;

$$Fat\% = ((dissected\ fat\ weight) / carcass\ weight) \times 100$$

Purchas et al (1991) established that increases in fat % and M: B, and the increase followed by a decrease for meat yield % can be attributed to the opposing effects of the increases in fat percent and the increase in M: B. The fat % effect, which led to increasing amounts of excess fat having to be trimmed, became dominant at higher weights due to the high allometric growth

ratio for fat. Thus, LMY% will increase when there is an increase in M:B, a decrease in fat% or any combination of these (Purchas et al, 2002; Figure 2.3).

**Figure 2.2:** The relationship between saleable meat yield and carcass fat percentage at different M:B ratios (Purchas et al, 2002). The equation used to produce these line is:  $SMY\% = (100 - fat\%) \times (M:B) / ((M:B)+1)$ .



### 2.3.3 Tissue distribution

Although carcass size and composition are the main traits affecting carcass value, tissue distribution and fat partitioning can have an effect on the efficiency of production and also for consumers who consider marbling as a meat quality attribute (Young, et al, 2001; Macfarlane et al, 2009).

#### 2.3.4.3 Fat partitioning and distribution

Fat partitioning and distribution considers how total fat is partitioned between fat depots, or distributed within a depot. Carcass fat is partitioned among subcutaneous, intermuscular, and intramuscular depots. Unlike subcutaneous fat, intermuscular fat is difficult to trim, risking fatty meat being presented to consumers. A minimum of 3% intramuscular fat is needed for acceptable meat quality characteristics (MacFarlane et al, 2009) related to visual appearance, nutritional value, juiciness, flavour and tenderness (Lambe et al, 2008). Therefore selection to decrease overall carcass fatness may diminish eating quality (MacFarlane et al, 2009). Intramuscular fat content could be responsible for part of the differences in meat lightness found between animals raised in different production systems. Fat is lighter in colour than muscle and therefore its presence could contribute to an increased lightness value (Priolo et al, 2001).

### *2.3.4 Fat and soft-tissue depths*

For carcass classification purposes measures of fat depth or soft-tissue depths are made as indicators of carcass fat% (Purchas et al, 2002). The soft tissue depth, GR is made subjectively due to high slaughter-chain speeds (Stanford et al, 1998). GR is the depth of muscle and fat tissue from the surface of the carcass to the lateral surface of the twelfth rib 110mm from the midline (Hopkins, 1994). Depths of subcutaneous fat, measured either on the intact carcass after making a small cut or directly on a quartered carcass, have proved to be one of the simplest and most effective predictors of carcass fat% and LMY% for all production animals (Purchas, 2012).

### *2.3.5 Carcass shape and muscularity*

Historically, carcass conformation has had little weighting on carcass quality and has been mainly linked to fat thickness measurements and carcass weight (Fisher et al, 2003). Carcass conformation is commonly referred to as the thickness of muscle plus fat relative to a skeletal dimension (Purchas, 2012). It involves such measurements as; carcass fat percent; M:B; LMY%; partitioning and distribution of fat; muscle distribution and carcass shape (Fisher et al, 2003). Carcass composition assessment assigns value to the carcass, allowing for the sorting of carcasses for further processing and relay of valuable information back to the producer.

A greater muscularity is often related with a higher M:B ratio and meat yield (Purchas, 2012). However, whereas M:B is the ratio of the weights of muscle and bone from a carcass or cut, muscularity is the depth of muscle relative to a bone dimension such as a bone length (Purchas et al, 1991). Generally, carcasses with a high muscularity will also have a high M:B ratio, but this is not necessarily the case (Purchas et al, 1991). For example, if two animals had the same M:B ratio, but the bones of one are longer and finer, then that animal would have a lower muscularity score. As a consequence, if M:B ratio was evaluated from visual assessments of muscularity (as is commonly done), then the carcass of that animal may be placed in a lower muscularity class. In addition to being a useful indicator of M:B ratio (and therefore SMY%), muscularity also affects the thickness of cuts relative to their weight, which can be commercially important (Purchas, 2012).

Some researchers use the total circumference of the hind quarters of the lamb carcass as a indirect measure of muscularity and composition (Bain et al, 2010; Johnston et al, 2009). Lambe *et al.* (2009) have reported high correlations between hind quarter circumference and dissected lean meat yield of 0.72 and 0.62 for Texel and Scottish Blackface sheep respectively. Bain et al.

(2010) showed that of the measurements assessed, hind quarter circumference was the best individual measurement for predicting VIAscan® carcass lean meat yield.

### *2.3.6 The contribution of carcass characteristics to meat quality*

Carcass composition and characteristics have an indirect effect on meat quality attributes (Purchas et al, 1991; Purchas, 2012). An increase in the intramuscular fat is associated with improvements in the meat tenderness, juiciness and can influence the flavour and colour. Increased subcutaneous fat depths can help to prevent cold-shortening by insulating the carcass and slowing the rate of chilling and this has positive effects on tenderness (Priolo et al, 2001).

Meat quality, especially tenderness, may be influenced by muscularity though an effect on muscle thickness (Dumont, 1978). In some sheep increases in muscularity have been associated with an increase in shear force and hence a decrease in tenderness (Fisher et al, 2003). The reverse has also been observed and appears to be a consequence of the decrease in connective tissue content with increasing muscle thickness (Dumont, 1978).

The ability to change carcass characteristics as a means to improve meat quality is seen as a method to be able to control meat quality or segregate carcass for distinct markets. This relies on a balance between meeting optimal carcass specifications (carcass weight and GR) for maximising yield whilst facilitating the right carcass traits to achieve consumer desired eating attributes. For this initiative to progress, there is a requirement for greater understanding of how using on-farm mechanisms to change the carcass characteristics can alter the intrinsic factors that drive meat quality (Troy & Kerry, 2010).

## 2.4 Meat quality characteristics of lamb

The perceived quality for the consumer encompasses characteristics relating to the appearance and palatability (Troy & Kerry, 2010). The point of purchase is where initial quality assessments are made and the appearance characteristics provide meat quality cues for the consumer at the point of purchase (Purchas et al, 1989).

Palatability characteristics such as flavour, tenderness and juiciness define meat quality at consumption and will contribute to repurchasing decisions and influence the perceived value of the meat. Due to the subjective nature of the meat quality characteristics, the consumers' perception of meat quality and the meat eating experience is difficult for the meat industry to measure (Troy & Kerry, 2010). However if the consumer's point of view on meat quality could be defined, it would provide considerable scope for directing improvements in meat eating quality (Safari et al, 2002).

### 2.4.1 Flavour

Flavour is one of the most important sensory aspects contributing to the overall acceptability of meat products. Raw meat possesses little or no odour and only a mild taste (Schreurs et al, 2008). During cooking, a complex series of thermally induced reactions occur between non-volatile components of lean and fatty tissues resulting in a large number of reaction products. The volatile compounds, formed during cooking, determine the aroma attributes and contribute to the characteristic flavours of meat (Mottram, 1998).

The overall flavour perceived by the consumer has three determinants; normal meaty flavours; off flavours and foreign flavours. Normal "meaty" flavours are those associated with individual species. Off flavours can develop during storage or as a result of bacterial spoilage and have a negative effect on the meat product. Foreign flavours or taints are undesirable and can also affect the sale of the meat product by being an unacceptable characteristic to the consumer (Schreurs et al, 2008).

#### 2.4.1.1 Intrinsic determinants of meat flavour

##### 2.4.1.1.1 Flavour Compounds

Over 1000 volatile compounds have been identified as being accountable for meat flavour, some of which can be influenced by the animal's dietary composition (Priolo et al, 2001). Aspects of production systems, such as animal genetics, management practices, and feeding regimes, produce lamb meat with flavours that are regionally unique (Resconi et al, 2010).



Cooking procedures exert important chemical changes on meat volatile fatty acids, developing majority of the compounds which are mainly responsible for meat flavour (Vasta & Priolo, 2006). The main reactions during cooking, which result in aroma volatiles, are the Maillard reaction between amino acids and reducing sugars, and the thermal degradation of lipids. Related reactions (e.g. Strecker degradation) yield other simple compounds such as aldehydes, ammonia and hydrogen sulfide. The meat flavour once cooked therefore results from the interaction of many different intermediate compounds (Mottram, 1998).

Cooked meat contains a complex mixture of volatile compounds, derived from both lipid- and water-soluble precursors (Mottram, 1998). Flavour compounds have different threshold concentrations at which they are detected. A detection threshold is a measure of how sensitive the respondent is to a compound. Some highly volatile compounds only need to be present in very low concentrations to have a significant flavour or odour effect. Only compounds with a low detection are likely to contribute to meat flavour (Mottram, 1992).

The odour threshold values for lipid-derived compounds are, in general, much higher than those for the sulfur- and nitrogen-containing heterocyclic compounds in meat volatiles which are derived from the water-soluble precursors (Mottram, 1998). Sulphur volatile compounds occur in meat at very low concentrations, but they are very potent contributors to meat flavour because of their low thresholds of sensory detection. In particular, aldehydes from polyunsaturated fatty acids (PUFA) play an important role in the synthesis of sulphur heterocyclic compounds (Vasta & Priolo, 2006). If a compound exceeds its threshold value, it may provide an important contribution to meat flavour. However, at concentrations much higher than threshold, it may transfer foreign or undesirable flavours (Wasserman, 1979).

Sheep meat flavour has been associated with the methyl-branched-chain fatty acids (BCFA), particularly 4-methyloctanoic and 4-methylnonanoic acids. Although BCFA contribute to the characteristic sheep meat flavour, it seems that this is not correlated with 3-methylindole (skatole) (Priolo et al, 2001). Skatole at a low concentration contributes to desirable odours and flavours in foods but at a higher concentration has a nauseating faecal odour (Schreurs et al, 2008). These volatile compounds are formed from propionate, originating from the rumen by the fermentation of dietary carbohydrates (Vasta & Priolo, 2006). Schreurs et al, 2008, found that fat from lambs grazed on pasture showed a greater concentration of skatole and were associated more with 'animal' odours and flavours compared to lambs fed a grain-based diet. Pasture is rich in PUFAs, and despite the presence of vitamin E, the high sensitivity of these fatty acids to thermal degradation could favour the appearance of aldehydes (Vasta & Priolo, 2006).

Aldehydes, as major lipid degradation products, are also likely to be involved in the certain species flavour characteristics (Mottram, 1998).

Terpenes are a group of compounds that are exclusively synthesised by plants and include the monoterpenes, sesquiterpenes and diterpenes, and their derivatives. Terpenes found in meat of animals that graze pasture are thought to originate from the fermentation of chlorophyll by rumen microbes while the other plant terpenoid compounds are absorbed unaltered from the rumen (Vasta & Priolo, 2006; Young et al, 1999). Diterpenoids are considered as one cause of undesirable flavour in forage finished lamb (Young et al, 1997).

#### **2.4.1.1.2 pH**

Madruga and Mottram (1995) have demonstrated that with decreasing pH values some sulphur volatiles increase in concentration. According to these authors, lower pH values favour the breakdown of cysteine and, thus, the appearance of sulphur volatiles in meat. This is consistent with data reported by Braggins (1996) who found that dimethyl disulphide and dimethyl trisulphide concentrations decreased with increasing meat ultimate pH values (from pH 6.26 to 6.81). The higher pH values favour the formation of thiazoles because basic pH increases the availability of amino groups from amino acid degradation. According to Priolo et al. (2001), ultimate pH of meat from lambs raised on pasture tended to be slightly higher than pH values obtained in meat from animals fed concentrate diets.

#### *2.4.1.2 Measuring and assessing meat flavour*

##### **2.4.1.2.1 Consumer sensory analysis**

Consumer perceptions of meat can be investigated through qualitative consumer studies (40-50 consumers minimum). In these studies, consumers either participate in a group discussion or are interviewed on an individual basis. The participant is a naive user of the product, and recruited based on this and other demographic criteria (e.g., age, frequency of use; Munoz, 1998). For each product the respondent rates a variety of criteria including odour, flavour, tenderness, juiciness, overall liking, perceived colour of the meat, fat content, and value for money, giving a measure of perceived quality cues (Pethick et al, 2006). Consumer-led product development initiates the potential for successful new products, where the development is based on input from consumers (Grunert et al, 2004).

##### **2.4.1.2.2 Trained panellist assessment**

Sensory evaluation is used to measure, analyse and interpret responses to products as perceived through an individual's senses. An essential aspect of measuring these responses rely

on the assessors who are able to accurately describe the characteristics of the stimuli that they are receiving and capture the response accurately on the questionnaire (van Ruth, 2011). Trained sensory panels are used for two basic types of test when evaluating muscle foods, difference and descriptive attitude testing. Descriptive tests are used to quantify specific sensory attributes such as appearance, odour, textural and flavour attributes of a product and differences between products. Acceptance test is used to determine the degree of acceptance or liking (Miller, 1998).

Most trained taste panels evaluate cooked meat using a quantitative descriptive analysis (Resconi, et al, 2008; Table 5.1). Panellists are asked to assess certain meat quality attributes of the products on their intensity. For formal evaluation, trained panellists can also be asked to identify flavour descriptors of cooked lamb especially if the lambs have been exposed to variable diets (Fraser et al, 1996). Trained panels will generally have smaller variance than consumer testing, but the training procedures can often lead to biased results (Thompson et al, 2005).

#### ***2.4.1.2.3 Gas Chromatography – Mass spectrometry***

Gas chromatography is used for separating and isolating trace amounts of volatile compounds and is coupled with mass spectrometry, infra-red or nuclear magnetic resonance for identification of individual volatile compounds (Price & Schweigert, 1987). Volatile flavour compounds exhibit sufficient vapour pressure to be present in the gas phase. Therefore, the gas can be injected into a gas chromatograph to be analysed (Nollet & Toldra, 2011). Quantitative data of the favour compounds is then obtained. The identification of the volatile compounds is based on comparison of the spectra of the volatile compounds with the reference spectra (Raes et al, 2003). However, this information is generally only useful if the detection threshold and flavour or odour attributes associated with a compound are known.

**Table 2.2:** Common lamb flavour attributes of meat from forage and/or concentrate finished lambs.

Reference	Treatments	Flavour attributes	Units of measurement	Major findings
Priolo et al, (2001)	Pasture vs. Concentrate	Grassy Milky Gamey Sour Sweet Barnyard	0-10 (scale of intensity) 0 = none to 10 = very high	Negative flavours that are more intense in meat from animals fed pasture compared to those fed grain, can be described as “grassy”, “barnyard”, “faecal”, “milky” and “sheepy”
Priolo et al (2002)	Pasture vs. Concentrate	Lamb Rancid Liver Milky Fatty Barnyard	0-10 (scale of intensity) 0 = none to 10 = very high	Lamb flavour and fatty flavour higher and livery flavour lower in stall-fed lambs.
Fraser et al (1996)	Ryegrass White Clover Plantain Lotus	Sheep meat Foreign	0-10 (scale of intensity) 0 = absent to 10 = intense	Pasture species influenced sheep meat odour, foreign odours and flavours, but did not affect sheep flavour.
Prescott et al (2001)	Level of skatole (none, low, high) and added BCFAs	Barnyard Grassy Milky Sheep meat Sour Sweet	Each attribute had a line scale with descriptors ‘none’ and ‘extreme’ at the right and left ends of the scale respectively.	Samples containing high levels of both BCFAs and skatole, were strongly associated with barnyard and sour odours and flavours, milky flavour and strong aftertastes which influenced the acceptability of the samples.
Campbell et al (2011)	‘Goliath’ ‘Winfred’ ‘Hunter’ Radish Pasture Plantain Red clover	Lamb	1- Poor to 9- excellent	There were no significant effects of forage treatment on any of the eating quality measurements, aroma, flavour, texture, succulence or overall acceptability.
Mclean et al (2010)	Pasture	Lamb	Scale of 1 (undesirable) to 8 (desirable) 1- Extremely weak to 8- extremely strong	Overall the means and ranges for each trait were similar between years.
Prache et al (2011)	Organically reared pasture vs. Conventionally reared pasture	Lamb Rancid Liver Milky Fatty Barnyard	0-10 (10cm scale of intensity) 0cm – Weak intensity 10cm – High intensity	Lambs from pasture fed lambs had a stronger and less preferred odour and flavour when lamb has grazed a white clover rich diet compared with a rich grass diet.
Fraser et al (2004)	Red clover Lucerne Ryegrass	Lamb Flavour Abnormal flavour	24 point intensity scale	There were no significant effects of finishing treatment, sex or finishing treatment x sex interaction on eating quality.

## 2.4.2 Tenderness

### 2.4.2.1 Role of tenderness in meat quality

Lamb meat tenderness is an important quality parameter for international markets, especially in frozen lamb, which makes up 70% of total export volume for New Zealand (Beef and lamb economic service, 2012). The muscle environment during the pre-rigor period is critical for obtaining key quality attributes (Simmons et al, 2000). The amount and solubility of connective tissue, sarcomere shortening during rigor development (Koochmaraie & Geesink, 2006) and the level of post mortem proteolysis activity are key determinants (Simmons et al, 2000). Variation in both the rate and extent of postmortem tenderization of meat can result in inconsistencies of meat tenderness seen at the consumer level (Koochmaraie & Geesink, 2006).

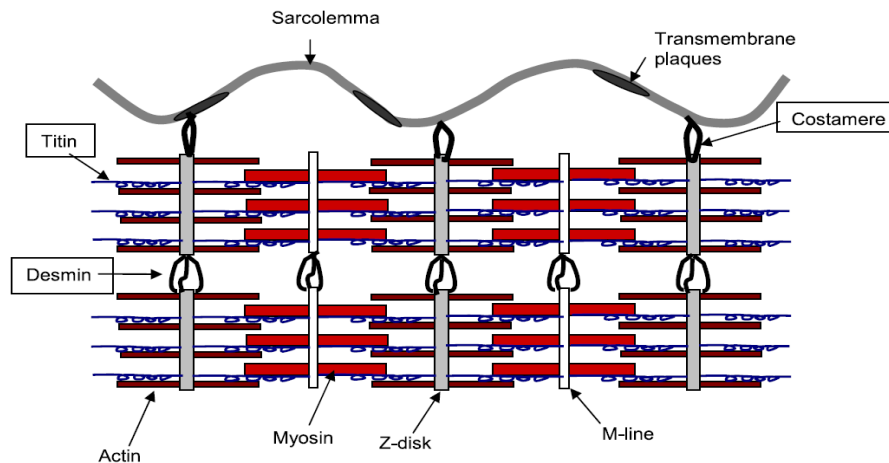
### 2.4.2.2 Intrinsic determinants of meat tenderness

#### 2.4.2.2.1 Muscle structure and composition

The intracellular environment of the skeletal muscle is a major factor in the control of meat quality development (Huff Lonergan et al, 2010). The connective tissue sheath consists of three layers: the endomysium, perimysium and epimysium, with collagen being the major component of all three layers. Endomysium, encloses each muscle fibre and has a random arrangement of collagen fibrils. Perimysium holds groups of fibres together by the network of collagen. Epimysium has two layers of collagen sheets that encapsulate the network that provides support for the muscles (Harper, 1999).

The primary structure of importance in the skeletal muscle cell is the myofibril. Myofibrils are made up of a number of proteins including actin, myosin, troponin, tropomyosin, C-protein, titin and nebulin (Kemp, 2010.; Figure 2.4). Proteolysis of some of the myofibrillar proteins can occur pre-rigor which can influence the final tenderness of the meat. Myosin has enzymatic activity which hydrolyses Adenosine triphosphate (ATP) and therefore supplying energy. This provides energy for myosin bound to actin to swivel and ultimately pull the filaments toward the centre of the sarcomere. This process shortens the myofibril and eventually produces a contraction. The myosin and actin can dissociate when the new ATP molecule is bound to the myosin head (Huff Lonergan et al, 2010).

**Figure 2.3:** Major components of the muscle sarcomere (Kemp et al, 2010).



#### 2.4.2.2.2 Proteolysis (Aging)

Tenderization is primarily dependent on post-mortem proteolysis mediated by the calpain system (Veiseth et al, 2006). During post mortem tenderisation there are major changes in the myofibrillar structure predominantly due to the proteolysis of key myofibrillar and associated proteins (Pearce et al, 2011). The calpain system has been shown to influence post-mortem proteolysis and the calpain-specific inhibitor calpastatin has an important role in influencing tenderisation (Kemp et al, 2010). The main endogenous proteases are believed to be the calpains;  $\mu$ -calpain and m-calpain (Pearce et al, 2011). Both enzymes require the presence of calcium to maintain activity and function to cleave the myofibrillar proteins and weaken the myofibrillar structures (Kemp et al, 2010).

The degradation of the structural myofibrils increases tenderisation. The major proteins actin and myosin are not degraded during post mortem proteolysis (Pearce et al, 2011). Calpastatin is an unstructured protein but when it binds calpain it adopts a structure which allows inhibition to take place. Calpastatin inhibits both  $\mu$ - and m-calpain and this process requires calcium concentrations that are reported to be close to or below those that are required to activate calpain (Kemp et al, 2010). Calpastatin is degraded in postmortem muscle reportedly by calpains. The rate of calpastatin degradation is related to rate of proteolysis and tenderization of the meat. Oxidising conditions in post-mortem muscle leads to the modification or inactivation of calpain (Huff Lonergan et al, 2010).

Lamb *longissimus dorsi* achieves 74%, 87% and 95% of its maximum tenderness by 24hr, 48 hr and 4 days (aged commercially at 1°C) respectively. Thus the maximum, a change in tenderness due to proteolytic activity is 95% achieved by 4 days (Bickerstaffe et al, 2001).

#### **2.4.2.2.3 Cold shortening**

Post slaughter, muscle filaments are in a constant state of contraction and relaxation. As muscle is converted to meat there are changes that occur; a gradual depletion of ATP; a shift from aerobic to anaerobic metabolism favouring lactic acid production and the resulting decrease in tissue pH and rise in ionic strength. These changes have a profound effect on numerous proteins in the intracellular environment. Once the available supply of creatine phosphate is depleted, ATP begins to decline rapidly leading to the loss of the ability of myosin to dissociate from actin (Huff Lonergan et al, 2010).

ATP depletion causes the filaments to develop rigor bonds leading to the potential shortening of the myofibrils and a contracted state. As a consequence of the chemical interaction between the contractile proteins, actin and myosin, and other associated filament proteins, the overlap between thick and thin filaments increases (Hopkins & Huff-Lonergan, 2004). The amount of shortening of the myofibrils and overlap of the filaments has an influence on the tenderness of meat (Huff Lonergan et al, 2010).

Muscles can be prevented from shortening during rigor development. While the toughening phase is similar in all carcasses, the tenderization process is highly variable. Electrical stimulation accelerates post-mortem glycolysis and rigor onset, so that rapid cooling or freezing of carcasses may be carried out soon after slaughter without risk of the muscles cold shortening. This technique also been adopted in commercial slaughtering as a method of meat tenderisation in lamb (Wiklund et al, 2001).

#### **2.4.2.2.4 pH**

Meat pH decline plays a significant role in tenderness development of muscle post-mortem (Purchas et al, 1989). Post mortem, extracellular glucose can no longer provide energy for metabolism so that only intramuscular sources are available for the continuation of glycolysis (Price & Schweigert, 1987). As rigor bonds develop, lactate begins to accumulate due to muscle metabolism quickly changing from aerobic to anaerobic forcing the anaerobic glycolytic pathway to be the primary generator of ATP (Huff Lonergan et al, 2010). Therefore, a decrease in the concentration of glycogen in muscle at the time of slaughter will result in a higher ultimate pH value (Purchas et al, 1989).

Post slaughter, glycolysis continues at a diminishing rate until either the glycogen stores are completely depleted or the pH is lowered enough to completely inhibit the glycolytic enzymes (Price & Schweigert, 1987). The rate of pH decline may have an effect on the rate of proteolysis

of myofibrillar proteins. Muscles that experience a slightly accelerated pH decline can also have an accelerated rate of tenderization (Huff Lonergan et al, 2010). High mean ultimate pH values for meat affect keeping quality and can adversely affect flavour and aroma (Young et al, 1994).

Glycogen levels above a certain threshold will not affect pH, but below the threshold there is a linear relationship with decreasing glycogen levels resulting in increased pH (Thompson et al, 2002). Many authors have reported a bell shaped relationship between ultimate pH and tenderness in sheep *longissimus dorsi* (Purchas et al, 2002; Thompson, 2002; Devine et al, 1993), with toughening between 5.8 and 6.2, although some studies do not always support these findings. This is presumably because meat with an intermediate pH range is highly variable in tenderness.

#### *2.4.2.3 Measuring and assessing meat tenderness*

##### **2.4.2.3.1 Sensory analysis**

Tenderness is commonly tested by a sensory panel alongside other meat characteristics including flavour, colour, juiciness and texture. The common method for this analysis is described in section '2.4.1.2.2 Trained panellist assessment' of this thesis. Table 2.2 illustrates descriptors used to analyse meat tenderness in a selection of published research studies.

##### **2.4.2.3.2 Objective measurement**

Due to meat tenderness being largely a mechanical based property, many tenderometers have been developed to provide objective measurements. Widely used mechanical measures of cooked meat tenderness include shear values (kg) from the Warner-Bratzler shear machine and force scores (Newtons) from the MIRINZ tendometer, a machine that has a biting action rather than a shearing/tearing action (Purchas et al, 1989). Based on the "New Zealand Beef and Lamb Quality Mark Standards", the threshold for mean shear force is 78.4 N (8 kgF) using a MIRINZ tenderometer. This equates to approximately 117.7 N (12 kgF) shear force using Warner-Bratzler (Johnson et al, 2005). Shear force values determined by the MIRINZ machine are highly correlated ( $r=0.97$ ) with consumer sensory evaluations on the same cut (Bickerstaffe et al, 2001).

Frozen loin samples are thawed at 4°C, cooked in a 100°C water bath in a plastic bag with a temperature probe inserted into the core of the sample. Samples are cooked to an internal temperature of 75°C and allowed to cool to 2°C. Meat is then cut 1cm apart with a set scalpel into four samples, then cut with a knife along the grain of the muscle. Sample strips should be cut with a 10x 10 mm square cross-section and fibre direction parallel to a long dimension of at



least 30 mm. Peak shear force measurements are then taken using a tendometer (Honikel, 1997). A single blade to cuts a core meat sample sheared at right angle to the muscle fibres (Johnson et al, 2005). Both blade and sample shape can vary (e.g. cylindrical or rectangular sample cross-section and triangular or rectangular shaped hole in the shear blade (Honikel, 1997).

The result is a measure of force required to shear the sample. The higher the force, the tougher the meat. Generally, meat with a shear force of greater than 11KgF is considered tough and therefore not acceptable to the consumers (Johnson et al, 2005). It should be noted that although these methods are the most common used for meat tenderness analysis, variations in test procedure (sample preparation, dimensions, end point cooking temperature, blade dimension) can be expected amongst research institutes.

**Table 2.3:** Common tenderness attributes of meat from forage and/or concentrate finished lambs.

Reference	Treatments	Tenderness attributes	Units of measurement	Major findings
Priolo et al (2002)	Pasture vs. concentrate	Extremely tough Extremely tender	0-10 (scale of intensity) 0 = none to 10 = very high	Tenderness values were correlated with carcass fatness. Stall lambs were marginally more tender than grass-fed
Martinez-Cerezo et al (2005)	Breed Slaughter weight Aging time	Ease of chewing the sample between the molar teeth	Unstructured line scale of 100 points. 1- Very tough, 100- very tender	Panellist scores for tenderness were significantly affected by the three factors considered (breed, slaughter weight and aging).
Prache et al (2011)	Organically reared vs. Conventionally reared pasture	Tenderness intensity	0-10 (10cm scale of intensity) 0cm – Weak intensity 10cm – High intensity	Firmness did not differ between organic or conventionally grazed lambs in two year groups but in the third group there was a significant difference with conventional lambs were being tougher.
Fraser et al (2004)	Red clover Lucerne Ryegrass	Tenderness intensity	24 point intensity scale	There were no significant effects of finishing treatment, sex or finishing treatment x sex interaction on eating quality.
Safari et al (2001)	Genotype	Tenderness liking	Continuous 100 point scale (very tough to very tender)	There were no significant differences between genotypes for sensory panel assessment of eating quality attributes, except flavour.
Young et al (1994)	Ryegrass Tall fescue Cocksfoot Phalaris Lucerne Prairie grass	Tenderness acceptability	1-9 scale of tenderness acceptance. 9 meant extremely tender or was liked extremely and 1 meant extremely tough or was disliked intensely	<i>Phalaris</i> treatment, had lambs with significantly increased tenderness compared to lambs grazed on the other treatments.

### 2.4.3 Meat colour

#### 2.4.3.1 Role of colour and colour stability in meat quality

Meat colour as a quality parameter is the single most important sensory attribute affecting consumer purchasing decisions of red meat (Luciano et al, 2009). Freshness and therefore quality of meat is commonly judged by how bright and red meat is on display (Prieto et al, 2009; Khlijji et al, 2010). The colour of fresh meat depends chiefly on the relative amounts of three pigment derivatives; myoglobin-reduced myoglobin, oxymyoglobin and metmyoglobin present at the surface.

Knowledge of consumer perception of lamb meat colour is vital in the development of methods for enhancing initial colour and colour stability so as to satisfy consumer demand (Khlijji et al, 2010). Lamb meat that is packed in Styrofoam trays with a polyvinyl chloride over wrap, generally has a surface colour change from red to brown in 1–7 days. Retailers often discount meat after 2 days of display to avoid detection of this colour change by consumers (Jacob et al, 2007). Meat colour stability is important for the international chilled lamb meat market due to the time spent in transit before reaching supermarket shelves (Luciano et al, 2009). The most important factors affecting meat colour stability are temperature, the gaseous environment in the package, oxygen consumption and the reducing capacity of the meat (MacDougall et al, 1982).

#### 2.4.3.2 Intrinsic determinants of meat colour

Meat colour is dependent on the concentration and chemical state of the meat pigments, primarily myoglobin and haemoglobin, and on the physical characteristics of meat, such as its light scattering and absorbing properties (Troy & Kerry, 2010). These characteristics are affected by factors such as age, exercise, diet of the animal, as well as genetic and environmental factors (Priolo et al, 2001). The key meat colour determinants are described.

##### 2.4.3.2.1 Myoglobin

Meat colour depends on the state of myoglobin, a pigment that can exist in one of three forms: deoxymyoglobin, oxymyoglobin or metmyoglobin (Renerre & Labas, 1987). Deoxymyoglobin, frequently referred to as myoglobin or reduced myoglobin, contains a haem iron in the ferrous state ( $Fe^{2+}$ ; Troy & Kerry, 2010). This results in the purplish-red or purplish-pink colour typically associated with vacuum packaged product and muscle immediately after cutting. Very low oxygen tension ( $<1.4$  mm Hg) is required to maintain myoglobin in a deoxygenated state (Mancini & Hunt, 2005). Oxymyoglobin, a bright red form of the pigment, forms very quickly

after exposure of deoxymyoglobin to oxygen (Purchas et al, 1989). The pigment must be in the ferrous state for oxygenation to occur and oxygen occupies the sixth binding site of the ferrous haem iron (Troy & Kerry, 2010). As exposure to oxygen increases, the oxymyoglobin penetrates deeper beneath the meat surface. The depth of oxygen penetration and thickness of the oxymyoglobin layer depend on the meats temperature, oxygen partial pressure, pH, and competition for oxygen by other respiratory processes (Mancini & Hunt, 2005).

The colour of red meats is relatively short-lived and both deoxymyoglobin and oxymyoglobin readily oxidise to metmyoglobin, in which the haem iron has been oxidised to the ferric (Fe<sup>3+</sup>) state (Renerre & Labas, 1987). In red meats oxymyoglobin imparts the colour that consumers associate with freshness (Troy & Kerry, 2010). Metmyoglobin is incapable of binding oxygen and is therefore physiologically inactive. This gives meat a brown colour which consumers associate with a lack of freshness and unacceptability. A number of factors contribute to discoloration in meat during storage and the rate of metmyoglobin accumulation is related to intrinsic factors such as muscle pH, muscle fibre type and the age, breed, sex and diet of animals, as well as extrinsic factors such as pre-slaughter treatment of animals and hot-boning, electrical stimulation and chilling of carcasses. Additionally, during retail display environmental factors such as temperature, oxygen availability, type of lighting, microbial growth and packaging storage atmosphere all influence the shelf-life and potential retail sale of meat (Troy & Kerry, 2010).

#### **2.4.3.2.3 pH**

The ultimate pH and the rate of pH decline during early post mortem muscle influence meat colour and colour stability. High pH (mainly due to preslaughter stress) can be recognised by its dark red colour commonly called “dark cutting” meat (Rosenvold & Wiklund, 2011). High pH conditions cause muscle fibres to swell, which results in a tightly packed surface layer of the meat. This scatters less light and forms a barrier to oxygen diffusion, and consequently increased reduced myoglobin (Okeudo & Moss, 2005). Shelf life is reduced when pH exceeds 5.8 and as pH increases meat becomes darker, affecting consumer purchase decisions (Hopkins et al, 2011). In contrast, low pH or meat with very fast pH fall (pH below 5.8 within 45 min) is associated with increased light reflectance and also enhanced myoglobin oxidation to metmyoglobin (Okeudo & Moss, 2005). Low water holding capacity creates a more porous structure and allows more water to migrate to meat surfaces resulting in light scatter (pale in colour; Rosenvold & Wiklund, 2011).

### 2.4.3.3 Measuring and assessing meat colour

#### 2.4.3.3.1 Sensory assessment

A major rationale for the use of visual appraisal of meat colour is that it is closely related to consumer evaluations. Although human judgement reflects the total impression of meat surface, the consistency, and repeatability of visual evaluation can be influenced by personal preference, lighting, and visual deficiencies in the eye. The method for analysing meat colour is described in section '2.4.2.3.2 Trained panellist assessment' of this thesis. The relationship between sensory evaluation of meat colour deterioration and its instrumental measurement has been recently studied and it has been shown that, over time of storage, while  $b^*$  values (yellowness) were positively related to sensory appreciation of meat colour degradation,  $a^*$  values (redness) were negatively correlated to the sensory evaluation of discolouration (Luciano et al, 2009). Structured scoring scales and visual guides (such as pictorial colour standards or coloured chips with built-in textural traits) can be utilized to improve consistency.

#### 2.4.3.3.2 Chromameters

Reflectance measurements of colour are usually used to assess the colour characteristics of meat surfaces (Khlijji et al, 2010). The reflectance of an object is dependent on the amount of light absorbed and scattered (MacDougall et al, 1982). Analysis of reflectance spectra of meat is concerned with changes in percentage reflectance at two specific wavelengths. The wavelength 525nm is specific for all three myoglobin reduction states and the percentage reflectance at this wavelength is an indicator of the total myoglobin content and the overall colour intensity of the meat. 572 nm is only for oxymyoglobin and reduced myoglobin, and a change in reflectance at this wavelength represents a change in the level of metmyoglobin relative to the two ferrous pigments. Light of a prescribed wavelength is directed onto the meats surface and the proportion that is reflected is measured. High reflectance values generally indicate a lighter or brighter colour (Purchas et al, 1989). The measurements are commonly measured using the CIE colour system. Three fundamental colour coordinates are used  $L^*$ ,  $a^*$  and  $b^*$ .  $L^*$  is lightness and is a measure of the light reflected (100 = all light reflected; 0 = all the light absorbed);  $a^*$  (positive red, negative green) and  $b^*$  (positive yellow, negative blue; Priolo, Micol, & Agabriel, 2001). Alcalde & Negueruela (2001) reported that tristimulus coordinates (XYZ) also were useful for measuring lamb carcass colour but are not considered any further in this thesis.

Meat colour measurements are taken on every loin at each time point. Each loin is sliced into three pieces wrapped with an oxygen permeable plastic film and allowed 2 hours of aerobic display at 4°C before colour is measured (Campbell et al, 2011). The same steak is measured

daily for ~7 days at varying time points using a spectrophotometer (Farouk et al, 2007) through the package film at three random locations on each steak and averaged (Luciano et al, 2009). The first colour measurement is generally measured at two hours and then at 24, 48, 96 (four days) and 168 hours (seven days; Campbell et al, 2011). While lightness ( $L^*$ ) is generally not considered an appropriate index of meat discoloration, the loss of redness ( $a^*$ ) and the changes in yellowness ( $b^*$ ) over a period of display are used to describe meat browning (Purchas et al, 1989). Post data collection, colour deterioration can be calculated. This is the product of two variables, namely initial colour and the rate of colour deterioration. Varying protocol can ascertain the time (hours) for the  $a^*$  colour to deteriorate to the undesirable level of 16 by regressing the colour readings against time (MacDougall et al, 1982). The hue angle and the saturation can also be calculated from this data but are not considered in this thesis.

#### *2.4.4 Texture*

##### *2.4.4.1 Role of texture in meat quality*

Meat texture measures the fineness of a cut surface which can vary from light to a coarse rough structure (Chandraratne et al, 2006). Texture is often a proxy for tenderness and so, the properties of meat texture are often described using parameters such as the initial (first bite) and overall tenderness (after multiple chews) as well as more complex sensory attributes of chewing and mouth feel with multiple descriptors such as cohesiveness, adhesion, springiness, softness, toughness, amount of residual connective tissue, rubberiness, and hardness (Purchas et al, 2012). Among texture attributes, toughness is the most important to the consumer, as it decides the commercial value of the meat (Ruiz de Huidobro et al, 2005).

Textural parameters (collagen content, sarcomere length, intramuscular fat and water, instrumental texture, etc.) also affect meat tenderness (Martinez-Cerezo et al, 2005). If meat is acceptably tender, textural attributes relating to juiciness, fragmentation and characteristics such as mouth-feel, become important (Purchas et al, 1989). These are influenced by the size, length and thickness of the muscle fibres visible on a transversely cut surface (Chandraratne et al, 2006).

Texture values in ovine meat mainly depend on characteristics of the animal such as breed, age and sex (Ouali, 1992), on anatomical characteristics such as type of muscle, on factors external to the animal, as handling and feeding characteristics, or on post-slaughter conditions such as electrical stimulation or meat cooking method (Ruiz de Huidobro et al, 2005). Other influencing factors include pH, the contractile state of the muscle, the degree of post mortem degradation of the myofibrillar component, and connective tissue properties (Sanudo et al, 2003).

#### *2.4.4.2 Intrinsic determinants in meat texture*

##### **2.4.4.2.1 Collagen content**

Muscle connective tissue consists mainly of collagen, the major connective tissue protein, which is an integral component of muscle tissue and, because of this, is a dominant factor contributing to the texture of meat (McCormick et al, 1994). Connective tissue provides support in the muscle at a number of levels and maintains the integrity of the contractile system made up of myofibrillar proteins such as actin and myosin and important associated proteins such as titin and nebulin (Purchas et al, 1989).

Variations in meat texture originate from the difference in structure of muscle tissue due to protein structure, connective tissue framework, lipid and carbohydrate components (van Ruth, 2011). The amount of collagen and collagen crosslinking are responsible for the development of force, tension, compression and toughening in cooked meat (McCormick et al, 1994). Connective tissue varies from muscle to muscle but the same muscle can also vary in the same animal at different ages (Chandraratne et al, 2006). External factors such as cooking methods and post mortem handling play a key role in meat texture quality (van Ruth, 2011). Coarseness and fineness of meat are linked to muscle type determined by the total number of fibres or the cross sectional area of the fibres that are present per unit of weight of the muscle.

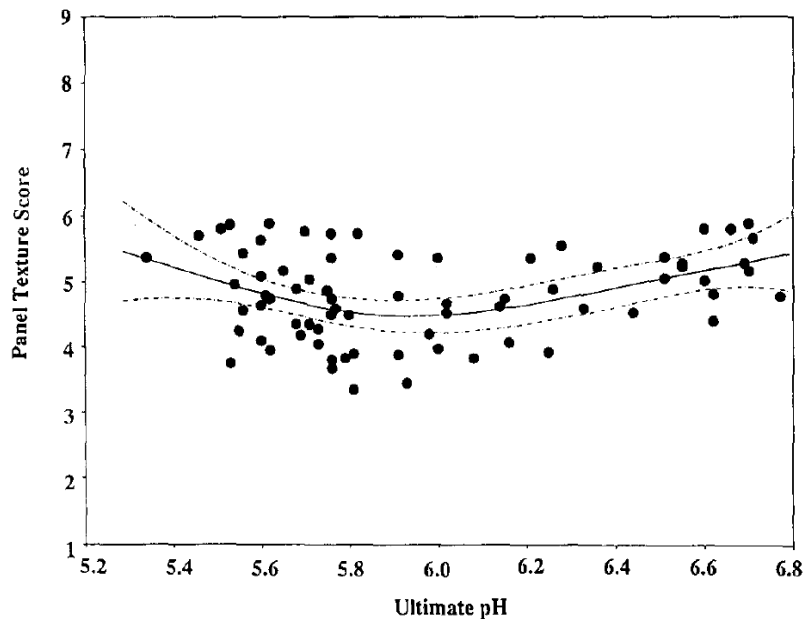
##### **2.4.4.2.2 Proteolysis**

Development of meat texture is a complex process originating from a softening of the structural elements, especially myofibrils. This process involves proteolytic systems and a physicochemical mechanism based on the important post mortem rise in muscle osmotic pressure (Ouali, 1992). Refer to section '2.4.3.2.2 Proteolysis' for further information.

##### **2.4.4.2.3 pH**

Texture as an eating quality attribute is affected by post mortem pH of the meat. As pH values decline there is a significant decrease in meat acceptance. Texture (like tenderness) shows a decrease in acceptance at pH 5.9 (Figure 2.5; Devine, 1993). If the post mortem pH decreases rapidly (i.e. whilst the muscle temperature is still high, the myosin heads denature and shrink; Offer, 1983). Denaturation of the myosin heads is also thought to make a significant contribution to myofibrillar lateral shrinkage and the ability of denatured myosin to bind water resulting in decreased water-holding capacity (WHC). As the ultimate pH increases from 5.5 to 6.0 the texture of cooked meat also decreases, and above pH 6.0 the effect is reversed (Braggins et al, 1996).

**Figure 2.4:** The effect of ultimate lamb meat pH levels on the texture scores as assessed by trained taste panellists. In this case texture is acting as a proxy for tenderness with texture scored on a 9-point hedonic scale, where a score of 1 meant 'dislike intensely' and a score of 9 meant 'like extremely' (Devine 1993).



#### 2.4.4.3 Measuring and assessing meat texture

##### 2.4.4.3.1 Shear test

The most commonly used quality indicator of meat sensory hardness is the Warner–Braztler (WB) shear test. This test measures the force in Newtons necessary to shear a piece of meat. The resistance of the meat sample to shearing is recorded and tested multiple times (Ruiz de Huidobro et al, 2005). Refer to section ‘2.4.3.2 Objective measurements’ for more information on this method. The MIRINZ tenderometer has a significant linear relationship with WB shear test signifying both instruments measure the same property (Honikel, 1997).

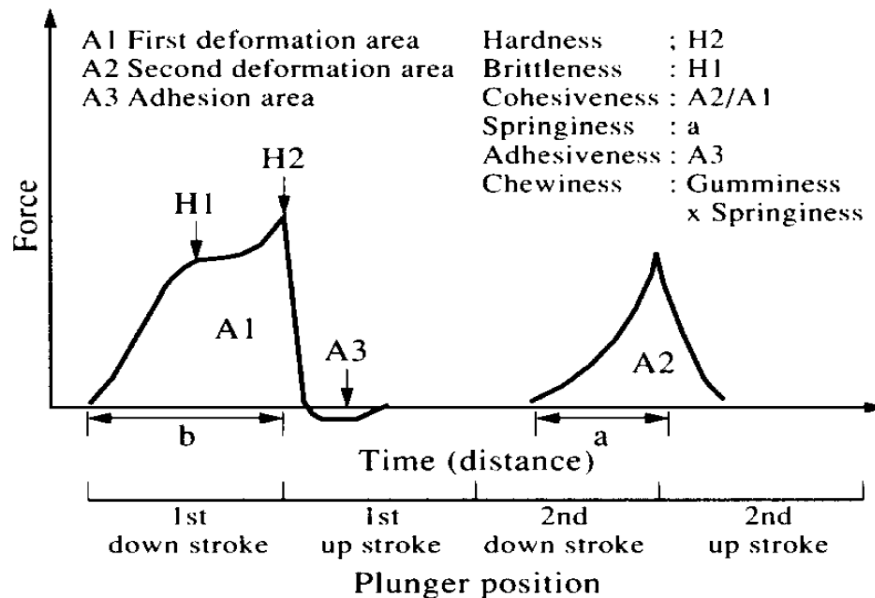
##### 2.4.4.3.2 Penetration

The penetration method employs a cylindrical flat-ended plunger (diameter 1.13 cm, area = 1 cm) driven vertically 80% of the way through a 1 cm thick meat sample cut at a constant speed. The direction of the plunger penetration is perpendicular to the direction of the muscle fibres. The plunger is driven twice into the meat at each location. The work and force deformation curves are recorded (Honikel, 1997). It determines the resistance to puncture products and the results are then used to compare relative toughness/hardness (van Ruth, 2011). The following parameters are generally recorded (see Figure 5.4); Hardness: maximal force for first



deformation (N); Cohesiveness: ratio of work done during the second penetration, relative to the first; Gumminess: Hardness x cohesiveness (Honikel, 1997).

**Figure 2.5:** Representative graph of penetrometer test showing the measured parameters of hardness, brittleness, cohesiveness, springiness, adhesiveness and chewiness (Honikel et al, 1997).



#### 2.4.4.3.3 Texture Profile Analysis

Texture profile analysis (TPA) is not commonly used on meat products. This test measures the compression force (Newtons) developed by the texturometer when compressing a piece of meat (Ruiz de Huidobro et al, 2005). Samples are thawed until an internal temperature of 17–20 °C. Rectangular samples 2–3 cm-long are then cut parallel to the muscle fibres (Martinez-Cerezo et al, 2005). A cylindrical sample is compressed to a certain predetermined deformation during the first cycle, pressure is released, and then the sample is compressed a second time (van Ruth, 2011). The main advantage of TPA is that one can assess many variants with a double compression cycle. Variants that can be assessed with this analysis are: hardness, springiness, and cohesiveness; the three altogether permit the calculation of chewiness (Ruiz de Huidobro et al, 2005). However, at present, there are no objective methods for measuring these alternative textural attributes such texture or the ‘mouth-feel’ of meat, but sensory panellists can be trained to measure cohesiveness, softness, and juiciness (Simmons et al, 2000).

#### 2.4.4.3.4 Sensory evaluation

Although physical characteristics of meat are usually assessed instrumentally, meat texture characteristics are of no value if they are not supported by sensory evaluation, as only this will reflect exactly what will be experienced during meat consumption (Ruiz de Huidobro et al, 2005; Table 2.3). Please refer to section '2.4.2.3.2 Trained panellist assessment' for further information on trained panel analysis.

**Table 2.4:** Attributes of some common texture descriptors of meat from pasture finished lambs.

References	Treatments	Units of measurement	Major findings
Campbell et al (2011)	'Goliath' 'Winfred' 'Hunter' Radish Pasture Plantain Red clover	1- Poor to 9- excellent	There were no significant effects of forage treatment on any of the eating quality measurements, aroma, flavour, texture, succulence or overall acceptability.
Mclean et al (2010)	Pasture	Scale of 1 (undesirable) to 8 (desirable) 1- Extremely tough to 8- extremely tender	Overall the means and ranges for each trait were similar between years.
Lambe et al (2009)	Texel breed Scottish- Blackface breed	8 point category scale 1=Extremely tough to 8=extremely tender	Texture was mostly uncorrelated with the predictor traits, with some exceptions in the leg. However, when significant, correlations with measures of fatness tended to be positive across the two breeds and the two muscles.

#### 2.4.5 Juiciness

##### 2.4.5.1 Role of juiciness in meat quality

Meat juiciness is an important quality attribute to the consumer that drives consumer perceptions of sheep meat quality (Pethick et al, 2005). The sensation of juiciness is complex, encompassing both the water content of the meat and the volume of saliva production stimulated by the intrinsic determinants of meat such as intramuscular fat (Purchas et al, 1989). Water holding capacity is important regarding water and weight losses during storage, manufacturing, processing and preparation of the meat, for yield and colour and for appreciation by the consumer (Van Oeckel et al, 1999) However, juiciness is a poorly understood aspect of the eating quality of meat.

#### *2.4.5.2 Intrinsic determinants in meat juiciness*

##### **2.4.5.2.1 Water holding capacity**

The water holding capacity (WHC) is one of the most important quality traits of meat, and it is related to texture, tenderness, and juiciness (Wiklund et al, 2009). The mobility of the extra-myofibrillar water is suggested to be of utmost importance for high water release during chewing and thereby the perception of meat juiciness (Pearce et al, 2011). In living muscle, most of the water is held in the spaces between the thick and the thin filaments (Offer, 1983). Water losses originate from volume changes of myofibrils induced by pre-rigor pH fall, where myofibrils shrink owing to pH fall or contraction followed by the attachment of myosin heads to actin filaments (Honikel, 1998). During rigor, muscle fiber diameter decreases and extracellular space increases with a compensating movement of water from intra- to extracellular locations (Fennema, 1990).

Proteins play a critical role in immobilising water in meat with the denaturing of proteins contributing to reduced WHC and increased drip loss (Pearce et al, 2011). During heating, proteins denature though at varying temperatures (37-75°C; Honikel et al, 1997). Such structural changes lead to substantial loss of water (cooking loss; Pearce et al, 2011). The combined effect of high temperature and low pH causes a shortening of the myosin heads (Offer 1983), which leads to the shrinkage of muscle fibres, denaturation of the fibrillar proteins, the aggregation of sarcoplasmic proteins and the shrinkage of the connective tissue. These events, give rise to cooking losses in meat when heat is applied (Honikel et al, 1997).

##### **2.4.5.2.2 Intramuscular fat**

From a consumer point of view, meat should contain only a small amount of fat. Too much fat discourages the purchase of meat and is commonly removed either before cooking or during the meal. However to maximise eating quality, meat from lambs and young sheep with high intramuscular fat content is required (Thompson et al, 2004). Increased marbling is linked to higher tenderness, flavour and juiciness, and therefore has a positive general effect on palatability (Young et al, 2009). The positive effect of marbling relies upon the higher fat levels in marbled meat stimulating salivation and giving the perception of increased juiciness of meat whilst chewing. Meat with a higher intramuscular fat content will sustain the feel of juiciness in the mouth longer (Thompson et al, 2004). Many factors in production such as diet, age of weaning, breed, sex, and body weight have effects on adipose tissue and muscle fatty acid composition.

#### **2.4.5.2.3 pH**

The ultimate pH of meat is determined by the animal's pre-slaughter reserves of muscle glycogen. After death, the muscle breaks down glycogen via the anaerobic glycolytic pathway to produce lactic acid. Increased lactic acid is responsible for lowering muscle pH (Braggins, 1996). If the animal's glycogen reserves were depleted preslaughter, for example by stress or exercise, insufficient lactic acid is produced to lower the pH of the muscle to its normal value, around pH 5.6 (Devine, 1993). At a pH greater than 5, charges on both thick and thin filaments are negative (repulsive), and increasing the pH increases their negative charge on the filaments. This swelling of the filaments improves WHC (Offer and Trinick, 1983).

#### *2.4.5.3 Measuring and assessing meat juiciness*

##### **2.4.5.3.1. Sensory analysis**

Sensory assessment of juiciness of meat (alongside other eating quality attributes) can be undertaken using either trained or untrained consumer panels (Thompson et al, 2005; Table 2.4). However, panel analysis is time-consuming, costly and destructive for evaluating juiciness (Van Oeckel, 1999) and hence objective measurements are commonly assessed. Refer to section 2.4.2.3.2 description of the taste panel assessment.

##### **2.4.5.3.2 Filter paper press method**

The filter paper press method gives an estimation of the WHC of the meat sample. A force such as pressure can be applied to the meat sample and the amount of released water is measured (Van Oeckel, 1999). According to Hamm et al (1986), the method is carried out by placing 300 mg of homogenised meat on a filter paper between two cover glasses under a pressure of 1 kg for 5 min. The difference between the areas (RZ), as determined by planimeter, of the pressed meat (M) and the wet area on the filter paper (T) is a measure of the exudative juice or WHC. Alternatively, the WHC can be expressed as the ratio of M over RZ or the ratio of M over T. However, the filter paper press method is laborious compared to sensory evaluation due to the cutting, homogenising and weighing procedures required (Van Oeckel 1999).

##### **2.4.5.3.3 Filter paper method**

The filter paper method uses suction on a meat sample to determine the amount of released water (Van Oeckel, 1999). This method is generally carried as described by (Kauffman et al, 1986). A filter paper of known weight is applied to the meat sample with a rubber plug of weight 90 g. The sample is first exposed to the air for 15 min. Within three seconds the filter paper is removed and reweighed to give weight of absorbed water. In addition a visual score is

given to the filter paper, according to Van der Wal et al. (1988), where 0,1, 2, 3, 4 and 5 equates to 0, 10, 25, 50, 75 and 100% of the surface being wet. The filter paper method is a good alternative to other methods because it is inexpensive and fast to execute without the need for specialised equipment (Van Oeckel, 1999).

**Table 2.5:** Attributes of some common juiciness descriptors of meat from forage and/or concentrate finished lambs.

Reference	Treatments	Juiciness attributes	Units of measurement	Major findings from study
Priolo et al (2002)	Pasture vs. concentrate	Juiciness	0–10 (scale of intensity)	Stall fed lambs were juicier than grass-fed lambs and carcass fatness was correlated to carcass fatness.
Lambe et al (2009)	Texel Scottish-Blackface	Juiciness	8 point category scale 1=Extremely dry to 8=extremely juicy	Some measurements associated with muscling or conformation were positively associated with juiciness of the leg muscle of SBF lambs.
Thompson et al (2005)	Lamb age Electrical stimulation	Juiciness	100mm line with 20mm gradients. Left end very dry, right end very juicy.	Sensory scores for tenderness, flavour, juiciness and over all liking were highly correlated from both roasted and grilled samples.
Martinez-Cerezo et al (2005)	Breed Slaughter time Aging time	Global juiciness (initial+sustained) perceived during chewing	Unstructured line scale of 100 points. 1=very dry. 100=very juicy.	Panellist scores for juiciness were significantly affected by the three factors considered (breed, slaughter weight and aging) but breed had the most important effect on juiciness.
Sanudo et al (1998)	Spanish lamb English lamb	Juiciness	Unstructured line scale of 100 points 1=extremely dry, 100 = extremely juicy.	Both panels scored juiciness higher for Spanish lamb than for British lamb.
Campbell et al, 2011	‘Goliath’ ‘Winfred’ ‘Hunter’ Radish Pasture Plantain Red clover	Succulence	1= Poor to 9=excellent	There were no significant effects of forage treatment on any of the eating quality measurements, aroma, flavour, texture, succulence or overall acceptability.
Mclean et al (2010)	Pasture	Juiciness	Scale of 1 (undesirable) to 8 (desirable) 1=Extremely dry to 8=extremely juicy	Overall the means and ranges for each trait were similar between years.
Fraser et al (2004)	Red clover Lucerne Ryegrass	Juiciness intensity	24 point intensity scale	There were no significant effects of finishing treatment, sex or finishing treatment on eating quality.

#### ***2.4.5.3.4 Raw meat drip loss***

In the drip loss method, pressure is exerted by gravity and shrinking during storage (Van Oeckel, 1999). The drip loss (Honikel & Hamm, 1987) is determined on meat samples of about 150 g, free of external fat and connective tissue. To minimize loss of drip before first weighing, sampling must be immediate, minimum previous manipulation must be employed and strict temperature control is necessary (Honikel et al, 1997). The samples were hung by a nylon cord in a plastic bag at 4°C for 48 hours, ensuring the meat had no contact with the juice in the bag. The difference in weight of the meat sample (after superficially wiping dry), before and after the hanging, divided by sample weight of 100 yields the % drip loss (Van Oeckel, 1999). The same samples can be used for further drip loss measurements, e.g. after two, seven days, etc., but in every case the initial weight is used as the reference point (Honikel et al, 1997).

## 2.5 Pre-slaughter factors affecting lamb growth and subsequent carcass quality characteristics

Pre-slaughter factors affecting meat quality can be broadly classified into environmental (pre-slaughter handling and diet) and animal factors (age, genetics and sex; Priolo et al, 2001; Campbell et al, 2011). Together these two groups of characteristics contribute to the value of the animal at time of slaughter. Lamb producers are being provided with strong incentives to gain better control over the growth performance of their animals. Different markets require different products, and the economic value of the different types of carcasses changes with different consumer requirements (McCoard et al, 2010).

### *2.5.1 The effect of lamb growth rate on carcass characteristics and meat quality*

The New Zealand sheep industry places a strong emphasis on selection for rapid lamb growth and high meat yield to obtain premium prices, and freeing up more land for other stock classes, reducing labour requirements and animal health costs (Golding et al, 2008; Judson et al, 2008). Faster growing lambs have a higher gross efficiency of conversion (kg lamb meat/unit feed intake) than slower growing lambs of the same weight. A high potential growth rate is also associated with less fat in the gain (Campbell et al, 2012). Deposition of lean tissue requires less energy to deposit than the same weight of fat, which further improves the efficiency of faster growing lambs (Kerr, 2000).

Growth rate of a group of animals can be manipulated by altering the amount or quality of feed available for growth, whether this alteration is by nutritional or other management options, or due to seasonal conditions (Perry & Thompson, 2005). The growth rate is related to the muscle protein accretion, the difference between the rates of muscle protein synthesis and degradation. The higher the protein accretion at a set rate of degradation, the higher the growth rate of the animal, which is one of the most economically important traits in meat production (Therkildsen & Oksbjerg, 2009).

There has been little research with sheep into the correlation of meat quality trait responses to the selection for growth rate and saleable meat yield. High growth rates have been reported to have negative effects on meat quality for pig, beef and poultry (Dransfield et al, 1999). However, Campbell et al, (2012) found that there was no difference in the eating quality of low and high yielding lambs but, higher growth rate lambs had poorer eating quality than lower growth rate lambs, although all lambs were assessed to have good eating quality.



The effects of age and weight are often known to be difficult to separate as they usually increase simultaneously. Over time as the animal ages the flavour of meat generally becomes stronger, meat tenderness declines and the concentration of red pigment myoglobin increases (Purchas et al. 1989). Collagen fibres within meat become tougher and more difficult to dissolve with cooking in older animals because crosslinks form between collagen protein molecules. With increasing age and maturity, the water binding capacity of the muscle also increases and therefore cooking loss is decreased. Generally it appears that there is a reasonable likelihood for tenderness to decline as the age of the lamb increases above about six months (Kerr, 2000). The darkness, toughness, strength of flavour and presence of off-flavours increase with age but over the age range (3 to 9 months) when most lambs are slaughtered in New Zealand, few differences have been detected (Bray, 1988).

### *2.5.2 Forage effects on lamb growth and carcass attributes*

In New Zealand it is becoming more common to supplement traditional ryegrass/white clover pastures with forage crops to finish lambs (Campbell et al, 2009). Inadequate feed supply relative to animal requirement and changing nutrient composition is a major limitation of pasture feed supply (Komolong et al, 1992). The feeding value (FV) of forage is a function of intake and nutritive value (NV). Animal performance on grazing forages is usually limited by energy intake because structural fibre can slow herbage digestibility and intake (Komolong et al, 1992). A high FV can only be attained when feed supply is not limiting (Waghorn et al, 2004).

Pasture species that are drought resistant or recover more rapidly following dry periods have been recommended to replace the traditional ryegrass/white clover pasture in certain regions (Young et al, 1994). The development of pastoral systems based on the use of forage species with higher feeding value than ryegrass based pastures has the potential to increase the efficiency and productivity of lamb production in New Zealand (Golding et al, 2011).

#### **2.5.2.1 Herbs**

Herbs are a perennial forage species that can provide a leafy, high quality feed over spring, autumn and summer with high content of trace minerals that can improve the growth rates of grazing animals compared to those on traditional pasture (Athanasiadou et al, 2007). This group of forages produce high yields with moderate to high levels of both crude protein (CP) and metabolisable energy (ME). Brookes & Nicol, (2007) recommended the CP concentration for any herbage to be between 15 and 18% for good lamb growth. CP levels are often over 20% of dry matter (DM), though ME is rarely above 11 MJ/ KgDM (Houjik et al, 2011).

A range of herb species are used as specialist crops in New Zealand lamb finishing systems. Chicory (*Cichorium intybus*) and Plantain (*Plantago lanceolata*) are the two main herb species with a variety of cultivars available. Chicory can grow at a rate in excess of 15-18 t DM/ha/year (Hopkins et al, 1995) and Plantain 20 t DM/ha/year under favourable conditions (Stewart et al, 1996). These forages are mineral-rich and contain biologically active compounds, some of which may influence rumen function and reduce scouring and dags in lambs (Kerr, 2000). These valuable agronomic features have led both species to become widely used pasture herbs in many parts of New Zealand (Moorhead et al, 2002).

Finishing lambs on chicory is increasingly popular as it may support higher growth rates than grass/clover, particularly in the face of gastrointestinal nematode parasitism (Houdijk et al, 2011). Lambs grazing on herbs generally have higher live weight gain compared to those grazing on traditional ryegrass/white clover pastures (Athanasiadou et al, 2007). Fraser and Rowarth (1996) found that lambs grew between 84 and 141g/day in a three year period on plantain, similar to ryegrass but significantly less than chicory and white clover. However, they also reported low animal liveweight gain on plantain swards in which 60 % of DM on offer was seed head. Moorhead et al (2002) found there was a faster rate of average daily live weight gain for lambs grazing plantain (222 g/day) compared to ryegrass swards (135 g/day) produced an extra 7.3 kg over the ryegrass treatment over 85 days. These authors also reported chicory producing a comparable yield enabling lambs to grow at 181-214 g/day.

Houdijk et al (2011), in the UK found that finishing lambs on a pure sward of chicory resulted in heavier carcasses with better killing-out percentages and conformation scores than those finished on ryegrass/whiteclover mix. Fraser & Rowath (1996) also found in both years of the trial, that lambs grazing chicory had higher growth rates, hot carcass weights and GR than lambs grazing ryegrass or plantain. Deaker *et al.*, (1994) reported that the hot carcass weights were lower for lambs on plantain than chicory and white clover but higher than ryegrass. The average dressing out percentage was similar, the muscle on the carcass of lambs grazing chicory and plantain was greater than other forages (4.52 vs. 4.48kg), but not significantly different (Deaker et al, 1994). Farmers can obtain greater individual carcass weights and net carcass per ha by feeding herb-clover mixes rather than ryegrass pasture during the spring (Sinhadipathige et al, 2012).

### **2.5.2.2 Brassica crops**

Brassica forage crops are a widely used form of supplementary feed throughout New Zealand. Swedes, kale, rape and turnip species all have specific uses as additional winter feed or as a

summer feed in areas which experience drought conditions (Lindsay et al, 2007). Hybrid leafy turnips have become popular, for lamb finishing over the summer and early autumn months. They have a higher percentage of leaf than other turnip crops, and have the ability to re-grow and be grazed repeatedly within a single season (Lindsay et al, 2007). Forage rape is sown in spring and used in late spring–early summer, when pasture quality is declining markedly (Speijers et al, 2004). It is highly digestible, but intake and ME can be constrained by the high water content of the crop (Dove & Milne, 2006).

There is evidence that lambs finished on forage rape will be fatter than those finished on grass. Lindsay et al, (2007) and Campbell et al (2011), both found that lamb growth rates on leafy turnips were higher than on new pasture (Table 2.5). However, despite a high concentration of available energy and adequate nitrogen, brassicas have given variable responses in growth rates of sheep (Reid et al, 1994). Some of the variability can be attributed to the toxic consequences of ingestion of S-methyl-cysteine sulphoxide (SMCO), glucosinolates or high levels of nitrate (de Ruiter et al, 2007). The presence of these metabolic inhibitors can affect animal health and reduce gains in cattle and sheep (Reid et al, 1994). Rumen microorganisms degrade SMCO and produce dimethyl disulphide which is absorbed and causes lysis of red blood cells and haemolytic anemia. High levels of nitrate can be an issue through the excessive fertilizer on kale crops (de Ruiter et al, 2007). Rape scald can also commonly affect lambs fed immature or second growth rape. The number of dangers associated with feeding brassicas can often be avoided by care transitioning between diets, offering alternative supplements and/or, having numerous (2-3) smaller breaks during the day (Kemp et al, 2007).

Hopkins et al (1995) found that rape-fed lambs had higher dressing percentage and the carcasses were significantly heavier than for pasture-fed lambs. Consistent with the fat score, rape-fed lambs were fatter than pasture-fed lambs based on the GR measurement. However, due to over fatness, only one-third of the lambs slaughtered off the forage rape met the specification of 18-26 kg carcass weight and fat score 2 or 3, whereas most of the pasture-fed lambs met this specification. Excess deposition of fat may be a problem for heavy lambs finished on rape unless they are left entire. However this could be controlled by selection of lambs for sale based on a fat score.

### 2.5.2.3 Legumes

The development of legume-based pastoral systems provides the flexibility to lift sheep performance during spring, summer and autumn (Golding et al, 2011). In New Zealand, lucerne (*Medicago sativa*), red clover (*Trifolium pratense*), and white clover (*Trifolium repens*) are the

main species used. Sulla (*Hedysarum coronarium*) and Bird's-foot Trefoil (*Lotus Corniculatus*) are not commonly used (de Ruiter *et al*, 2007). The combined benefits of a high crude protein concentration, and possible protein protection and higher voluntary intake make forage legumes potentially attractive as a natural means of increasing liveweight gain and decreasing time to slaughter of lambs in lamb finishing systems (Fraser *et al*, 2004; Speijers *et al*, 2004). The relatively high levels of protein and fibre as well as low levels of water soluble carbohydrates in forage legumes mean that nitrogen utilisation is often low.

Condensed tannins (CT) are plant secondary compounds that bind strongly with leaf protein after chewing, thereby reducing protein degradation in the rumen at pH 6.0–7.0. The CT-protein complex dissociates at pH < 3.5, typical of the abomasums, thereby increasing essential amino acid (EAA) absorption from the small intestine (Wang *et al*, 1994). The benefits of some types of CT on animal performance reviewed by Waghorn and McNabb (2003) include; improved live weight gains, wool growth, milk production, reduced methane, prevention of bloat, reduced impact of gastrointestinal parasites and lower incidence of dags and flystrike in sheep.

Lucerne is a traditional summer pasture where its perennial growth habit and persistence are highly valued, but under moisture stress its quality declines (Hopkins *et al*, 1995). Fraser & Rowarth (1996) found white clover produced the highest live weight gain in lambs compared to a range of crops and legumes, due to high crude protein concentrations, and more rapid passage of the clover through the rumen, allowing greater intakes. Lindsay *et al*, (2007) also found lambs grew fastest grazing on the predominant white clover sward, with over half growing faster than 300 g/day. The lambs grazing red clover also performed better overall compared to those grazing lucerne (Lindsay *et al*, 2007). This could be in part due to the polyphenol oxidase present in red clover, which appears to inhibit proteolysis resulting in the crude protein in red clover being less degradable in the rumen than that in lucerne (Speijers *et al*, 2004). Lucerne, red clover and white clover have a high bloat risk so intensive grazing management is required (de Ruiter *et al*, 2007).

The improvements in production of animals grazed legume forages can be achieved without compromising carcass quality. These improvements in animal production can be achieved without compromising carcass quality. In addition, lambs grazing red clover have heavier carcasses due to a higher killing out percentage (Speijers *et al*, 2004). Quantity of total fat and each of the three major fat depot sites (subcutaneous, seam, and mesenteric) are reduced in lucerne-finished lambs compared with fat in lambs fed concentrate at some time during finishing (Campbell *et al*. 2009) found that legume-fed lambs had higher carcass dressing

percentages than pasture-fed lambs probably reflecting lower gut-fill as found with other legumes.

#### 2.5.2.4 Grasses

Perennial ryegrass (*Lolium perenne*) is the most commonly sown pasture species in New Zealand, reflected by the large number of commercial cultivars available (Easton et al, 1999). Perennial ryegrass establishes quickly, is highly competitive and tolerant of treading damage and hard grazing. Annual DM yields vary with environment but range from 10 to 25 t DM/ha under high fertility conditions. It is a winter-active grass (12% of annual DM production) with a flush of production in early spring (40% of annual production). Grass maturation affects the proportion of leaf, stem and dead matter. The proportion of fibre increases and both CP and soluble carbohydrates decrease with a reduction in NV (Kemp et al, 2007).

Perennial ryegrass is often characterised by low soluble carbohydrate concentrations, high concentrations of slowly degradable fibre that restrict feed intake, and rapidly degradable crude protein producing surplus ammonia when degraded in the rumen (Fraser & Rowath, 1996). Animal performance on ryegrass is generally less than pastoral herbs, brassicas and legumes. In summer the liveweight gains of lambs grazing perennial ryegrass-based pastures are typically 80–150 g/day (Golding et al, 2011). However, it can provide the flexibility to lift sheep performance during other periods of the year when other forage crops struggle (Golding et al, 2008).

**Table 2.7:** Lamb growth performance and carcass characteristics of lambs finished on different forage crops.

Reference	Origin of study	Treatment	Carcass weight (kg)	Dressing out %	GR (mm)	Average daily gain (g/d)
Deaker et al (1994)	NZ	Plantain	16.8	47.9		
		Chicory	18.3	47.9		
		White clover	20.1	48.2		
		Ryegrass	15.6	45.1		
Reid et al (1994)	US	Turnip hybrid		46.2		197
		Chinese cabbage hybrid		46.5		241
		Grass-clover		42.8		135
Hopkins et al (1995)	NZ	Forage rape	25.4	46.8	14.8	
		Irrigated pasture	21.2	41.6	12.6	
Golding et al (2011)	NZ	Herb/clover	15.2	41.8	4.2	247
		Plantain/pasture	14.8	41.5	3.5	107
		New pasture	14.6	38.8	3.4	119
Sinhadipathige et al (2012)	NZ	Pasture mix	21.2			322
		Plantain mix	21.8			336
		Chicory mix	22.3			360
Fraser et al (1996)	NZ	Chicory	18.3	47.9	9.8	
		Plantain	16.8	47.9	8.4	
		White clover	20.1	48.3	10.8	
		Lotus corniculatus	19.3		12	
		Ryegrass	15.6	45.2	7.2	
Fraser et al, (2004)	UK	Lucerne	18.8	47		243
		Red clover	18.4	48		305
		Perennial ryegrass	18.8	46		184
Campbell et al (2011)	NZ	Brassica (Goliath)	17.6			310
		Brassica (Winfred)	17			260
		Turnip	15.8			60
		Radish	17.1			60
		Pasture	15.4			140
		Plantain	15.3			130
		Red clover	15.3			111

### *2.5.3 The effect of type of animal on lamb growth and carcass composition*

#### *2.5.3.1 Effect of gender on lamb growth and carcass composition*

Lamb sex is one of the most important factors affecting growth performance and gain (Abdullah et al, 2010). It has an important influence on early postnatal growth along with other environmental influences. Ram lambs are characterized by having higher birth weights and growth rates than ewe lambs (Crouse, 1981; Peeters, 1996). When slaughtered at the same age, carcasses from ewe lambs are lighter and fatter than those from wethers and rams (Bennet et al, 1991). Abdullah et al. (1999) reported that there was a significant effect of lamb sex on feed intake. It was found that males consumed significantly more feed than females (Abdullah et al, 1999). Depending on feed availability, ram and cryptorchid lambs are very similar in growth rates, and approximately 10-20% better than ewes and wethers (wethers are 8 to 12% faster growing than ewes), they are also more likely to be laying down lean muscle than fat (Kerr, 2000).

The difference of fatness between sexes increases with carcass weight. Female carcasses have a higher proportion of fat. When the animals are slaughtered at a later age and heavier weight, females have better carcass conformation, which is in accordance with the allometric coefficient for fat covering (Pena et al, 2005). M:B are higher in heavier carcasses and in males that were associated with a better conformation (Hopkins et al, 1997).

#### *2.5.3.2 The effect of breed on lamb growth and carcass composition*

Improvement of productive and reproductive traits, especially in growth and meat production characteristics, has been a major aim for the sheep industry due to the dependence of production on these traits (Campbell et al, 2009). The genetic improvement of animals can be performed by selection, introduction of new sires, crossbreeding, or a combination of these methods (Abdullah et al, 2010). Selection for improved meat yield has been possible for over twenty years through the use of technologies, including ultrasound scanning and more recently computed tomography (Young et al, 1996). Sex and genotype affect the total growth from birth to near puberty (0–221 days; Abdullah et al, 2010). These differences may be due to the effect of type of crossing between different sires and dams, which may show the effect of the hybrid vigour and significantly affect average daily gain (Arvizu et al, 2011).

Improvement in carcass composition by genetic selection is possible for traits such as fat distribution which show a high degree of variation in individual animals within a breed but

would be limited for other traits such as muscle weight distributions which show very small variation either within or across breeds when sheep are compared at the same stage of maturity (Stanford et al, 1998). Heritability estimates for linear measures of carcass muscle and fat showed that in general they are moderately heritable, which suggests a moderate level of genetic variation (Johnson et al, 2005). The amount of intramuscular fat in the *longissimus dorsi* has a high phenotypic correlation with marbling but also with subcutaneous fat thickness therefore, highly marbled carcasses may also have increased fat trim losses (Stanford et al, 1998).

In terms of meat production the Texel is of most interest given previous overseas studies which have shown this breed to excel in aspects such as leanness, cross-sectional area of *m. longissimus et lumborum*, muscularity and muscle to bone ratio (Hopkins et al, 1997). Purebred Texel sired lambs have heavier carcasses and legs, higher dressing out percentages, shorter but wider carcasses and larger eye muscle areas, legs with more muscle, less fat and less bone, which equates to higher muscle to bone ratios and higher muscularity values when compared to Romney (Johnson et al, 2005).

Kremer et al, 2004 found that East Friesian lambs had GR soft tissue depths that were significantly lower than Corriedale, Southdown, Hampshire Down, Suffolk, and Texel, and the increase per kg of carcass weight was also the lowest. In Texel, GR was not lower than the rest of the breeds. Leymaster and Jenkins (1993) also reported that Texel sired lambs deposited proportionally more subcutaneous fat and less inter and intramuscular fat than those sired by Suffolk sires. Both situations could be indicative of between-breed variations in fat partitioning and/or a genetically inherent capacity for lipid deposition independent of mature size. Kirton et al. (1996) pointed out that although the differences between breeds in proportion of cuts were usually significant, the size of the difference was less than 1%.



## 2.6 Pre-slaughter factors affecting lamb meat quality

Meat quality can be influenced by many farm production practices, that can be directly linked to the animal (breed, age, sex etc) or to external factors that immediately influence the animal (diet, weather, slaughter; Priolo et al, 2001). Variation in meat quality can be introduced at all stages during production, from the farm to the marketplace (Farouk et al, 2007). The New Zealand meat industry has traditionally focused on processing and packaging as the main avenues for improvement of lamb meat quality. However, meat quality is also influenced by genetics and farm management practices, such as feed type and quality, age, sex and stress levels (Purchas et al, 1989).

### 2.6.1 Effect of forage type on meat quality

Lamb diet can affect meat quality characteristics directly or indirectly. Direct effects of nutrition result in specific components of the diet ending up in the meat and affecting perceived quality. An indirect effect occurs because of animal factors such as weight, growth rate or level of fatness that in turn effect the meat attributes (Purchas et al, 1991; Bray, 1988). Forage species, pasture management and harvest time all play an important role in forage fatty acid composition and therefore some animal meat quality characteristics (Clapham et al, 2005).

Plant components are absorbed directly from the stomach compartments of the ruminant and transferred to the muscle and adipose tissue where they influence meat flavour. A number of studies have investigated the impact of different forages on the quality of meat, with some studies reporting stronger flavours in lambs fed on white clover than lambs fed on ryegrass (Schreurs et al, 2008) and stronger flavour of lambs fed on brassica than those fed on pasture (Hopkins et al, 1995; Resconi et al, 2010; Bray, 1988). The quantity of intramuscular fat or the degree of marbling is a key contributor to the differences in flavour observed across the forage varieties (Troy & Kerry, 2010).

Lambs finished on legumes have significantly higher proportions of three of the polyunsaturated fatty acids (PUFA), linoleic acid and  $\alpha$ -linolenic acids (Fraser et al, 2004). Meat from animals grazing legumes has been attributed to having a higher incidence of foreign flavours and less desirable meat flavour than that of animals grazing grass forages (Priolo et al, 2001). Lambs grazed on perennial ryegrass (*lolium perenne*)/ white clover (*Trifolium repens*) dominant pasture develop meat described as having a pastoral flavour (Schreurs et al, 2007). Lucerne pastures have been reported to give a more intense, unacceptable “sharp” and “sickly” flavour to lamb compared to grass pastures, and the flavour became more intense with length of time grazing lucerne (Fraser et al, 2004).

*Lotus corniculatus*, a tannin-containing forage, reduced the rumen formation of indole and skatole in sheep relative to white clover (*Trifolium repens*) (WC) or ryegrass (*Lolium perenne*) (RG) with marginal effects on the meat odour and flavour (Farouk et al, 2007). CT-containing forages reduce the formation of indole and skatole in the rumen by decreasing protein degradation and rumen microbes forming indole and skatoles (Schreurs et al, 2008). Using alternative forages to reduce the formation of pastoral flavour compounds and alter meat flavour is potentially a practical option in improving lamb meat quality (Wang, et al, 1994).

Forage treatment pre slaughter may have a significant interaction the pH meat cuts post slaughter. Animals grazing on Phalaris (*Phalaris aquaticus*) generate meat samples with significant foreign flavour intensity and a high ultimate-pH variability (Priolo et al, 2001). Those grazing white clover or birdsfoot trefoil (*Lotus corniculatus*) generally have a lower mean pH than those fed on plantain (*Plantago lanceolata*) or perennial ryegrass with those grazing chicory (*Cichorium intybus*) having intermediate ultimate pH between these two groups (Campbell et al, 2011).

**Table 2.7:** Summary of literature evaluating the quality of meat from lambs on different forage types.

Reference	Origin of study	Treatment	Shear Force	Colour L*	Colour a*	Colour b*	Ultimate pH	Lamb Flavour <sup>1</sup>	Juiciness
Hopkins et al (1995)	NZ	Forage rape	2.7 kgF	37.1	15.2	8.9	5.49	5.4	
		Irrigated pasture	3.1 kgF	35.1	15.0	8.1	5.58	5.6	
Fraser et al (1996)	NZ	Chicory					5.75	5.1	
		Plantain					5.89	5.2	
		White clover					5.66	5.3	
		Lotus corniculatus					5.72	5.4	
		Ryegrass					5.97	5.7	
Fraser et al, (2004)	UK	Lucerne	18.0 N					16.5	16.4
		Red clover	16.6 N					16.3	16.1
		Perennial ryegrass	16.3 N					18.1	16.3
Campbell et al (2011)	NZ	Brassica (Goliath)	7.9 kgF	41.0	20.3		5.58		
		Brassica (Winfred)	7.7 kgF	41.0	20.2		5.59		
		Turnip	6.7 kgF	40.8	20.5		5.64		
		Radish	7.3 kgF	41.5	20.7		5.64		
		Pasture	5.8 kgF	41.4	20.2		5.62		
		Plantain	7.4 kgF	41.6	21.3		5.61		
		Red clover	6.8 kgF	40.8	20.5		5.58		

<sup>1</sup>- Measured on a scale of intensity with a higher number being a more intense flavour.

### 2.6.2 Effect of gender on lamb meat quality

The castration of male sheep is standard practice on many farms, however, intact males grow faster, utilize feed more efficiently and produce higher yielding carcasses than castrated counterparts at the same age. However, there are variable meat quality concerns from the various sex classes, including entire and castrate male and females and cryptorchids (Purchas et al, 1989). New Zealand pasture fed lambs slaughtered according to standard weight or age parameters are generally assessed as having similar flavour, juiciness and tenderness independent of the animal's sex (Bray, 1988; Johnson et al, 2005). However, there is a difference between the two sex types as age and maturity increase.

The quality of meat from ewe lambs is better than that from ram lambs in terms of lower shear values (as a measure of tenderness), a lower ultimate pH, and a slightly lighter and redder colour (Johnson et al, 2005). The greater tendency of female lambs to accumulate fat from a young age affects the fatty acid composition of total lipid. This may partly explain the lower shear force and cooking loss values in the female lambs, since intramuscular fat has been negatively correlated to shear force (Koohmaraie and Geesink 2006).

Vasectomised rams contain significantly higher polyunsaturated fatty acid proportion in the *m. longissimus dorsi* than intact rams, castrates and ewes (Okeudo and Moss 2008). Concentrations and hence, the intensity of 'sheep' odours and flavours, tend to be higher in ram lambs than castrates and increase with age (Schreurs et al, 2008).

### 2.6.3 The effect of breed on lamb meat quality characteristics

The effect of breed is an important factor influencing lamb quality. To produce lambs with consumer appeal, producers and processors need to recognise the importance of the interactions between breed, animal age, and sex (Hoffman et al, 2003).

Tenderness is an important sensory attribute contributing to lamb meat eating quality. Different breeds of sheep for meat production are associated with different composition and conformation attributes that are inherently related to differences in meat yield and quality (Safari et al, 2001). The actual structure and composition of collagen network varies widely between muscles according to function, species and breed (Nimishmura et al, 2010). Speck et al. (1997) reported a 20% variation in tenderness between common NZ genotypes at 1 day post-mortem but differences disappeared after ageing 7 days demonstrating the importance of ageing. Young & Dobbie (1994) found no differences in collagen content of the hindquarter muscles semimembranosus or *biceps femoris*, or in the forequarter muscle *supraspinatus* from 8

month old Texel x Romney crosses, as compared to Romney lambs. Therefore, any tenderness differences ascribed to breeds might be apparent within 30 to 48 hours post slaughter but the breed differences disappear if lambs are chilled 1-6 weeks at 1°C and any minor variations are probably due to sire effects within a breed rather than differences between breeds.

Ultimate pH is an important indicator of meat quality with a value greater than 5.8 regarded as undesirable (Devine et al., 1993). In New Zealand, Young, Reid and Scales (1993) reported a higher pH and an associated increase in foreign flavours for meat from Merino lambs compared to crossbred lambs. The mean ultimate pH of the pure Merino lambs was higher than that of pure Coopworths and the mean pH values of the Merino-cross breeds lay between the two (Young 1993). However, Hoffman et al (2003) had no significant correlation between pH and any of the sensory attributes. Other studies have found no significant sire breed or genotype effect on lamb eating quality attributes (Safari et al, 2001; Hopkins and Fogarty, 1998).

## 2.7 Research objectives

From the previous research it can be seen that there is potential for type-of-animal and environment effects to be manipulated while the lamb is growing to alter the quality of the meat product. However, very few studies have taken a “pasture-to-plate” approach to trace the effects of on-farm environment or animal factors through to the consumer by considering meat quality.

The purpose of this research is to investigate the effects of forage diet, lamb sex and breed during the post-weaning to finishing phase on lamb growth, carcass, and meat quality attributes. The overarching objective is to provide a set of recommendations regarding on-farm practices that can influence the meat quality and eating experience of meat. The information would potentially be relayed to lamb finishers as part of an integrated supply chain approach to enhance the New Zealand lamb meat sector’s position in the export and domestic market place. . The recommendations will allow producers to develop and differentiate their breeding objective and their management policy to fit the ‘pasture to plate’ model.

A better understanding of how changes in forage diet are reflected in the animal’s tissue composition and how these intrinsic changes alter the palatability and appearance characteristics of the meat was the objective of a primary experiment (Chapter 4).

The objective of the second experiment was to build on the results from the first experiment to gain insight into how breed, sex and diet interact to influence growth, carcass and meat quality characteristics (Chapter 5). Included in the experiment were two modern composite breeds (Primera and Lamb Supreme) which each provide a unique set of genetic attributes for comparison.

## Chapter 3: Material and Methods

### 3.1 Experimental design

Two experiments were conducted in parallel using lambs; born 9<sup>th</sup> – 30<sup>th</sup> September 2010; sourced from commercial Hawkes Bay farms. Lambs were weaned in the period 2<sup>nd</sup> -23<sup>rd</sup> December 2010 at a mean age of 95 days. Weaned animals were transported to Pohuetai Farms, Dannevirke where both experiments were executed. Lambs in Experiment 1 and Experiment 2 were slaughtered in three groups on the 15 March, 19 April and 25 May 2011. This design was implemented to achieve a similar slaughter weight for all lambs in the experiments. However, lambs across the three slaughter groups had different average ages (Table 3.1).

#### 3.1.1 Experiment One

Experiment 1 used 1178 weaned male and female Rissington Primera lambs. All lambs were assigned to one of five forage treatments balanced for weight at the start of experiment on 4<sup>th</sup> February 2011. The forage treatments were: Lucerne (*Medicago sativa*; n=495), Rape cv. Titan (*Brassica napus* n=485), Rape cv. Spitfire (*Brassica napus*; n=206), Perennial ryegrass based pasture (*Lolium perenne*; n=479), and Chicory (*Cichorium intybus*; n=107). The five forage treatments were sown spring 2010 and grazed over summer. (Further details are available in Chapter 4)

#### 3.1.2 Experiment Two

Experiment 2 used 1459 weaned male and female lambs from the Rissington Primera, Landcorp Lamb Supreme and Landcorp Texel breed lines. All lambs were assigned to one of three forage treatments balanced for weight at the start of experiment on 4<sup>th</sup> February 2011. The forage treatments were: Lucerne (*Medicago sativa*; n=495), Perennial ryegrass based pasture (*Lolium perenne*; n=479) and Rape cv. Titan (*Brassica napus* n=485). The three forage treatments were sown spring 2010. (Further details are available in Chapter 5)

**Table 3.1:** Average lamb age and live weight for lambs in each experiment at each of three slaughter dates.

	<b>Number of lambs</b>	<b>Time on treatment (days)</b>	<b>Mean lamb age at slaughter (days)</b>	<b>Mean lamb live weight at slaughter (kg)</b>
<i>Experiment One</i>				
Slaughter One (15/03/2011)	390	39	181	44.5
Slaughter Two (19/04/2011)	408	74	214	46.7
Slaughter Three (25/05/2011)	380	110	250	46.7
<i>Experiment Two:</i>				
Slaughter One (15/03/2011)	486	39	178	43.9
Slaughter Two (19/04/2011)	499	74	211	45.8
Slaughter Three (25/05/2011)	474	110	247	45.7

### 3.2 On-farm management

All lambs were treated orally with an anthelmintic at weaning and at 28 day intervals thereafter to control internal parasites. Animals were individually identified using electronic identification (EID). Lambs were set stocked and the stocking rates were reviewed weekly to ensure the feed available did not drop below 1000 kg DM/ha. Lamb live weight was measured at docking, prior to allocation to treatments and prior to slaughter. Lambs were taken off feed in their mobs immediately prior to live weight measurements. Lambs with no tags or a non-readable tag were removed to alleviate identification issues in the carcass sequencing process at slaughter and have not been included in the data analysis. However, no pre- and post pasture covers were measured and no herbage samples were collected for nutritive analysis. Therefore, when considering the differences in growth and carcass characteristics between forage diets, reference is made to the literature and to established knowledge to elucidate the cause of the differences.

### 3.3 Pre- and post-slaughter management

Animals left the farm for the abattoir one day before slaughter; (i.e., 14<sup>th</sup> March, 18<sup>th</sup> April and 24<sup>th</sup> May 2011). In the 24 hours prior to slaughter, lambs were removed from their forage treatments, weighed, sorted and directly loaded for transport to the abattoir.

Lambs were in lairage with *ad libitum* water access for approximately 12 hours. Lambs were slaughtered using approved Halal procedures, electrically stimulated and dressed according to

standard commercial procedures for New Zealand lamb. Electrical stimulated was applied within 30 minutes of slaughter at 1130V peak at 14.3 alternating pulses per second applied for 90 seconds. The carcasses were hung overnight in a chiller at 4°C. The day following slaughter the carcass was dissected into commercial cuts.

### **3.4 Carcass measurements and meat sampling**

To allow tracing of individual animals, each carcass was given an identification number. The carcass number was linked to the EID of each lamb. Soft tissue depth assessment (GR) based on the measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass was measured by a trained Silver Fern Farms (SFF) GR grader. Hot carcass weight was measured and grade classification allocated by a certified SFF grader following industry standards. The circumference of the hind quarters was measured using a flexible tape measure on the dressed carcasses hanging from their hindquarters and represented the circumference when taken in a horizontal parallel plane at the upper edge of the anal opening. Carcasses were chilled at 4°C. After 24 hours chilling, two boneless short loins (*M. longissimus dorsi*; fat cap off) were collected from each animal. One loin was halved by a lateral cut and the two halves vacuum packed. One of the half loins was chilled at -1°C and used for colour stability and pH assessments and the other half frozen at -20°C for testing tenderness. The second loin was vacuum-packed, chilled at -1°C and air freighted, with a temperature logger, to Bristol University, United Kingdom.

### **3.5 Meat Quality tests**

The objective meat quality assessments for colour, pH and tenderness were tested at AgResearch Ltd, Mosgiel.

#### *3.5.1 Ultimate pH*

Meat pH measurements were conducted on chilled (-1°C) half-loins, eight weeks post-slaughter. Three replicate measurements were taken from each chilled half-loin along a cranial to caudal plane using a meat probe and WTW pH330i pH meter. The three replicates were averaged to achieve a pH value for each loin.

#### *3.5.2 Colour stability*



Three slices (2cm thick) were cut from the middle of the chilled loin and were put on polystyrene trays, over wrapped with an oxygen-permeable PVC. Samples were refrigerated at 4°C throughout the experimental period. Colour CIE measurements  $L^*$ ,  $a^*$  and  $b^*$  were recorded using a Minolta CR-400, D65 illuminant with an 8 mm aperture, calibrated with a CR-A44 white calibration plate. Measurements were taken through the film from each of the slices at time periods of 24, 48, 96 and 168 hours after slicing.

### *3.5.3 Tenderness*

Frozen loin from each animal were thawed at 4°C, cooked in a 100°C water bath in a sealed plastic bag with a temperature probe inserted into the core of the sample. Samples were cooked to an internal temperature of 75°C and allowed to cool to 2°C. Meat was then cut parallel to the muscle fibre direction, to create 12 cores with a 13 by 13mm cross sectional area. Twelve shears (one per core), perpendicular to the fibre axis were performed using the v-shaped (8mm wide) tooth of the MIRINZ pneumatic tenderometer. Peak shear force (kgF) was recorded.

## **3.6 Sensory panel assessment**

Sensory panel assessments were conducted eight weeks post slaughter. The sensory panel consisted of ten people screened and trained according to the methods of the British Standards Institute for taste sensitivity (British Standards Institute, 2011).

### *3.6.1 Sample preparation*

On the morning of sensory assessment, ten steaks 2cm thick were cut from each loin. Loin steaks were cooked with a domestic grill set at high, turning every 3 minutes to an internal temperature of 75°C measured by a thermocouple probe. The steaks were then removed from the grill and placed in a 60°C incubator to keep warm until presented to the taste panel. For presentation to the panellists, the steaks were trimmed of all extraneous residual fat and connective tissue and the lean cores individually wrapped in aluminium foil, and identified with a unique 3-digit number.

### *3.6.2 Sensory evaluation*

All panellists assessed the same loins on the same day. Each loin was evaluated by each panellist once. No more than 25 samples were assessed per panellist per session. Cooked samples were presented in the aluminium foil on hot blocks in sensory booths. Panellists were in individual booths with positive air pressure, under a red light.

Samples were rated (Table 3.2) for texture, juiciness, lamb flavour intensity, and overall liking using a 8 point scale where 1 is attributed as undesirable, 8 is attributed as desirable as described by Sanudo et al. (1998). Each tasting booth was equipped with a computerised system used to directly record the panellist responses. Data for sensory panelist assessment was provided as average scores of panelists and therefore no panelist effects could be investigated.

**Table 3.2:** Eight point category scale used in the sensory assessment of grilled lamb loin steaks.

<b>Score</b>	<b>Texture</b>	<b>Juiciness</b>	<b>Lamb flavour intensity</b>	<b>Overall liking</b>
<b>8</b>	Extremely tender	Extremely juicy	Extremely strong	Like extremely
<b>7</b>	Very tender	Very juicy	Very strong	Like very much
<b>6</b>	Moderately tender	Moderately juicy	Moderately strong	Like moderately
<b>5</b>	Slightly tender	Slightly juicy	Slightly strong	Like slightly
<b>4</b>	Slightly tough	Slightly dry	Slightly weak	Dislike slightly
<b>3</b>	Moderately tough	Moderately dry	Moderately weak	Dislike moderately
<b>2</b>	Very tough	Very dry	Very weak	Dislike very much
<b>1</b>	Extremely tough	Extremely dry	Extremely weak	Dislike extremely

### 3.7 Data and calculations

Dressing out percentage was calculated using pre-slaughter lamb live weight (kg) and hot carcass weight (kg).

$$\text{Dressing out percentage (\%)} = (\text{Hot carcass weight} / \text{pre-slaughter live weight}) \times 100$$

The average daily live weight gain (g/day) of each lambs was calculated using lamb weight at the start of the experiment, pre-slaughter live weight and the number of days from the start of the experiment to the slaughter date for each lamb.

$$\text{Average daily gain} = (\text{pre-slaughter live weight} - \text{live weight at the start of the experiment}) / \text{number of days on the finishing treatment}$$

Further details on the data analysis of Experiments 1 and 2 are available in Chapters 4 and 5, respectively.

## Chapter 4: Effect of different forage diets on growth, carcass and meat quality characteristics of Primera lambs

### 4.1 Introduction

A number of factors within the lamb finishing system can significantly contribute to carcass characteristics and the eating quality of lamb meat. New Zealand lamb is exported to a number of markets which have varying quality preferences. Therefore, the development of methods to produce consistent high quality product is essential.

The forage species grazed by a lamb can affect carcass and meat quality characteristics (Fraser et al, 1996; Fraser et al, 2004; Campbell et al, 2011). This preliminary study used the Primera sire line to investigate the effect of forage diet on growth, carcass and meat quality characteristics. Primera® is a terminal composite sheep breed designed by Rissington Breedline Ltd (now part of Focus Genetics) to supply high performance finishing lambs which excel in meat and carcass characteristics.

The effect of forage type for finishing both male and female Primera lambs was investigated with the aim of establishing a finishing diet that could promote optimal carcass characteristics and meat quality attributes for Primera lambs.

### 4.2 Material and methods

#### 4.2.1 Experimental design

This experiment examined the effect of different forage diets only. Due to insufficient numbers, no male lambs were allocated to the chicory treatment and so male and female lambs are considered separately.

Weaned Primera lambs that averaged 147 days of age were sourced from two commercial farms located in the Hawkes Bay region of New Zealand (n=1178). All lambs were assigned to one of five forage treatments with no consideration of farm-of-origin taken into account (Table 4.1). These forages were: Lucerne (*Medicago sativa*; n=152 for females and n=144 for males), Rape cv. Titan (*Brassica napus*; n=152 for females and n=136 for males), Rape cv. Spitfire (*Brassica napus*; n=107 for females and n=99 for males), Perennial ryegrass based pasture (*Lolium perenne*; n=148 for females and n=133 for males), and Chicory (*Cichorium intybus*; n=107 for females). All forage treatments were grown in Central Hawkes Bay, New Zealand on Pohuetai farm. Animals achieving a weight in the top 30% within each treatment at the set dates of 15<sup>th</sup>

March, 19<sup>th</sup> April and 24<sup>th</sup> May 2011 were sent to Silverfern Farms, Takapau plant for slaughter and processing (for full details on carcass measurements and meat sampling see Chapter 3).

No pre- or post-grazing pasture covers were measured and no herbage samples were collected for nutritive analysis. Therefore, when considering the differences growth and carcass characteristics between forage diets, reference is made to the literature and to established knowledge to elucidate the cause of the differences.

**Table 4.1:** Number of male and female Primera lambs grazed on the dietary treatments of Chicory, Lucerne, Ryegrass, Spitfire and Titan.

	<b>Chicory</b>	<b>Lucerne</b>	<b>Ryegrass</b>	<b>Spitfire</b>	<b>Titan</b>
Males	0	144	133	99	136
Females	107	152	148	107	152
Total	107	296	281	206	288

#### *4.2.5 Statistical analysis and calculations*

Data were tested using PROC UNIVARIATE in SAS for a normal distribution and the Levene test was used to assess homogeneity of variance (SAS Institute Inc., 2010). The random effect of slaughter group was analysed for all growth, carcass and meat quality variables and was removed from the statistical model if found not to be significant ( $P > 0.05$ ). Farm-of-origin of the lambs was not investigated in this statistical analysis.

##### *4.2.5.1 Carcass and growth analysis*

An analysis of variance determined the effect of forage on lamb growth and carcass quality (PROC MIXED, SAS). The statistical model considered the fixed effect of forage type. Hot carcass weight was fitted as a covariate for hind quarter circumference. Starting live weight was deemed the weight of each lamb on 4<sup>th</sup> February 2011 when the lambs were sorted into forage treatment mobs. Pre-slaughter live weight was the weight taken on-farm prior to slaughter. The growth rate over the period of grazing the forages (between the start and pre-slaughter dates) was calculated for each of the 1178 lambs. See Chapter 3 for further details on the calculations used in this experiment.

#### *4.2.5.2 Meat quality analysis*

An analysis of variance determined the effect of forage on meat quality (PROC MIXED, SAS). The forage treatment was fitted as the fixed effect in the model. The tenderness values were log-transformed for analysis and means back transformed to present in the results tables. Linear and quadratic effects of pH and the linear effect of GR were fitted as covariates in the tenderness and taste panel analyses. Colour measurements taken over time were analysed using a repeated-measures analysis (PROC MIXED; SAS).

## 4.3 Results

### 4.3.1 Lamb growth performance

Lambs grazed on the brassicas Titan and Spitfire had greater growth rates from the start of the experiment to slaughter (184 and 189 g/day respectively) and from docking to slaughter, than lambs grazed on other forage treatments ( $P < 0.001$ ; Table 4.2 and 4.3). Lambs fed on Lucerne had the lowest average daily gain from the start of the experiment to slaughter. Lambs fed chicory and ryegrass (164 and 157 g/day) were intermediate between lambs fed on brassicas. Female and male lambs finished on Spitfire and Titan had the highest pre-slaughter liveweight compared to all other forages with Chicory the next highest ( $P < 0.001$ ).

### 4.3.2 Carcass Characteristics

Spitfire and Titan fed lambs had the highest carcass weights, GR, DO% and hind quarter circumference compared to lambs finished on other forages (Table 4.2). Lambs fed Chicory were intermediate for GR, DO% and hind quarter circumference, between brassicas and Lucerne and Ryegrass ( $P < 0.001$ ).

Random effect of slaughter group remained in the model for male and female GR depth analyses. Male lambs had higher carcass weights than female lambs, however female lambs had a greater GR and DO% than male lambs (Table 4.2 and 4.3). Hind quarter circumference was not different between sexes. However, given the difference in treatment allocation for male and female lambs the two sexes were not compared statistically.

**Table 4.2** The effect of forage species on female Primera lamb carcass composition and lamb growth performance. Values are presented as the mean  $\pm$  the standard error of the mean.

	Chicory	Lucerne	Ryegrass	Spitfire	Titan	P-value	Hot carcass weight covariate
<i>Lamb growth performance:</i>							
Weight at start of experiment (kg)	33.8 $\pm$ 0.4	34.2 $\pm$ 0.3	33.7 $\pm$ 0.3	33.2 $\pm$ 0.4	33.8 $\pm$ 0.3	NS	-
Pre-slaughter live weight (kg)	45.5 $\pm$ 0.3b	41.1 $\pm$ 0.2d	44.5 $\pm$ 0.2c	46.4 $\pm$ 0.3a	47.0 $\pm$ 0.2a	<0.001	-
ADG from start to slaughter (g/day) <sup>1</sup>	164.1 $\pm$ 4.66b	85.7 $\pm$ 3.91c	157.2 $\pm$ 4.0b	184.1 $\pm$ 4.7a	189.2 $\pm$ 3.9a	<0.001	-
ADG from docking to slaughter (g/day) <sup>1</sup>	167.6 $\pm$ 2.2b	142.1 $\pm$ 1.8c	165.9 $\pm$ 1.9b	177.3 $\pm$ 2.2a	178.3 $\pm$ 1.8a	<0.001	-
<i>Carcass characteristics</i>							
Hot carcass weight (kg)	21.7 $\pm$ 0.2b	18.4 $\pm$ 0.1d	19.8 $\pm$ 0.1c	22.3 $\pm$ 0.2a	22.7 $\pm$ 0.1a	<0.001	-
GR depth (mm) <sup>2</sup>	10.6 $\pm$ 1.5b	6.9 $\pm$ 1.5d	9.0 $\pm$ 1.5c	13.6 $\pm$ 1.5a	14.1 $\pm$ 1.5a	<0.001	-
Dressing out percentage (%) <sup>2</sup>	47.6 $\pm$ 0.2b	44.7 $\pm$ 0.1c	44.4 $\pm$ 0.2c	48.1 $\pm$ 0.2ab	48.3 $\pm$ 0.2a	<0.001	-
Hind quarter circumference (cm) <sup>3</sup>	67.8 $\pm$ 0.2b	65.2 $\pm$ 0.1d	66.1 $\pm$ 0.1c	68.1 $\pm$ 0.2b	68.6 $\pm$ 0.1a	<0.001	<0.001

*a,b,c,d* = Means in the same row with different letters are significantly different ( $P \leq 0.05$ ). NS =  $P > 0.05$

<sup>1</sup> ADG = Average daily gain.

<sup>2</sup> GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight

<sup>3</sup> Hind quarter circumference = the circumference of the back end of the carcass. Hind quarter circumference values are presented as carcass weight adjusted values.

**Table 4.3** The effect of forage species of male Primera lambs on carcass composition and lamb growth performance. Values are presented as the mean  $\pm$  the standard error of the mean.

	Lucerne	Ryegrass	Spitfire	Titan	P-value	Hot carcass weight covariate
<i>Lamb performance</i>						
Weight at start of experiment (kg)	36.93 $\pm$ 0.34a	34.89 $\pm$ 0.35b	34.68 $\pm$ 0.41b	35.07 $\pm$ 0.35b	<0.001	-
Pre-slaughter live weight (kg)	46.45 $\pm$ 0.28c	46.16d $\pm$ 0.29c	49.61 $\pm$ 0.34a	48.54 $\pm$ 0.29b	<0.001	-
ADG start to slaughter (g/day) <sup>1</sup>	126.19 $\pm$ 4.56c	173.68 $\pm$ 4.75b	213.74 $\pm$ 5.51a	200.28 $\pm$ 4.71a	<0.001	-
ADG docking to slaughter (g/day) <sup>1</sup>	172.31 $\pm$ 2.03c	180.99 $\pm$ 2.11b	199.24 $\pm$ 2.44a	196.23 $\pm$ 2.08a	<0.001	-
<i>Carcass data</i>						
Hot carcass weight (kg)	20.79 $\pm$ 0.17b	19.83 $\pm$ 0.18c	23.01 $\pm$ 0.21a	22.69 $\pm$ 0.18a	<0.001	-
GR depth (mm) <sup>2</sup>	6.69 $\pm$ 0.28c	4.91 $\pm$ 0.30d	9.15 $\pm$ 0.34b	10.66 $\pm$ 0.29a	<0.001	-
Dressing out percentage (%) <sup>2</sup>	44.73 $\pm$ 0.2b	42.94 $\pm$ 0.21c	46.34 $\pm$ 0.24a	46.73 $\pm$ 0.21a	<0.001	-
Hind quarter circumference (cm) <sup>3</sup>	66.72 $\pm$ 0.15b	65.91 $\pm$ 0.16c	68.13 $\pm$ 0.18a	67.80 $\pm$ 0.16a	<0.001	<0.001

*a,b,c,d* = Means in the same row with different letters are significantly different ( $P \leq 0.05$ ).

<sup>1</sup>ADG = Average daily gain.

<sup>2</sup> GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight.

<sup>3</sup> Hind quarter circumference = the circumference of the back end of the carcass. Hind quarter circumference values are presented as carcass weight adjusted values.



### 4.3.3 Meat quality and sensory

#### *Objective meat quality measurements*

Female lambs finished on Ryegrass had higher shear force values than those grazed on Chicory and the brassicas, Spitfire and Titan ( $P < 0.001$ ; Table 4.4). For male lambs finished on Ryegrass, Spitfire and Titan the shear force values were higher than in those from male lambs grazed on Lucerne ( $P < 0.001$ ; Table 4.5).

#### *Sensory assessment*

The flavour of female lambs finished on Chicory and Titan scored higher for the intensity of flavour than females fed other forages ( $P < 0.05$ ). Male lambs finished on Titan had greater lamb flavour intensity than other forage fed males ( $P < 0.001$ ). Lamb from male lambs fed Lucerne were juicier than those fed Chicory and the brassica varieties ( $P < 0.001$ ). Spitfire fed male lambs had meat with the highest overall liking compared to males finished on other forages ( $P < 0.01$ ).

#### *Colour stability*

Over time the lamb darkened (lower  $L^*$  values) steadily until day 2 of retail conditions. From day 2 to 4 the meat lightened gradually then plateaued after day 4 under retail display conditions. Lamb redness decreased gradually over the whole display period whilst also decreasing in yellowness steadily until day 4 where it reached its lowest values.

Meat from female lambs finished on Spitfire, Titan and Ryegrass had lighter meat after 24 hours in retail packaging compared to meat from lambs fed other forages ( $P < 0.001$ ). Lamb from females fed Ryegrass was reddest after 24 hours in retail packaging ( $P < 0.001$ ). Spitfire grazed male lambs had lighter, redder and yellower lamb after 1 day of retail packaging compared to males fed other forages ( $P < 0.001$ ). Lucerne and Ryegrass fed lambs had meat with the lowest redness, lightness and yellowness.

Lamb from Titan finished female lambs was lighter and yellower over the 7-day simulated display time ( $P < 0.001$ ; Figure 4.1 and 4.5). Females finished on Ryegrass had redder meat and a slower decline of redness over the 7-day simulated display time ( $P < 0.001$ ; Figure 4.3). Over the whole display time period, lamb from Spitfire fed male lambs was the lightest and yellowest (Figures 4.2 and 4.6). Ryegrass and Titan fed male lambs had the reddest meat up to day 7 after air exposure (Figure 4.4).

**Table 4.4:** The effect of five forage species on female Primera lamb loin meat quality. Values are presented as the mean  $\pm$  the standard error of the mean.

	Chicory	Lucerne	Ryegrass	Spitfire	Titan	P-value	pH covariate		GR effect
							Linear	Quadratic	Linear
<i>Objective Tests<sup>1</sup></i>									
Shear force (log kgF)	0.66 $\pm$ 0.02b	0.69 $\pm$ 0.01ab	0.72 $\pm$ 0.01a	0.65 $\pm$ 0.02b	0.63 $\pm$ 0.01b	<0.001	<0.001	<0.001	<0.001
Shear force (kgF)	4.57	4.90	5.25	4.47	4.27				
L* (Lightness)	40.89 $\pm$ 0.2b	40.96 $\pm$ 0.17b	41.53 $\pm$ 0.17a	41.36 $\pm$ 0.2a	41.87 $\pm$ 0.17a	<0.001	<0.001	<0.001	-
a* (Redness)	14.85 $\pm$ 0.16b	15.28 $\pm$ 0.13b	16.04 $\pm$ 0.13b	15.34 $\pm$ 0.16b	15.27 $\pm$ 0.13b	<0.001	0.001	0.002	-
b* (Yellowness)	40.87 $\pm$ 0.2b	40.96 $\pm$ 0.17b	41.53 $\pm$ 0.17a	41.36 $\pm$ 0.2ab	41.87 $\pm$ 0.17a	<0.001	<0.001	<0.001	-
<i>Sensory Panel<sup>2</sup></i>									
Texture	4.94 $\pm$ 0.07	5.00 $\pm$ 0.05	5.09 $\pm$ 0.05	5.07 $\pm$ 0.07	5.18 $\pm$ 0.05	NS	0.002	0.002	<0.001
Lamb Flavour	2.62 $\pm$ 0.08a	2.51 $\pm$ 0.06b	2.43 $\pm$ 0.06c	2.52 $\pm$ 0.08b	2.56 $\pm$ 0.06a	0.039	<0.001	<0.001	NS
Juiciness	4.46 $\pm$ 0.06	4.47 $\pm$ 0.04	4.46 $\pm$ 0.04	4.52 $\pm$ 0.06	4.45 $\pm$ 0.04	NS	NS	NS	NS
Overall Liking	4.93 $\pm$ 0.09	5.04 $\pm$ 0.06	5.09 $\pm$ 0.06	5.03 $\pm$ 0.09	5.02 $\pm$ 0.06	NS	0.012	0.028	NS

a,b,c, d = Means in the same row with different letters are significantly different ( $P < 0.05$ ).

<sup>1</sup>Log KGF = Shearforce values  $\text{Log}_{10}$ ; Shearforce  $10^x$  = back transformed means. Colour stability measurements taken after 1 day of simulated retail conditions

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

**Table 4.5:** The effect of four forage species on male Primera lamb loin meat quality. Values are presented as the mean  $\pm$  the standard error of the mean.

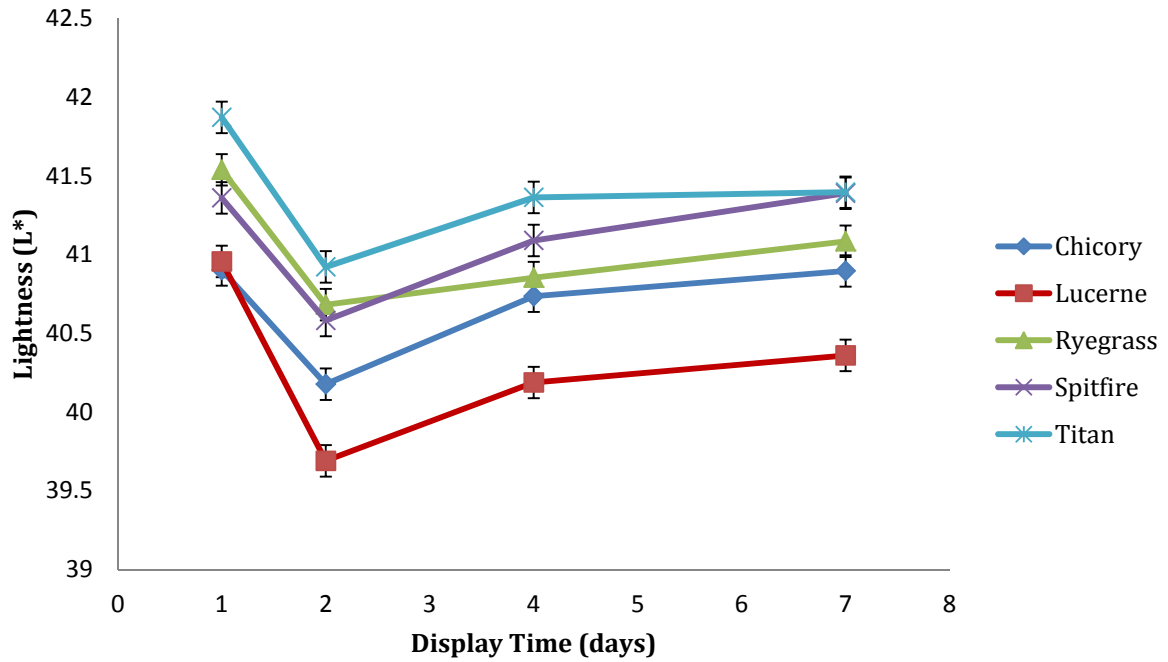
	Lucerne	Ryegrass	Spitfire	Titan	P-value	pH covariate effect		GR effect
						Linear	Quadratic	Linear
<i>Objective Tests<sup>1</sup></i>								
Shear force (logkgF)	0.64 $\pm$ 0.01b	0.80 $\pm$ 0.01a	0.77 $\pm$ 0.02a	0.78 $\pm$ 0.01a	<0.001	<0.001	<0.001	<0.001
Shear force (kgF)	4.37	6.31	5.89	6.03				
L* (Lightness)	38.93 $\pm$ 0.26c	39.39 $\pm$ 0.27c	42.54 $\pm$ 0.31a	41.16 $\pm$ 0.27b	<0.001	<0.001	<0.001	<0.001
a* (Redness)	14.05 $\pm$ 0.15b	13.80 $\pm$ 0.15b	15.02 $\pm$ 0.18a	14.19 $\pm$ 0.15b	<0.001	<0.001	<0.001	0.002
b* (Yellowness)	10.09 $\pm$ 0.16c	10.37 $\pm$ 0.16c	12.17 $\pm$ 0.19a	11.39 $\pm$ 0.16b	<0.001	<0.001	<0.001	<0.001
<i>Sensory panel<sup>2</sup></i>								
Texture	5.45 $\pm$ 0.06	5.41 $\pm$ 0.06	5.51 $\pm$ 0.08	5.43 $\pm$ 0.06	NS	0.002	0.002	0.002
Lamb Flavour	4.86 $\pm$ 0.04b	4.93 $\pm$ 0.04b	4.92 $\pm$ 0.06b	5.13 $\pm$ 0.04a	<0.001	<0.001	<0.001	<0.001
Juiciness	3.29 $\pm$ 0.11a	2.94 $\pm$ 0.11b	2.64 $\pm$ 0.15c	2.98 $\pm$ 0.11b	<0.001	NS	NS	NS
Overall Liking	4.11 $\pm$ 0.05b	4.18 $\pm$ 0.05b	4.94 $\pm$ 0.07a	4.22 $\pm$ 0.05b	<0.001	0.012	0.012	0.028

a,b,c,d = Means in the same row with different letters are significantly different ( $P < 0.05$ ).

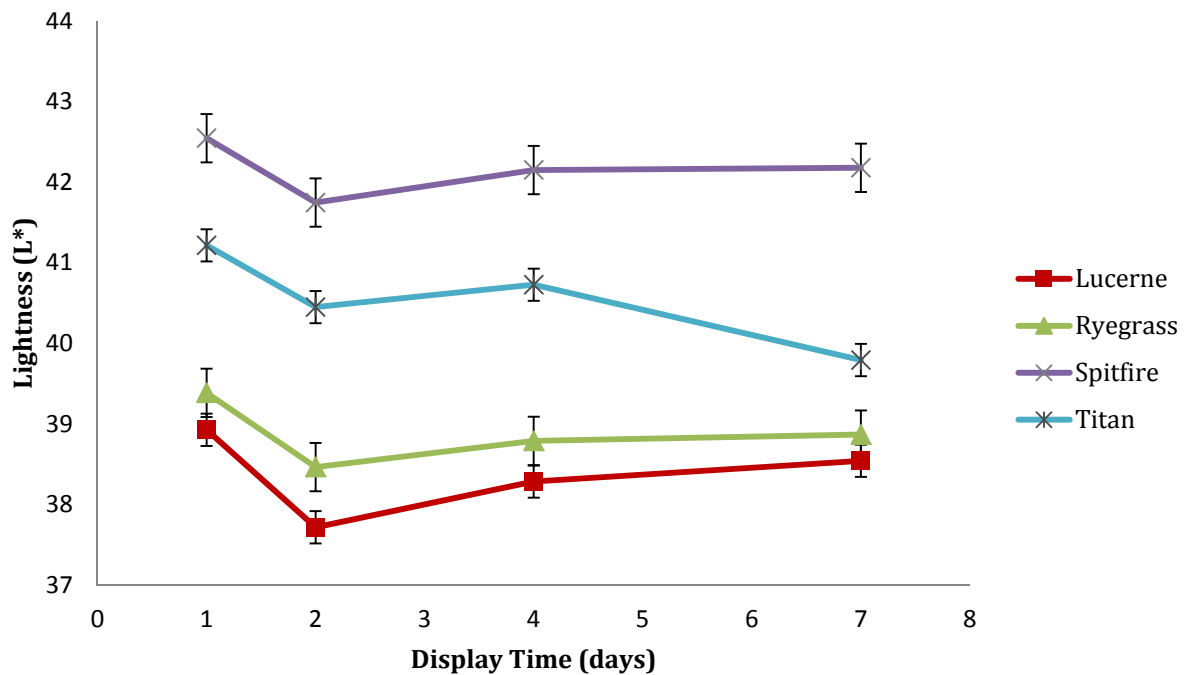
<sup>1</sup>Log KGF = Shearforce values  $\text{Log}_{10}$ ; Shearforce  $10^x$  = back transformed means. Colour stability measurements L\*, a\* and b\* were taken after 1 day of simulated retail conditions.

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

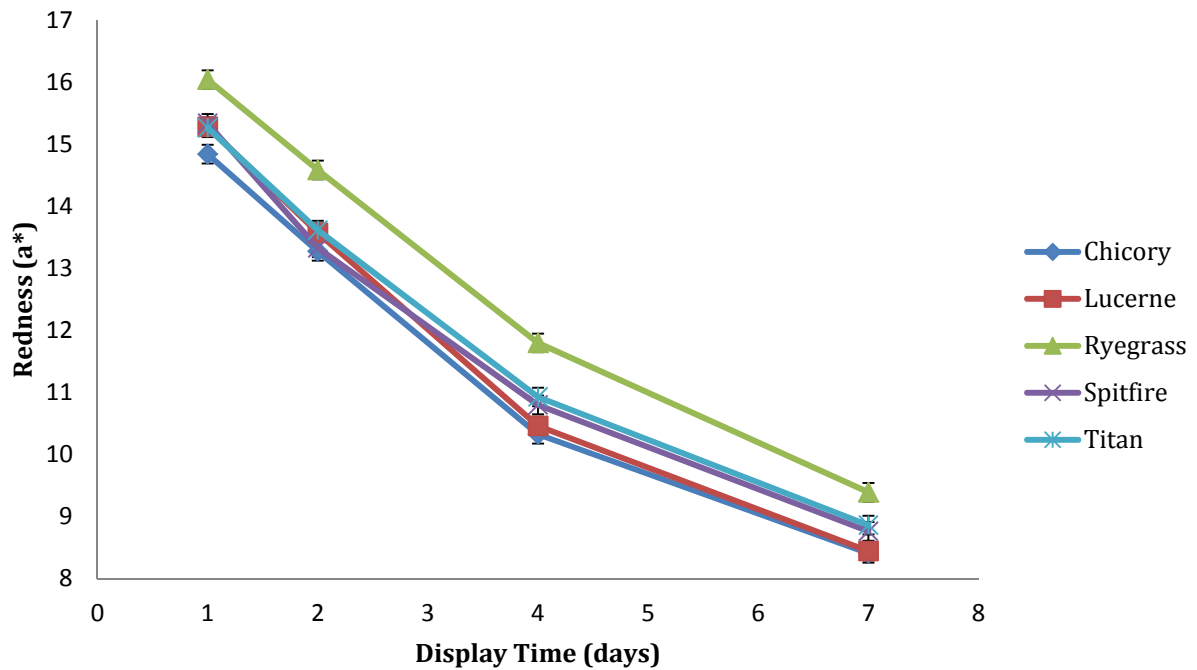
**Figure 4.1:** Least square means  $\pm$  standard errors of Lightness ( $L^*$ ) colour measurements of meat over a seven day blooming period following slaughter from female Primera lambs finished one of five diets prior to slaughter.



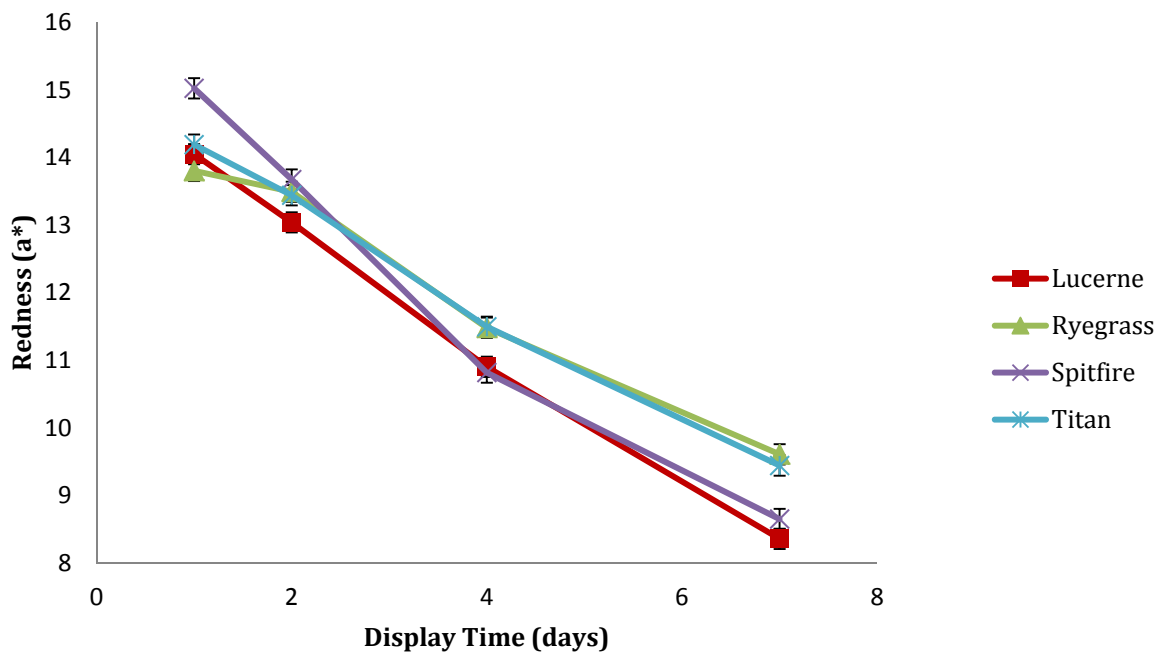
**Figure 4.2:** Least square means  $\pm$  standard errors of Lightness ( $L^*$ ) colour measurements of meat over a seven day blooming period following slaughter from male Primera lambs finished one of five diets prior to slaughter.



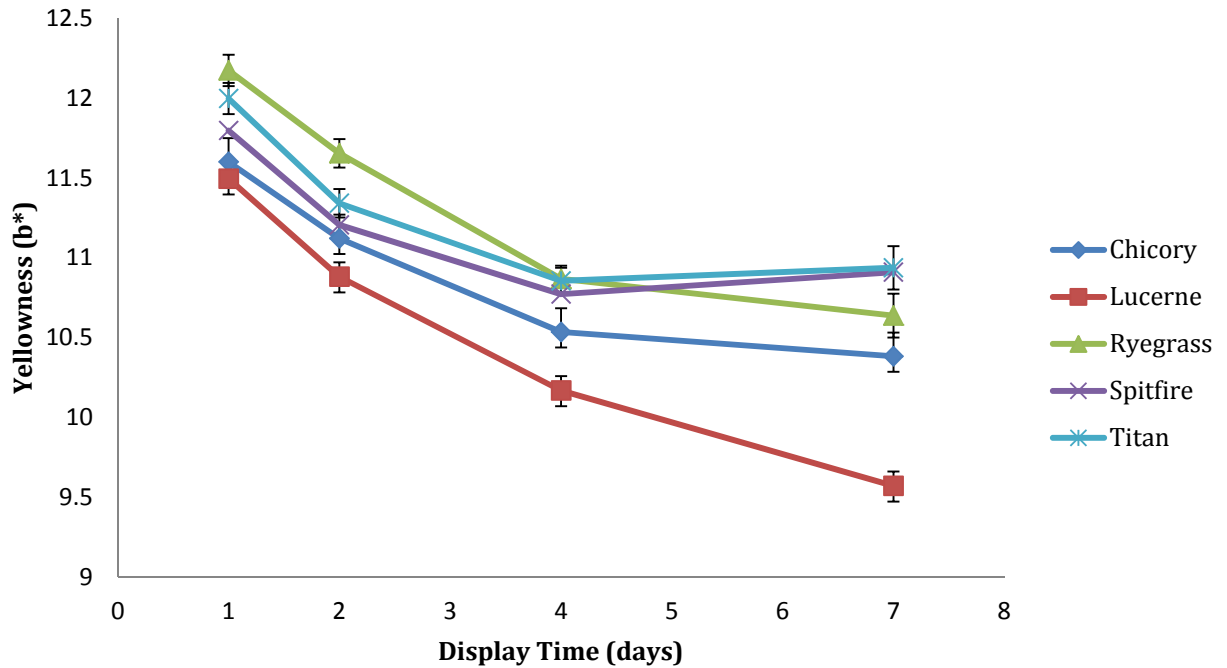
**Figure 4.3:** Least square means  $\pm$  standard errors of redness ( $a^*$ ) colour measurements of meat over a seven day period following slaughter from Primera female lambs finished five prior to slaughter.



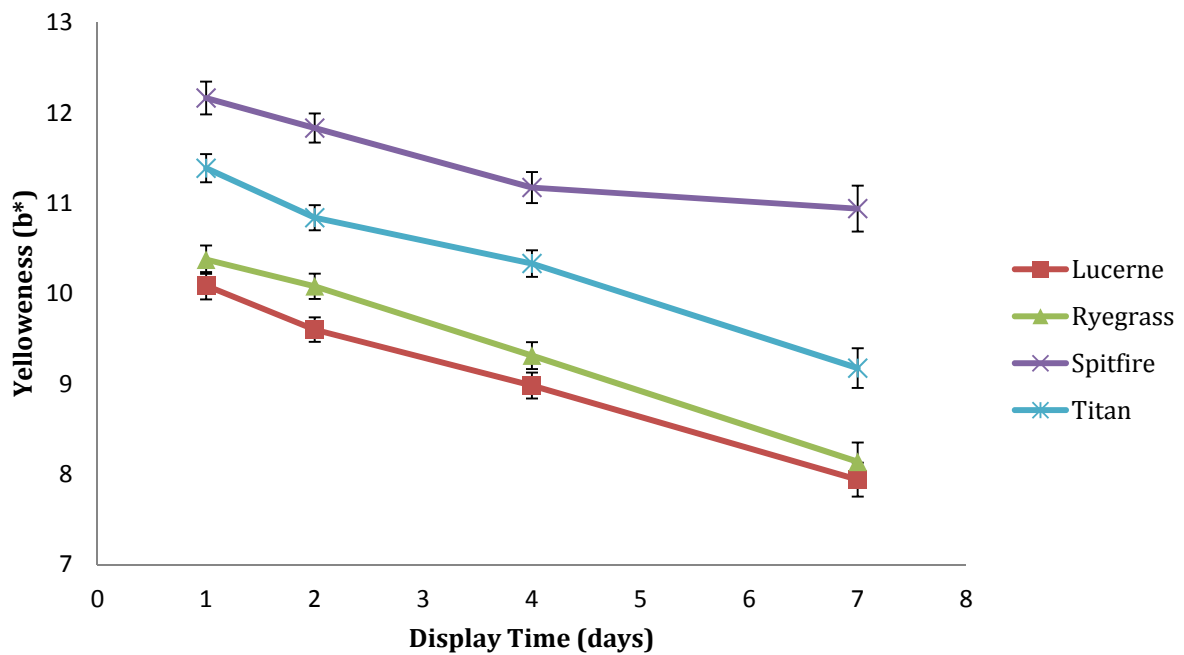
**Figure 4.4:** Least square means  $\pm$  standard errors of redness ( $a^*$ ) colour measurements of meat over a seven day period following slaughter from Primera male lambs finished five prior to slaughter.



**Figure 4.5:** Least square means  $\pm$  standard errors of yellowness ( $b^*$ ) colour measurements of meat over a seven day period following slaughter from Primera female lambs finished five diets prior to slaughter.



**Figure 4.6:** Least square means  $\pm$  standard errors of yellowness ( $b^*$ ) colour measurements of meat over a seven day period following slaughter from Primera male lambs finished five diets prior to slaughter.



## 4.4 Discussion

The objective of this experiment was to investigate the effect of post weaning forage diet on male and female Primera lamb growth, carcass, and meat and eating quality attributes. Alternative forage crops have the potential to improve animal growth performance substantially due to high nutritive value and high feed intakes, compared with traditional perennial ryegrass (Speijers et al, 2004; Fraser & Rowarth, 1996). Feeding value (FV) is a function of intake and dietary nutritive value (NV). The NV of a diet is a measure of available nutrients that are required by the animal. Nutrients include nitrogen (often expressed as crude protein; CP) lipids, fat-soluble vitamins, macro-elements micro-elements and energy. ME is derived from microbial and intestinal digestion and absorption of nutrients (Waghorn & Clark, 2004).

### 4.4.1 Lamb growth performance

Faster lamb growth seen with specialist forages is a consequence of several interacting factors including: greater amount of feed available allowing for a greater intake, better digestibility, faster rumen degradation, a composition that allows for better nutrient utilisation and an improved grazing capacity for a greater feed intake. In lamb finishing systems, the faster a lamb achieves slaughter weight the more efficient it is at converting herbage to meat. Unfortunately no measure of pre and post grazing masses were recorded nor were samples collected for herbage analysis. Therefore the potential causes of lower performance on the various herbages can only be made based on previous literature. Forage crops are typically 85-90% digestible with a metabolisable energy (ME) concentration of approximately 12MJ/kg DM and a protein content (CP) of 15-25% of DM in the leaves (White et al, 2007). In order to achieve high liveweight gain lambs need access to high quality feed with ME concentrations of 11 MJME/kgDM or more and CP concentrations of 15 and 18% (Kerr, 2000; Brookes, & Nicol, 2007).

Brassicas provide highly digestible and quality feed for finishing animals during periods of low pasture growth and poor nutritive value as a consequence of increased reproductive growth (Dove & Milne, 2006). Rape cultivars have a high soluble sugar content and lucerne has a consistently low soluble sugar content which may produce considerable differences in carcass composition. Rape cultivar crops therefore, are a valuable supplementary forage crop for grow lambs during the summer finishing period. Legume and herb species with high feeding values have consistently been found to enable lamb growth rates of 250 g/day (Kemp et al, 2010; Kerr, 2000). The greater feeding value of herb and legume forage species results from both greater

voluntary intake and greater nutritive value than perennial ryegrass (Barry, 1998). Forage herbs and legumes produce high DM yields with moderate to high levels of both CP and ME. CP levels for chicory are often over 20% of dry matter and ME concentration of 11 MJ/kgDM (Houjik *et al*, 2011). Lucerne forage quality is highest at about 1500 kgDM/ha with a ME content of at least 12 MJ/kgDM and CP content above 30% (Brown & Moot, 2004). To maximise animal liveweight gain animals should be grazed for 6-8 weeks at an allowance of 2.5-4.0kg DM/hd/day during summer. During the autumn the ratio of shoot to root production decreases, decreasing in nutritive value (Moot *et al*, 2003). As stem fraction increases ME content decreases to around 8 MJ/kgDM and CP to about 10% (Brown & Moot, 2004).

Lamb growth rates have been variable when lambs graze brassicas and this has been attributed to metabolic inhibitors in the plant or lack of effective fibre in diet which reduced the feeding value (Reid *et al*, 1994). In this study, lambs finished on the rape cultivars 'Titan' and 'Spitfire' showed the fastest growth rates. Lamb growth rates in other studies have also been recorded as being superior on brassicas when compared to pasture over the summer finishing period (Lindsay *et al*, 2007; Campbell *et al*, 2011; Reid *et al*, 1994; Dove & Milne, 2006). Female lambs finished on Chicory and Lucerne had slower growth rates compared to the brassica. The limitation of ME in herbs compared to brassica crops could provide an explanation as to the crops inferior animal performance. However, other factors could be involved including grazing management and climatic factors. Male lambs grazed on Lucerne also demonstrated poor lamb growth performance compared to ryegrass and the brassicas. Intensive grazing management is required for lucerne crops. Poor grazing management and adverse environmental conditions could have impacted on crop performance and therefore lamb production parameters in this trial (White *et al*, 2007). This trial was run predominantly in the autumn period, which may have had an effect on the results in this trial compared to other trials run in the summer months.

#### *4.4.2 Carcass characteristics*

Lambs finished on brassicas produced heavier carcass weights, higher GR, greater dressing out percentage and larger hind quarter circumference compared to lambs grazed on other forages. The higher carcass weights primarily reflect higher slaughter weights because of the ranking of the forages for end weights and carcass weights. Brassica-fed lambs had a greater carcass GR which could indicate a greater deposition of fat however GR is a measurement of tissue depth, not just fat. Brassicas perform well over the summer producing high yields of highly digestible feed (Dove & Milne, 2006). The rape crops produced animals with superior hind quarter



muscling and a larger fat depth at the 12<sup>th</sup> rib at similar carcass weights. This is a likely consequence of rape providing a larger quantity of digestible nutrients that allowed for the deposition of more body tissues including fat.

The additional deposition of fat may be a problem for heavy lambs finished on rape. The New Zealand lamb carcass classification is based on carcass weight and fat classes. Within any one carcass grade, the income per carcass increases with increasing carcass weight but decreases with increasing fat depth between grades (GR soft tissue depth; Kerr, 2000). Therefore, animals finished on rape with additional deposition of fat could incur a lower schedule price per kg of liveweight. This is an important consideration for producers due to rising costs of generating high quality feed and hence, increasing the profitability of a lamb-production enterprise (McCoard et al, 2010).

Male lambs had lower GR depths than females in these experiments, therefore grazing entire male lambs on forage rape can produce heavy lean lambs over the summer period that do not gain a penalty for being excessively fat (Hopkins et al, 1995). Testosterone is a driver for lean growth enabling ram lambs to have higher growth rates, heavier carcasses at a set age and less fat deposition than ewe lambs (Dransfield et al, 1990; Lee *et al.* 1990). Closer monitoring of female lambs on specialist forage brassicas would be required to ensure that over fatness does not occur. Selection of lambs for slaughter based on condition score could be implemented or restriction of the feed intake of the specialist forages could also be considered at a compromise to growth rates (Hopkins et al, 1995).

The greater hind quarter circumference for animals on the chicory and brassicas (when adjusted to an equal carcass weight) suggest that lambs finished on these forages deposit more carcass tissue (either lean or fat) than those fed other diets. The circumference gives an indicator of carcass shape and if the animal has deposited more tissue (either muscle or fat tissue) this could reflect a greater propensity for deposition via improved average daily gain. This indicates lambs finished on brassicas and Chicory promote a better production efficiency than the other forages due to achieving a slaughter carcass weight at a lower live weight than lambs on other diets. One of the biggest variables in DO% is the weight of the contents of the gastrointestinal tract at the time of measuring the final liveweight . Gut fill increases when the digestibility of the forage is lower. A lower gut fill may also be contributing to the higher DO% with lambs fed on brassicas and Chicory (Bray, 1988: Litherland *et al*, 2010).

#### *4.4.3 Meat quality*

Meat flavour is a very important component of the eating quality of meat which varies between meat of animals finished on pasture and those on alternative forages. The main meat quality attributes considered by the consumer on purchase are those attributing to visual appearance (lean meat and fat colour) and the quality parameters assessed post cooking (sensory and palatability attributes). However, although the values between forages for the meat quality results in this study are statistically different, the numerical differences are not large and so the consumer may not actually be able to detect a difference.

Lambs finished on ryegrass had tougher meat than those grazed on the alternative forages suggesting finishing lambs on brassicas, herbs or legumes can increase palatability increasing meat tenderness. Fatness and pH can influence tenderness but this was accounted for by using pH and GR as covariates in the statistical analysis. Another influence may have been collagen which was not measured in this study.

Diet affects the composition of fatty acids and compounds that are precursors for flavour (Mottram, 1998). Feeding Chicory and Titan to lambs increased lamb flavour intensity when there was no difference in meat pH. A number of studies have investigated the impact of different forages on the quality of meat, with some studies reporting stronger flavours in lambs fed on white clover than lambs fed on ryegrass (Schreurs et al, 2008) and stronger flavour of lambs fed on brassica than those fed on pasture (Hopkins et al, 1995) and the mechanism seems to be the alteration of the concentration of flavour compounds in the meat fat (Schreurs et al., 2008). The flavour intensity scores were very low (only in the range 2.5-2.6 out of 8) so regardless of the forage the lamb flavour was mild and it is not likely the consumer will detect the small differences in the intensity of lamb flavour observed in this study. Spitfire fed lambs had meat with the highest overall liking compared to males finished on other forages which agrees with the results of the other sensory attributes.

Wheeler, (1974) observed lambs fed forage rape only sometimes had a strong, characteristic flavour. Scales et al. (1993) indicated no adverse effect on meat flavour caused by grazing lambs on forage rape. Forage rape has a high concentration of sulphur containing compounds and previous studies have suggested brassicas have a higher content of lipid soluble components such as unsaturated fatty acids. Polyunsaturated fatty acids (PUFAs) have a high sensitivity to thermal degradation which could favour the appearance of aldehydes (Vasta et al, 2006). A combination of these compounds could be the origin of the more intense flavours found with meat from lambs fed the brassicas. However, this does not explain the intense flavour assessed

in lamb from animals finished on chicory. Previous studies have found that meat flavours and odours for sheep on chicory are similar to those for sheep fed grass and are less intense than the meat from sheep fed legumes (Priolo et al, 2001).

Lamb from Titan finished lambs was highest for GR depth in both experiments. Fat content contributes to the flavour of meat. Therefore, the heavier and fatter animals produced on Titan could have more intense flavour (Crouse et al, 1981). Lucerne and Ryegrass had lower flavour intensity but higher juiciness which does not concur with previous studies which have proven lucerne to give a more intense, unacceptable “sharp” and “sickly” flavour compared to pasture (Park et al, 1972).

The main colour measurement of interest is CIE a\* which represents the degree of redness, with redness highly correlated with consumers subjective measurement of colour acceptability (Moore & Young, 1991; Mclean et al, 2009). Changes in redness over a period of time describe meat colour deterioration from red to brown, and reflect the myoglobin pigment going through a process of oxidation to form metmyoglobin (Luciano et al, 2009). Retailers often discount meat after 2 days of display to reflect the decreased value associated with the colour change of meat (Jacob et al, 2007).

The colour stability measures in this study were used to identify if any particular meat from animals finished on different forage crops hold the acceptable red colour longer on retail display than the other forages. This quality attribute is beneficial for both the retailer and the consumer. The initial redness values in this trial (after one day of simulated retail display conditions) were statistically different between dietary treatments, however, these values are unlikely to create noticeable difference in the appearance of the colour for the consumer. This would indicate that the objective colour analyses used in this experiment were precise and minimal variation was seen between loins from the same lamb. Khiji et al, (2010) found that for fresh meat when the a\* (redness) and L\* (lightness) values are equal to or exceed 9.5 and 34, respectively, on average consumers will consider the meat colour acceptable. However a\* must be much higher (14.5) to have 95% confidence that a randomly selected consumer will consider a sample acceptable (Khiji et al, 2010). Therefore in this trial, meat from females and males fed all forage types were acceptable for lamb redness from day 2 – 4 of air exposure. Thereafter redness colour values deteriorated below 9.5.

Brassica fed lambs produced lighter coloured meat which is consistent with previous findings (Hopkins et al, 1994; Hopkins et al, 1995). The difference in lightness (which is actually

numerically small) is likely to be due to more fat in the muscle diluting muscle fibres therefore, diluting myoglobin (Priolo et al, 2001). Alternatively, it could be because the animals are younger (myoglobin concentration increases with age and an increase in myoglobin concentration reduces the lightness values of the chromameter measures). However, because lambs were slaughtered at similar ages it is likely to be an influence of intramuscular fat (Young et al, 1999).

Johnson et al (2008) established that from 2 to 24 hours post slaughter the CIE  $a^*$  values increased indicating a brighter red colour. The method of measurement for colour stability in this trial did not obtain CIE  $L^*$   $a^*$  and  $b^*$  measurements at time zero when the meat was first cut. The first time point recorded was at 1 day after placement into retail display packaging. Therefore a complete measure of the changes involved in the first 24hours including the process of blooming were not evaluated. For future studies, colour change within the first 24hours after placement into retail display packaging could be considered. This may establish whether on-farm treatments affect the oxygenation (blooming) process in the initial 24hours of packaging.

## **Chapter 5: Growth, carcass and meat quality characteristics of male and female lambs of three breeds finished on different forage diets.**

### **5.1 Introduction**

Lamb producers are being provided with incentives to encourage production efficiency and to get lambs to slaughter when schedule price is high. Genetic improvement, especially in growth, and carcass weights, have been a key element in the dramatic increase in productivity of the meat sheep industry over recent decades. Many studies have evaluated the effect of forage diet on lamb meat quality, however there are many other on-farm factors that affect lamb growth and subsequent carcass and meat quality characteristics (Campbell et al, 2011).

Landcorp Farming Ltd has a terminal sire breeding programme called the Lamb Supreme Programme. The programme has developed a composite breed with growth and carcass characteristics to maximise meat yield and production efficiencies (Nicoll et al, 1992). Along similar lines, the Primera composite breed was developed to provide a highly productive terminal breed. The Landcorp Farming Ltd Texel has been selected for improved carcass meat production without increased weight of fat. These breeds have been developed for meat production and are likely to reflect the genotypes that are used in future production systems. Therefore, the influence of these breeds not only on growth and carcass characteristics but also meat quality characteristics is an important consideration for establishing their value for producing meat for discerning markets.

Another factor that needs to be considered is the influence of the sex of the lamb. While ram lambs are preferred for their faster growth rates and superior carcass attributes such as a greater lean percentage and more muscling, female lambs have benefits of producing higher dressing out percentages and depositing more fat which can increase the intramuscular fat percentage and have a positive influence on meat quality attributes such as flavour, and tenderness. These attributes between the different sexes of lamb may be subtle in young animals and may not be exhibited when different forages are fed or when specific breeds are used (McCoard et al, 2010).

Hence, establishing the integrated effects of sex, breed and forage type may impact the current management decisions that are made on-farm. The aim of this study was to assess the interacting impact of different diet, sex and sire breed line treatments on post-weaning lamb growth, carcass performance and subsequent meat quality. Interactions between treatments

may be valuable in giving farmers recommendations to produce lambs of superior meat and carcass quality for specific markets.

## 5.2 Material and methods

### 5.2.1 Experimental design

This second experiment was a 3 x 2 x 3 factorial design. Progeny were sired by one of 3 breeds. There were two composite breeds, Rissington Primera and Landcorp Supreme and Landcorp Farming Ltd's purebred Texel. Female and entire male lambs were distributed across the 3 forage treatments (Table 5.1). All lambs were assigned to one of three forage treatments. The forages were: Lucerne (*Medicago sativa*; n=495), forage rape cv. Titan (*Brassica napus* n=485), and Perennial ryegrass based pasture (*Lolium perenne* n=479). Animals achieving a weight in the top 30% at the set dates of 15<sup>th</sup> March, 19<sup>th</sup> April and 24<sup>th</sup> May 2011 were sent to Silverfern Farms, Takapau plant for slaughter and processing (for full details see chapter 3). The on-farm management of animals and pastures and the measurements of the carcass and meat quality are described in Chapter 3.

No pre- and post-grazing pasture covers were measured and no herbage samples were collected for nutritive analysis. Therefore, when considering the differences growth and carcass characteristics between forage diets, reference is made to the literature and to established knowledge to elucidate the cause of the differences.

**Table 5.1:** Number of male and female Lamb supreme, Primera and Texel lambs grazed on the dietary treatments of Lucerne, Ryegrass and Titan.

	Lucerne	Ryegrass	Titan
<b>Lamb Supreme</b>			
Male	57	61	136
Female	60	55	152
<b>Primera</b>			
Male	144	133	52
Female	152	148	52
<b>Texel</b>			
Male	43	40	49
Female	39	42	44
<b>Total for forage</b>	<b>495</b>	<b>479</b>	<b>485</b>

### *5.2.2 Statistical analyses and calculations*

PROC UNIVARIATE in SAS was used to assess the data for a normal distribution and the Levene test was used to assess homogeneity of variance (SAS Institute Inc., 2010). A random effect of slaughter group was analysed for all growth, carcass and meat quality variables. The random effect was taken out of the statistical model if it was not significant ( $P > 0.05$ ). See Chapter 3 for details of the calculations used in this experiment.

The results of the fixed effects of forage type grazed, lamb breed and sex are considered first in this study followed by separate consideration of the interactions of these fixed effects.

#### *5.2.2.1 Carcass and growth analyses*

A mixed model (PROC MIXED; SAS) was used to investigate the fixed effects of forage, sex and breed on lamb growth and carcass quality. The mixed model allowed the random effect of slaughter group to be included. Hot carcass weight was fitted as a covariate for hind quarter circumference. Starting live weight was deemed the weight of each lamb on 4<sup>th</sup> February 2011 when the lambs were sorted into forage treatment mobs. Final live weight was measured the day of trucking to the slaughter plant which was one of three trucking dates on the day prior to slaughter i.e., 14<sup>th</sup> March 2011; 18<sup>th</sup> April 2011; or 24<sup>th</sup> May 2011. The growth rate over the period of grazing the forages was calculated for each of the 1772 lambs. Two way and three-way interactions were analyzed and non-significant interactions were removed from the final statistical model.

#### *5.2.2.2 Meat quality*

A mixed model (PROC MIXED; SAS) was used to investigate the fixed effects of forage, breed and sex on the meat quality. The tenderness values were log-transformed to achieve a normal distribution for analysis and the means back transformed to present in the results tables. Linear and quadratic effects of pH and the linear effect of GR were fitted as covariates in all the meat quality analyses as they are known drivers of meat quality (Although GR not considered as a covariate for colour for meat samples 1 day under retail packaging conditions). Two way and three-way interactions were analyzed and non-significant interactions were removed from the final statistical model. Colour measurements taken over time to assess colour stability were analysed using a repeated measure analysis (PROC MIXED; SAS) following the statistical method of Littell et al. (1998).

## 5.3 Results

### 5.3.1 Lamb growth performance

Lambs grazed on the forage rape Titan had the fastest growth rates from the start of the experiment to slaughter and from docking to slaughter compared to lambs grazed on other forage treatments ( $P < 0.001$ ; Table 5.2). Lambs finished on Lucerne had the lowest growth rate during the experiment, compared to lambs finished on Ryegrass and Titan ( $P < 0.001$ ). Final live weight was greater for lambs grazed on Titan compared to lambs grazed on the Ryegrass and Lucerne ( $P < 0.001$ ).

Male lambs were heavier at slaughter compared to females ( $P < 0.001$ ; Table 5.3). This was a consequence of a greater live weight of males at the start of the experiment ( $P < 0.001$ ) and greater growth rates during the experiment ( $P < 0.001$ ; Table 5.3).

Primera and Lamb Supreme sired lambs were heavier at the start of the experiment than Texel lambs ( $P < 0.001$ ; Table 5.4). As a consequence of the higher start weight the final liveweight was greater for Primera lambs compared to Texel and Lamb Supreme ( $P < 0.001$ ).

Although males tended to have faster growth rates during the experiment, when female Lamb Supreme or Texel lambs were fed ryegrass or Titan they expressed faster growth rates than the males ( $P < 0.001$ ; Table 5.5). Primera lambs showed the heaviest final liveweights however, when lambs were fed on Titan the final liveweight tended to equalize between the breeds (Table 5.5).

### 5.3.2 Carcass characteristics

Hot carcass weight was higher for lambs finished on Titan compared to lambs grazed on Ryegrass and Lucerne ( $P < 0.001$ ; Table 5.2). Lambs finished on Titan had a greater DO%, hind quarter circumference, and GR compared to lambs finished on other forages ( $P < 0.001$ ). Lucerne fed lambs had the lowest carcass weight, GR and hind quarter circumference ( $P < 0.001$ ; Table 5.2).

Male lambs had higher weight at the start and final weight and carcass weight than female lambs ( $P < 0.001$ ; Table 5.3). Female lambs had a greater GR (8.3mm) than male lambs (7.2mm;  $P < 0.001$ ).

Primera lambs had higher carcass weight, GR and DO% compared to Texel and Lamb Supreme lambs ( $P < 0.001$ ; Table 5.4). Texel and Lamb Supreme lambs were not different for carcass



weight and GR. Primera and Texel lambs had larger hind quarter circumferences compared to Lamb Supreme lambs ( $P < 0.001$ ; Table 5.4).

Carcass weight and hind quarter circumference was greater for Primera lambs, however, when lambs were finished on Titan there was no difference between breeds ( $P < 0.001$ ; Table 5.5). GR was also higher for Primera lambs, but when lambs were finished on Titan, Primera and Texel lambs had a similar GR ( $P < 0.001$ ; Table 5.5). Overall, Primera and Texel were highest for DO%, however when lambs were fed Titan there was no breed difference ( $P < 0.01$ ).

Males had higher carcass weight and hind quarter circumference than females, however, when lambs were fed Titan, there was no difference between the sexes ( $P < 0.001$  Table 5.5). The GR and DO% were higher for females compared to males, however, when lambs were fed Lucerne the males had the higher GR and DO% ( $P < 0.001$ ; Table 5.5).

**Table 5.2:** The effect of forage species on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).

	Lucerne	Ryegrass	Titan	P-value	Hot carcass weight covariate
<i>Lamb growth performance</i>					
Weight at start of experiment (kg)	34.2 ± 0.3a	33.8 ± 0.3a	33.7 ± 0.3a	NS	-
Pre-slaughter weight (kg)	42.3 ± 0.2c	44.8 ± 0.2b	47.4 ± 0.2a	<0.001	-
ADG from the start to slaughter (g/day) <sup>1</sup>	102.9 ± 3.6c	161.6 ± 3.6b	200.9 ± 3.5a	<0.001	-
ADG from docking to slaughter (g/day) <sup>1</sup>	146.0 ± 1.7c	163.7 ± 1.7b	179.4 ± 1.7a	<0.001	-
<i>Carcass data</i>					
Hot carcass weight (kg)	18.7 ± 0.1c	19.4 ± 0.1b	22.6 ± 0.1a	<0.001	-
GR depth (mm) <sup>2</sup>	5.3 ± 0.3c	6.1 ± 0.3b	12.0 ± 0.3a	<0.001	-
Dressing out percentage (%) <sup>2</sup>	44.1 ± 0.1b	43.2 ± 0.1c	47.7 ± 0.1a	<0.001	-
Hind quarter circumference (cm) <sup>2</sup>	65.3 ± 0.1c	65.7 ± 0.1b	68.1 ± 0.1a	<0.001	<0.001

*a,b,c, d = Means in the same row with different letters are significantly different (P <0.05).*

<sup>1</sup>ADG = Average daily gain

<sup>2</sup>GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight. Hind quarter circumference = the circumference of the back end of the carcass.

**Table 5.3:** The effect of lamb sex on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).

	Male	Female	P-value	Hot carcass weight covariate
<i>Lamb growth performance</i>				
Weight at start of experiment (kg)	34.7 ± 0.3a	33.0 ± 0.3b	<0.001	-
Pre-slaughter weight (kg)	46.2 ± 0.2a	43.4 ± 0.2b	<0.001	-
ADG from the start to slaughter (g/day) <sup>1</sup>	163.7 ± 3.6a	146.5 ± 3.6b	<0.001	-
ADG from docking to slaughter (g/day) <sup>1</sup>	169.3 ± 1.7a	156.8 ± 1.7b	<0.001	-
<i>Carcass data</i>				
Hot carcass weight (kg)	20.8 ± 0.13a	19.6 ± 0.1b	<0.001	-
GR depth (mm) <sup>2</sup>	7.2 ± 0.2b	8.3 ± 0.3a	<0.001	-
Dressing out percentage (%) <sup>2</sup>	45.0 ± 0.17a	45.0 ± 0.2a	NS	-
Hind quarter circumference (cm) <sup>2</sup>	66.8 ± 0.1a	66.0 ± 0.1b	<0.001	<0.001

*a,b,c, d = Means in the same row with different letters are significantly different (P <0.05).*

<sup>1</sup>ADG = Average daily gain

<sup>2</sup>GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight. Hind quarter circumference = the circumference of the back end of the carcass.

**Table 5.4:** The effect breed on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).

	Primera	Lamb Supreme	Texel	P-value	Hot carcass weight covariate
<i>Lamb growth performance</i>					
Weight at start of experiment (kg)	34.8 ± 0.2a	34.1 ± 0.2a	32.8 ± 0.2b	<0.001	-
Pre-slaughter weight (kg)	48.8 ± 0.1a	45.6 ± 0.2b	44.1 ± 0.3c	<0.001	-
ADG from the start to slaughter (g/day) <sup>1</sup>	155.4 ± 2.5a	154.4 ± 3.9a	155.6 ± 4.5a	NS	-
ADG from docking to slaughter (g/day) <sup>1</sup>	161.1 ± 1.2b	172.7 ± 1.9a	155.4 ± 2.2c	<0.001	-
<i>Carcass data</i>					
Hot carcass weight (kg)	20.6a ± 0.1	20.0b ± 0.1	19.9b ± 0.2	<0.001	-
GR depth (mm) <sup>2</sup>	8.7a ± 0.2	7.1b ± 0.3	7.5b ± 0.3	<0.001	-
Dressing out percentage (%) <sup>2</sup>	45.3a ± 0.1	44.5b ± 0.1	45.2a ± 0.2	<0.001	-
Hind quarter circumference (cm) <sup>2</sup>	66.7a ± 0.1	66.3b ± 0.1	66.7a ± 0.2	<0.001	<0.001

*a,b,c, d = Means in the same row with different letters are significantly different (P <0.05).*

<sup>1</sup> ADG = Average daily gain

<sup>2</sup> GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight. Hind quarter circumference = the circumference of the back end of the carcass.

**Table 5.5:** The effect forage species (F), lamb breed (B) and lamb sex (S) interactions on lamb growth performance over the summer finishing period and carcass components at slaughter. Data presented as predicted means and standard error of the means (SEM).

	Lucerne						Ryegrass						Titan						Significance of interaction			
	Primera		Lamb Supreme		Texel		Primera		Lamb Supreme		Texel		Primera		Lamb Supreme		Texel		FxB	FoS	BxS	FxBxS
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F				
<i>Lamb growth performance</i>																						
Weight at start (kg)	36.9	34.2	34.3	33.6	33.9	32.3	34.9	33.7	35.1	33.3	34.4	31.3	35.1	33.8	35.1	33.2	33.0	32.1	NS	NS	NS	NS
	±0.2	±0.4	±0.4	±0.4	±0.3	±0.3	±0.2	±0.2	±0.3	±0.4	±0.3	±0.3	±0.3	±0.3	±0.2	±0.2	±0.4	±0.3				
Pre-slaughter weight (kg)	46.5	41.1	44.0	39.4	44.4	38.2	46.2	44.5	45.7	44.1	45.5	45.1	48.5	47.0	48.1a	47.6	46.8	46.5	<0.001	NS	NS	NS
	±0.2ab	±0.2cd	±0.3c	±0.3d	±0.3c	±0.3d	±0.2b	±0.2c	±0.3b	±0.3c	±0.3b	±0.3b	±0.2a	±0.2a	±0.3	±0.3a	±0.3a	±0.3ab				
ADG (start to slaughter)	126	86	132	72	135	67	174	157	150	165	159	164	200	189	195a	212	203	205	NS	<0.001	NS	NS
	±1.5c	±1.5d	±2.5c	±2.5d	±2.9c	±2.9d	±1.6b	±2.5c	±2.5c	±2.5b	±2.9c	±2.9b	±1.5a	±1.6a	±2.6	±2.6a	±2.8a	±2.8a				
ADG (docking to slaughter)	172	142	153	131	149	121	181	166	158	166	160	152	196	178	180	179	175	175	NS	NS	NS	<0.001
	±2.0b	±2.0d	±3.3c	±3.2e	±3.9cd	±3.7e	±2.1a	±2.0bc	±3.1c	±3.3bc	±3.9c	±3.8c	±2.1a	±2.0ab	±3.4a	±3.4a	±3.5ab	±3.7ab				
<i>Carcass data</i>																						
Hot carcass weight (kg)	20.8	18.4	19.1	17.0	19.9	16.7	19.4	19.8	19.7	18.8	19.9	18.2	22.8	22.6 ±	22.8	22.6	22.5	22.3	<0.001	<0.001	NS	NS
	±0.1b	±0.2c	±0.2b	±0.2d	±0.2b	±0.2d	±0.1bc	±0.1b	±0.2b	±0.8c	±0.2b	±0.2c	±0.1a	0.1a	±0.2a	±0.2a	±0.2a	±0.2a				
GR soft-tissue depth (mm)	6.7	7.0	4.9	3.5	5.4	4.0	4.9	9.0	5.0	6.2	5.5	5.9	10.7	14.1	10.5	12.3	11.4 ±	12.7	0.009	<0.001	NS	NS
	±0.2d	±0.2d	±0.3de	±0.3e	±0.4d	±0.4e	±0.2e	±0.2c	±0.4de	±0.4d	±0.4d	±0.4d	±0.2c	±0.2a	±0.4c	±0.4b	0.4bc	±0.4b				
Dressing out (%)	44.7	44.7	43.5	43.2	44.8	43.8	43.0	44.4	43.0	42.5	43.8	42.8	46.7	48.3	47.4	47.5	48.0	47.9	0.008	<0.001	NS	NS
	±0.1b	±0.1b	±0.2c	±0.2c	±0.3b	±0.3bc	±0.2c	±0.2b	±0.2c	±0.2c	±0.3bc	±0.3c	±0.1a	±0.1a	±0.2a	±0.2a	±0.3a	±0.3a				
Hindquarter circumference(cm)	66.7	65.2	65.7	63.8	66.7	63.7	65.9	66.1	66.2	65.4	66.0	64.8	67.8	68.6	68.3	68.2	67.9	68.0	<0.001	<0.001	<0.001	NS
	±0.1a	±0.1c	±0.2c	±0.2cd	±0.2ab	±0.2d	±0.1b	±0.1b	±0.2b	±0.2c	±0.2b	±0.2cd	±0.1a	±0.1a	±0.2a	±0.2a	±0.2a	±0.2a				

*a,b,c, d = Means in the same row with different letters are significantly different (P <0.05).*

<sup>1</sup> ADG = Average daily gain (g/day)

<sup>2</sup> GR depth = measurement of total tissue depth (mm) over the 12th rib at a point 11cm from the midline of the carcass. Dressing out percentage = calculated as the hot carcass weight as a percentage of pre-slaughter weight. Hind quarter circumference= the circumference of the back end of the carcass.

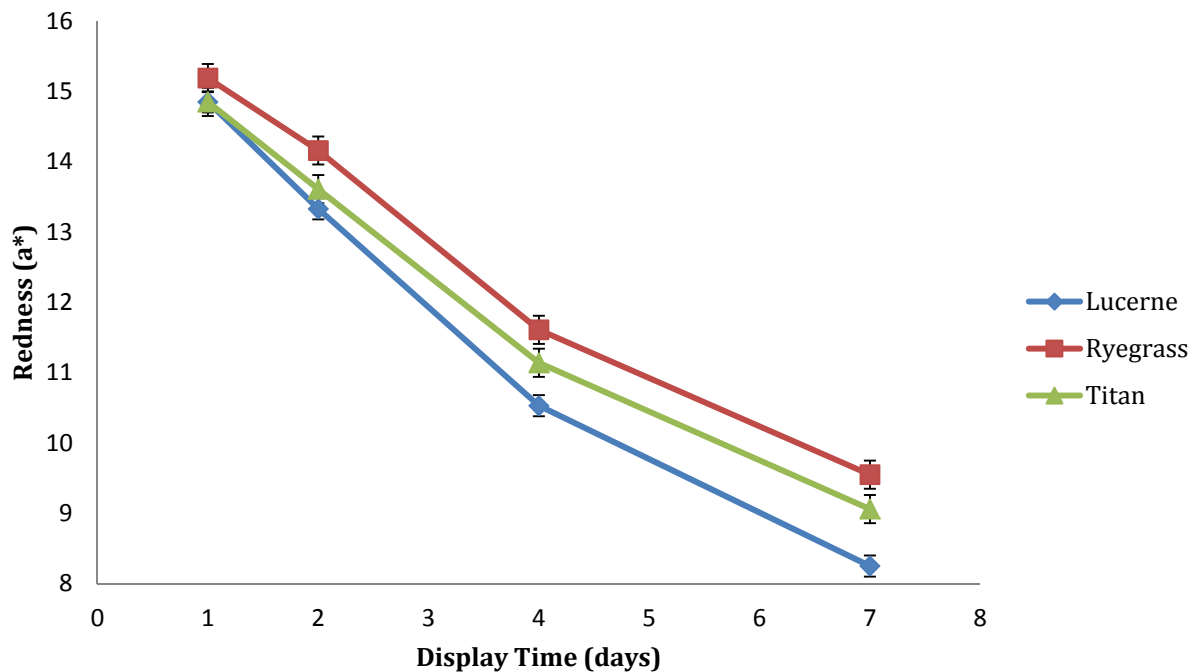
### 5.3.3 Meat quality

#### 5.3.3.1 Forage effect

The meat from lambs finished on lucerne and Titan had lower shear force values than meat from Ryegrass fed lambs ( $P < 0.05$ ; Table 5.6). Meat from lambs finished on Titan had the lightest and yellowest colour after a day in retail packaging compared to meat from lambs fed other forages ( $P < 0.001$ ). Lambs finished on Ryegrass had the reddest meat after a day in retail packaging compared to lambs fed Lucerne and Titan ( $P < 0.001$ ). Lambs finished on Ryegrass had redder meat and a slower decline of redness over the 7-day simulated retail display period. The fastest decline in redness values was seen with the meat from lambs fed Lucerne ( $P < 0.01$ ; Figure 5.1).

The sensory panel scored Titan finished lambs higher for texture, and Lucerne finished lambs had the lowest scores for texture ( $P < 0.05$ ; Table 5.6). Lamb flavour was considered more intense with meat from lambs that had grazed Ryegrass compared to lambs that grazed Lucerne and Titan. The overall liking was higher for meat from lambs grazed on Ryegrass compared to lambs that grazed Lucerne or Titan ( $P = 0.001$ ; Table 5.6).

**Figure 5.1:** Least square means  $\pm$  standard errors of redness ( $a^*$ ) colour measurements of meat over a seven day period following slaughter from lambs fed three diets prior to slaughter.

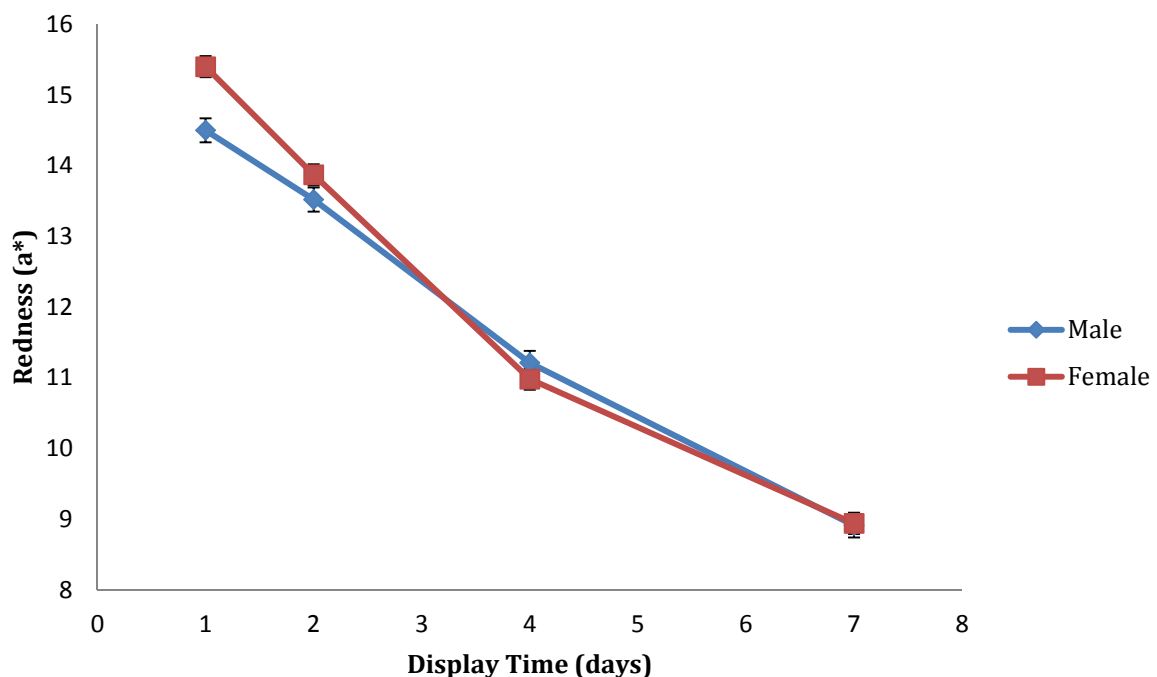


### 5.3.3.2 Sex effect

Meat from male lambs had a higher shear force than female lambs ( $P=0.004$ ; Table 5.7). Female lambs had lighter and redder meat after 1 day under simulated retail display conditions compared to male lambs ( $P<0.01$ ). The sex of the lamb did not affect the yellowness values yellowness after 1 day under simulated retail display conditions (Figure 5.6). Females had redder meat compared to males after 2 days of simulated retail display conditions. However, there was no difference between the sexes after day 4 and day 7 under simulated retail display conditions ( $P<0.01$ ; Figure 5.2).

The sex of the lamb had no influence on the sensory panel score for texture, lamb flavour and juiciness. However, the overall liking was higher for meat from female compared to male lambs ( $P<0.002$ ; Table 5.7).

**Figure 5.2:** Least square means  $\pm$  standard errors of redness ( $a^*$ ) colour measurements of meat over a seven day period following slaughter from ram and ewe lambs.

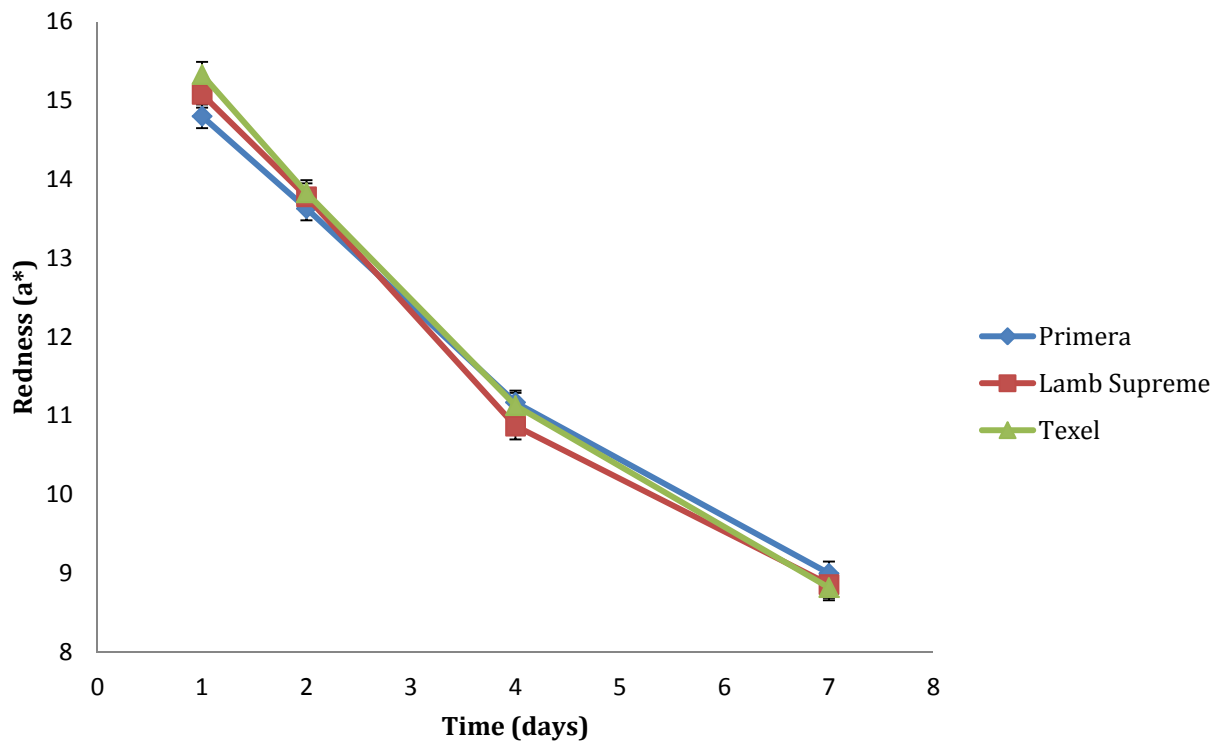


### 5.3.3.3 Breed effect

There was no influence of the breeds on the objective meat quality tests ( $P>0.05$ ; Table 5.8). There was no effect of lamb breed on meat redness or the rate at which the redness declined over a 7-day period under simulated retail display conditions (Figure 5.3).

The meat from Primera lambs received higher sensory panel scores for the intensity of meat flavour compared to the Lamb Supreme and Texel (P 0.022; Table 5.8). All other sensory panel assessed attributes were not affected by breed.

**Figure 5.3:** Least square means  $\pm$  standard errors of redness ( $a^*$ ) colour measurements of meat from lambs of three composite breeds over a seven-day simulated retail display period.



#### 5.3.3.4 Fixed effect interactions

The effect of the sex of the lamb on meat colour depends on which breed was being considered. The meat from female Primera and Texel lambs was redder and yellower after 1 day of stimulated retail display conditions compared to meat from their male cohorts. However, meat from Lamb Supreme male lambs tended to have higher redness and yellowness after 1 day under retail display conditions than meat from Lamb Supreme female lambs (P<0.001; Table 5.9).

Male lambs had a more intense lamb flavour as assessed by a sensory panel (P<0.001) however, when lambs were fed on ryegrass the difference in lamb flavour between the sexes disappeared. When lambs were fed on Ryegrass or Titan the female lambs had a more intense lamb flavour (P=0.028; Table 5.9).



**Table 5.6:** The effect of forage species of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH and GR.

				P-value	pH covariate		GR covariate
	Lucerne	Ryegrass	Titan		Linear	Quadratic	Linear
<i>Objective Test<sup>1</sup></i>							
Shear force (log kgF)	0.70 ± 0.01b	0.76 ± 0.01a	0.66 ± 0.01c	0.025	<0.001	<0.001	0.009
Shear force (kgF)	5.01	5.75	4.57				
L* (Lightness)	40.93 ± 0.18c	41.42 ± 0.18b	42.02 ± 0.18a	<0.001	NS	NS	-
a* (Redness)	15.14 ± 0.12ab	15.25 ± 0.12a	14.69 ± 0.12b	<0.001	0.011	0.027	-
b* (Yellowness)	11.46 ± 0.11b	11.70 ± 0.11ab	11.78 ± 0.11a	<0.001	<0.001	<0.001	-
<i>Sensory panel<sup>2</sup></i>							
Texture	5.44 ± 0.05b	5.45 ± 0.05ab	5.65 ± 0.04a	0.0119	<0.001	<0.001	NS
Lamb Flavour	5.29 ± 0.08b	6.10 ± 0.08a	5.10 ± 0.08b	0.0024	<0.001	<0.001	NS
Juiciness	4.95 ± 0.05	4.99 ± 0.05	5.14 ± 0.05	NS	NS	NS	0.002
Overall liking	4.74 ± 0.09b	4.91 ± 0.09a	4.73 ± 0.09b	0.002	<0.001	0.002	<0.001

a,b,c, d = Means in the same row with different letters are significantly different ( $P < 0.05$ ). NS =  $P > 0.05$ .

<sup>1</sup>Log kgF = Shearforce values  $\text{Log}_{10}$ ; Shearforce kgF = back transformed means. Colour stability measurements taken after 1 day of simulated retail conditions

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

**Table 5.7:** The effect of the sex of the lamb on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH and GR.

	Male	Female	P-value	pH covariate		GR covariate
				Linear	Quadratic	Linear
<i>Objective Test<sup>1</sup></i>						
Shear force (log kgF)	0.73 ±0.01a	0.69 ±0.01b	0.004	<0.001	<0.001	<0.001
Shear force (kgF)	5.37	4.88				
L* (Lightness)	41.24 ±0.20b	41.66 ±0.17a	0.003	NS	NS	-
a* (Redness)	14.86 ±0.13b	15.21 ±0.08a	0.001	0.011	0.027	-
b* (Yellowness)	11.72 ±0.07	11.62 ±0.07	NS	<0.001	<0.001	-
<i>Sensory panel<sup>2</sup></i>						
Texture	5.50 ±0.03	5.53 ±0.03	NS	<0.001	<0.001	NS
Lamb Flavour	5.72 ±0.05	5.42 ±0.05	NS	<0.001	<0.001	NS
Juiciness	4.98±0.05	5.08 ±0.03	NS	NS	NS	<0.001
Overall liking	4.74 ±0.05b	4.88 ±0.05a	0.002	<0.001	0.002	<0.001

*a,b,c, d = Means in the same row with different letters are significantly different (P <0.05).*

<sup>1</sup>Log KGF = Tenderness values Log<sub>10</sub>; Tenderness 10<sup>x</sup> = back transformed means. Colour stability measurements taken after 1 day of simulated retail conditions

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

**Table 5.8:** The effect of breed of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH and GR.

	Primera	Lamb Supreme	Texel	P-value	pH covariate effect		GR effect
					Linear	Quadratic	Linear
<i>Objective Test<sup>1</sup></i>							
Shearforce (log kgF)	0.73 ±0.01	0.72 ±0.01	0.70 ±0.01	NS	<0.001	<0.001	0.005
Shearforce (kgF)	5.37	5.25	4.90				
L* (Lightness)	41.25 ±0.13	41.47 ±0.13	41.65 ±0.13	NS	NS	NS	-
a* (Redness)	14.98 ±0.13	14.96 ±0.14	15.17 ±0.13	NS	0.011	0.027	-
b* (Yellowness)	11.70 ±0.07	11.60 ±0.12	11.72 ±0.14	NS	<0.001	<0.001	-
<i>Sensory panel<sup>2</sup></i>							
Texture	5.49 ±0.03	5.52 ±0.05	5.55 ±0.07	NS	<0.001	<0.001	NS
Lamb Flavour	5.76 ±0.05a	5.63 ±0.08b	5.34 ±0.12c	0.022	<0.001	<0.001	NS
Juiciness	5.05 ±0.03	5.03 ±0.04	5.01 ±0.06	NS	0.008	0.011	0.002
Overall liking	4.82 ±0.05	4.79 ±0.07	4.83 ±0.13	NS	<0.001	0.0019	<0.001

a,b,c, d = Means in the same row with different letters are significantly different ( $P < 0.05$ ). NS =  $P > 0.05$ .

<sup>1</sup>Log KGF = Shearforce values  $\text{Log}_{10}$ ; Shearforce  $10^x$  = back transformed means. Colour stability measurements taken after 1 day of simulated retail conditions

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

**Table 5.9:** The effect of forage species (F), lamb sex (S) and breed (B) interactions of summer finished lambs on meat quality parameters. Data presented as predicted means and standard error of the means (SEM). Adjusted for ultimate pH.

	Lucerne						Ryegrass						Titan						Interactions			
	Primera		Lamb Supreme		Texel		Primera		Lamb Supreme		Texel		Primera		Lamb Supreme		Texel		FxB	FxS	BxS	FxBxS
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F				
<i>Objective Tests<sup>1</sup></i>																						
Tenderness (log kgF)	0.6 ±0.01	0.7 ±0.02	0.7 ±0.02	0.8 ±0.01	0.7 ±0.02	0.7 ±0.02	0.8 ±0.01	0.7 ±0.01	0.8 ±0.02	0.8 ±0.02	0.8 ±0.02	0.7 ±0.02	0.8 ±0.01	0.6 ±0.01	0.7 ±0.02	0.7 ±0.02	0.7 ±0.02	0.6 ±0.02	NS	NS	NS	NS
Tenderness (kgF)	4.8	5.2	5.5	6.1	5.5	5.6	6.8	5.6	6.2	6.0	6.2	5.5	6.5	4.7	5.1	4.8	4.9	4.4				
L* (Lightness)	38.9 ±0.15	41.0 ±0.15	41.0 ±0.24	40.3 ±0.24	41.4 ±0.28	40.6 ±0.28	39.4 ±0.15	41.5 ±0.15	41.8 ±0.24	41.4 ±0.24	41.9 ±0.28	42.6 ±0.28	41.2 ±0.15	41.9 ±0.15	43.7 ±0.24	42.3 ±0.24	42.7 ±0.28	42.3 ±0.28	NS	NS	NS	NS
a* (Redness)	14.1 ±0.11c	15.3 ±0.11b	15.1 ±0.16b	14.9 ±0.16bc	15.2 ±0.17b	15.1 ±0.17b	13.8 ±0.10c	16.2 ±0.10a	15.3 ±0.16b	15.3 ±0.16b	15.4 ±0.17b	16.1 ±0.17a	14.2 ±0.10c	15.3 ±0.10b	15.0 ±0.16bc	14.7 ±0.16c	15.0 ±0.19b	15.2 ±0.19b	NS	NS	<0.001	NS
b* (Yellowness)	10.1 ±0.09d	11.5 ±0.09c	11.4 ±0.14c	11.1 ±0.14c	11.7 ±0.17c	11.1 ±0.17c	10.4 ±0.09d	12.2 ±0.09b	11.9 ±0.14bc	12.0 ±0.14b	12.0 ±0.17b	12.5 ±0.17a	11.4 ±0.09c	12.0 ±0.09b	12.6 ±0.14a	11.9 ±0.14bc	12.1 ±0.17b	12.5 ±0.17a	NS	NS	<0.001	NS
<i>Sensory Panel<sup>2</sup></i>																						
Texture	4.7 ±0.03	5.0 ±0.03	5.0 ±0.05	5.0 ±0.05	4.9 ±0.1	5.0 ±0.1	4.9 ±0.03	5.1 ±0.03	4.9 ±0.05	5.2 ±0.05	4.9 ±0.1	4.9 ±0.1	5.1 ±0.03	5.2 ±0.03	5.1 ±0.05	5.2 ±0.05	5.1 ±0.1	5.3 ±0.1	NS	NS	NS	NS
Lamb Flavour	3.3 ±0.06a	2.5 ±0.06c	2.8 ±0.09b	2.7 ±0.09c	3.0 ±0.17a	2.6 ±0.17c	2.9 ±0.06b	2.4 ±0.06c	2.4 ±0.1c	2.4 ±0.1c	2.3 ±0.15d	2.3 ±0.15d	3.0 ±0.06ab	2.6 ±0.06c	2.8 ±0.11b	2.5 ±0.11c	2.3 ±0.13d	2.5 ±0.13c	NS	0.028	NS	NS
Juiciness	4.1 ±0.03	4.5 ±0.03	4.3 ±0.05	4.4 ±0.05	4.5 ±0.09	4.3 ±0.09	4.2 ±0.03	4.5 ±0.03	4.3 ±0.05	4.5 ±0.05	4.4 ±0.08	4.4 ±0.08	4.2 ±0.03	4.5 ±0.03	4.3 ±0.06	4.4 ±0.06	4.5 ±0.07	4.5 ±0.07	NS	NS	NS	NS
Overall Liking	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	4.8 ±0.05	4.8 ±0.07	4.8 ±0.13	NS	NS	NS	NS

a,b,c, d = Means in the same row with different letters are significantly different ( $P < 0.05$ ). NS =  $P > 0.05$ .

<sup>1</sup>Log kgF = Shearforce values Log<sub>10</sub>; Shearforce kgF = back transformed means. Colour stability measurements taken after 1 day of simulated retail conditions

<sup>2</sup>Sensory panel assessment of Texture, Lamb flavour, juiciness and overall likeness was on a scale of 1 (not intense) to 8 (very intense).

## 5.4 Discussion

The objective of this study was to investigate the interacting effects of different diets, breeds and sexes during the finishing phase on the growth, carcass characteristics and meat quality attributes of lamb.

### 5.4.1 Lamb growth performance

The type of forage used to finish lambs affected growth performance and carcass characteristics. High dry matter (DM) yield and superior nutritional value of some forage crops promote rapid lamb growth. Lamb live weight gains on specialist forage crops can be variable, with reports of gains above 300 g/day being achieved (Kemp et al., 2007; Kerr, 2000).

Lambs finished on Titan had superior liveweight gain than lambs on Ryegrass and Lucerne. Brasscias are highly digestible, high yielding and have a high nutritive value as a consequence of higher soluble carbohydrate contents. The superiority of this crop is clearly shown by the higher lamb growth achieved relative to other forage crops. However, pre and post pasture residuals and nutrient composition samples were not taken in this study.

Digestibility of pasture decreases over the summer period as the perennial ryegrass approaches its reproductive state and increases in neutral detergent fibre which lowers the digestibility and the metabolisable energy concentration (Kemp et al, 2007; Lindsay et al, 2007). Kerr (2000) suggested that an ME content of at least 11 MJ/kg DM is required to sustain high lamb growth rates. As a result, grazing traditional ryegrass-based pasture may not allow growing lambs to achieve their potential growth rates over the summer (Barry 1981; Fraser & Rowarth 1996). The combined effects of improved nutritive value of the Titan and a potentially declining nutritive value of the Ryegrass-based pasture are likely to be the reasons why however without measuring these characteristics in this study it is hard to accurately quantify these claims.

The high crude protein concentration and digestibility of forage legumes make plants such as Lucerne, attractive as a natural means of increasing growth rates in lamb finishing systems (Fraser et al, 2004). In previous studies, the grazing of Lucerne by lambs has provided high lamb growth rates of above 200g/day (Kemp et al., 2007). However, feed quality of Lucerne is influenced by grazing management. There is a rapid decline in the nutritive value of Lucerne if it is allowed to go into its mature state with woody growth over the summer period (Moot et al, 2003). The low liveweight gain of the lambs that were finished on Lucerne compared to those finished on Ryegrass or Titan, are likely to be a consequence of the fall in nutritive value that Lucerne exhibits with mature growth over summer.

All breeds used in this trial had been selected for high growth potential. The Texel breed, as a consequence of its high mature weight and heavy muscling compared to the other breeds in this study, has fast growth rates and lean growth. The terminal composite breeds of Lamb Supreme and Primera have been developed and selected for fast growth rates. Nicoll et al, (1998), found that Lamb Supreme-sired lambs displayed rapid growth and a comparable weight of saleable meat to Suffolks and Texel-sired lambs at the same age, and lower carcass fat compared with Suffolks and Texel sire genotypes at the same carcass weight. There was no effect of the three breeds on growth rate during the current experiment. This indicates that in this population of lambs there was no difference in growth based on sire-breed. Caution is required before it can be assessed that these results represent all animals with these breeds as there can be more variation within breed than between breeds.

Interactions of the forage and breed on the final liveweight and of forage and sex with the growth rate suggests that lambs of the Lamb Supreme or Texel breeds need improved diets such as the specialist forages to be able to express their genetic potential for growth. This may have important implications for hill country grazing where the quality of feed can be suboptimal. Once given a higher plane of nutrition, either through increased allowances or diets with better nutritive value, female lambs are capable of having a growth performance equal, or even greater, than that of male lambs which have the growth promoting effects of testosterone.

#### *5.4.2 Carcass characteristics*

As a consequence of the greater growth rates the lambs fed the brassica Titan had a greater weight at slaughter and this was reflected in higher carcass weights. The lambs from the Titan treatment also had a greater GR soft tissue depth, dressing out percentage and hind quarter circumference compared to lambs from the Lucerne and Ryegrass treatments.

Live weight prior to slaughter increases and dressing-out percentage are positively correlated as a greater proportion of the live weight tends to be associated with the carcass tissues (Bray et al., 1988; Kirton et al, 1989; Litherland et al 2010). Legume- fed lambs generally have higher carcass dressing percentages than pasture-fed lambs, reflecting lower gut-fill (Campbell et al, 2011). It is likely that brassica crops like Titan will also be associated with less gut fill as they have a high digestibility, like the legumes (Dove & Milne, 2006). Thus the higher dressing-out percentage of lambs fed Titan is likely a consequence of lower gut fill and a higher live weight at slaughter. A lower gut fill was likely to be the reasoning for the dressing out percentage being greater for Lucerne lambs compared to Ryegrass lambs (Litherland et al, 2010) although lambs from the Ryegrass treatment had the higher live weight and carcass weight at slaughter.

Lambs that grow faster to slaughter are often fatter than their slower growing cohorts (Dove & Milne, 2006). This happens when the faster growth occurs due to animals being on a higher plane of nutrition which allows some nutrients to be partitioned to fat growth (Hopkins et al., 2007). The higher GR soft tissue depth associated with lambs finished on Ryegrass compared to Lucerne and Titan is likely to reflect a greater deposition of fat as a consequence of more available nutrients from the diets (Dove & Milne, 2006).

Male lambs were associated with higher carcass weights and lower GR soft tissue depths which reflect the higher growth rates and live weights prior to slaughter and the propensity for a more lean growth compared to females. This effect has been observed in previous studies which have compared the growth and composition of male and female lambs (Crouse et al, 1981; Wylie et al, 1997; Bennet et al, 1991; Kremer et al, 2004; Dransfield et al. 1999; Craigie et al, 2012). With male lambs the testes often comprise a significant proportion of the live weight which can result in male lambs being associated with lower dressing out percentages when compared to female lambs however, with young lambs the differences in dressing out percentage are often negligible (Kirton et al, 1989; Hopkins, 1992). The male lambs were associated with a greater hind quarter circumference when compared to female carcasses of equal weight. This suggests there was more flesh over the hind quarters of the male and this is likely to be a consequence of greater muscularity that is often seen with male lambs compared to female lambs.

Different breeds of sheep for meat production are associated with different composition and conformation attributes that are inherently related to differences in the yield of saleable meat (Safari et al, 2001). Genotype can have a significant influence on dressing out percent, carcass weight and carcass composition characteristics (Kirton et al, 1989). Of the terminal sire breeds used, Primera had heavier carcass weights than the Lamb Supreme and Texel sired lambs reflecting the growth characteristics of these breeds, in particular the pre-slaughter weights. However the growth differences between these breeds weren't significant.

Texel and Primera sired lambs had a higher dressing out percentage and hind quarter circumference which is a sign of greater deposition of tissues in the carcass. The Primera lambs also had a higher GR soft tissue depth than the Lamb Supreme and Texel breed suggesting that the greater tissue deposition with the Primera breed may be associated with more fat tissue and the greater tissue deposition with the Texel is associated with more lean tissue. This agrees with studies where Texel has been shown to excel in aspects such as leanness, cross-sectional area of

loin, , muscularity and muscle to bone ratio (Hopkins et al, 1997; Nicoll et al, 1998; Johnson et al, 2005).

#### *5.4.2 Meat quality*

Meat quality is important for determining the final value of the meat product. Meat quality is also important for influencing the consumers purchasing and repurchasing decisions. Therefore, it is important to consider how farm-based management decisions are likely to impact on the meat quality of lamb and also to consider whether on-farm inputs to the lamb meat production system can be altered to manipulate the lamb meat quality to fit the consumer requirements and to potentially increase the value of the lamb products. Tenderness, flavour and colour are considered to be the more important quality attributes for consumers of lamb (Troy & Kerry, 2010).

##### *5.4.2.1 Forage effect*

The lower shear force values for the meat from lambs grazed on Titan is difficult to explain as the effects of the intrinsic factors of pH and fatness (via GR) that could influence tenderness are adjusted for. Potentially, there could be diet induced differences in collagen content or collagen solubility that could be having an influence (Thompson, 2002). The low shear force values (below 6 kgF) indicate that the small differences in the shear force values are unlikely to be detected as a difference in tenderness by consumers.

The composition of a lamb's diet influences the products of digestion and the compounds that can be deposited in meat and fat tissues. Consequently, meat odour and flavour can be altered when feeding different diets (Bray, 1988; Schreurs et al., 2008). Ryegrass fed lambs had the highest lamb flavour intensity and overall liking, compared to Lucerne and Titan fed lambs. The composition of brassica and legume diets could have had an effect on eating quality (Campbell et al, 2011; Hopkins et al, 1995). Off flavours have been noted as a consequence of feeding brassicas and legume forages (Bray, 1988). However, Titan fed lambs were the juiciest, which could be an indirect effect of nutrient components within the brassica forage crops. Potentially minerals in the brassica diet could possibly be allowing for more water to be retained in the muscle tissues.

The meat from the Ryegrass finished lambs was redder initially and showed the slowest decline of redness indicating better colour stability. This would suggest lambs fed ryegrass would have a redder appearance after 7days on simulated retail display indicating a longer shelf life and therefore, could be more appealing to consumers to purchase for a longer time period.



#### *5.4.2.2 Sex effect*

Compared to male lambs the meat from female lambs was more tender, juicier, achieved higher scores for the sensory panel assessment of overall liking and had a slightly redder colour. The results of this trial are similar to the findings of Johnson et al (2005) shear force values were higher in ram lambs than ewe lambs raised and slaughtered under the same conditions although the quality differences were relatively small. In contrast, differences in meat quality between female and male lambs for quality characteristics such as pH, colour and tenderness are generally not statistically significant in previous studies (Craigie et al, 2012; Lambe et al, 2010; Arsenos et al, 2002; Dransfield, Nute, Hogg, & Walters, 1990), although Bickerstaffe, Palmer, Geesink, Bekhit, and Billington (2000) reported that meat from ram lambs was of lower quality. Navajas et al. (2008) reported that there were no differences between ram and ewe in sensory toughness, although consumers preferred ewe to ram meat, there was no difference between sexes for overall liking of the cuts.

Female lambs have been recorded to have higher intramuscular fat than entire or vasectomised male lambs (Okeudo et al, 2008), and this may partly explain better tenderness and higher juiciness in the female lambs, since intramuscular fat has been negatively correlated to shear force. However, differences in fatness in the current study were adjusted for by including the GR soft tissue depth as a covariate. However, Craigie et al (2012) found that differences in *Longissimus dorsi* intramuscular fat percentage or ultimate pH did not explain the sex effect on shear force when tested individually or together as additional covariates in the model.

#### *5.4.2.3 Breed effect*

The meat from the progeny of sires which are extreme in either muscling or fatness have been found to produce meat which is unacceptable to the consumer via changes in tenderness or juiciness/flavour (IMF) (Warner et al, 2007). There was no difference between breeds for all meat eating quality traits except lamb flavour. Lamb flavour intensity was greatest for Primera lambs compared to Lamb Supreme and Texel. Primera also had higher GR depth which may indicate that fat was greater in all carcass depots and so, the intramuscular fat may have been greater, allowing for a greater concentration of flavour volatiles that are harbored in the meat which was assessed by the sensory panel.

#### *5.4.2.4 Interacting effects of forage-type grazed, sex and breed of the lamb*

There were very few significant interactions between the forage type grazed and the sex or the breed of the lambs which indicates that it is likely to be individual factors rather than

interacting factors that are influencing meat quality. From the consideration of each factor it appears that the forage type grazed by the lamb has the strongest influence on the meat quality attributes, especially in terms of the intensity lamb meat flavour.

## Chapter 6: Conclusions and recommendations

The purpose of this research was to investigate the effects of forage diet, lamb sex and breed during the post-weaning to finishing phase on lamb growth, carcass, and meat quality attributes. The objective was to provide a set of recommendations for on-farm practices that can influence meat quality. The information could be relayed to lamb finishers as part of an integrated supply chain approach. A preliminary experiment (Chapter 4) was conducted to develop an understanding of how differences in forage diets affect animal tissue composition and the palatability and appearance characteristics of lamb meat. The objective of the second experiment was to build on the results from the first experiment and to gain insight on how breed, sex and diet may interact to influence growth, carcass and meat quality characteristics (Chapter 5).

In Chapter 4 it was established that by grazing finishing lambs on rape cultivars Titan and Spitfire it is possible to improve liveweight gain thereby increasing production efficiency. These improvements in growth and liveweight can be achieved without compromising carcass and meat quality. In addition, lambs grazing Titan and Spitfire had heavier carcasses due to a higher dressing out percentage indicating that a lower finishing liveweight can be used to achieve a prime classified carcass of a set weight.

The second experiment considered forage type, breed and sex of the lambs in order to better define the source of variability in growth, carcass and meat quality characteristics. Male progeny were superior in growth performance, leading to larger carcass weights, lower levels of fatness and higher muscularity suggesting males would have higher lean meat yields compared to female lambs. Female lambs were fatter at the same weight, however there was no effect of sex on dressing out percentage. Lamb meat from females was more tender, redder, lighter and juicier than lamb from males, indicating that lamb from females would be liked by consumers more so than males however, the numerical differences are unlikely to be detected by most consumers.

Lambs fed Titan were superior in all growth performance and carcass aspects, indicating Titan produces lamb with high pre-slaughter and carcass weights, superior muscularity over the hind quarters and higher dressing out percentage. However, high fatness over the 12<sup>th</sup> rib may suggest that stocking rates and feed allocation may need to be revised on this crop to prevent animals becoming over fat and getting penalised. Lambs on lucerne performed poorly, being out performed by animals on both Ryegrass and Titan. The meat from lambs fed Titan was more tender, lighter, juicier and had a better overall liking than the other forages. Meat from ryegrass

produced lambs however, was redder suggesting that meat from Titan fed lambs would deteriorate quicker than ryegrass fed lamb when on retail display. Lamb flavour intensity was also lower for Titan fed lambs compared to Ryegrass and Lucerne.

Primera lambs displayed heavier pre-slaughter weight, high dressing out percentages, and muscularity. However, increased levels of fatness were also displayed. These carcass quality attributes were further implicated by high lamb flavour intensity relative to the other breeds, but no difference between breeds was shown for any of the other meat quality parameters. In contrast, meat from Texel sired lambs displayed low pre-slaughter and carcass weights, average fat depth. However, high dressing out percentages alongside superiority in saleable meat productivity at a given carcass weight indicated that Texel sired lambs would provide carcasses with consistently high saleable meat content at carcass weights specified by market requirements without the problem of over fatness or negative effects on meat quality parameters. Lamb supreme lambs tended to display rapid growth from docking to slaughter, low carcass fat and comparable carcass weights compared with the other genotypes. This would suggest the targeting of genetic control for improving meat quality attributes will not have an effect on the composite and purebred sheep breeds studied. This is a positive result for encouraging the use of Landcorp Farming Limited and Rissington Breedline (now both part of Focus Genetics) sheep genotypes by New Zealand farmers.

Further research is required into establishing a carcass valuing schedule whereby farmers will be rewarded for superior meat quality. Setting or recommending farm management practices to optimise meat eating quality is feasible. Farmers already obtain information on pastures and breeds to maximise growth rates, therefore suggestions to optimise eating quality could be feasible if these parameters were rewarded in the lamb schedule. This will need some strong scientific evidence across all environments and breeds to convince farmers and processors of their validity and benefits.

The method of measurement for colour stability in the studies of this thesis did not obtain CIE L\* a\* and b\* measurements at time zero when the meat was first cut. The first time point recorded was 1 day post cutting which did not give a complete understanding of the changes involved in the first day of blooming. Johnson et al (2008) established that from 2 to 24 hours post slaughter the CIE a\* values increased indicating a brighter red colour. This could not be established in this trial. Therefore, future studies should consider incorporating a meat colour recording from the time of cutting.

The resulting pH of lamb meat is related to biochemical processes during the transformation of muscle to meat. pH may well be explained by potential that may exist between forages for lambs

to synthesise and build reserves of muscle and liver glycogen given the differences in soluble sugar profiles. Glycolytic potential is something that needs to be investigated in future trials as well as investigating what metabolic pathways are active in each group of animals through flavour compound profiling. There is a need to identify the flavour volatiles associated with desirable/undesirable flavour and link this to on farm factors (breed, sex, diet etc) that influence the concentration or production of the flavour volatiles in the meat. This could give a clue as to the origin of desirable/undesirable flavour which leads into practical methodologies that could be used to modify the odour and flavour profile of the meat to suit consumer requirements. Future studies should collect herbage samples to look at quality parameters to explain differences between forages and pasture pre and post grazing residual measurements.

Further development of online, rapid assessment and identification of meat quality would be a recommended area of research. For example, the use of visible and near infrared reflectance spectroscopy in the abattoir to discriminate between carcasses for the diet the animal received prior to slaughter and meat colour and tenderness could provide evidence to develop a payment system structured on both carcass composition and meat quality characteristics. Currently there is no premium paid for the distribution of the meat, however selection should be made on measures of overall meat yield. Breeding programmes could include breeding values for each of the three most valuable muscle/meat regions in anticipation of future differential payments.

This study could be further developed to determine the genetic differences for carcass cuts measured and lamb growth parameters between breeds. This work highlighted the supply chain benefits in using terminal sires with concentrated breeding selection for early life growth and muscling potential. The important role of nutrition in capturing the genetic potential for growth was also a clear outcome. Economic indices could be established suitable for use in New Zealand. This has been investigated in New Zealand with many breeds and could be further investigated for the three genotypes assessed in this experiment. Further trials should be done to look at traits of further breeds under various environments.

Forage rape cultivars Titan and Spitfire performed well in this trial and therefore have the potential to be a vital component of New Zealand lamb finishing systems. The potential of rape will only be realised if the returns for these lambs are sufficient to account for the additional cost of this system of production. The use of rape cultivars is therefore recommended for growth and carcass performance. Further studies with these and other forages at different times of year and environments would be recommended. To elucidate the effects on lamb growth and meat quality of the plant nutrients, and also differences in intake with different forages, studies

need to consider measuring herbage mass disappearance from the paddock and to use nutrient and chemical composition tests on forage samples.

Information collected on the differences between sex classes and their composition during growth and development could be used by farmers when developing management strategies for producing carcasses that best meet processor specifications. In experiment two female lambs had better meat quality attributes than males but in previous studies, consumers could not distinguish a difference between sexes of lamb less than 9 months of age. This would suggest that farmers can produce either male or female lambs up to 9 months of age and will not incur meat quality disadvantages. However further research to examine the different sexes are differing ages would be beneficial.

## Chapter 7: References

- Abdullah, A. Y., Purchas, R.W., Davies, A.S., & Kirton, A.H. (1993). "Relationships between objective and subjective measurements of carcass muscularity." Proceedings of the New Zealand Society of Animal Production 53: 397-402.
- Abdullah, A. Y., Muwalla, M.M., & Harb, M.Y. (1999). "Evaluation of various protein sources for growing and finishing Awassi lambs." Turkey Journal of Veterinary Animal Science 23: 475-482.
- Abdullah, A. Y., Kridli, R.T., Shaker, M.M., Obeidat, M.D. (2010). "Investigation of growth and carcass characteristics of pure and crossbred Awassi lambs." Small Ruminant Research 94: 167-175.
- Alcalde, M. J., & Negueruela, A.I. (2001). "The influence of final conditions on meat colour in light lamb carcasses." Meat Science 57: 117-123.
- Arsenos, G., Banos, G., Fortomaris, P., Katsaounis, N., Stamataris, C., Tsaras, L. (2002). Eating quality of lamb meat: Effect of breed, sex, degree of maturity and nutritional Management. Meat Science, 60, 379-387.
- Arvizu, R. R., Dominguez, I.A., Rubio, M.S., Borquez, J.L., & Pinos-Rodriguez, J.M. (2011). "Effects of genotype, level of supplementation, and organic chromium on growth performance, carcass, and meat traits grazing lambs." Meat Science 88: 404-408.
- Athanasiadou, S., Gray, D., Younie, D., & Tzamaloukas, O. (2007). "The use of chicory for parasite control in organic ewes and their lambs." Parasitology 134: 299-307.
- Bain, W. E., McEwan, J.C., McLean, N.J., & Johnson, P.L. (2010). "BRIEF COMMUNICATION: Carcass linear measurements as predictors of meat yield in lambs determined by VIAscan." Proceedings of the New Zealand Society of Animal Production 70: 130-132.
- Barry, T. N. (1998). "The feeding value of chicory (*Chicorium intybus*) for ruminant livestock." Journal of Agricultural Science 131: 251-257.
- Bass, J. J., Hodgkinson, S.C., Breier, B.H., Carter, W.D., & Gluckman, P.D. (1992). "Effects of bovine somatotrophin on insulin-like growth factor-I, insulin, growth and carcass composition of lambs." Livestock Production Science 31: 321-334.
- Beef and Lamb New Zealand Economic Service. (2011). New Season Outlook 2011-12. B. a. L. N. Z. Limited. Wellington, New Zealand.
- Bekhit, A. E. D., Richardson, A., MacLennan, G., Lindsay, S., & Grant, C. (2011). "BRIEF COMMUNICATION: Effect of red wine lees on lamb meat quality." Proceedings of the New Zealand Society of Animal Production 71: 211-213.
- Bello Acebron, L., & Calvo Dopico, D. (2000). "The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef." Food Quality and Preference 11: 229-238.
- Bennet, G. L., Kirton, A.H., Johnson, D.L., & Carter, A.H. (1991). "Genetic and environmental effects on carcass characteristics of Southdown x Romney lambs: I. Growth rate, sex, and rearing effects." Journal Animal Science 69: 1856-1863.

- Bickerstaffe, R., Bekhit, A.E.D., Robertson, L.J., Roberts, N., & Geesink, G.H. (2001). "Impact of introducing specifications on the tenderness of retail meat." Meat Science 59(3): 303-315.
- Bickerstaffe, R., Palmer, B. R., Geesink, G. H., Bekhit, A. E. D., & Billington, C. (2000). The effect of gender on meat quality of lamb longissimus dorsi. Proceedings of the International Congress of Meat Science and Technology, 46, 104-105.
- Binnie, D. B., Clarke, J.N., Clayton, J.B., Mowat, C.M., & Purchas, R.W. (1995). "Effects of genotype and nutrition on sheep carcass fat and eye muscle development between weaning and 14 months of age." Proceedings of the New Zealand Society of Animal Production 55(104-107).
- Braggins, T. J. (1996). "Effect of Stress-Related Changes in Sheepmeat Ultimate pH on Cooked Odor and Flavor." Journal of Agriculture and Food Chemistry 44: 2352-2360.
- Bray, A. R. (1988). "Farm factors that influence the eating qualities of lamb meat." Proceedings of the New Zealand Society of Animal Production 48: 7-12.
- British Standards Institute (2011). Sensory Analysis. Methodology. Method of Investigating Sensitivity of Taste. B S I Standards.
- Brookes, I. M., & Nicol, A.M. (2007). Chapter 11: The Protein Requirements of Grazing Livestock. Pasture and Supplements for grazing animals. P. V. Rattray, Brookes, I.M., & Nicol, A.M.(Eds) Hamilton, New Zealand, New Zealand Society of Animal Production. Occasional Publication No.14: 173-188.
- Brown, H. E., & Moot, D.J. (2004). "Quality and quantity of chicory, lucerne and red clover production under irrigation." Proceedings of the New Zealand Grassland Association 66: 257-264.
- Campbell, A. W., MacLennan, G., Judson, H.G., Lindsay, S., Behrent, M.R., Mackie, A., & Kerslake, J.I. (2011). "BRIEF COMMUNICATION: The effects of different forage types on lamb performance and meat quality." Proceedings of the New Zealand Society of Animal Production 71: 208-210.
- Chandraratne, M. R., Samarasinghe, S., Kulasiri, D., & Bickerstaffe, R. (2006). "Prediction of lamb tenderness using image surface texture features." Journal of Food Engineering 77: 492-499.
- Christensen, L., Gunvig, A., Torngren, M.A., Aaslyng, M.D., Knochel, S., & Christensen, M. (2012). "Sensory characteristics of meat cooked for prolonged times at low temperature." Meat Science 90: 485-489.
- Clapham, W. M., Foster, J.G., Neel, J.P.S., & Fedders, J.M. (2005). "Fatty Acid Composition of Traditional and Novel Forages." Journal of Agricultural and Food Chemistry 53(26): 10068-10073.
- Clarke, J. N., Nicoll, G.B., & Mowat, C.M. (1998). "Genetic parameters for liveweight and live animal ultra-sound fat and eye muscle dimensions in a synthetic terminal sire breed." Proceedings of the New Zealand Society of Animal Production 58: 140-142.



- Craigie, C. R., Lambe, N.R., Richardson, R.I., Haresign, W., Maltin, C.A., Rehfeldt, C., Roehe, R., Morris, S.T., & Bunger, L. (2012). "The effect of sex on some carcass and meat quality traits in Texel ewe and ram lambs." Animal Production Science 52: 601-607.
- Crouse, J. D., Busboom, J.R., Field, R.A., & Ferrell, C.L. (1981). "The effects of breed, diet, sex, location and slaughter weight on lamb growth carcass composition and meat flavour." Journal of Animal Science 53(2): 376-386.
- Cruz, G. D., Strathe, A.B., Rossow, H.A., & Fadel, J.G. (2012). "Characterizing bovine adipocyte distribution and its relationship with carcass and meat characteristics using a finite mixture model." Journal of Animal Science.
- Deaker, J. M., Young, M.J., Fraser, T.J., & Rowarth, J.S. (1994). "Carcass, liver and kidney characteristics of lambs grazing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), white clover (*Trifolium repens*) or perennial ryegrass (*Lolium perenne*)." Proceedings of the New Zealand Society of Animal Production 54: 197-200.
- de Ruiter, J. M., Dalley, D.E., Hughes, T.P., Fraser, T.J., & Dewhurst, R.J. (2007). Types of supplements: Their nutritive value and use. In Pasture and Supplements for Grazing Animals. P. V. Rattray, Brookes, I.M., & Nicol, A.M. Hamilton, New Zealand, New Zealand Society of Animal Production (Inc.). Occasional Publication No.14: 97-116.
- Devine, C. E., Graadhuis, A.E., Muir, P.D., & Chrystall, B.B. (1993). "The effect of growth rate and ultimate pH on meat quality of lambs." Meat Science 35: 63-77.
- Diaz, M. T., Caneque, V., Lauzurica, S., Velasco, S., Ruiz de Huido bro., & Perez, C. (2004). "Prediction of suckling lamb carcass composition from objective and subjective carcass measurements." Meat Science 66: 895-902.
- Dikeman, M. E. (2007). "Effects of metabolic modifiers on carcass traits and meat quality." Meat Science 77: 121-135.
- Dove, H., & Milne, J.A. (2006). "Intake and productivity of lambs grazing leafy or stemmy forage rape and the effect of energy or protein supplements." Australian Journal of Experimental Agriculture 46: 763-769.
- Dransfield, E., Nute, G. R., Hogg, B. W., & Walters, B. R. (1990). Carcass and eating quality of ram, castrated ram and ewe lambs. Animal Production, 50, 291-299.
- Dransfield, E., & Sosnicki, A.A. (1999). "Relationship Between Muscle Growth and Poultry Meat Quality." Poultry Science 78: 743-746.
- Dumont, B.L. (1978). Variation and impact of muscle thickness. Pp 133-146 in Patterns of growth and development in cattle. DeBoer, H., Martin, J. Ed. The Hague, Martinus Nijhoff.
- Dunsha, F. R., D'Souza, D.N., Pethick, D.W., Harper, G.S., & Warner, R.D. (2005). "Effects of dietary factors and other metabolic modifiers on quality and nutritional value of meat." Meat Science 71: 8-38.
- Easton, H. S. (1999). "Endophyte in New Zealand ryegrass pastures, an overview." Grasslands Research and Practice Series 7: 1-9.
- Elsley, F. W. H., McDonald, I., & Fowler, V.R. (1964). "The effect of plant of nutrition on the carcasses of pigs and lambs when variations in fat content are excluded." Animal

Production 6: 141-154.

- Farouk, M. M., Tavendale, M., Lane, G., Pulford, D., & Waller, J. (2007). "Comparison of white clover, perennial ryegrass and the high tannin containing forage *Lotus pedunculatus* as finishing diets: Effect on sheepmeat quality." Proceedings of the New Zealand Society of Animal Production 67: 426-430.
- Fennema, O. R. (1990). "Comparative water holding properties of various muscle foods: A critical review relating to definitions, methods of measurement, governing factors, comparative data and mechanistic matters." Journal of Muscle Foods 1: 363-381.
- Fisher, A. V., Green, D.M., Whittemore, C.T., Wood, J.D., & Schofield, C.P. (2003). "Growth of carcass components and its relation with conformation in pigs of three types." Meat Science 65(1): 639-650.
- Fraser, M. D., Speijers, M.H.M., Theobald, V.J., Fychan, R., & Jones, R. (2004). "Production performance and meat quality of grazing lambs finished on red clover, lucerne or perennial ryegrass swards." Grass and Forage Science 59: 345-356.
- Fraser, T. J., & Rowarth, J.S. (1996). "Legumes, herbs or grass for lamb performance?" Proceedings of the New Zealand Grassland Association 58: 49-52.
- Geesink, G. H., Bekhit, A.D., & Bickerstaffe, R. (2000). "Rigor temperature and meat quality characteristics of lamb longissimus muscle ." Journal of Animal Science 78: 2842-2848.
- Golding, K. P., Kemp, P.D., Kenyon, P.R., & Morris, S.T. (2008). "High weaned lamb live weight gains on herbs." Agronomy New Zealand 38: 33-39.
- Golding, K. P., Wilson, G.D., Kemp, P.D., Pain, S.J., Kenyon, P.R., Morris, S.T., & Hutton, P.G. (2011). "Mixed herb and legume pasture improves the growth of lambs post-weaning." Animal Production science 51: 717-723.
- Grunert, K. G., Bredahl, L., Brunso, K. (2004). "Consumer perception of meat quality and implications for product development in the meat sector—a review." Meat Science 66: 259-272.
- Hamm, R. (1986). Functional properties of the myofibrillar system and their measurements. In Muscle as food. P. J. Bechtel. Orlando, USA, Academic Press: 135-199.
- Hofbauer, P., Smulders, F.J.M. (2011). The muscle biological background of meat quality including that of game species. Game meat hygiene in focus. P. Paulsen, Bauer, A., Vodnansky, M., Winkelmayer, R., Smulders, F.J.M., Wageningen Academic Publishers: 273-295.
- Hopkins, D. L., & Huff-Lonergan, E. (2004). Tenderizing mechanisms: Chemical and enzymatic. Encyclopedia of Meat Sciences. W. K. Jensen, Devine, C., & Dikeman, M. Oxford, UK, Elsevier Academic Press. 3: 11363-11369
- Honikel, K. O., & Hamm, R. (1987). Critical evaluation of methods detecting effects of processing on meat protein characteristics. Chemical changes during food processing. Proceedings of the IUFOST Symposium. Valencia, Spain, Consejo Superior de Investigaciones Cientificas. 2: 64-82.

- Honikel, K. O. (1997). "Reference methods supported by OECD and their use in Mediterranean meat products." Food Chemistry 59(4): 573-582.
- Honikel, K. O. (1998). "Reference methods for the assessment of physical characteristics of meat." Meat Science 49(4): 447-457.
- Hood, D. E., & Riordan, E.B. (1973). "Discolouration in prepackaged beef: measurement by reflectance spectrophotometry and shopper discrimination." Journal of Food Technology 8: 333-343.
- Hopkins, D. L. (1994). "Predicting the weight of lean meat in lamb carcasses and the suitability of this characteristic as a basis for valuing carcasses." Meat Science 38: 235-241.
- Hopkins, D. L., Holst, P.J., Hall, D.G., & Atkinson, W.R. (1995). "Carcass and meat quality of second-cross cryptorchid lambs grazed on chicory (*Cichorium intybus*) or lucerne (*Medicago sativa*)." Australian Journal of Experimental Agriculture 35: 693-697.
- Hopkins, D. L., Beattie, A.S., & Pirlot, K.L. (1995). "Meat quality, carcass fatness, and growth of short scrotum lambs grazing either forage rape or irrigated perennial pasture." Australian Journal of Experimental Agriculture 35: 453-459.
- Hopkins, D. L. (1997). "Differences in Composition, Muscularity, Muscle:Bone Ratio and Cut Dimensions between Six Lamb Genotypes." Meat Science 45(4): 439-450.
- Hopkins, D. L., Stanley, D.F., Martin, L.C., Toohey, E.S., & Gilmour, A.R. (2007). "Genotype and age effects on sheep meat production 3. Meat quality." Australian Journal of Experimental Agriculture 47: 1155-1164.
- Hopkins, D. L., Fogarty, N.M., & Mortimer, S.I. (2011). "Genetic related effects on sheep meat quality." Small Ruminant Research 101(1-3): 160-172.
- Houdijk, J. G. M., Baker, A., Navajas, E.A., Richardson, R.I., Ross, D.W. (2011). Finishing lambs on chicory increases killing out percentage and carcass conformation score without detrimental effects on sensory meat eating quality. British Society of Animal Science Annual Conference. University of Nottingham, UK.
- Huff Lonergan, E., Zhang, W., & Lonergan, S.M. (2010). "Biochemistry of postmortem muscle - lessons on mechanisms of meat tenderization." Meat Science 86(1): 184-195.
- Hunter, T. E., Suster, D., Dunshea, F.R., Cummins, L.J., Egan, A.R., & Leury, B.J. (2011). "Dual energy X-ray absorptiometry (DXA) can be used to predict live animal and whole carcass composition of sheep." Small Ruminant Research 100: 143-152.
- Jacob, R. H., D'Antuono, M., Smith, G.M., Pethick, D.W., & Warner, R.D. (2007). "Effect of lamb age and electrical stimulation on the colour stability of fresh lamb meat." Australian Journal of Agricultural Research 58(4): 374-382.
- Jeremiah, L. E. (1998). "Development of a quality classification system for lamb carcasses." Meat Science 48: 211-223.
- Johnson, P.L.; Dodds, K.G.; Bain, W.E.; Greer, G.J.; McLean, N.J.; McLaren, R.J.; Galloway, S. M.; van Stijn, T. C.; McEwan, J. C. 2009: Investigations into the GDF8 g+6723G-A polymorphism in New Zealand Texel sheep. Journal of Animal Science 87: 1856-1864.

- Johnson, P. L., Purchas, R.W., McEwan, J.C., & Blair, H.T. (2005). "Carcass composition and meat quality differences between pasture-reared ewe and ram lambs." Meat Science 71: 383-391.
- Johnson, P. L., Mclean, N.J., Bain, W.E., Young, E., & Campbell, A.W. (2008). "BRIEF COMMUNICATION: Factors affecting colour stability of fresh chilled lamb meat." Proceedings of the New Zealand Society of Animal Production 68: 164-165.
- Jopson, N. J., McEwan, J.C., Logan, C.M., & Muir, P.D. (2009). "Genetic parameters for primal cut meat yield traits in sheep." Proceedings of the New Zealand Society of Animal Production 69: 215-219.
- Judson, H. G., McAnulty, R., & Sedcole, R. (2009). "Evaluation of 'Ceres Tonic' plantain (*Plantago lanceolata*) as a lactation feed for twin-bearing ewes. Proceedings of the New Zealand Grassland Association 71: 201-205.
- Kemp, C. M., Sensky, P.L., Bardsley, R.G., Buttery, P.J., & Parr, T. (2010). "Tenderness – An enzymatic view." Meat Science 84: 248-256.
- Kemp, P.D. Kenyon, P.R. and Morris, S.T. (2010). The use of legume and herb forage species to create high performance pastures for sheep and cattle grazing systems. Revista Brasileira de Zootecnia 39: 169-174.
- Kemp, P. D., Matthew, C., & Lucas, R.J. (2007). Pasture species and cultivars. New Zealand Pasture and Crop Science. J. White, & Hodgson, J. Melbourne, Australia, Oxford University Press: 83-100.
- Kerr, P. (2000). 400 Plus: A guide to improved lamb growth and for farmers and advisors. New Zealand Sheep Council.
- Kerslake, J. L., Hely, F.S., MacLennan, G., Lindsay, S., Behrent, M.R., & Campbell, A.W. (2012). "BRIEF COMMUNICATION: Does castration status have an effect on the quality of lamb meat?" Proceedings of the New Zealand Society of Animal Production 72: 144-146.
- Khlijji, S., van de Ven, R., Lamb, T.A., Lanza, M., & Hopkins, D.L. (2010). "Relationship between consumer ranking of lamb colour and objective measures of colour." Meat Science 85: 224-229.
- Kirton, A. H., Duganzich, D.M., Mercer, G.J.K., Clarke, J.N., Dobbie, J.L., & Wilson, J.A. (1997). "Muscle distribution in lamb progeny from several breeds." Proceedings of the New Zealand Society of Animal Production 57: 267-270.
- Kirton, A. H., & Morris, C.A. (1989). The effect of mature size, sex and breed on patterns of change during growth and development. Meat production and processing. R. W. Purchas, Butler-Hogg, B.W., & Davies, A.S. Palmerston North, New Zealand, New Zealand Society of Animal Production (Inc.). Occasional Publication No.11: 73-86.
- Knaffman, R. G., Eikelenboom, G., van der Wal, P.G., & Merkus, G. (1986). "The use of filter paper to estimate drip loss of porcine musculature." Meat Science 18: 191-200.
- Komolong, M., Nicol, A.M., Poppi, D.P., Fraser, T.J., & Kirsopp, S. (1992). "Nutrient supply for

- lamb growth from Grasslands Puna chicory (*Cichorium intybus*) and Wana cocksfoot (*Dactylis glomerata*)." Proceedings of the New Zealand Society of Animal Production 52: 85-87.
- Koohmaraie, M., & Geesink, G.H. (2006). "Contribution of postmortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system." Meat Science 74: 34-43.
- Kremer, R., Barbato, G., Castro, L., Rista, L., Roses, L., Herrera, V., & Neirotti, V. (2004). "Effect of sire breed, year, sex and weight on carcass characteristics of lambs." Small Ruminant Research 53: 117-124.
- Lambe, N. R., Navajas, E.A., Schofield, C.P., Fisher, A.V., Simm, G., Roeche, R., & Bunger, L. (2008). "The use of various live animal measurements to predict carcass and meat quality in two divergent lamb breeds." Meat Science 80: 1138-1149.
- Lambe, N. R., Navajas, E.A., Fisher, A.V., Simm, G., Roehe, R., & Bunger, L. (2009). "Prediction of lamb meat eating quality in two divergent breeds using various live animal and carcass measurements." Meat Science 83: 366-375.
- Lambert, M. G., Clark, D.A., & Litherland, A.J. (2004). "Advances in pasture management for animal productivity and health." New Zealand Veterinary Journal 52(6): 311-319.
- Leymaster, K. A., & Jenkins, T.G. (1993). "Comparison of Texel- and Suffolk-sired crossbred lambs for survival, growth, and compositional traits." Journal of Animal Science 71(4): 859-869.
- Lindsay, C. L., Kemp, P.D., Kenyon, P.R., & Morris, S.T. (2007). "Summer lamb finishing on forage crops." Proceedings of the New Zealand Society of Animal Production 67: 121-125.
- Littell R. C., P. R. Henry and C. B. Ammerman (1998). Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci., 76(4): 1216-1231.
- Litherland, A. J., Dynes, R.A., & Moss, R.A. (2010). "Factors affecting dressing-out percentage of lambs." Proceedings of the New Zealand Society of Animal Production 70: 121-126.
- Luciano, G., Monahan, F.J., Vasta, V., Biondi, L., Lanza, M., & Priolo, A. (2009). "Dietary tannins improve lamb meat colour stability." Meat Science 81: 120-125.
- MacDougall, D. B. (1982). "Changes in the colour and opacity of meat." Food Chemistry 9: 75-88.
- MacFarlane, J. M., Lewis, R.M., Emmans, G.C., Young, M.J., & Simm, G. (2009). "Predicting tissue distribution and partitioning in terminal sire sheep using x-ray computed tomography." Journal of Animal Science 87: 107-118.
- Madrunga, M. S., & Mottram, D.S. (1995). "The effect of pH on the formation of maillard-derived aroma volatiles using a cooked meat system." Journal of the Science of Food and Agriculture 68(3): 305-310.
- Mancini, R. A., & Hunt, M.C. (2005). "Current research in meat colour." Meat Science 71: 100-121.
- Marley, C. L., Fraser, M.D., Fychan, R., Theobald, V.J., & Jones, R. (2005). "Effect of forage legumes and anthelmintic treatment on the performance, nutritional status and nematode

- parasites of grazing lambs." Veterinary parasitology 131: 267-282.
- Martinez-Cerezo, S., Sanudo, C., Panea, B., Medel, I., Delfa, R., Sierra, I., Beltran, J.A., Cepero, R., & Olleta, J.L. (2005). "Breed, slaughter weight and ageing time effects on physico-chemical characteristics of lamb meat." Meat Science 69: 325-333.
- McCoard, S. A., Koolaard, J., Charteris, A., & Luo, D. (2010). "BRIEF COMMUNICATION: Effect of twinning and sex on carcass weight and composition in lambs." Proceedings of the New Zealand Society of Animal Production 70: 133-136.
- McCormick, R. J. (1994). "The flexibility of the collagen compartment of muscle." Meat Science 36: 79-91.
- McDermott, A., Saunders, C., Zellman, E., Hope, T., & Fisher, A. (2008). Sheep Meat: The key elements of success and failure in the NZ sheep meat industry from 1980 - 2007. Christchurch, New Zealand, Agribusiness Research and Education Network.
- Mclean, N. J., Jopson, N.B., Campbell, A.W., Knowler, K., Behrent, M., Cruickshank, G., Logan, C.M., Muir, P.D., Wilson, T., & McEwan, J.C. (2006). "An evaluation of sheep meat genetics in New Zealand: The central progeny test (CPT)." Proceedings of the New Zealand Society of Animal Production 66: 368-372.
- Mclean, N. J., Johnson, P.L., Bain, W.E., Greer, G.J., & Dodds, K.G. (2009). "BRIEF COMMUNICATION: Genetic parameters for colour stability of chilled lamb." Proceedings of the New Zealand Society of Animal Production 69: 220-222.
- Mclean, N. J., Johnson, P.L., & Charteris, A. (2010). "BRIEF COMMUNICATION: Determining sensory panel traits which contribute to the overall liking of New Zealand lamb as assessed by a British sensory panel." Proceedings of the New Zealand Society of Animal Production 70: 127-129.
- Meat Industry Association of New Zealand (Inc). (2011). "Meat Industry Association of New Zealand (Inc)." from <http://www.mia.co.nz/>.
- Miguel, E., Onega, E., Caneque, V., Velasco, S., Diaz, M.T., Lauzurica, S., Perez, C., Blazques, & B., Ruiz de Huidobro. (2003). "Carcass classification in suckling lambs. Discrimination ability of the European Union scale." Meat Science 63: 107-117.
- Miller, R. (1998). "Sensory Evaluation of Pork." National Pork Board, Pork Quality, American Meat Science Association: 1-20.
- Ministry of Agriculture and Forestry. (2009). Meat: The Future. Opportunities and challenges for the New Zealand sheep meat and beef sector over the next 10 to 15 years. Wellington, New Zealand: 1-87.
- Ministry for Primary Industries (2012a). "Industry requirements." Retrieved 28 August 2012, from [www.mpi.govt.nz](http://www.mpi.govt.nz).
- Ministry for Primary Industries. (2012b). Situation and Outlook for Primary Industries. Wellington, New Zealand.
- Moore, V. J., & Young, O.A. (1991). "The effects of electrical stimulation, thawing, ageing and packaging on the colour and display life of lamb chops." Meat Science 30: 131-145.

- Moorhead, A. J. E., Judson, H.G., & Stewart, A.V. (2002). "Liveweight gain of lambs grazing 'Ceres Tonic' plantain (*Plantago lanceolata*) or perennialryegrass (*Lolium perenne*)."  
Proceedings of the New Zealand Society of Animal Production 62: 171-173.
- Moot, D. J., Brown, H.E., Teixeira, E.I & Pollock, K.M. (2003). Crop growth and development affect seasonal priorities for lucerne management. Legumes in Dryland Pastures. D. J. Moot. Palmerston North, New Zealand., New Zealand Grassland Association: 201-208.
- Moot, D. J., Matthew, C., Kemp, P.D., & Scott, W.R. (2007). Husbandry and role of pastures and forage crops in grazing systems. In Pasture and Supplements for Grazing Animals. P. V. Rattray, Brookes, I.M., & Nicol, A.M. Hamilton, New Zealand, New Zealand Society of Animal Production (Inc.). Occasional Publication No.14: 23-34.
- Morris, S. T. (2009). "Economics of sheep production." Small Ruminant Research 86: 59-62.
- Mottram, D. S. (1992). "Meat flavour, the chemistry of meat flavour." Meat Focus International June: 87-93.
- Mottram, D. S. (1998). "Flavour formation in meat and meat products: a review." Food Chemistry 62(4): 415-424.
- Munoz, A. M. (1998). "Consumer Perceptions of Meat. Understanding These Results Through Descriptive Analysis." Meat Science 49: S287-S295.
- Navajas, E. A., Lambe, N.R., Fisher, A.V., Nute, G.R., Bunger, L., & Simm, G. (2008). "Muscularity and eating quality of lambs: Effects of breed, sex and selection of sires using muscularity measurements by computed tomography." Meat Science 79: 105-112.
- Nicol, G.B., Alderton, M.J., Annandale, D.D., Coleman, I.D., Grimwood, T.J., Thomson, J.A. (1992). "A terminal sire breeding programme based on screening for hogget liveweight." Proceedings of the New Zealand Society of Animal Production 52: 125-127.
- Nicoll, G. B. (1995). "Using genetic variation for greater profit." Proceedings of the New Zealand Society of Animal Production 55: 328-333.
- Nicoll, G. B., Skerritt, J.W., Dobbie, J.L., & Grimwood, T.J. (1998). "Effect of sire genotype on lamb growth and carcass productivity." Proceedings of the New Zealand Society of Animal Production 58: 136-139.
- Offer, G., & Trinick, J. (1983). "On the mechanism of water holding in meat: The swelling and shrinking of myofibrils." Meat Science 8: 245-281.
- O'Keefe, M., & Hood, D.E. (1982). "Biochemical factors influencing metmyoglobin formation on beef from muscles of differing colour stability." Meat Science 7(3): 209-228.
- Okeudo, N. J., & Moss, B.W. (2005). "Interrelationships amongst carcass and meat quality characteristics of sheep." Meat Science 69: 1-8.
- Okeudo, N. J., & Moss, B.W. (2008). "Production performance and meat quality characteristics of sheep comprising four sex-types over a range of slaughter weights produced following commercial practice." Meat Science 80: 522-528.
- Ouali, A. (1992). "Proteolytic and physicochemical mechanisms involved in meat texture

- development." Biochemie 74: 251.
- Park, R.J., Corbett, J.L., & Furnival, E.P. (1972). Flavour differences in meat from lambs grazed on lucerne (*Medicago sativa*) or phalaris (*Phalaris tuberosa*) pasture. Journal of Agricultural Science, Cambridge. 78, 47-52.
- Payne, G. M., Campbell, A.W., Jopson, N.B., McEwan, J.C., Logan, C.M., & Muir, P.D. (2009). "Genetic and phenotypic parameter estimates for growth, yield and meat quality traits in lamb." Proceedings of the New Zealand Society of Animal Production 69: 210-214.
- Peachey, B.M, Purchas, R.W, & Duizer, L.M. (2002). "Relationship between sensory and objective measures of meat tenderness of beef *m.longissimus thoracis* from bulls and steers." Meat Science 60: 211-218.
- Pearce, K. L., Rosenvold, K., Andersen, H.J., & Hopkins, D.L. (2011). "Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes — A review." Meat Science 89: 111-124.
- Peeters, R., Kox, G., & van Isterdael, J. (1996). "Environmental and maternal effects on early postnatal growth of lambs of different genotypes." Small Ruminant Research 19: 45-53.
- Pena, F., Cano, T., Domenech, V., Alcalde, M.J., Martos, J., Garcia-Martinez, A., Herrera, M., & Rodero, E. (2005). "Influence of sex, slaughter weight and carcass weight on "non-carcass" and carcass quality in segureña lambs." Small Ruminant Research 60: 247-254.
- Perry, D., & Thompson, J.M. (2005). "The effect of growth rate during backgrounding and finishing on meat quality traits in beef cattle." Meat Science 69: 691-702.
- Pethick, D. W., Hopkins, D.L., Souza, D.N.D., Thompson, J.M., & Walker, P.J. (2005). "Effects of animal age on the eating quality of sheep meat." Australian Journal of Experimental Agriculture 45: 491-498.
- Pethick, D. W., Pleasants, A.B., Gee, A.M., Hopkins, D.L., & Ross, I.R. (2006). "Eating quality of commercial meat cuts from Australian lambs and sheep." Proceedings of the New Zealand Society of Animal Production 66: 363-367.
- Ponnampalam, E. N., Hosking, B.J., & Egan, A.R. (2003). "Rate of carcass components gain, carcass characteristics, and muscle longissimus tenderness in lambs fed dietary protein sources with a low quality roughage diet." Meat Science 63: 143-149.
- Ponnampalam, E. N., Hopkins, D.L., Butler, K.L., Dunshea, F.R., & Warner, R.D. (2007). "Genotype and age effects on sheep production 2. Carcass quality traits." Australian Journal of Agricultural Research 47: 1147-1154.
- Prache, S., Gatellier, P., Thomas, A., Picard, B. & Bauchart, D. (2011). "Comparison of meat and carcass quality in organically-reared and conventionally-reared pasture-fed lambs." Animal 5(12): 2001-2009.
- Prescott, J., Young, O., & O'Neill, L. (2001). "The impact of variations in flavour compounds on meat acceptability: a comparison of Japanese and New Zealand consumers." Food Quality and Preference 12: 257-264.
- Preston, R. L. (1999). "Hormone containing growth promoting implants in farmed livestock." Advanced Drug Delivery Reviews 38: 123-138.



- Prieto, N., Roehe, R., Lavin, P., Batten, G., & Andres, S. (2009). "Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review." Meat Science 83(2): 175-186.
- Priolo, A., Micol, D., & Agabriel, J. (2001). "Effects of grass feeding systems on ruminant meat colour and flavour. A review." Animal Research 50: 185-200.
- Priolo, A., Micol, D., Agabriel, J., Prache, S., Dransfield, E. (2002). "Effect of grass or concentrate feeding systems on lamb carcass and meat quality." Meat Science 62: 179-185.
- Purchas, R. W. (2012). Chapter 18: Carcass Evaluation. In: Handbook of Meat and Meat Processing (2<sup>nd</sup> ed). Y. H. Hui (Ed.). Boca Raton, FL, Taylor and Francis Group, LLC.
- Purchas, R. W., Davies, A.S., & Abdullah, A.Y. (1991). "An objective measure of muscularity: changes with animal growth and differences between genetic lines of Southdown sheep." Meat Science 30: 81-94.
- Purchas, R. W., Silva Sobrinho, A.G., Garrick, D.J., & Lowe, K.I. (2002). "Effects of age at slaughter and sire genotype on fatness, muscularity, and the quality of meat from ram lambs born to Romney ewes." New Zealand Journal of Agricultural Research 45(2): 77-86.
- Purchas, R.W., Butler-Hogg, B.W., & Davies, A.S. (1989). Meat production and processing. Purchas, R.W., Butler-Hogg, B.W., Davies, A.S. *ed* New Zealand Society of Animal Production, occasional publication number 11.
- Purchas, R.W., Davies, A.S., Abdullah, A.Y. (1991). "An objective measure of muscularity: changes with animal growth and differences between genetic lines of Southdown sheep." Meat Science 30: 81-94.
- Raes, K., Balcaen, A., Dirinck, P., De Winne, A., Claeys, E., Demeyer, D., & De Smet, S. (2003). "Meat quality, fatty acid composition and flavour analysis on Belgian retail beef." Meat Science 65(4): 1237-1246.
- Ramirez-Restrepo, C. A., Barry, T.N., Pomroy, W.E., Lopez-Villalobos, N., McNabb, W.C., & Kemp, P.D. (2005). "Use of Lotus corniculatus containing condensed tannins to increase summer lamb growth under commercial dryland farming conditions with minimal anthelmintic drench input." Animal Feed Science and Technology 122: 197-217.
- Reid, R. L., Puoli, J.R., Jung, G.A., Cox-Ganser, J.M., & McCoy, A. (1994). "Evaluation of Brassicas in Grazing Systems for Sheep: I. Quality of Forage and Animal Performance." Journal of Animal Science 72: 1823-1831.
- Renner, M., & Labas, R. (1987). "Biochemical factors influencing metmyoglobin formation in beef muscles." Meat Science 19: 151-165.
- Resconi, V. C., Campo, M.M., Montossi, F., Ferreira, V., Sanudo, C., & Escudero, A. (2010). "Relationship between odour-active compounds and flavour perception in meat from lambs fed different diets." Meat Science 85(4): 700-706.
- Rosenvold, K., & Wiklund, E. (2011). "Retail colour display life of chilled lamb as affected by processing conditions and storage temperature." Meat Science 88(3): 354-360.
- Ruiz de Huidobro, F., Miguel, E., Blazquez, B., & Onega, E. (2005). "A comparison between two

- methods (Warner–Bratzler and texture profile analysis) for testing either raw meat or cooked meat." Meat Science 69: 527-536.
- Safari, E., Hopkins, D.L., & Fogarty, N.M. (2001). "Diverse lamb genotypes 4. Predicting the yield of saleable meat and high value trimmed cuts from carcass measurements." Meat Science 58: 207-214.
- Safari, E., Channon, H., Hopkins, D.L., & van de Ven, R. (2002). "A national audit of retail lamb loin quality in Australia." Meat Science 61: 267-272.
- Sante-Lhoutellier, V., Engel, E., & Gatellier, P. (2008). "Assessment of the influence of diet on lamb meat oxidation." Food Chemistry 109: 573-579.
- Sanudo, C., Nute, G.R., Campo, M.M., Maria, G., Baker, A., Sierra, I., Enser, M.E., & Wood, J.D. (1998). "Assessment of Commercial Lamb Meat Quality by British and Spanish Taste Panels." Meat Science 48(1): 91-100.
- Sanudo, C., Enser, M.E., Campo, M.M., Nute, G.R., Maria, G., Sierra, I., & Wood, J.D. (2000a). "Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain." Meat Science 54: 339-346.
- Sanudo, C., Alfonso, M., Sanchez, A., Delfa, R., & Teixeira, A. (2000b). "Carcass and meat quality in light lambs from different fat classes in the EU carcass classification system." Meat Science 56: 89-94.
- Sanudo, C., Alfonso, M., Sanchez, A., Berge, P., Dransfield, E., Zygoyiannis, D., Stamataris, C., Thorkelsson, G., Valdimarsdottir, T., Piasentier, E., Mills, C., Nute, G.R., & Fisher, A.V. (2003). "Meat texture of lambs from different European production systems." Australian Journal of Agricultural Research 54: 551-560.
- Scales, G. H., Knight, T.L., & Saville, D.J. (1994). "Effect of herbage species and feeding level on internal parasites and production performance of grazing lambs." New Zealand Journal of Agricultural Research 38: 237-247.
- Schreurs, N. M., Lane, G.A., Tavendale, M.H., Barry, T.N., & McNabb, W.C. (2008). "Pastoral flavour in meat products from ruminants fed fresh forages and its amelioration by forage condensed tannins." Animal Feed Science and Technology 146: 193-221.
- Scott, J. D. J., Rattray, P.V., & Smeaton, D.C. (1976). "Environmental factors associated with summer-autumn growth rates of cattle and sheep." Proceedings of the New Zealand Society of Animal Production 36: 103-119.
- Sepulveda, W. S., Maza, M.T., & Pardos, L. (2011). "Aspects of quality related to the consumption and production of lamb meat. Consumers versus producers." Meat Science 87: 366-372.
- Simmons, N. J., Daly, C.C., & Gilbert, K.V. (2000). "Manipulating processing to generate meat quality attributes appropriate for diverse markets." Proceedings of the New Zealand Society of Animal Production 60: 107-109.
- Sinhadipathige, S. C. S., Kenyon, P.R., Kemp, P.D., Morris, S.T., & Morel, P.C.H. (2012). "Can herb-clover mixes increase lamb liveweight gains in spring?" Proceedings of the New Zealand Grassland Association 74: 137-142.

- Smeaton, D. C. (2003). Optimising beef production from pasture. Profitable Beef Production. D. C. Smeaton, Meat and Wool New Zealand Beef Council.
- Smith, G. C., Dutson, T.R., Hostetler, R.L., & Carpenter, Z.L. (1976). "Fatness, rate of chilling and tenderness of lamb." Journal of Food Science 41: 748-756.
- Smith, G. C., Pendell, D.L., Tatum, J.D., Belk, K.E., & Sofos, J.N. (2008). "Post-slaughter traceability." Meat Science 80: 66-74.
- Speck, P. A., Clarke, J.N., & Morris, C.A. (1997). "Effects of strain and selection for growth on tenderness in sheep and beef meats." Proceedings of the Association of the Advancement of Animal Breeding and Genetics. 12: 567-570.
- Speijers, M. H. M., Fraser, M.D., Theobald, V.J., & Haresign, W. (2004). "The effects of grazing forage legumes on the performance of finishing lambs." Journal of Agricultural Science 142: 483-493.
- Stanford, K., Jones, S.D.M., & Price, M.A. (1998). "Methods of predicting lamb carcass composition: A review." Small Ruminant Research 29: 241-254.
- Statistics New Zealand. (2012). "Statistics New Zealand." Retrieved 25 November, 2012, from <http://www.stats.gov.nz>.
- Stewart, A. V. (1996). "Plantain (*Plantago lanceolata* L.): A potential pasture species." Proceedings of the New Zealand Grassland Association 58: 77-86.
- Sun, X. Z., Waghorn, G.C., Hoskin, S.O., Harrison, S.J., Muetzel, S., & Pacheco, D. (2012). "Methane emissions from sheep fed fresh brassicas (*Brassica* spp.) compared to perennial ryegrass (*Lolium perenne*)." Animal Feed Science and Technology 176: 107-116.
- Therkildsen, M., & Oksbjerg, M. (2009). Muscle protein turnover. Applied Muscle Biology and Meat Science. M. Du, & McCormick, R.J. Florida, USA, CRC Press: pp.115-128.
- Thompson, J. (2002). "Managing meat tenderness." Meat Science 62: 295-308.
- Thompson, J. M. (2004). "The effects of marbling on flavour and juiciness scores of cooked beef after adjusting to a constant tenderness." Australian Journal of Experimental Agriculture 44: 645-652.
- Thompson, J. M., Gee, A., Hopkins, A., Hopkins, D.L., Pethick, D.W., Baud, S.R., & Halloran, W.J.O. (2005). "Development of a sensory protocol for testing palatability of sheep meats." Australian Journal of Experimental Agriculture 45: 469-476.
- Troy, D. J., & Kerry, J.P. (2010). "Consumer perception and the role of science in the meat industry." Meat Science 86: 214-226.
- van der Wal, P. G., Bolink, A.H., & Merkus, G.S.M. (1988). "Differences in quality characteristics of normal, PSE and DFD pork." Meat Science 24(1): 79-84.
- Van Oeckel, M. J., Warnants, N., & Boucque, C.V. (1999). "Comparison of different methods for measuring water holding capacity and juiciness of pork versus on-line screening methods." Meat Science 51: 313-320.

- Vasta, V., & Priolo, A. (2006). "Ruminant fat volatiles as affected by diet. A review." Meat Science 73: 218-228.
- van Ruth, S. M. (2011). Techniques for sampling and identification of volatile compounds contributing to sensory perception. Sensory analysis of foods of animal origin. L. M. L. Nollet, & Toldra, F. Florida, USA, Taylor & Francis.
- Veiseth, E., Shackelford, S.D., Wheeler, T.L., & Koohmaraie, M. (2004). "Indicators of tenderization are detectable by 12 h postmortem in ovine longissimus." Journal Animal Science 82(5): 1428-1436.
- Veseith, E., Shackelford, S., Wheeler, T.L., & Koohmaraie, M. (2006). "Factors regulating lamb longissimus dorsi tenderness are affected by age at slaughter." Meat Science 68: 635-640.
- Waghorn, G. C., & Clark, D.A. (2004). "Feeding value of pastures for ruminants." New Zealand Veterinary Journal 52(6): 320-331.
- Waghorn, G. C., & McNabb, W.C. (2003). "Consequences of plant phenolic compounds for productivity and health of ruminants." Proceedings of the Nutrition Society 62: 383-392.
- Wang, Y., Waghorn, G.C., Douglas, G.B., Barry, T.N., & Wilson, G.F. (1994). "The effects of condensed tannin in *Lotus corniculatus* upon nutrient metabolism and upon body and wool growth in grazing sheep." Proceedings of the New Zealand Society of Animal Production 54: 219-222.
- Warner, R. D., Pethick, D.W., Greenwood, P.L., Ponnampalam, E.N., Banks, R.G., & Hopkins, D.L. (2007). "Unravelling the complex interactions between genetics, animal age and nutrition as they impact on tissue deposition, muscle characteristics and quality of Australian sheep meat." Australian Journal of Experimental Agriculture 47: 1229-1238.
- Warner, R. D., Greenwood, P.L., Pethick, D.W., & Ferguson, D.M. (2010). "Genetic and environmental effects on meat quality." Meat Science 86: 171-183.
- Wasserman, A. E. (1979). "Symposium on meat flavour chemical basis of meat flavour: a review." Journal of Food Science 44: 6-11.
- White, J. G. H., Matthew, C., & Kemp, P.D. (2007). Supplementary feeding systems. New Zealand Pasture and Crop Science. J. White, & Hodgson, J. Oxford, UK, Oxford University Press: pp.175-198
- Wiklund, E., Stevenson-Barry, J.M., Duncan, S.J., & Littlejohn, R.P. (2001). "Electrical stimulation of red deer (*Cervus elaphus*) carcasses - effects on rate of pH-decline, meat tenderness, colour stability and water-holding capacity." Meat Science 59(2): 211-220.
- Wiklund, E., Farouk, M.M., Stuart, A., Cartwright, S., Penney, N., & Rosenvold, K. (2009). "Brief communication: Quality of chilled-never-frozen versus chilled-frozen-thawed lamb." Proceedings of the New Zealand Society of Animal Production 69: 108-111.
- Wolff, J. E., & Bass, J.J. (1987). "The use of growth promotants for lamb production in New Zealand." Proceedings of the Society of sheep and cattle veterinarians NZVA, 17th Annual seminar.: 98-107.

- Wylie, A. R. G., Chestnutt, D.M.B., & Kilpatrick, D.J. (1997). "Growth and carcass characteristics of heavy slaughter weight lambs: effects of sire breed and sex of lamb and relationships to serum metabolites and IGF-1." Animal Science 64: 309-318.
- Young, E. A., Bain, W.E., McLean, N.J., Campbell, A.W., & Johnson, P.L. (2009). "Investigating marbling and its relationship to meat quality in New Zealand pasture fed lamb." Proceedings of the New Zealand Society of Animal Production 69: 104-107.
- Young, M. J., Simm, G., & Glasbey, C.A. (2001). "Computerised tomography for carcass analysis." Proceedings of the British Society of Animal Science: 250-254.
- Young, O. A., Cruickshank, G.J., MacLean, K.S., & Muir, P.D. (1994). "Quality of meat from lambs grazed on seven pasture species in Hawkes Bay." New Zealand Journal of Agricultural Research 37: 177-186.
- Young, O. A., & Dobbie, P. (1994). "Characteristics of intramuscular collagen in two sheep breeds." New Zealand Journal of Agricultural Research 37: 93-97.
- Young, O. A., Priolo, A., Simmons, N.J., & West, J. (1999). "Effects of rigor attainment temperature on meat blooming and colour display." Meat Science 52: 47-56.