Growth, carcass characteristics and meat quality of heifers and steers born to beef-cross-dairy cows

A thesis presented in partial fulfilment of the requirements for the degree
Master of Science
In
Animal Science

Massey University, Palmerston North,
New Zealand

Lucy Wesley Coleman

2016

Abstract

In New Zealand, there is an increasing influence of dairy breeds in the production of beef. First-cross beef-cross-dairy cows have shown potential as beef breeding cows due to their greater milk yield than straight-bred beef cows. There have been few studies examining the finishing characteristics of the progeny of such cows. The objectives of this study were to investigate the effect of breed-cross on growth, carcass characteristics and meat quality attributes for progeny of beef and beef-cross-dairy cows grown in a New Zealand pastoral production system. This study also aimed to determine if there were differences in breed effects between heifers and steers.

Growth, carcass characteristics and the meat quality were assessed for steers and heifers from beef and beef-cross-dairy cows. Heifers (n=53) and steers (n=50) were born to Angus (AA), Angus-cross-Friesian (AF), Angus-cross-KiwiCross (AK) and Angus-cross-Jersey (AJ) cows and sired by Charolais (C) bulls. Heifers and steers were grazed on pasture until slaughter at 574 and 784 days of age respectively. Live animal measurements were considered separately for heifers and steers. Carcass characteristics and meat quality attributes were compared among breed-crosses and between heifers and steers.

The C-AA heifers (226.8±4.7 kg) and steers (238.8±4.6 kg) were lighter at weaning than the beef-cross-dairy breed heifers (C-AJ = 239.9 ±4.6 kg, C-AK = 254.7±6.3 kg, C-AF = 258.9±5.7 kg) and steers (C-AJ = 256.1±4.9 kg, C-AK = 257.0±7.2 kg, C-AF = 267.0±5.7 kg) ($P<0.05$); however, there were no differences in the final live weight of breed-crosses ($P>0.05$). The C-AA (53.1±0.3 %) steers had a greater dressing-out percentage than C-AF (51.9±0.4 %) and C-AJ (51.5±0.3 %) steers ($P<0.05$). There were no differences in carcass weight, length, eye muscle area and fat depth C among breed-crosses ($P>0.05$). Steers were longer, heavier, had a greater fat depth C and greater proportion of intramuscular fat than heifers ($P<0.05$). Generally there was no difference in the meat quality among breed-crosses ($P>0.05$), except that C-AJ cattle had yellower fat than C-AA, and C-AA and C-AF cattle had redder fat than C-AK. There was no interaction of breed-cross with sex effects. Therefore, the C-AA cattle were more suited to a finishing system than C-AF, C-AK and C-AJ cattle.

Acknowledgements

I would first like to thank my supervisors Dr Rebecca Hickson and Dr Nicola Schreurs (Institute of Veterinary, Animal and Biomedical Sciences, Massey University) for their support, patience, advice and encouragement throughout this study. It would not have been possible without them.

I would also like to acknowledge the other members of the IVABS staff and postgraduates especially Stacey, Rhiannon, Isabel, Vanessa and Emma for their friendship, support, encouragement and motivation during particularly tense moments. To Dr Penny Back your encouragement, chocolate, chats and allowing me to visit the heifers when I got stressed were very much appreciated.

Special thanks to the staff at Massey University's Tuapaka and Riverside farms, and technicians Dean Burnham, Geoff Purchas and Natalia Martin for weighing the cattle and taking measurements both on the live animals and at slaughter. I wish to acknowledge the staff at the Land Meat Whanganui processing plant, and Faye Yu for her assistance and company during the meat quality analysis.

I am extremely appreciative for the provision of funds in the form of the ADB Williams Trust scholarship, the Tararua Province of Federated Farmers scholarship, and the Leonard Condell farming postgraduate scholarship.

Ultimately I must thank my friends and flatmates for their confidence in me and for feeding and supporting me, and most importantly to my family for their unwavering support and advice, even when I pretend not to listen.

Table of Contents

Abstract i

Acknowledgements ii

Table of Contents iii

List of Tables vi

List of Figures viii

1. Review of Literature 9

1.1. New Zealand Beef Industry 9

1.1.1. Role of the New Zealand dairy Industry 9

1.1.2. Carcass classification of beef in New Zealand 10

1.2. Influence of breed and sex in beef production 11

1.2.1. Beef breeds 11

1.2.2. Dairy breeds for beef production 12

1.2.3. Sex classifications in beef production 13

1.3. Growth characteristics 15

1.3.1. Influence of breed on growth characteristics 16

1.3.2. Influence of sex classification and age on growth characteristics 16

1.4. Carcass Characteristics 19

1.4.1. Dressing-out percentage 19

1.4.1.1. Influence of breed on dressing-out percentage 20

1.4.1.2. Influence of sex classification and age on dressing-out percentage 21

1.4.2. Eye Muscle Area 24

1.4.2.1. Influence of breed on eye muscle area 24

1.4.3. Subcutaneous Fat depth 26

1.4.3.1. Influence of breed on subcutaneous fat depth 26

1.4.4. Intramuscular Fat 27

1.4.4.1. Influence of breed on intramuscular fat 29

1.4.5. Influence of sex and age on carcass composition 29

1.4.3. Carcass Conformation 30

1.5. Meat Quality Characteristics 33

1.5.1. Appearance 33

1.5.1.1. Meat Colour 33
1.5.1.2. Effect of breed on lean meat colour 34
1.5.1.3. Effect of sex and age on lean meat colour 34
1.5.1.4. Fat Colour 34
1.5.1.5. Influence of breed on fat colour 35
1.5.1.6. Influence of sex and age on fat colour 35
1.5.2. Palatability 36
1.5.2.1. Tenderness 36
1.5.2.2. Influence of breed on tenderness 37
1.5.2.3. Influence of sex and age on tenderness 38
1.5.2.4. Juiciness 39
1.5.2.5. Influence of breed, sex and age on juiciness 39
1.5.2.6. Flavour 40
1.5.2.7. Influence of breed, sex and age on flavour 40

1.6. Research Objectives 41

2. Materials and Methods 42

2.1. Animals and Management 42

2.2. Growth and ultrasound carcass measurements on the live animal . 43

2.3. Slaughter and carcass measurements 43

2.4. Meat quality 44
2.4.1. Ultimate pH 45
2.4.2. Lean meat and subcutaneous fat colour 45
2.4.3. Area and density 47
2.4.4. Tenderness and related measures 47
2.4.5. Water-holding measures 48
2.4.6. Intramuscular fat 49

2.5. Statistical Analysis 49

3. Results 51

3.1. Growth and ultrasound carcass characteristics 51
3.1.1. Heifers 51
3.1.2. Steers 54

3.2. Carcass characteristics 58

3.3. Meat quality 60

3.3.1. Ultimate pH 60
3.3.2. Tenderness and related attributes 60
3.3.3. Lean meat and subcutaneous fat colour 60
3.3.4. Water-holding measures 60

4. Discussion 60

4.1. Growth characteristics 62

4.2. Carcass characteristics 62

4.3. Meat Quality 65

4.4. Limitations 65

4.5. Implications 67

4.6. Future Research 67

4.7. Conclusions 68

Reference List 70

List of Tables

Table 1: Standard reference mature weights (kg) for different cattle breeds from *et al.* (2007), including whether the breed is early or late maturing 13

Table 2: Growth rate (as average daily gain (ADG), kg/day) from different sire breeds between two ages (months). 17

Table 3: Growth rate (ADG, kg/day) from different sex classes between two ages (months). 18

Table 4: Heritability ranges for carcass composition traits from (Irshad *et al.*, 2013). Low = 0-0.25, moderate = 0.25-0.5, high = 0.5-1. 19

Table 5: Dressing-out percentage from different sire breeds at a range of ages (months). 22

Table 6: Dressing-out percentage from different sex classes at a range of ages (months). 23

Table 7: Eye muscle area (cm^2) measured on the carcass at slaughter from different sire breeds at a range of ages (months). 25

Table 8: Subcutaneous fat depth C (mm) at slaughter among breeds at a range of ages (months). 28

Table 9: Eye muscle area (cm^2) measured on the carcass at slaughter from different sex classes at a range of ages (months). 32

Table 10: Subcutaneous fat depth C (mm) at slaughter from different sex classes at a range of ages (months). 32

Table 11: Numbers of cattle utilised in the experiment within each breed-cross and sex group. Cattle were Charolais-sired (C-) from Angus (AA), Angus-cross-Friesian (AF), Angus-cross-KiwiCross (AK) and Angus-cross-Jersey (AJ) dams. 42

Table 12: Growth characteristics from weaning until slaughter, for Charolais (C-) sired heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows. Values are least squares means ± standard error of the mean. 52

Table 13: Ultrasound carcass characteristics for Charolais (C-) sired heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, measured at 415 and 553 days of age. Values are least squares means ± standard error of the mean. 54

Table 14: Growth characteristics from weaning until slaughter, for Charolais (C-) sired steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows. Values are least squares means ± standard error of the mean. 56

Table 15: Ultrasound carcass characteristics for Charolais sired (C-) steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, measured at 415, 553 and 723 days of age. Values are least squares means ± standard error. 58

Table 16: Carcass weight, dressing-out percentage, carcass length, eye muscle area (EMA) and fat depth C measured on the carcass at slaughter, and *Longissimus lumborum* muscle area and density measured during meat quality testing from Charolais sired (C-) heifers and steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, slaughtered at 574 and 784 days old respectively. Values are least squares means ± standard error of the mean. 59

Table 17: Meat quality characteristics analysed on aged *Longissimus lumborum* muscle samples from Charolais sired (C-) heifers and steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, slaughtered at 574 and 784 days old respectively. Values are least squares means ± standard error of the mean. 61

List of Figures

Figure 1: Proportions of different breeds making up the total New Zealand beef herd over the 2012-2013 season, numbers include stock kept for breeding and finishing stock (Beef + Lamb NZ, 2015a). 12

Figure 2: Composition of export beef (not including veal) production by sex class for the period 2013-14 and estimated values for the 2014-15 period (Beef + Lamb NZ, 2015b). Values expressed as percentage of total exported tonnes of beef as bone in carcass weight. 14

Figure 3: Body weight over age illustrating growth curves (a) from birth until weaning for Brahman bulls of three frame sizes, (b) from weaning until 20 or 32 months of age for males and females respectively, and (c) from 32 to 120 months of age for cows of three frame sizes. From Menchaca *et al.* (1996). 15

Figure 4: Differences between early and late maturing animals on the rate of increase in different fat depots, from Irshad *et al.* (2013). 27

Figure 5: Schematic of beef striploin (*Longissimus lumborum*) portioning for meat quality analysis. 46

Figure 6: Un-fasted live weight for Charolais sired (C-) heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows from weaning at 193 days of age until three weeks prior to slaughter. Points are least squares means, with standard error bars. P-values are presented within the figure. 53

Figure 7: Body condition score for Charolais sired (C-) heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows measured at 241, 302, 423 and 553 days of age. Points are least squares means, with standard error bars. P-values are presented within the figure. 53

Figure 8: Un-fasted live weight for Charolais (C-) sired steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows from weaning at 193 days of age until slaughter. Points are least squares means, with standard error bars. P-values are presented within the figure. 57

Figure 9: Body condition score for Charolais sired (C-) steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows measured at 241, 302, 423 and 553 days of age. Points are least squares means, with standard error bars. P-values are presented within the figure. 57

1. Review of Literature

1.1. New Zealand Beef Industry

Beef production in New Zealand is largely pasture-based. Pastoral beef production allows for a low-cost and economically-sustainable system enabling the industry to be globally competitive (Morris and Kenyon, 2014). The production of beef primarily consists of the raising and finishing of bulls and steers and the processing of beef and dairy cull cows, heifers and bobby calves (Morris and Kenyon, 2014, Beef + Lamb NZ, 2015a).

Approximately 633,000 tonnes of beef is produced annually in New Zealand, of which 80-95% is exported overseas (Morris and Kenyon, 2014, Beef + Lamb NZ, 2015a). Markets for New Zealand export beef are primarily North America (52% total tonnes shipped weight) and North Asia (29%) with smaller markets in South Asia, the Middle East, the European Union and the Pacific (Beef + Lamb NZ, 2015a, Beef + Lamb NZ, 2015b).

As of June 2014, there were 3.6 million beef cattle in New Zealand, consisting of both finishing and breeding animals (Beef + Lamb NZ, 2015a). Beef breeding farms are often separate to finishing farms, each with different trait requirements depending on the system and sex of the animals. The New Zealand national beef recording scheme BreedPlan has a range of estimated breeding values (EBV's) based on desirable traits. Traits for breeding cows are focussed on fertility, calving ease, and milk production, whereas traits for finishing cattle include live-weight at 200, 400 and 600 days, and carcass traits including carcass weight, eye muscle area, fat depth and intramuscular fat (Breedplan, 2015).

1.1.1. Role of the New Zealand dairy Industry

The dairy industry plays an increasing role in beef production in New Zealand, with an estimated 65% of the beef produced in New Zealand originating from dairy herds (Morris, 2008). The dairy industry contributes to beef production through cull cows and by the sale of four-day-old calves for slaughter or rearing and weaned 12 week old calves for rearing (Morris, 2013, Morris and Kenyon, 2014). The New Zealand dairy industry produced 4.1 million calves in 2014 of which 1.07 million were retained as dairy replacements, 1.7 million were slaughtered as four-day-old calves, and 836,000 were reared as beef cattle both for meat production and breeding animals (Cook, 2014, Hickson *et al.*, 2015b).

Beef-cross-dairy-breed heifers can either be finished or kept as breeding cows in the beef herd. Dairy cows are selected for milk composition and volume, liveweight, fertility and survivability in the herd. Bulls used for artificial breeding are chosen on these characteristics for dairy heifer replacements. Bulls selected for natural mating, of which the purpose is to attain a pregnancy for milk production, focusses on calving ease and short gestation length, rather than to produce calves for beef production.

The use of beef-cross-dairy cows in the beef breeding herd takes advantage of the increased milk production abilities of the dairy breeds resulting in heavier calves at weaning; and can increase the efficiency of beef production through hybrid vigour and the potential for greater growth rates (Morris *et al.*, 1992, Morris *et al.*, 1993, Hickson *et al.*, 2012, Roca Fraga *et al.*, 2013, Collier *et al.*, 2015, Hickson *et al.*, 2015a, Little *et al.*, 2015). From previous research, the beef-cross-dairy cow has been shown to perform well as a beef breeding cow in terms of their production of weaned calves (Hickson *et al.*, 2014) , but it is important that these calves continue to perform well beyond weaning.

1.1.2. Carcass classification of beef in New Zealand

In New Zealand, carcasses are categorised according to sex class or castration status. Each sex class is graded separately with the exception of steers and heifers which are grouped together. Calves younger than two weeks old are not given a classification at slaughter (New Zealand Meat, 2004). Female cattle are categorised as heifers if they have no more than 6 permanent incisor teeth (assumed to be under 3 years of age), or as cows if they have more than 6 permanent incisor teeth (assumed to be older than 3 years old) (New Zealand Meat, 2004).

Although steers and heifers have different growth patterns, the cattle are still relatively young at slaughter, with little influence of fat, the carcasses have a similar composition and conformation at similar weights, allowing them to be graded in the same category, as prime steer/heifer (Kirton, 1989, New Zealand Meat, 2004). Cows are either classified as ‘prime cow’ or ‘M (manufacturing) cow’ depending on the level of finishing as defined by fat depth over the eye muscle.

Manufacturing cow also includes heifers and steers that did not reach the minimum weight or fat level (New Zealand Meat, 2004). In addition, any heifer, steer or cow that has excessively yellow fat, is also classified as ‘M cow’ (New Zealand Meat, 2004). All bulls are graded as ‘M (manufacturing) bull’ (New Zealand Meat, 2004).

In addition to carcass grades, all adult cattle other than those graded as ‘M’ cow, are also given one of three muscling scores (New Zealand Meat, 2004). Muscling scores are based on the degree of muscling over the carcass particularly in the hindquarters (New Zealand Meat, 2004). The muscling class ‘1’ represents high muscling, ‘2’ represents medium muscling and ‘3’ is poor muscling. Muscling scores ‘1’ and ‘3’ respectively increase or decrease the schedule price which represents a muscling score of ‘2’.

The ‘prime cow’ and steer/heifer category includes a range of grades, ‘P’ representing fat depths between 3 and 10 mm and generates the highest return per kg, ‘A’ and ‘L’ represent lesser fat depth and ‘T’ and ‘F’ represent greater fat depth (New Zealand Meat, 2004). Manufacturing bull are graded into two fat classes, ‘M’ and ‘TM’, representing fat depths below and above 3 mm. Cattle with a carcass classification of P return the greatest price to the farmer (cents/kg carcass weight) with other carcass classifications receiving a reduction in the price. Carcasses with more muscling are rewarded with a higher price per kg carcass weight, because increased muscling is associated with an increase in lean meat yield.

1.2. Influence of breed and sex in beef production

1.2.1. Beef breeds

Beef breeds used in New Zealand are British beef breeds Angus and Hereford, and the Friesian breed (Figure 1); with small populations of European beef breeds, including Charolais, Simmental and Limousin (Bass *et al.*, 1975, Carter, 1975, Baker *et al.*, 1990, Purchas *et al.*, 1992b, Akbas *et al.*, 2006, Morris, 2008, Purchas and Zou, 2008, Beef + Lamb NZ, 2015a). Straight-bred Angus made up the largest proportion (34%) of the national beef herd in the 2012-13 season, 21% were unspecified ‘mixed’ breed, 14% Friesian, 10% Hereford and 7% classed as other (Figure 1) (Beef + Lamb NZ, 2015a).

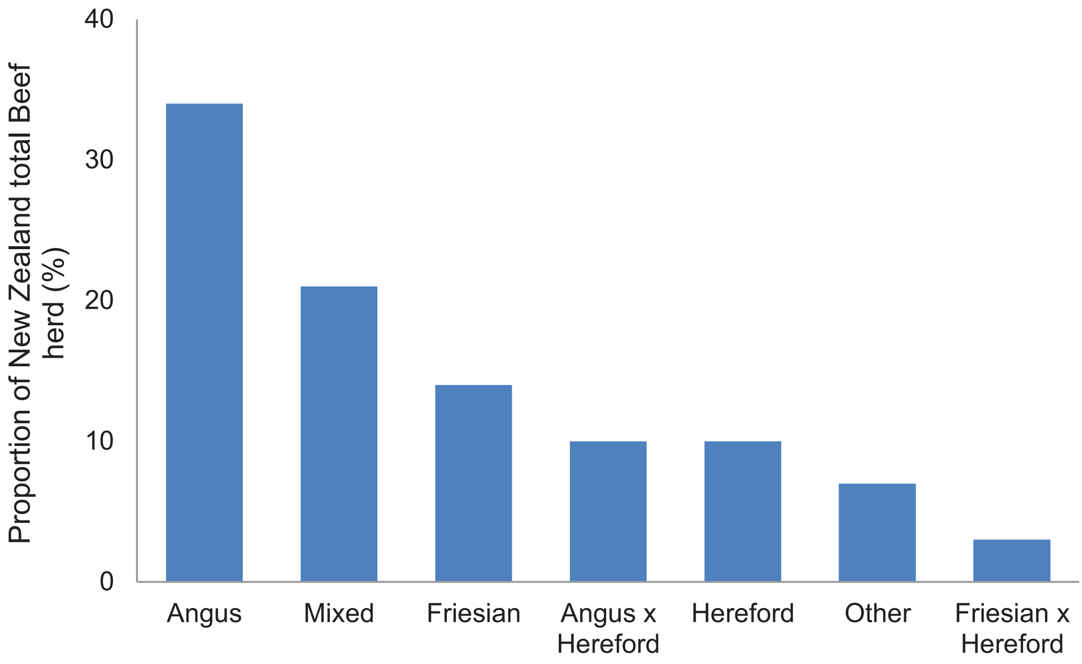


Figure 1: Proportions of different breeds making up the total New Zealand beef herd over the 2012-2013 season, numbers include stock kept for breeding and finishing stock (Beef + Lamb NZ, 2015a).

There is no breed of cattle that excels at all traits for beef production and so, cross-breeding allows for the utilisation of heterosis and combining of desired characteristics not present in any parent breed alone (Cundiff, 1970, Bass *et al.*, 1975, Neville *et al.*, 1984, Wheeler *et al.*, 2004, Wheeler *et al.*, 2005, Huuskonen *et al.*, 2013).

Utilising a cattle breed which is suited to the environment and production system can increase the productivity of the beef cattle in terms of animal growth and carcass production (Morris *et al.*, 1993, Alberti *et al.*, 2008, Keane and Moloney, 2009). The European beef breeds are used both as purebreds and as a cross with British and dairy breeds (Morris, 2008). Crossbreeding European breeds over Angus or Hereford cattle has been reported to improve growth rate and meat yield compared with straight-bred Angus or Hereford cattle (Carter, 1975, Purchas *et al.*, 1992b).

1.2.2. Dairy breeds for beef production

The composition of the New Zealand dairy industry is Friesian-Jersey cross (43%), Holstein Friesian (37%), and Jersey (11%) (DairyNZ, 2014). The Friesian-Jersey cross is now considered as a breed in itself and called “KiwiCross” (Garrick and Lopez-Villalobos, 1998). There is a preference for Friesian or beef-cross-Friesian calves to be selected for beef production rather than Jersey or KiwiCross calves. The Jersey breed has been largely excluded from the beef industry due to slower growth, lighter carcasses and yellower fat, leading to inferior grading at slaughter and a lower price per kg carcass (Butler-Hogg and Wood, 1982, Barton *et al.*, 1994, Burke *et al.*, 1998).

There is a view in the beef industry that meat from dairy breeds is of inferior eating quality compared to British and European beef breeds, which apart from differences in fat colour, is generally not supported by experimental evidence (Muir *et al.*, 2000). Although not genetically selected for beef production, there are very little differences among the meat quality characteristics from different breeds of cattle and any differences are unlikely to be identified by the consumer (Koch *et al.*, 1976, Purchas and Barton, 1976, Purchas *et al.*, 1992a). However, smaller-sized, slow-growing cattle can negatively influence the return to the farmer, as they are on farm longer and have lighter carcass weights.

Typically Angus and Hereford cattle along with Jersey are classified as early maturing, with Limousin, Friesian, Charolais and Simmental being late maturing. Cattle of a smaller frame size are typical of earlier maturing cattle, reaching lighter mature weights than late maturing cattle (Table 1) (Freer *et al.* 2007, Schreurs *et al.*, 2008).

Table 1: Standard reference mature weights (kg) for different cattle breeds from Freer *et al.* (2007), including whether the breed is early or late maturing

Breed	Cows	Steers	Bulls	Early/Late Maturing
Jersey	400	480	560	Early
Angus, Hereford	500	600	700	Early
Limousin, Friesian	550	660	770	Late
Charolais, Simmental	650	780	910	Late

1.2.3. Sex classifications in beef production

The proportion of total export beef from steers, heifers, cows and bulls from New Zealand is outlined in Figure 2. The higher proportion of beef from cows, rather than bulls or steers reflects the large number of cull dairy cows (Beef + Lamb NZ, 2015b). The lower proportion of export beef from heifers reflects that many heifers are kept for breeding rather than finished for slaughter, and that more males than females born to dairy cows are reared and finished for beef (Kirton and Morris, 1989, Beef + Lamb NZ, 2015b).

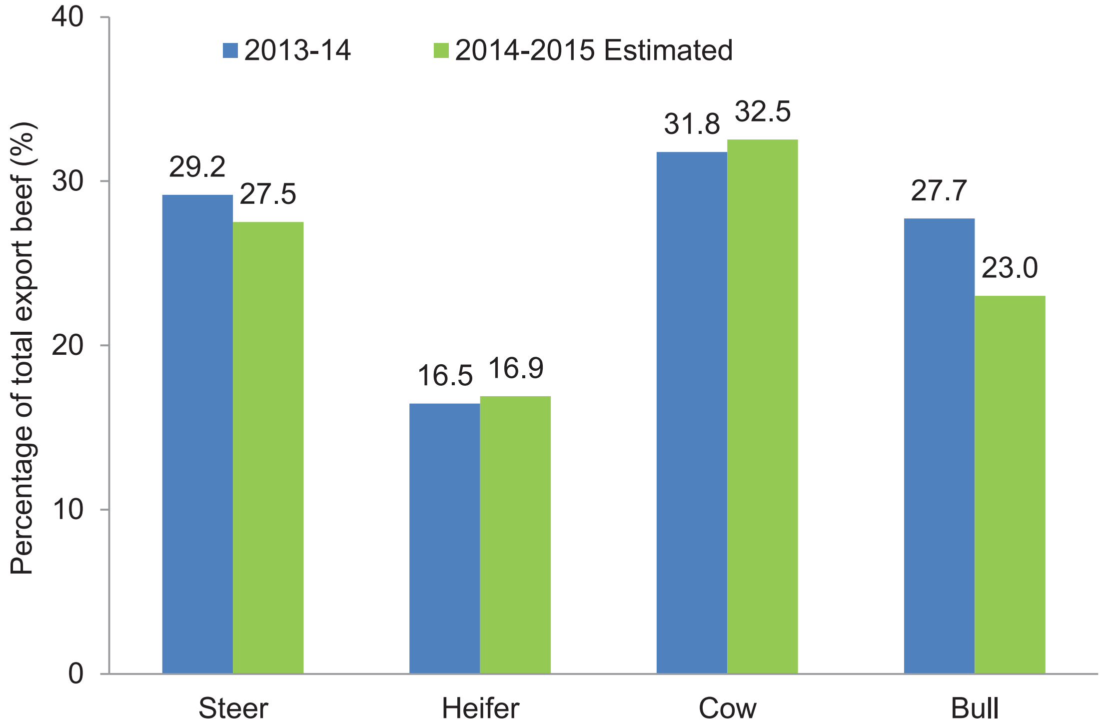


Figure 2: Composition of export beef (not including veal) production by sex class for the period 2013-14 and estimated values for the 2014-15 period (Beef + Lamb NZ, 2015b). Values expressed as percentage of total exported tonnes of beef as bone in carcass weight.

Castration is performed on males for management reasons because castrated males are more placid and can be grazed with females without unwanted mating although bulls are faster growing and reach heavier carcass weights (Kirton and Morris, 1989). Castration has the potential to improve the return from the carcass because steers graded as P receive a greater return per kg than bulls (New Zealand Meat, 2004).

1.3. Growth characteristics

The extent of an animal's growth is determined by its genetically defined mature weight. Most animals follow a sigmoidal growth pattern to attain their mature weight (Figure 3). However, animals exclusively used for meat production are slaughtered before mature weight is attained. The slope of the sigmoidal growth curve (Figure 3 A, C) gives the growth rate and is usually expressed as average daily gain (ADG, kg/day). Growth rate is an important economic driver in a finishing system because it determines time on-farm and amount of feed used for maintenance.

Cattle of a smaller frame size are typically early maturing breeds and they exhibit a slower growth rate, reaching lighter mature weights than the late maturing cattle (Table 1, Figure 3 A, C (Menchaca *et al.*, 1996, Schreurs *et al.*, 2008).

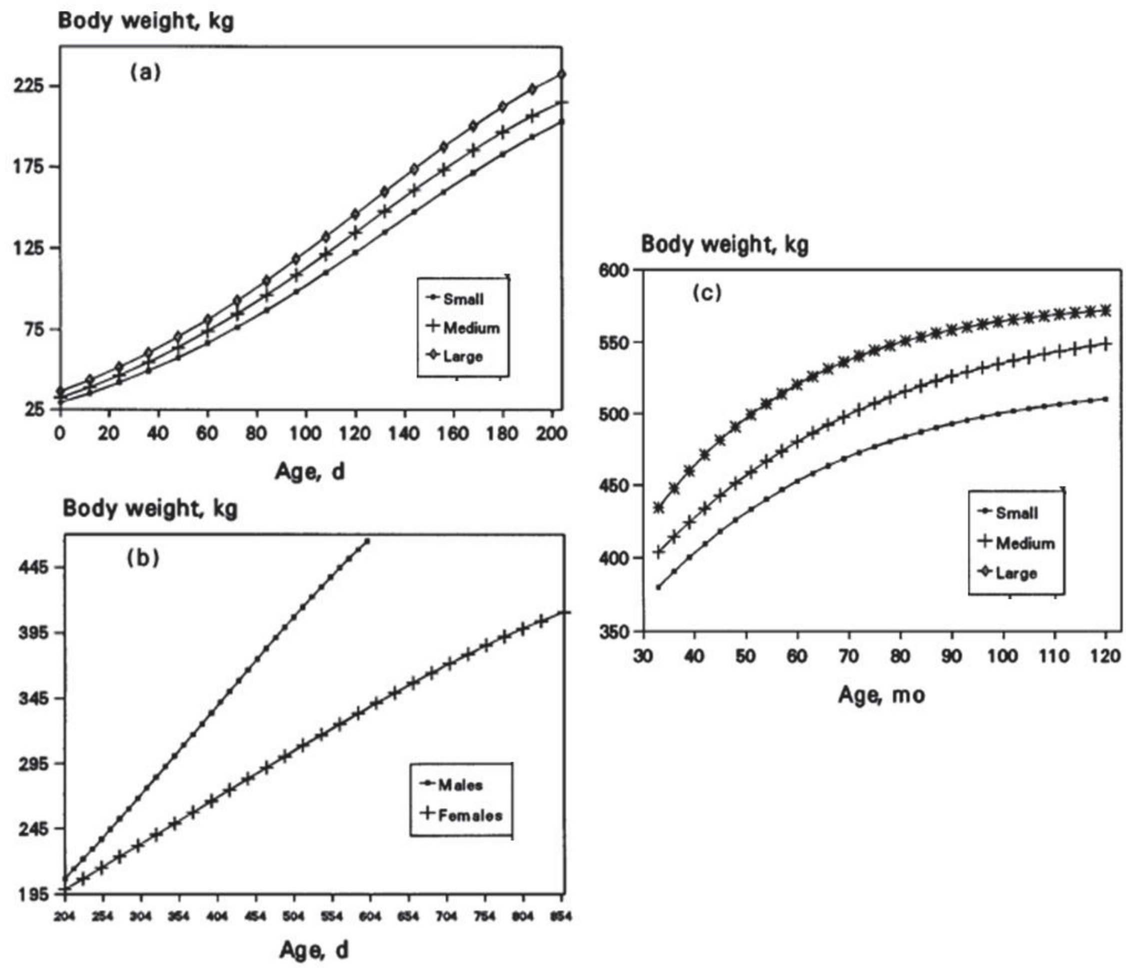


Figure 3: Body weight over age illustrating growth curves (a) from birth until weaning for Brahman bulls of three frame sizes, (b) from weaning until 20 or 32 months of age for males and females respectively, and (c) from 32 to 120 months of age for cows of three frame sizes. From Menchaca *et al.* (1996).

1.3.1. Influence of breed on growth characteristics

Experiments have shown similar growth rates from 6 – 13 months old until slaughter at an age varying from 13 to 29 months among Angus, Hereford, Charolais, Simmental and Limousin breeds of cattle (Table 2) (Laster *et al.*, 1976, Smith *et al.*, 1976, Gregory *et al.*, 1978, Young *et al.*, 1978, Laster *et al.*, 1979, Long *et al.*, 1979, Neville *et al.*, 1984, Baker *et al.*, 1990, Purchas *et al.*, 1992a, Mandell *et al.*, 1997a, Alberti *et al.*, 2008). However, one experiment in Europe found Angus bulls had faster growth rates between 9 and 15 months of age when compared with Charolais, Simmental and Limousin bulls (Table 2) (Alberti *et al.*, 2008). Friesian cattle grow faster than Jersey cattle at all ages, while Friesian-Jersey crossbred cattle have intermediate growth rates (Table 2) (Long *et al.*, 1979, Baker *et al.*, 1990, Barton *et al.*, 1994, Burke *et al.*, 1998, Alberti *et al.*, 2008).

1.3.2. Influence of sex classification and age on growth characteristics

There is a difference in the growth rate among cattle of different sexes (Kirton and Morris, 1989, Menchaca *et al.*, 1996, Burnham, 2000). Males, both entire and castrate, are associated with faster growth than females because they are growing towards a larger mature weight (Table 3, Figure 3 b) (Wilson *et al.*, 1969, Lambe *et al.*, 2010, Bures and Barton, 2012, Lage *et al.*, 2012). Bulls generally grow faster than steers (Table 3) (Bailey *et al.*, 1966, Kirton and Morris, 1989, Purchas *et al.*, 2002a). However, during less favourable conditions there is less of a difference among the growth rates of different sexes (Burnham, 2000).

Table 2: Growth rate (as average daily gain (ADG), kg/day) from different sire breeds between two ages (months).

Description	Start age	End age	Ang	Here	Cha	Sim	Lim	Fr	Jer	F-J	Location	Diet	Source
Pure- and crossbred steers [1]	0	23						0.6	0.5	0.6	NZ	Pasture	Barton *et al.* (1994)
Crossbred steers and bulls [1]	6	13	0.4	0.4	0.4	0.4	0.4	0.5	0.4		NZ	Pasture	Baker *et al.* (1990)
Purebred Heifers [1]	6	18	0.5	0.4							USA	Corn silage / concentrate	Gregory *et al.* (1978)
Crossbred Heifers [1]	6	18	0.5	0.5							USA	Corn silage / Alfalfa haylage / Pasture	Laster *et al.* (1979)
Crossbred Steers	7	13			1.2	1.3	1.1		1.0		USA	Corn silage based concentrate	Smith *et al.* (1976)
Crossbred Heifers [1]	7	18			0.5	0.5	0.5		0.4		USA	Corn silage & grass haylage	Laster *et al.* (1976)
Crossbred heifers	7	31						0.4	0.4		NZ	Pasture	Burke *et al.* (1998)
Purebred Steers	8	16			1.5		1.4				Canada	Concentrate	Mandell *et al.* (1997)
Purebred bulls	9	15	2.0		1.5		1.5	1.2	1.1		UK, EU	Barley concentrate and straw	Alberti *et al.* (2008)
Purebred Steers	9	19	0.7	0.8							USA	Oats & Pasture	Neville *et al.* (1984)
Purebred Heifers	9	21	0.5	0.5				0.6	0.4		USA	Sorghum concentrate	Long *et al.* (1979)
Crossbred steers	9	29		0.5		0.6	0.6				NZ	Pasture	Purchas *et al.* (1992a)
Crossbred Heifers	13	18			0.5	0.5	0.5	0.4			USA	Corn silage / Alfalfa / grass haylage	Young *et al.* (1978)

Ang = Angus, Here = Hereford, Cha = Charolais, Sim = Simmental, Lim = Limousin, Fr = Friesian, Jer = Jersey, F-J = Friesian-cross-Jersey
NZ = New Zealand, USA, United States, UK = United Kingdom, EU = European Union
[1] Calculated using published weights at two ages

Table 3: Growth rate (ADG, kg/day) from different sex classes between two ages (months).

Description	Start age	End age	Bulls	Steers	Heifers	Location	Diet	Source
Purebred Hereford	7	15		1.0	0.9	USA	Corn meal concentrate	Wilson *et al.* (1969)
Purebred Hereford	7	14	1.2	1.1		USA	Grain concentrate	Bailey *et al.* (1966)
Crossbred Charolais	8	14	1.4		1.1	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Crossbred Simmental	8	18	1.3		0.9	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Crossbred Angus [1]	15	19		1.4	1.3	UK	Grass silage / cereal concentrate	Lambe *et al.* (2010)
Crossbred Limousin [1]	15	19		1.3	1.3		Grass silage / cereal concentrate	Lambe *et al.* (2010)
Crossbred Zebu	18	22		1.1	1.1	Brazil	Corn silage concentrate	Lage *et al.* (2012)
Pure- and Crossbred Angus	8	17	1.3	1.1		NZ	Pasture	Purchas *et al.* (2002a)

NZ = New Zealand, USA, United States, UK = United Kingdom, EU = European Union
[1] Calculated using published weights at two ages

1.4. Carcass Characteristics

Carcass characteristics are measured on the carcass after slaughter, but it is possible to predict these traits on the live animal through the use of ultrasound and knowledge of the breed and differences among cattle of different production types and maturities (Irshad *et al.*, 2013).

Carcass characteristics include dressing out percentage, eye muscle area, subcutaneous fat depth, intramuscular fat, and the conformation of the carcass. The dressing out percentage and shape (conformation) of the carcass can be directly measured at slaughter. Carcass composition can only be estimated through measuring eye muscle area (a predictor of total lean muscle yield, (Johnson *et al.*, 1994)), subcutaneous fat depth or intramuscular fat (predictors of total fat content, Taylor *et al.* (1996)). Eye muscle area and subcutaneous fat are measured on the carcass at slaughter or by ultrasound on the live animal or carcass. Intramuscular fat can only be measured by ultrasound.

Carcass characteristic traits have generally moderate to high heritability's, and so can be influenced significantly by breed (Table 4) (Irshad *et al.*, 2013). Crossbreeding is a viable option to alter these characteristics as there is a wide variability among breeds for all traits (Alberti *et al.*, 2008).

Table 4: Heritability ranges for carcass composition traits from (Irshad *et al.*, 2013). Low = 0-0.25, moderate = 0.25-0.5, high = 0.5-1.

Trait	Heritability
Dressing-out percentage	Low – moderate
Ultrasound eye muscle area	Moderate – high
Ultrasound fat depth	Moderate – high
Carcass length	High

1.4.1. Dressing-out percentage

Dressing-out percentage is the proportion of live weight that is carcass tissue. Dressing-out percentage is difficult to compare among studies, due to variations in gut fill and gut weight, fat content in carcass and non-carcass, and factors which influence the live weight such as skin or hide weight (Kirton and Morris, 1989, Purchas, 2003). Dressing-out percentage has a low heritability (Table 4) (Kirton and Morris, 1989, Purchas, 2003, Irshad *et al.*, 2013).

1.4.1.1. *Influence of breed on dressing-out percentage*

Dressing-out percentages tend to be lower in British breeds when compared with continental European breeds of cattle at the same age, because British breeds tend to be closer to maturity and have a larger proportion of fat in non-carcass depots (Wheeler *et al.*, 2005, Irshad *et al.*, 2013). Crossing British or Dairy breeds with later-maturing European breeds has the potential to increase growth rates, and increase the dressing-out percentage and meat yield when compared with other crosses (Purchas *et al.*, 1992b).

In New Zealand studies, Limousin and Charolais cattle had a greater dressing-out percentage than Simmental and Hereford cattle, Angus cattle tended to have the lowest dressing-out percentage of New Zealand beef breeds (Table 5) (Morris *et al.*, 1990, Barton and Pleasants, 1997, Collier *et al.*, 2015). In studies outside of New Zealand where concentrate feeds were fed, the Angus breed had generally greater or equal dressing-out percentage to that of Hereford and Simmental (Table 5) (Wheeler *et al.*, 2004, Wheeler *et al.*, 2005, Alberti *et al.*, 2008, Wheeler *et al.*, 2010). In Australian studies, where pasture was also fed, Angus cattle had similar dressing-out percentages to that of Hereford and Charolais (Table 5) (Arthur *et al.*, 1995).

The Friesian or Holstein-Friesian breed had a greater dressing-out percentage than Jersey cattle (Table 5) (Butler-Hogg and Wood, 1982, Morris *et al.*, 1990, Barton *et al.*, 1994, Barton and Pleasants, 1997, Purchas and Morris, 2007, Alberti *et al.*, 2008). Barton *et al.* (1994) reported that crossbreed Friesian-Jersey steers had a similar dressing-out percentage to Friesian (Table 5).

Purebred and crossbred Jersey cattle had a lower or similar dressing-out percentage to Angus cattle, and a lower dressing-out percentage than other beef breeds and Friesian cattle (Table 5) (Morris *et al.*, 1990, Barton and Pleasants, 1997, Purchas and Morris, 2007, Alberti *et al.*, 2008). Friesian cattle tended to have a lower dressing-out percentage than European beef breeds (Limousin, Charolais and Simmental) and Hereford cattle (Table 5) (Morris *et al.*, 1990, Barton and Pleasants, 1997, Muir *et al.*, 2000, Wheeler *et al.*, 2004, Alberti *et al.*, 2008). The differences between Friesian and Angus breed cattle dressing-out percentages differed among studies that varied among ages in New Zealand studies (Table 5) (Morris *et al.*, 1990, Barton and Pleasants, 1997, Purchas and Morris, 2007). Previous research on progeny of the dams used for this experiment reported greater dressing-out percentages from crossbred Angus and Friesian steers than Jersey steers (Schreurs *et al.*, 2014, Collier *et al.*, 2015).

1.4.1.2. *Influence of sex classification and age on dressing-out percentage*

Bulls had a greater dressing-out percentage than both heifers and steers, and steers had a lower dressing-out percentage than heifers (Table 6) (Bailey *et al.*, 1966, Wilson *et al.*, 1969, Purchas and Aungsupakorn, 1993, Purchas and Grant, 1995, Purchas *et al.*, 1997, Bures and Barton, 2012, Lage *et al.*, 2012), but the differences were small and are likely dependent on the feed, housing system and slaughter procedure. The dressing-out percentage increases as the animal ages (Morris *et al.*, 1990, Warren *et al.*, 2008).

Table 5: Dressing-out percentage from different sire breeds at a range of ages (months).

Description	Age	Ang	Here	Cha	Sim	Lim	Fr	Jer	F-J	Location	Diet	Source
Purebred steers	0.5						54.5	49.6		UK	Concentrate	Butler-Hogg and Wood (1982)
Purebred steers	3						45.5	43.5		UK	Concentrate	Butler-Hogg and Wood (1982)
Purebred steers	5						49.0	42.6		UK	Concentrate	Butler-Hogg and Wood (1982)
Purebred steers	11						54.8	50.6		UK	Concentrate	Butler-Hogg and Wood (1982)
Crossbred steers	14	61.1	60.5	61.3	60.8	61.8				USA	Corn silage concentrate	Wheeler *et al.* (2005)
Crossbred steers	14	60.8	61.0							USA	Corn silage concentrate	Wheeler *et al.* (2010)
Crossbred steers	15	61.4	61.4				60.9			USA	Corn silage concentrate	Wheeler *et al.* (2004)
Purebred bulls [1]	15	56.2		61.0	55.5	63.7	55.7	50.1		EU	Barley concentrate & straw	Alberti *et al.* (2008)
Crossbred steers and heifers	15	55.7	55.6	56.6						Australia	Pasture	Arthur *et al.* (1995)
Purebred steers	16						58.0	54.9		UK	Maize & Alfalfa concentrate	Butler-Hogg and Wood (1982)
Crossbred steers and bulls	20	50.1	51.3	52.1	51.1	52.6	50.7	49.5		NZ	Pasture	Morris *et al.* (1990)
Crossbred steers	22	50.8			52.2					NZ	Pasture	Collier *et al.* (2015)
Pure- and cross-bred steers	23						52.1	51.2	52.2	NZ	Pasture	Barton *et al.* (1994)
Pure- and cross-bred steers	27		53.3				51.5			NZ	Pasture	Muir *et al.* (2000)
Purebred steers	27	51.7					51.4	50.2		NZ	Pasture	Purchas and Morris (2007)
Crossbred steers	27	58.7	58.8	59.2						Australia	Pasture	Arthur *et al.* (1995)
Purebred steers	30	52.7	54.1				51.2	48.5		NZ	Pasture	Barton and Pleasants (1997)
Crossbred steers and bulls	30	50.9	52.5	52.9	51.7	53.3	51.4	50.3		NZ	Pasture	Morris *et al.* (1990)
Crossbred heifers [2]	31						50.0	50.0		NZ	Pasture	Burke *et al.* (1998)

Ang = Angus, Her = Hereford, Cha = Charolais, Sim = Simmental, Lim = Limousin, Fr = Friesian, Jer = Jersey, F-J = Friesian-cross-Jersey
NZ = New Zealand, USA, United States, UK = United Kingdom, EU = European Union

[1] Dressing-out % calculated using least squares means for final live weight and hot carcass weight

[2] Adjusted for carcass weight

Table 6: Dressing-out percentage from different sex classes at a range of ages (months).

Description	Age	Bulls	Steers	Heifers	Location	Diet	Source
Charolais cross Simmental [1]	14	56.6		55.3	EU	Maize and Alfalfa concentrate	Bures and Barton (2012)
Purebred Hereford [1]	14	61.3	61.1		USA	Grain concentrate	Bailey *et al.* (1966)
Purebred Hereford	15		62.0	62.5	USA	Corn meal concentrate	Wilson *et al.* (1969)
Charolais cross Simmental [1]	18	56.9		55.2	EU	Maize and Alfalfa concentrate	Bures and Barton (2012)
Crossbred Zebu [1]	22		56.4	57.6	Brazil	Grain concentrate	Lage *et al.* (2012)
Crossbred Hereford	25	51.5	50.6		NZ	Pasture	Purchas *et al.* (1997)
Crossbred Hereford	25	50.0	49.2		NZ	Pasture	Purchas and Grant (1995)
Crossbred Friesian	27	51.5	49.8		NZ	Pasture	Purchas and Aungsupakorn (1993)

EU = European Union, USA = United States of America, NZ = New Zealand
[1] Dressing-out % calculated using least squares means for final live weight and hot carcass weight

1.4.2. Eye Muscle Area

A common approach to estimate the lean muscle component of carcass composition, is to measure the transverse surface area of the *Longissimus thoracis et lumborum* muscle (Purchas *et al.*, 2002b). A larger eye muscle area is indicative of a carcass with a larger proportion of lean muscle. Eye muscle area is a moderate predictor of lean or saleable meat yield (Purchas, 2012).

Eye muscle area can be measured on a live animal by ultrasound scanning, over the *Longissimus thoracis* muscle between the 12^{th} and 13^{th} rib; or by tracing around the muscle at slaughter after the carcass has been quartered between the 12^{th} and 13^{th} rib. Eye muscle area measured by ultrasound has a moderate to high heritability (Table 4) (Irshad *et al.*, 2013).

1.4.2.1. Influence of breed on eye muscle area

In experiments outside of New Zealand, eye muscle area measurements at slaughter for Angus and Hereford cattle were not different between the breeds (Table 7) (Koch *et al.*, 1976, Neville *et al.*, 1984, Morris *et al.*, 1990, Wheeler *et al.*, 2004, Wheeler *et al.*, 2005, Purchas and Morris, 2007, Wheeler *et al.*, 2010). Similarly the published data also showed no differences among the European beef breeds Charolais, Simmental and Limousin (Table 7) (Koch *et al.*, 1976, Morris *et al.*, 1990, Purchas *et al.*, 1992a, Wheeler *et al.*, 2005). European beef breeds have been shown to have greater eye muscle areas than British beef breeds relative to carcass weight (Table 7) (Koch *et al.*, 1976, Morris *et al.*, 1990, Purchas *et al.*, 1992a, Wheeler *et al.*, 2005).

When adjusted for carcass weight, New Zealand Friesian and Jersey cattle had similar eye muscle areas (Table 7) (Morris *et al.*, 1990, Burke *et al.*, 1998). Without adjusting for carcass weight, Friesian cattle had greater eye muscle areas compared with Jersey cattle, Friesian-cross-Jersey cattle were the same as Friesian (Table 7) (Barton *et al.*, 1994). Dairy cattle tended to have smaller eye muscle areas, compared with European beef breeds, and were similar to British breeds (Table 7) (Koch *et al.*, 1976, Morris *et al.*, 1990, Wheeler *et al.*, 2004, Purchas and Morris, 2007). Previous research on progeny of the dams used for this experiment reported similar eye muscle areas from crossbred Angus and dairy steers in which ¼ of the genetics differed among breed-crosses (Schreurs *et al.*, 2014).

Table 7: Eye muscle area (cm^2) measured on the carcass at slaughter from different sire breeds at a range of ages (months).

Description	Age	Ang	Here	Cha	Sim	Lim	Fr	Jer	F-J	Location	Diet	Source
Crossbred steers[1]	14	83	80.1	88	87.3	90				USA	Corn silage concentrate	Wheeler *et al.* (2005)
Crossbred steers[1]	14	80	79.9							USA	Corn silage concentrate	Wheeler *et al.* (2010)
Crossbred steers[1]	15	71	69.7	79	77.7	82		70		USA	Corn silage concentrate	Koch *et al.* (1976)
Crossbred steers	15	82	83.6				80			USA	Corn silage concentrate	Wheeler *et al.* (2004)
Purebred steers	19	57	57							USA	Oats and Pasture	Neville *et al.* (1984)
Crossbred steers and bulls[1]	20	79	73	85	80.3	85	76	75		NZ	Pasture	Morris *et al.* (1990)
Purebred and crossed steers	23						60	51	58	NZ	Pasture	Barton *et al.* (1994)
Purebred and crossed steers[1]	27	67	68.3					67		NZ	Pasture	Purchas and Morris (2007)
Crossbred steers[1]	29		63.8		65.4	69				NZ	Pasture	Purchas *et al.* (1992a)
Crossbred heifers[1]	31						59	60		NZ	Pasture	Burke *et al.* (1998)
Crossbred steers and bulls[1]	31	97	93	104	101	104	91	92		NZ	Pasture	Morris *et al.* (1990)

Ang = Angus, Her = Hereford, Cha = Charolais, Sim = Simmental, Lim = Limousin, Fr = Friesian, Jer = Jersey, F-J = Friesian-Jersey cross
[1] Adjusted for carcass weight

1.4.3. Subcutaneous Fat depth

Subcutaneous fat depth is an important factor in carcass classification (Kirton, 1989). As the depth of subcutaneous fat increases, the yield of muscle and/or saleable meat on the carcass tends to decrease, however, fatness is positively associated with palatability (Kirton, 1989). For most consumers a lower subcutaneous fat content is preferred (Kirton, 1989, Purchas, 2003). Subcutaneous fat depth is a good predictor of total fat content but not lean meat yield (Purchas, 2012).

Carcass subcutaneous fat is determined by measuring the fat thickness over the *Longissimus thoracis et lumborum* muscle either by ultrasound, or by direct measure on the carcass after carcass quartering (fat depth C between the 12^{th} and 13^{th} rib) (Kempster and Owen, 1981). Subcutaneous fat depth can be assessed at the P8 site on the rump. This is usually done by ultrasound on the live animal or carcass.

1.4.3.1. Influence of breed on subcutaneous fat depth

British beef breeds of Angus and Hereford have a similar fat depth C at the same age (Table 8) (Koch *et al.*, 1976, Neville *et al.*, 1984, Morris *et al.*, 1990, Barton and Pleasants, 1997, Wheeler *et al.*, 2004, Wheeler *et al.*, 2005, Purchas and Morris, 2007, Wheeler *et al.*, 2010). Continental European beef breeds Charolais, Simmental and Limousin also have very similar subcutaneous fat depths at the same ages (Table 8) (Koch *et al.*, 1976, Morris *et al.*, 1990, Purchas *et al.*, 1992a, Mandell *et al.*, 1997a, Wheeler *et al.*, 2005). European beef breeds had a consistently lower fat depth C than British beef breeds, when adjusted for carcass weight (Table 8) (Koch *et al.*, 1976, Morris *et al.*, 1990, Purchas *et al.*, 1992a, Wheeler *et al.*, 2005).

The Jersey and Friesian breeds have a similar fat depth C (rib fat) when compared at the same age; however, in a New Zealand experiment on older cattle, the Jersey cattle had slightly greater fat depths (Table 8) (Morris *et al.*, 1990, Barton *et al.*, 1994, Burke *et al.*, 1998). Friesian cattle have greater fat depth C than European beef breeds, and less than British beef breeds (Table 8) (Morris *et al.*, 1990, Barton and Pleasants, 1997, Wheeler *et al.*, 2004). Jersey cattle have fat depths similar to British beef breeds, greater than European breeds, although a New Zealand experiment, not adjusting for carcass weight, found Jersey cattle had lesser fat depth C than British beef breeds (Table 8) (Koch *et al.*, 1976, Morris *et al.*, 1990, Purchas and Morris, 2007). Previous research on progeny of the dams used for this experiment reported similar subcutaneous fat depths from crossbred Angus and dairy steers in which ¼ of the genetics differed among breed-crosses (Schreurs *et al.*, 2014).

1.4.4. Intramuscular Fat

The visual appearance of intramuscular fat (IMF) or marbling is often associated with greater palatability of beef, particularly tenderness and plays a role in purchasing decisions and price (Blumer, 1963, Chambaz *et al.*, 2003, Aass *et al.*, 2009). Intramuscular fat can be examined via ultrasound on the live animal, or chemically measured in lean meat, but is only visible post-slaughter when the cuts of meat are removed for sale. Intramuscular fat in literature is also assessed visually with a marbling score.

Although ultrasound scanning to determine IMF percentage is possible, it is not widely used, except for in stud herds. Research experiments determine the proportion of intramuscular fat via chemical analysis, but the beef producer generally will not know the proportion of intramuscular fat in the carcass of the cattle.

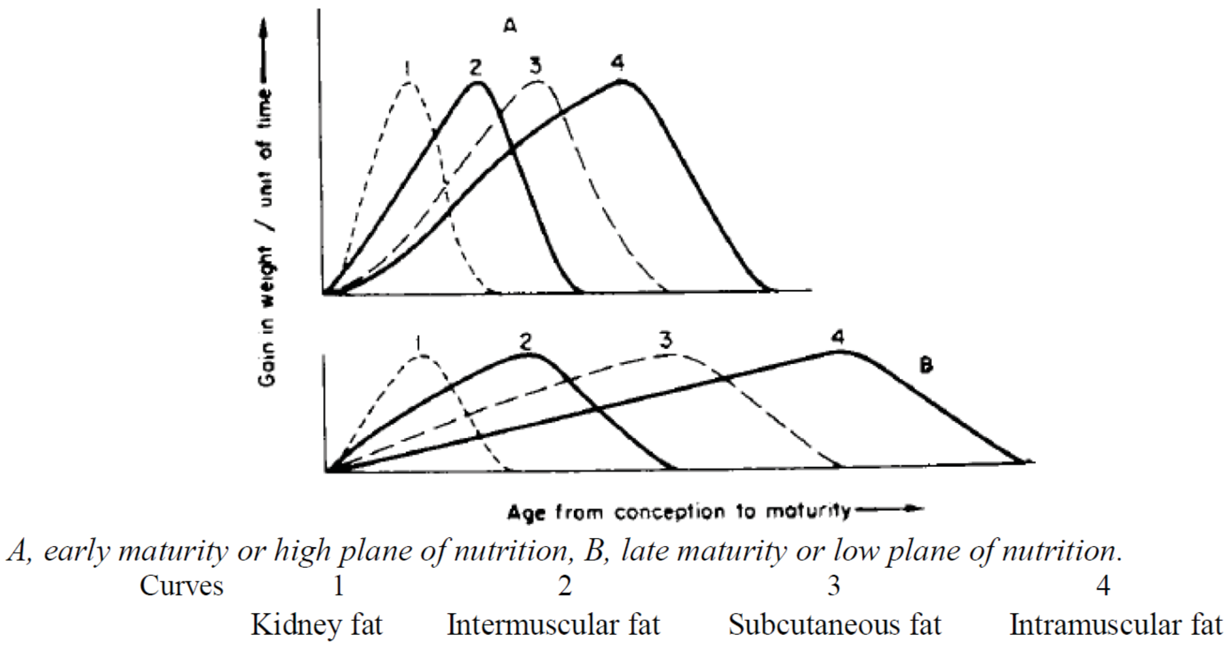


Figure 4: Differences between early and late maturing animals on the rate of increase in different fat depots, from Irshad *et al.* (2013).

Table 8: Subcutaneous fat depth C (mm) at slaughter among breeds at a range of ages (months).

Description	Age	Ang	Here	Cha	Sim	Lim	Fr	Jer	F-J	Location	Diet	Source
Crossbred steers[1]	14	14.0	13.1	7.6	8.1	9.6				USA	Corn silage concentrate	Wheeler *et al.* (2005)
Crossbred steers[1]	14	12.0	10.8							USA	Corn silage concentrate	Wheeler *et al.* (2010)
Crossbred steers[1]	15	18.0	14.3	7.6	9.1	9.7		14.0		USA	Corn silage concentrate	Koch *et al.* (1976)
Crossbred steers	15	12.0	9.3				9.0			USA	Corn silage concentrate	Wheeler *et al.* (2004)
Purebred steers	19	12.0	12.0							USA	Oats and Pasture	Neville *et al.* (1984)
Purebred Steers	16			6.3		5.1				Canada	Concentrate	Mandell *et al.* (1997)
Crossbred steers and bulls[1]	20	4.8	6.0	2.5	3.3	3.1	4.0	4.5		NZ	Pasture	Morris *et al.* (1990)
Purebred and crossed steers	23						2.0	2.6	3.3	NZ	Pasture	Barton *et al.* (1994)
Purebred and crossed steers	27	3.3	3.1					1.7		NZ	Pasture	Purchas and Morris (2007)
Crossbred steers[1]	29		7.2		4.8	4.6				NZ	Pasture	Purchas *et al.* (1992a)
Purebred steers	30	12.0	11.4				5.0			NZ	Pasture	Barton and Pleasants (1997)
Crossbred heifers[1]	31						6.0	7.6		NZ	Pasture	Burke *et al.* (1998)
Crossbred steers and bulls[1]	31	8.4	10.2	5.0	5.6	5.4	7.0	8.8		NZ	Pasture	Morris *et al.* (1990)

Ang = Angus, Her = Hereford, Cha = Charolais, Sim = Simmental, Lim = Limousin, Fr = Friesian, Jer = Jersey, F-J = Friesian-Jersey cross
[1] Adjusted for carcass weight

Intramuscular fat is a late-maturing fat depot which is deposited after subcutaneous fat (Figure 4) (Irshad *et al.*, 2013). Cattle breeds differ in their ability to lay down intramuscular fat due to mature size differences and genetic variation among breeds (Figure 4) (Johnson, 1987, Chambaz *et al.*, 2003, Pethick *et al.*, 2004, Irshad *et al.*, 2013). The deposition of intramuscular fat is also influenced by energy intake, as cattle finished on feedlots with high energy feed rather than on pasture, have an increased IMF percentage (Pethick *et al.*, 2004).

1.4.4.1. Influence of breed on intramuscular fat

Early-maturing breeds Angus, Hereford and Jersey have greater levels of intramuscular fat compared to the later-maturing, European breeds (Figure 4) (Siebert *et al.*, 1999, Purchas and Zou, 2008, Irshad *et al.*, 2013). In studies outside of New Zealand, where concentrate feeding is used, Angus cattle have a greater proportion of intramuscular fat than Hereford and Friesian cattle (Dubeski *et al.*, 1997). Charolais cattle have more intramuscular fat than Limousin cattle (Mandell *et al.*, 1997a). Jersey cattle have a tendency to have a higher proportion of intramuscular fat than British, and later maturing breeds at the same age (Purchas and Barton, 1976, Burke *et al.*, 1998, Purchas and Morris, 2007). Friesian cattle tend to have comparatively higher intramuscular fat than European late-maturing cattle at the same age, but less than British beef breeds (Johnson, 1987, Pfuhl *et al.*, 2007). However, in an experiment using progeny from the same dams used for the present experiment, Schreurs *et al.* (2014) found no difference between dairy and angus cross steers, where there was only ¼ difference in genetics among the steer breed-crosses.

1.4.5. Influence of sex and age on carcass composition

Males have greater eye muscle area, and are leaner compared with heifers at the same age (Table 9, Table 10, Figure 4) (Wilson *et al.*, 1969, Bures and Barton, 2012, Lage *et al.*, 2012, Irshad *et al.*, 2013). Bulls have more muscle than steers whereas steers have fatter carcasses than bulls, with significantly greater marbling (Table 9, Table 10) (Glimp *et al.*, 1971, Kirton and Morris, 1989, Purchas and Aungsupakorn, 1993, Purchas and Grant, 1995, Mandell *et al.*, 1997b, Purchas *et al.*, 1997, Irshad *et al.*, 2013). As shown in Figure 4, the fat content of cattle increases with age, with kidney fat developing first, followed by intermuscular then subcutaneous fat and intramuscular fat tending to develop last. Therefore, with increasing age, it would be expected that subcutaneous and intramuscular fat content increases (Arthuad *et al.*, 1977, Irshad *et al.*, 2013). The eye muscle area also increases with age likely as a result of increasing size of individual muscle fibres as the animal ages (Maltin *et al.*, 1998).

1.4.3. Carcass Conformation

Conformation scoring, both on the live animal and on the carcass is used widely internationally, although not used to the same extent in New Zealand. The conformation of a carcass is related to the shape of the carcass, and is determined by the degree of muscling and the level of fat cover over the carcass relative to the skeletal dimension (Purchas *et al.*, 2002b, Conroy *et al.*, 2010). The most common approaches to assessing carcass conformation or shape is at slaughter by visually assessing the muscularity and subcutaneous fat cover on carcasses at slaughter or to make measurements on the cut surface of the *Longissimus thoracis et lumborum* muscle (Purchas *et al.*, 2002b). Conformation is accounted for in the New Zealand carcass grading system where a muscling score is given.

Shorter, blockier, fleshier carcasses tend to have a conformation more suited to beef production as the degree of muscling relative to the skeletal length is greater than a longer carcass of the same weight (Butler, 1957, Kirton and Pickering, 1967). Carcass length has a high heritability (Table 4) (Irshad *et al.*, 2013) and so is highly influenced by breed. Superior muscularity is associated with higher saleable and lean meat yields, unless the shape is due to a high proportion of subcutaneous fat (Conroy *et al.*, 2010).

Conformation is associated to the distribution of muscle in the higher priced muscles (e.g. *Longissimus thoracis et lumborum*) and proportion of muscle relative to bone, which can be used to indicate carcass composition (Drennan *et al.*, 2008). The continental European beef breeds have a more desirable conformation than British beef breeds, and dairy breeds would have the least desirable conformation (McGee *et al.*, 2007, Warren *et al.*, 2008). As bulls have a greater ratio of muscle to bone, bulls have a better conformation than steers, and heifers the least desirable (Drennan *et al.*, 2008). Although as steers and heifers are slaughtered before they reach maturity, steers and heifers are of similar size and conformation, allowing the carcasses to be graded in the same category. As conformation is positively correlated to muscle development (Drennan *et al.*, 2008, Conroy *et al.*, 2010), the conformation scoring of cattle increases with age (Arthuad *et al.*, 1977, Warren *et al.*, 2008).

Table 9: Eye muscle area (cm^2) measured on the carcass at slaughter from different sex classes at a range of ages (months).

Description	Age	Bulls	Steers	Heifers	Location	Diet	Source
Charolais cross Simmental	14	60.1		57.8	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Purebred Hereford	15		70.2	67.9	USA	Corn meal concentrate	Wilson *et al.* (1969)
Charolais cross Simmental	18	71.6		58.6	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Crossbred Hereford	25	73.9	69.0		NZ	Pasture	Purchas *et al.* (1997)
Crossbred Hereford	25	69.7	63.2		NZ	Pasture	Purchas and Grant (1995)
Crossbred Friesian	27	70.3	60.9		NZ	Pasture	Purchas and Aungsupakorn (1993)
Crossbred Zebu	22		62.6	52.1	Brazil	Corn silage concentrate	Lage *et al.* (2012)

EU = European Union, USA = United Stated of America, NZ = New Zealand

Table 10: Subcutaneous fat depth C (mm) at slaughter from different sex classes at a range of ages (months).

Description	Age	Bulls	Steers	Heifers	Location	Diet	Source
Charolais cross Simmental	14	2.5		5.2	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Purebred Hereford	15		11.4	15.2	USA	Corn meal concentrate	Wilson *et al.* (1969)
Charolais cross Simmental	18	4.6		6.7	EU	Maize & Alfalfa concentrate	Bures and Barton (2012)
Crossbred Hereford	25	1.6	3.3		NZ	Pasture	Purchas *et al.* (1997)
Crossbred Hereford	25	1.7	4.0		NZ	Pasture	Purchas and Grant (1995)
Crossbred Friesian	27	1.0	2.3		NZ	Pasture	Purchas and Aungsupakorn (1993)
Crossbred Zebu	22		5	4	Brazil	Corn silage concentrate	Lage *et al.* (2012)

EU = European Union, USA = United Stated of America, NZ = New Zealand

1.5. Meat Quality Characteristics

The quality of meat relates to how the consumer accepts the beef product (Warner *et al.*, 2010) and is typically considered in relation to expectations or previous eating experience. Quality encompasses all reactions to quality from poor to good quality. The characteristics that are considered for meat quality include appearance and palatability (Purchas and Zou, 2008, Warner *et al.*, 2010). The important appearance attributes are the colour of the lean meat and the fat and the important palatability characteristics relate to the tenderness, juiciness and flavour of the meat (Purchas and Zou, 2008). Appearance of beef is important for informing purchasing decisions while palatability is important for meat eating experience and the decision to repurchase (Walker *et al.*, 1990, Muir *et al.*, 2000, Purchas and Zou, 2008).

Meat quality is predominately influenced by factors pre-slaughter, post-mortem, pre-rigor and post- rigor (Purchas, 2003, Bures and Barton, 2012). However, there is an interest in understanding if on-farm factors will influence meat quality either directly or through influences on age at slaughter, weight at slaughter (and hence growth rate) or carcass composition.

Differences among breeds of cattle used in New Zealand are rare due to differences being inundated with variation found among animals within a breed, especially for beef tenderness (Purchas, 2003). Although there is little variation among breeds, there is evidence of variation among sexes and due to differences in age (Renand *et al.*, 2001, Ruiz de Huidobro *et al.*, 2003).

1.5.1. Appearance

1.5.1.1. Meat Colour

The colour of meat is one of the most important characteristics looked at when a consumer is purchasing meat (Seideman *et al.*, 1984, Chambaz *et al.*, 2003, Troy and Kerry, 2010). Consumers relate the desirable bright, light red colour of the meat to freshness (Seideman *et al.*, 1984, Barton and Pleasants, 1993, Chambaz *et al.*, 2003, Troy and Kerry, 2010). Meat colour is measured differently across experiments, using both subjective and objective techniques. Variations in the colour of the meat are associated with intrinsic elements of the meat such as intramuscular fat content, muscle myoglobin concentration and chemical form, and pH (Muir *et al.*, 2000, Purchas, 2003, Bures and Barton, 2012). Animal factors such as breed, sex and age at slaughter do not generally alter these intrinsic determinants and so do not have an effect on the colour of lean meat (Seideman *et al.*, 1984, Renerre, 1990, Troy and Kerry, 2010).

1.5.1.2. Effect of breed on lean meat colour

New Zealand experiments have found no difference in lean meat colour when comparing British beef breeds to dairy breeds of the same age (Barton and Pleasants, 1993, Burke *et al.*, 1998, Muir *et al.*, 2000, Purchas and Zou, 2008). Experiments outside of New Zealand found that there was no difference in the redness or yellowness of meat from British and continental European beef and dairy breeds however, the meat from Simmental and Jersey breeds was darker than that from Angus, Hereford, Charolais and Limousin (Koch *et al.*, 1976, Chambaz *et al.*, 2003).

1.5.1.3. Effect of sex and age on lean meat colour

Bulls and steers have similar levels of myoglobin in the muscle, however, bulls tend to produce darker meat, which is thought to be attributed to the higher pH, a result of the more excitable temperament and therefore low muscle glycogen concentrations in bulls (Smith *et al.*, 1996, Destefanis *et al.*, 2003). Bures and Barton (2012) found no differences between bulls and heifers for lightness, redness or yellowness of the meat.

As the animal ages, the red colour tends to darken due to increasing concentration of the myoglobin pigment in animals, however, in animals with a small difference in age differences in meat colour are unlikely to be observed (Koch *et al.*, 1976, Seideman *et al.*, 1984, Purchas, 1989, Renerre, 1990, Dubeski *et al.*, 1997, Chambaz *et al.*, 2003, Bures and Barton, 2012).

1.5.1.4. Fat Colour

Some markets are tolerant of yellow fat but in general the yellow fat colour is considered undesirable and New Zealand carcass grading penalises for excessively yellow fat by downgrading the carcass (Morgan and Everitt, 1969, Morgan *et al.*, 1969, Kirton, 1989). Fat colour unlike lean meat colour is affected by breed and age (Muir *et al.*, 2000).

1.5.1.5. *Influence of breed on fat colour*

British beef type cattle were shown to have more yellow coloured fat than European cattle, but less yellow than the dairy breed cattle (Morgan and Everitt, 1969, Walker *et al.*, 1990, Muir *et al.*, 2000). When crossbreeding with dairy cattle, European breeds are more effective in reducing the intensity of the fat colour than British breeds (Morgan and Everitt, 1969).

Intensely coloured yellow fat is associated with Jersey cattle. The yellow colour in fat is due to the presence of carotenoid pigments (predominantly beta-carotene) which are abundant in forage diets (Morgan and Everitt, 1969, Morgan *et al.*, 1969, Walker *et al.*, 1990, Barton and Pleasants, 1993, Muir *et al.*, 2000). There is an incidence of yellow subcutaneous fat with all breeds but, it predominates with Jersey cattle. The Jersey breed is associated with an absence of the enzyme required to convert beta-carotene to vitamin A (which is colourless). The carotenoid pigments then enter the blood stream as evidenced by Jersey cattle tending to have a higher blood concentration of the carotene pigment than other breeds (Morgan and Everitt, 1969). Being a lipophilic compound, the carotene is deposited in adipose tissue, resulting in yellow coloured fat (Morgan and Everitt, 1969, Kirton, 1989, McDowell, 1989, Purchas, 1989).

1.5.1.6. *Influence of sex and age on fat colour*

The intensity of fat colour between steers and heifers up to 27 months of age showed no difference between sexes (Morgan and Everitt, 1969, Morgan *et al.*, 1969). females are considered to have yellower fat than bulls, but this is likely to be a consequence of bulls having less fat rather than pigment concentration in the fat (Morgan and Everitt, 1969). There is little difference between the fat colour of steers and heifers (Morgan *et al.*, 1969).

The intensity of yellow fat tends to increase with age, with the differences between breeds and among sexes becoming more apparent when the cattle are older (Morgan and Everitt, 1969, Purchas, 1989, Muir *et al.*, 2000). The age effect is primarily due to the time spent on forage and the fat depth rather than age itself (Walker *et al.*, 1990).

1.5.2. Palatability

Although the ability of the animal to absorb and digest the carotene pigment is a major factor influencing fat colour, there is a strong dietary interaction (Morgan and Everitt, 1969). Green pasture, especially young growing pasture, contains large quantities of carotenoid pigments (Morgan and Everitt, 1969, Morgan *et al.*, 1969). The resulting fat from pasture-fed cattle is darker and more yellow than that of cattle fed concentrates (Morgan and Everitt, 1969).

Ensuring a positive eating experience for beef consumers is important for informing repurchase decisions. Although palatability is not something that can be assessed at the point of sale, if palatability can be guaranteed especially tenderness, the consumers are willing to pay more for the meat (Troy and Kerry, 2010).

Palatability characteristics are those which directly relate to the eating quality of the meat and include flavour, juiciness and tenderness of the meat (Purchas, 2003, Troy and Kerry, 2010). Palatability traits are measured by both sensory and objective testing, which are highly correlated (Peachey *et al.*, 2002).

1.5.2.1. Tenderness

Tenderness is considered important for the palatability of beef as it can be the quality characteristic of beef which consumers are most dissatisfied and which can warrant a higher retail price if tenderness is assured (Wood *et al.*, 1999, Campo *et al.*, 2000, Daly, 2000, Smith *et al.*, 2000, Chambaz *et al.*, 2003, Purchas, 2003, Aass *et al.*, 2009, Troy and Kerry, 2010). Tenderness can be measured using both subjective tasting panels and using objective measurements, the most common method being Warner Bratzler shear force.

The intrinsic factors of beef that affect tenderness include intramuscular fat content of the meat, collagen concentration and solubility, sarcomere length, activity of proteolytic enzymes and pH (Purchas, 2003). The relationship between meat tenderness and intramuscular fat varies considerably, however, meat with a higher intramuscular fat generally has a lower resistance to shearing due to the dilution of the muscle fibres (Purchas and Barton, 1976, Wood *et al.*, 1999, Muir *et al.*, 2000, Morris *et al.*, 2001, Renand *et al.*, 2001, Wood *et al.*, 2008, McCormick, 2009).

Collagen is a fibrous tissue of muscle which helps maintain the muscle structure and transmit contraction forces. Increased collagen concentration or decreased collagen solubility (with cooking) are associated with reduced tenderness of meat (Renand *et al.*, 2001, Blanco *et al.*, 2013). Collagen solubility declines due to increased crosslinking between the collagen molecules (Blanco *et al.*, 2013).

Rapid chilling of the carcass pre-rigor is associated with an increased incidence of cold-shortening. Cold-shortening is a sustained contraction of the muscle post-rigor which can be quantified in meat by measuring sarcomere length (Purchas and Barton, 1976, Wood *et al.*, 1999). Increased fat in the subcutaneous and intramuscular depots helps provide insulation and can help slow the chilling rate of the muscle, preventing against cold shortening (Wood *et al.*, 1999).

Another factor influencing tenderness is the extent of proteolysis or ageing on structural proteins within the muscle fibres (Locker, 1989, Troy and Kerry, 2010). An increase in the proteolytic activity post-mortem is associated with increased meat tenderness. Calpains are a family of proteolytic enzymes which are able to degrade myofibrillar proteins resulting in more tender meat (Morris *et al.*, 2001, Wendt *et al.*, 2004, Hopkins and Geesink, 2009, Troy and Kerry, 2010).

The ultimate pH which the meat attains can influence tenderness. Beef with an intermediate pH of 5.8 - 6.2 has a greater shear force than meat with an ultimate pH below or above these values (Purchas and Aungsupakorn, 1993).

The influence that breed, sex and slaughter age have on the tenderness of beef is mediated through changes in the intrinsic determinants of tenderness in the meat and in turn, these intrinsic factors will be influenced by growth and carcass characteristics of the animal.

1.5.2.2. Influence of breed on tenderness

Cattle with higher growth rates (later maturing) tend to have a lower collagen content, and more tender meat than early maturing, slower growing animals breeds (Muir *et al.*, 1998, Renand *et al.*, 2001). However, when cattle of different maturities are grown at the same rate, there is little evidence to suggest any difference in tenderness (Muir *et al.*, 1998). The differences in tenderness have been attributed to an increased protein turnover from cattle with greater growth rates, and so higher concentrations of proteolytic enzymes are present at slaughter (Muir *et al.*, 1998).

Gregory *et al.* (1994) found British beef breeds to be more tender than European beef breeds, however, Homer *et al.* (1997), Mandell *et al.* (1997a) and Purchas and Zou (2008) found no difference between British and European beef breeds. Friesian cattle tend to have less tender meat than British and European beef cattle, however, ageing the meat, or comparing the cattle at the same maturity reduce the differences (Muir *et al.*, 2000, Purchas and Zou, 2008). Consistently, Jersey cattle tend to have tender beef, and are often more tender than other breeds, including Angus and Friesians, likely due to the increased likelihood of intramuscular fat from Jersey cattle (Koch *et al.*, 1976, Purchas and Barton, 1976, Purchas, 1989, Purchas, 2003, Blanco *et al.*, 2013).

1.5.2.3. Influence of sex and age on tenderness

Collagen crosslinking and hence tenderness is affected by sex and age in cattle (Purchas, 2000, Purchas *et al.*, 2002a, McCormick, 2009).

Bulls tend to have more intramuscular connective tissue and less intramuscular fat than steers and female cattle leading to less tender meat (Bures and Barton, 2012, Blanco *et al.*, 2013, Irshad *et al.*, 2013, Lucero-Borja *et al.*, 2014). Due to temperament, bulls have an increased risk of experiencing stress and decreased muscle glycogen concentration at slaughter, and therefore, tend to produce meat with a higher ultimate pH (Purchas, 1989, Destefanis *et al.*, 2003, Burnham *et al.*, 2005). Although steers do produce more tender meat than bulls, the differences are inconsistent and often small (Purchas, 1990).

Tenderness of meat generally declines as the slaughter age of the animal gets older (Purchas, 1989, Moloney *et al.*, 2001, Lucero-Borja *et al.*, 2014) and this is considered to be primarily a consequence of increased collagen content and decreased collagen solubility in the meat from older cattle (Schonfeldt and Strydom, 2011). The concentration of heat-stable collagen crosslinks develops with age (Campo *et al.*, 2000, McCormick, 2009, Schonfeldt and Strydom, 2011, Juarez *et al.*, 2012), and so tenderness decreases with age, although the difference is less clear over a small age range (Lucero-Borja *et al.*, 2014).

The effect of age on tenderness is likely to be minimal when animals are slaughtered while still relatively immature (Purchas, 1989).

1.5.2.4. Juiciness

The juiciness of meat is related to the amount of moisture released from the meat or the sensation of lubrication during chewing and salivation (Muir *et al.*, 1998, Juarez *et al.*, 2012). Juiciness is determined by both the water content (affecting sensory and laboratory procedures) and factors affecting salivation (predominantly affecting only sensory procedures) (Purchas, 2003). Juiciness of meat samples can be assessed by subjective sensory evaluations or by testing for water-holding capacity through cooking loss, driploss and expressed juice (Muir *et al.*, 2000, Wheeler *et al.*, 2004, Purchas and Zou, 2008). The intramuscular fat concentration of the meat is a measurement of consideration for juiciness as marbling fat contributes to the juices of cooked meat and acts as a lubricant and salivary stimulant during chewing. (Purchas, 1989, Muir *et al.*, 1998, Wood *et al.*, 2008). Positive relationships are seen between juiciness and increasing intramuscular fat at levels between 10 and 20% (Purchas, 1990, Purchas, 2003, Wood *et al.*, 2008).

1.5.2.5. Influence of breed, sex and age on juiciness

A sensory evaluation found that Angus and Simmental steers were less juicy than Charolais and Limousin, the scores were negatively correlated with cooking losses (Chambaz *et al.*, 2003). Purchas and Zou (2008) reported no difference in expressed juice among Friesian, Angus and Angus-cross- Charolais steers but Charolais-cross steers had the greatest cooking loss. Mandell *et al.* (1997a) found Limousin to have juicier meat than Charolais due to the meat from Charolais cattle having greater driploss. Friesian steers had juicier meat than Hereford steers at the same age (Muir *et al.*, 2000); these results were similar to those found in Wheeler *et al.* (2004) when comparing Hereford and Friesian steers at a common age although the difference was small. In contrast, Homer *et al.* (1997) found no differences in juiciness between British and European beef breeds.

Literature comparing the juiciness or water holding capacity from cattle of different sex classes is limited. Increased cooking loss and expressed juice was found in meat from steers compared to bulls (Purchas, 1990, Purchas and Aungsupakorn, 1993, Purchas *et al.*, 2002a), but, sensory testing found that meat from steers was juicier than meat from bulls and heifers (Purchas *et al.*, 2002a, Destefanis *et al.*, 2003, Lucero-Borja *et al.*, 2014).

Bures and Barton (2012) found juiciness of meat from bulls and heifers increased with age. In contrast, Chambaz *et al.* (2003) reported that with increasing age, cooking loss increased and resulted in less juicy meat.

1.5.2.6. Flavour

The attributes of flavour as well as aroma are important parts of the eating sensation, although are not easily measured by objective testing (Moloney *et al.*, 2001). There are hundreds of compounds present in meat which contribute to the flavour, and many of these compounds are altered during storage and cooking (Calkins and Hodgen, 2007).

The meaty flavours of cooked meat are produced through reactions between carbohydrates and proteins (Wood *et al.*, 1999, Moloney *et al.*, 2001, Calkins and Hodgen, 2007). The presence of fat also contributes to the flavour of the meat via fatty acids, flavour compounds stored in the adipose and then released at cooking by lipid oxidation (Wood *et al.*, 1999, Moloney *et al.*, 2001, Gorraiz *et al.*, 2002, Calkins and Hodgen, 2007, Koutsidis *et al.*, 2008). High pH meat is associated with abnormal or rancid flavours (Yancey *et al.*, 2005)

1.5.2.7. Influence of breed, sex and age on flavour

Sensory tests comparing European and British beef breeds found no differences among breeds in the flavour of the meat (Homer *et al.*, 1997, Mandell *et al.*, 1997a), similarly Koutsidis *et al.* (2008) tested for concentrations of a range of compounds contributing to flavour, finding few differences between Angus and Friesian breeds. Bulls have been associated with a less acceptable flavour than heifers which has been likened to boar taint associated with male pigs and could be related to genetic influence on development and the production of sex hormones, influencing the lipid composition (Hansen *et al.*, 2006).

1.6. Research Objectives

Differences among breeds especially straight-bred and first crosses have been researched. Previous studies have shown that the Angus breed is better than dairy breeds in terms of growth and dressing-out percentage. Jersey cattle have a smaller dressing out percentage than Angus and Friesian cattle and dairy breeds have a tendency to be fatter and are known to have yellower fat than beef breeds. Jersey cattle tend to have more tender meat than Angus and Friesian cattle.

In New Zealand the use of beef-cross-dairy cows is rising in popularity. The changing genetic composition of the dairy industry results in increasing proportions of Jersey in the dairy-beef heifers available for rearing as beef cows. The calves of such cows will be approximately one quarter dairy breed, and there is limited information about the potential effects of this on the performance of those calves. As no replacement heifers are kept from beef-cross-dairy cows in a beef breeding herd, all heifers are finished too as opposed to predominantly finishing male progeny in a self-replacing herd. Therefore the heifers become a much more important component of the system for meat production and should be investigated as well as the steers.

The objectives of this study were to investigate the effect of breed-cross on growth, carcass characteristics and meat quality attributes for Charolais-sired progeny of beef and beef-cross-dairy cows, namely Angus, Angus-Friesian, Angus-KiwiCross, and Angus-Jersey grown in a New Zealand pastoral production system. This study also aimed to determine if there were any breed effects that differed between heifer and steer cattle.

It is hypothesised that when compared at the same age, the half Angus cattle will perform better in terms of growth and dressing-out percentage, and will have greater eye muscle area and fat depths compared to progeny of beef-cross-dairy cattle. As the proportion of Jersey genetics in the cattle increases, it is hypothesised that at the same level of finish, the incidence of yellower fat will increase and meat will be tenderer, and that there will be no further differences between breed-crosses in terms of meat quality. It is also hypothesised that at the same level of finish steers will have a greater eye muscle area than heifers and a greater fat depth C, redder meat, yellower fat and decreased tenderness and juiciness than heifers.

2. Materials and Methods

2.1. Animals and Management

One hundred and three crossbred cattle born in 2012 at Massey University's Tuapaka farm were used in this experiment. These cattle were the third calves of four-year-old Angus (AA), Angus-cross-Friesian (AF), Angus-cross-Jersey (AJ) and Angus-cross-KiwiCross (AK) cows (Hickson *et al.*, 2014). The cows were mated in 2 mobs with 4 Charolais (C) bulls to produce the progeny utilised in this study. The 2 mobs represented early and late calving in the previous calving. Bulls were out for 9 weeks, with 2 bulls in each mob. The growth, carcass characteristics and meat quality were considered for both heifers and steers.

Table 11: Numbers of cattle utilised in the experiment within each breed-cross and sex group. Cattle were Charolais-sired (C-) from Angus (AA), Angus-cross-Friesian (AF), Angus-cross-KiwiCross (AK) and Angus-cross-Jersey (AJ) dams.

Breed-cross	Heifers	Steers	Total
C-AA	16	17[1]	33
C-AF	11	11	22
C-AK	9	7	16
C-AJ	17	15	32
Total	53	50	103

[1] One C-AA steer carcass did not have a meat sample taken and, therefore, was not analysed for meat quality.

Calves were reared on their dams until weaning at a mean age of 193 days (14 April 2013). From weaning until 252 days of age (16 June 2013) all cattle were grazed on pasture in a single group at Massey University's Tuapaka farm near Palmerston North (latitude 40° 20' south, longitude 175° 43' east). All ages presented are an average age from all animals calculated using a mean birthdate.

All animals were then involved in a wintering experiment (252 - 302 days of age) (Little *et al.*, 2015). The wintering experiment consisted of four feeding treatments: 1) green-feed black oats (oats), 2) set-stocked on pasture (set-stocked), 3) break-fed on pasture (break-fed) or 4) break-fed pasture during dry weather and contained on a feed-pad and fed baleage during wet weather (feed-pad) (Little *et al.*, 2015). Winter treatment groups were balanced for initial live weight, breed-cross and sex. At the completion of the wintering experiment all cattle were returned to a single group.

The cattle were separated and managed as steer and heifer groups from 324 days of age (28 August 2013). The cattle were moved to Massey University's Riverside farm near Masterton (latitude 40° 50' south, longitude 175° 37' east) when 345 days old (18 September 2013) grazing pasture until slaughter. Heifers and steers were slaughtered at a targeted average live weight of 500kg and 600kg, respectively.

2.2. Growth and ultrasound carcass measurements on the live animal

The unfasted live weight of the heifers and steers was measured at weaning and at approximately monthly intervals until slaughter. Heifers were weighed at 553 days old, 3 weeks prior to slaughter, which was used as the final live weight for this experiment. Final live weight of the steers was measured the day prior to slaughter at 785 days of age.

Body condition score was measured at 241, 302, 423 and 553 days of age for all animals on a 1-5 scale (Morris *et al.*, 2002). Height at the withers for all animals was measured at 302 and 553 days of age using a height stick.

Ultrasound was used on the live animals to measure the fat depth over the *Longissimus thoracis* muscle (fat depth C), the transverse area of the *Longissimus thoracis* muscle (eye muscle area; EMA), and intramuscular fat % (IMF) at a point between the 12^{th} and 13^{th} rib. Ultrasound was also used to ascertain the fat depth over the *Longissimus lumborum* muscle at the P8 rump site (Fat P8). The P8 rump site is located at the point of intersection of a horizontal line from the dorsal tuberosity of the Tripartite tuber ischia (pin bone) parallel to the backbone, and a vertical line from the crest on the spinous process of the third sacral vertebra (Hopkins, 1989). Ultrasound measurements were taken on both heifers and steers at 415 and 553 days of age, and for only the steers at 723 days of age by a BreedPlan accredited ultrasonographer.

2.3. Slaughter and carcass measurements

Heifers were transported from the farm to the abattoir on 04 May 2014, and were slaughtered on 05 May 2014 (574 days old). Steers were transported from the farm to the abattoir on 31 November 2014, and were slaughtered on 01 December 2014 (784 days old). Cattle were slaughtered approximately 24 hours after leaving the farm. All animals were slaughtered and carcasses prepared and graded at

Land Meat New Zealand LTD in Castlecliff, Whanganui following commercial procedures. Given than the steers were slaughtered at an older age than the heifers, the effect of sex is confounded with age at slaughter. The term ‘sex’ is used to refer to this effect throughout. The sex effect also accounts for the differential feeding of the steers and heifers prior to the heifers being slaughtered.

Hot carcass weight was measured and recorded at the slaughter plant after carcass halving. The length of each carcass side was measured from the distal end of the tarsal bones to the mid-point of the cranial edge of the first rib (Purchas and Morris, 2007). The mean of the two carcass sides was used as the measure of carcass length for each animal. Subcutaneous fat colour was visually assessed prior to carcasses entering the chiller, using reference standards numbered from 1 to 8 (where 1 is white and 8 is a deep yellow).

Dressing-out percentage for steers was calculated using the final live weight (31 November 2014) and the hot carcass weight. Dressing-out percentage was not calculated for heifers because pre-slaughter weight was not recorded. Carcasses were quartered before chilling for 24h at 7±1°C.

After chilling, a tracing of the eye muscle area and a measure of fat depth (fat depth C) over the eye muscle on the right front quarter of the carcass were obtained. The traced area was subsequently measured using a planimeter (Placom KP-90N, Tokyo, Japan). Fat depth C was measured in the same position as the ultrasound fat depth C measurements.

2.4. Meat quality

A sample of *Longissimus lumborum* muscle (striploin) from the caudal end of the muscle of approximately 1 kg size was taken the day after slaughter and vacuum packed for meat quality analysis. The muscle samples were aged for 7 days at 1°C before freezing at -20°C. Prior to analysis, samples were thawed at 1°C over a 24-hour period. To avoid the effect of freezing time on meat quality between the striploin of the heifers and steers slaughtered at different times, a time of 28 weeks post-slaughter was set for assessing meat quality.

The striploin within the vacuum-pack was weighed. After the striploin was removed from the packaging it was blotted dry using tissue paper and the whole striploin weighed. The vacuum-pack was dried and also weighed (Figure 5).

A 15 mm steak was cut from the cranial end of the striploin for the measurement of meat colour and then myofibrillar fragmentation. A 25 mm steak cut from the central part of the striploin was placed into a plastic bag to be cooked for the measurement of cooking loss and Warner Bratzler shear force. A 40 mm steak also cut from the central part of the striploin but caudal to the 25 mm steak was used to assess the transversal surface area of the *Longissimus lumborum* muscle, driploss, fat colour and expressed juice. The remaining portion of the striploin at the caudal end was used to measure pH following two methods and also for the measurement of sarcomere length. After all tests had been completed the remaining lean meat was minced, vacuum packed and frozen for subsequent analysis of intramuscular fat (IMF %) content.

2.4.1. Ultimate pH

Ultimate pH was measured using two techniques.

A pH spear (Eutech Instruments, Singapore) was used to measure ultimate pH at three points from medial to distal across a transverse internal cut surface of striploin. The pH spear was calibrated using standard buffers at pH 4.01, 7.0 and 10.01.

Ultimate pH was also measured by homogenising 2 g of diced lean meat in 10 ml of 150 mM KCl (pH 7.0) using an Ultra-Turrax homogeniser (18 mm shaft, on ⅓ speed) before using a Jenway 3020 pH meter (Bibby Scientific Ltd, Stone, UK) (Bendall, 1973, Purchas *et al.*, 2002a). The pH meter for the homogenate method was calibrated using pH 4.0 and 7.0 buffer solutions.

2.4.2. Lean meat and subcutaneous fat colour

After the cut surface of the 15 mm steak had been exposed to air for a minimum of 30 minutes, the lean meat colour was measured. The subcutaneous fat was trimmed off the 40 mm steak and then scraped with the edge of the knife to expose the fat and the colour assessed. Both lean meat and fat colour were measured using a Minolta Chromameter (CR-200; Konica Minolta, Mahwah, NJ, USA) that had been calibrated using a standard white tile. The CIE L^* (lightness), a^* (redness) and b^* (yellowness) values were measured (Illuminant D65, 8 mm diameter aperture, 0° viewing angle) through a polycarbonate petri dish lid at three locations across the sample.

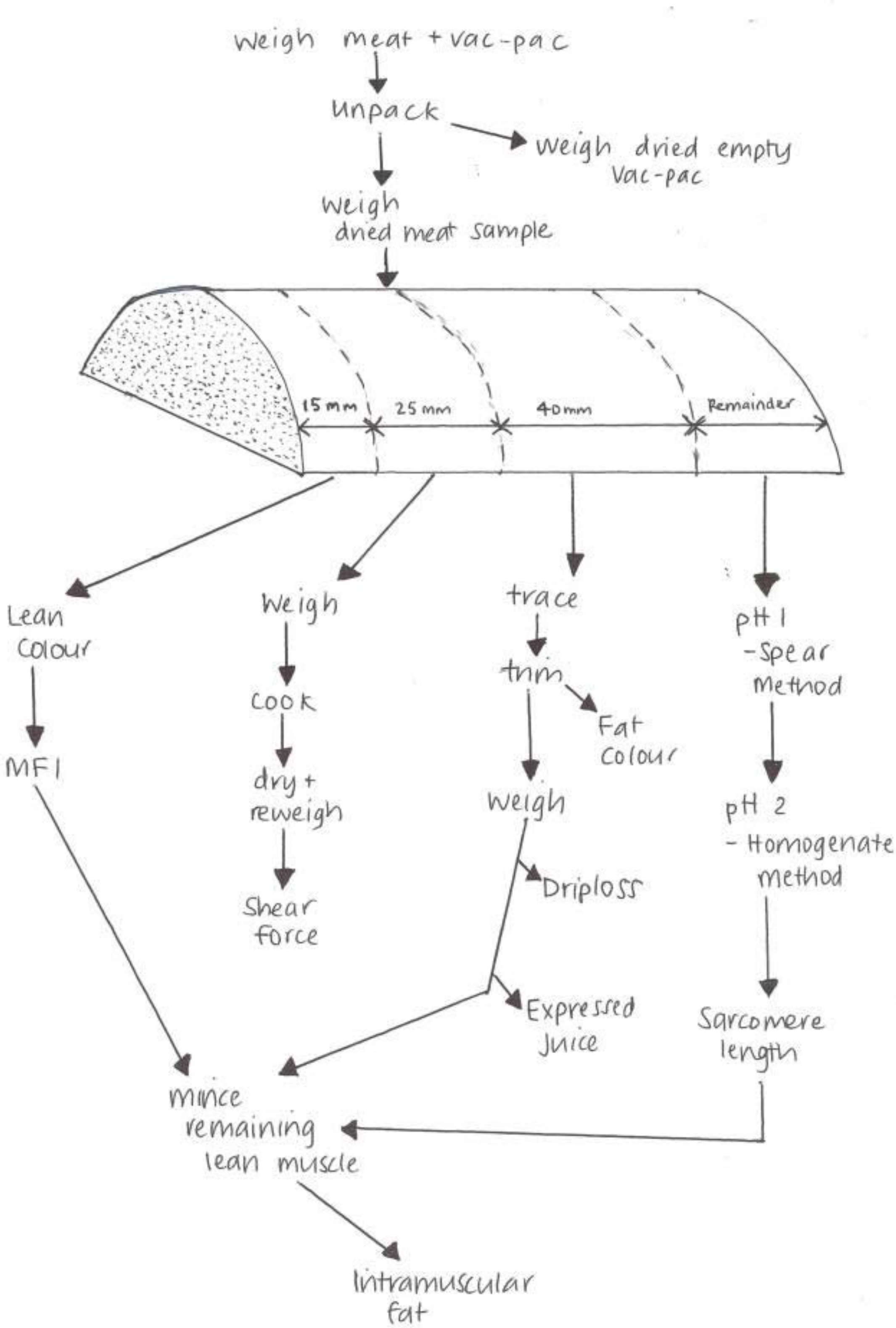


Figure 5: Schematic of beef striploin (*Longissimus lumborum*) portioning for meat quality analysis.

2.4.3. Area and density

The cross-sectional area of the 40 mm steak was traced, trimmed of subcutaneous fat and weighed. The traced area was measured with a Planimeter (Placom KP 90N, Tokyo, Japan) and the volume calculated using the thickness of the steak. Although volume was calculated on a defrosted sample, all muscles were treated the same, and so provides a relative measure to compare breeds within the study. Density of the *Longissimus lumborum* muscle was calculated as:

$$Longissimus\ lumborum \text{ muscle density } (\mathrm{g/cm^3}) = \frac{\text{Muscle weight}}{\text{Muscle volume}}$$

2.4.4. Tenderness and related measures

The 25mm steak was cooked in a water bath at 70°C for 90 minutes used for assessment of Warner-Bratzler shear force (Purchas, 1990). Warner-Bratzler shear force using a square blade was measured on cores with a surface area of 13 mm x 13 mm, produced by cutting along the grain of the muscle so that shears were made across muscle fibres (Purchas and Aungsupakorn, 1993). Parameters recorded were work done, initial yield and peak force. Work done is an average of 436 values produced during the shear to create a force by time curve. Initial yield is the force at which the meat sample first began to yield represented by a change in shear force, and appearing as an inflexion in the force by time curve. Peak force is the maximum recorded force over the shear (Bouton *et al.*, 1975, Purchas and Aungsupakorn, 1993). Twelve replicates were measured for each sample.

Sarcomere length was measured by laser diffraction as described by Purchas and Barton (1976). The method involves dissecting a segment from the raw beef sample with a 1 mm^2 cross section by 8-10mm long, along the length of the muscle fibres. The segment was then teased-out on a microscope slide with a scalpel blade. About 2-3 droplets of distilled water were added to the sample and a second microscope slide was pressed on top. The microscope slide was then placed on a microscope stage that was set at a distance of 100 mm from the white surface where the diffraction bands were observed. A He-Ne laser (2 mW, 632.8 nm wavelength, 0.8 mm beam diameter) was passed through the sample. The sample on the microscope stage was shifted horizontally in the laser beam until 3 bands were clearly visible. The distance between the first order diffraction bands was measured, and 12 measurements per sample were used to calculate the mean distance (mm). The following formula was used to calculate the sarcomere length:

$$Sarcomere\ length\ (\mu m) = 0.6328 * \left[\sqrt{\left\{\left(\frac{x}{20}\right)^2 + 100\right\}}\right] / (\frac{x}{20})$$

X = average sarcomere length in mm;

Myofibrillar fragmentation index (MFI) was measured by assessing muscle fragments that passed through a 231 μm stainless steel filter after a approx. 5 g sample had been homogenised (Ultra-Turrax, 18 mm diameter shaft, one-third speed) in 50 ml of physiological saline (0.85% NaCl). The MFI procedure includes a drying step at 30°C for 40 hours and so, values range from 78% when no fragments passed through the filter up to 100% when all fragments pass through (Purchas *et al.*, 1997).

2.4.5. Water-holding measures

Thaw loss (water loss from freezing and then thawing) was measured using the weights of the meat in the vacuum pack before unpacking and the weight of the dry meat sample and dry packaging separately. Thaw loss was calculated as:

$$\text{Thaw loss (\%)} = \frac{\text{whole weight - (package weight + meat weight after drying)}}{\text{(whole weight - package weight)}} \text{ x 100}$$

The weight of the 25mm steak was measured before and after cooking to establish cooking loss. Cooking loss was calculated as:

$$\text{Cooking loss (\%)} = \frac{\text{pre cooking weight} - \text{post cooking weight}}{\text{pre cooking weight}} \text{ x 100}$$

A 40 mm cube was weighed then suspended on a metal hook in a plastic bag at 1°C. After 24 and 48 hours the suspended cube was blotted dry using tissue paper and reweighed. Driploss was calculated as the original weight minus the weight at 24 or 48 hours and the value was expressed as a percentage of the original weight.

Expressed juice was measured by filter-paper-press method (Hamm, 1986, Purchas and Aungsupakorn, 1993). A cube of approximately 0.5 g was placed on Whatman No. 1 filter paper and pressed between two Perspex plates for 2 minutes using a 10 kg weight. The wetted area from expressed juice was measured using a Planimeter (Placom KP-90N, Tokyo, Japan) and the expressed juice value expressed as the total wetted area per unit weight of sample (cm^2/g).

2.4.6. Intramuscular fat

Internal samples of the *Longissimus lumborum* were finely minced (Kenwood MG450 with 3 mm hole-plate), vacuum packed and frozen for the analysis of fat content at the Massey University Nutrition Laboratory using an ether extraction procedure (AOAC 911.36).

2.5. Statistical Analysis

Data were analysed in SAS (version 9.4, SAS Institute Inc., Cary, NC, USA) using general linear and mixed models.

The average daily gain (ADG) calculated from weaning until the final weight and the age at slaughter were analysed using general linear models which included the breed-cross as a fixed effect. Heifers and steers were considered separately for live weight, body condition score, height and ultrasound traits with the repeat-measures mixed model having the fixed effect of breed-cross and day of measurement. The models included breed-cross and day of measurement as fixed effects, allowing for repeated measures. Animal was included as a random effect in all models allowing for repeated measures. Winter trial treatment was fitted as a fixed effect for live weight, body condition score, and height and ultrasound repeated measure models. When this effect was non-significant it was removed from the models. The birthdate deviation (from an average date of birth) was fitted as a covariate for all live-animal measurements, when this covariate was non-significant it was removed from the models, however all measurements were taken at the same day and so are presented as an average age. Tables and figures in the results specify whether winter trial or birthdate deviation was significant and therefore fitted in the final model, a non-significant (NS) P-value represents the effect having been removed from the model.

Carcass characteristics and meat quality attributes were analysed using general linear models. Data from heifers and steers were analysed together. These models included breed-cross and sex and their interaction as fixed effects. The birthdate deviation was fitted as a covariate for carcass weight. Carcass weight was fitted as a covariate for carcass length, eye muscle area, *Longissimus* *lumborum* muscle area. Ultimate pH by spear method was fitted as a covariate in the models for all meat quality attributes. When pH was not significant it was removed from the models. Tables and figures in the results specify whether carcass weight or pH was significant and therefore fitted in the final model, a non-significant (NS) P-value represents the effect having been removed from the model.

3. Results

3.1. Growth and ultrasound carcass characteristics

3.1.1. Heifers

At weaning (193 days of age), the C-AA heifers were the lightest and the C-AF heifers the heaviest while C-AJ and C-AK steers were intermediate (Table 12, Figure 6, P<0.05). The growth rate of the C-AJ heifers was slower than C-AF and C-AK heifers so that at the end of the wintering experiment at 302 days of age, the C-AA and C-AJ heifers were the lightest (Table 12, Figure 6, P<0.05). The C-AA and C-AF heifers were heavier than C-AJ heifers at 553 days of age, C-AK were intermediate (Table 12, Figure 6). The C-AJ and C-AK heifers had the slowest growth rate (ADG) and the C-AA heifers the fastest (Table 12, P<0.001). During this experiment C-AA and C-AK heifers were approximately 12 days younger than C-AF and C-AJ heifers (Table 12, P=0.011).

The C-AA heifers were lighter than all other breed-crosses until 241 days of age and lighter than C-AF heifers for the entirety of the experiment (Figure 6, P<0.05). The C-AJ, C-AK and C-AF heifers had a similar live weight until 423 days of age after which time C-AF heifers became heavier than the C-AK and C-AJ heifers (Figure 6).

There were no differences among breed-crosses for body condition score throughout the experiment. Body condition score increased between 302 and 423 days-of-age (Figure 7, P<0.05) but not at any other stage of the experiment.

The height of heifers increased by 140 mm between 302 and 553 days of age (P<0.001). The C-AA heifers (1179±6 mm) were shorter (P<0.05) than the C-AF (1204±7 mm) and C-AK heifers (1202±8 mm), the C-AJ heifers were intermediate (1189±6 mm). Height was influenced by birthdate (P<0.001) so that for every day older the heifer was, height increased 0.54±0.25 mm. Height was also influenced by winter trial treatment (P=0.014) in that the heifers in the set-stocked treatment were the tallest as opposed to those on the break-fed (-4.2 ±8.34 mm), feed-pad (-13.48±8.45) and oats (-26.78±8.35) treatments.

Table 12: Growth characteristics from weaning until slaughter, for Charolais (C-) sired heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows. Values are least squares means ± standard error of the mean.

	Breed-cross				P-Value
	C-AA	**C-AF**	**C-AK**	**C-AJ**	**Breed-cross**
n	16	11	9	17	
Weaning weight (kg)	226.8 ±4.7^{a}	258.9 ±5.7^{c}	254.7 ±6.3^{bc}	239.9 ±4.6^{b}	See Figure 6
Weight at end of the wintering trial weight (kg)	283.3 ±6.1^{a}	306.8 ±7.3^{b}	300.4 ±8.1^{ab}	288.5 ±5.9^{ab}	See Figure 6
ADG weaning to final weight (g/day)	499.2 ±7.5^{b}	514.0 ±9.0^{b}	498.7 ±10.0^{ab}	478.1 ±7.2^{a}	See Figure 6
Final weight (kg) [1]	493.0 ±7.9	517.6 ±9.5	491.0 ±10.5	485.6 ±7.6	0.073
Age at slaughter (d)	570.6 ±3.1^{ab}	580.4 ±3.8^{bc}	569.0 ±4.2^{a}	582.9 ±3.0^{c}	**0.011**

[1] Final live weight taken as weight at 553 days of age, three weeks prior to slaughter
^{abc} Differing superscript values within a row represent breeds which are significantly different ($P<0.05$)

Figure 6: Un-fasted live weight for Charolais sired (C-) heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows from weaning at 193 days of age until three weeks prior to slaughter. Points are least squares means, with standard error bars. P-values are presented within the figure. Age presented is an average age of all cattle.

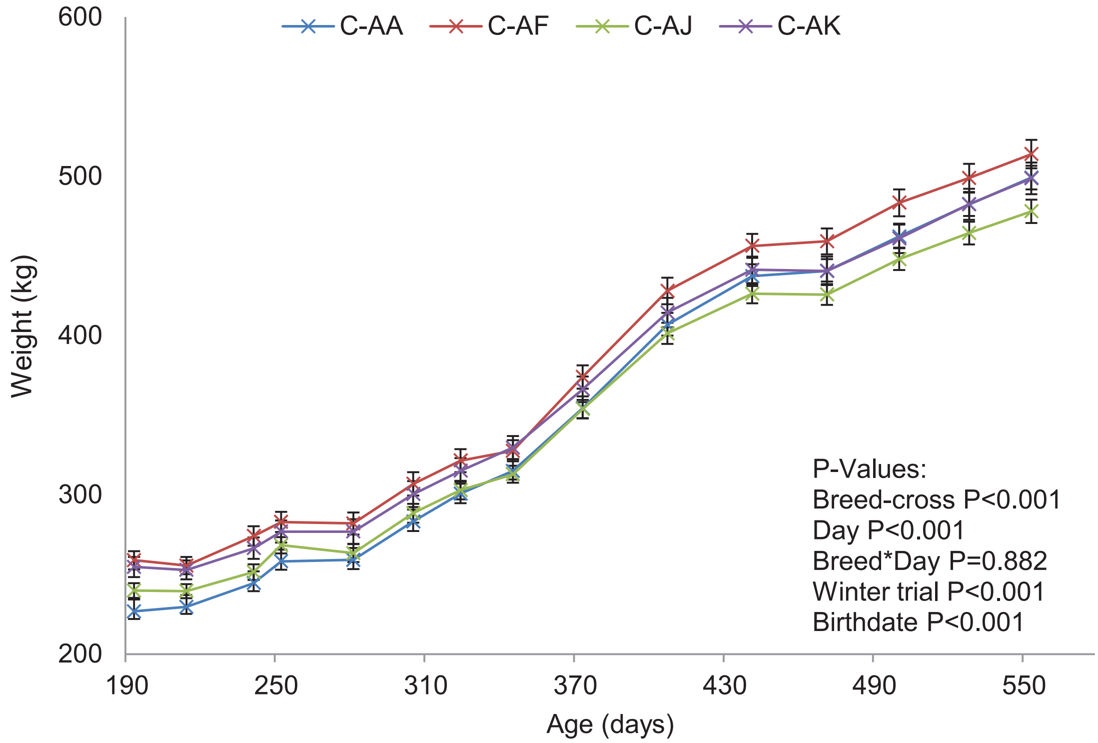
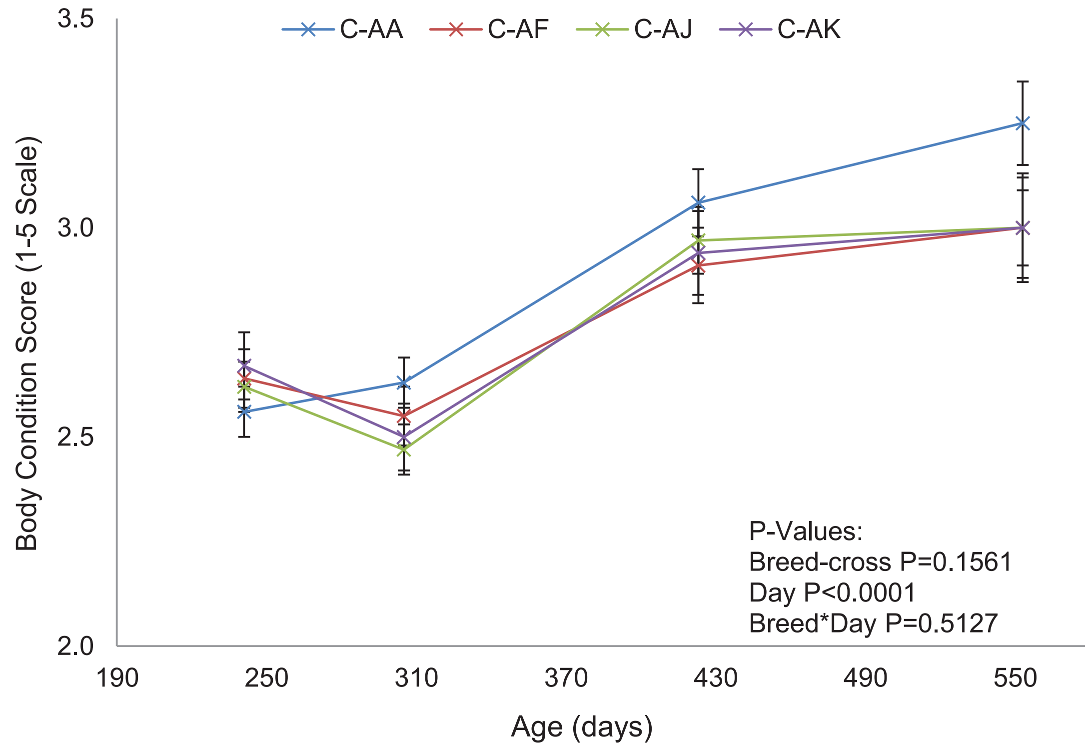


Figure 7: Body condition score for Charolais sired (C-) heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows measured at 241, 302, 423 and 553 days of age. Points are least squares means, with standard error bars. P-values are presented within the figure. Age presented is an average age of all cattle.



The ultrasound measurements of eye muscle area, fat depth C, P8 fat depth and intramuscular fat were similar for all breed-crosses (**Error! Not a valid bookmark self-reference.**, P>0.05). Ultrasound measurements of eye muscle area, fat depth C and P8 fat depth were greater at 553 days than 415 days of age (**Error! Not a valid bookmark self-reference.**, P<0.001). There was no difference in intramuscular fat at 415 versus 553 days of age (**Error! Not a valid bookmark self-reference.**).

Table 13: Ultrasound carcass characteristics for Charolais (C-) sired heifers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, measured at 415 and 553 days of age. Values are least squares means ± standard error of the mean. Age presented is an average age of all cattle.

	EMA (cm^2)	Fat depth C (mm)	IMF (%)	P8 fat depth (mm)
Breed-cross				
C-AA	70.0 ±1.6	2.9 ±0.2	2.9 ±0.7	4.5 ±0.2
C-AF	73.3 ±1.9	2.5 ±0.2	3.6 ±1.0	4.4 ±0.3
C-AK	75.0 ±2.1	2.8 ±0.2	3.1 ±1.1	4.3 ±0.3
C-AJ	68.7 ±1.5	2.6 ±0.2	4.9 ±0.8	4.6 ±0.2
Age (days)				
415	68.5 ±0.7[a]	2.3 ±0.1[a]	3.2 ±0.2	3.6 ±0.1[a]
553	75.0 ±1.6[b]	3.1 ±0.2[b]	4.0 ±0.9	5.3 ±0.2[b]
P-Values				
Breed-cross	0.065	0.470	0.343	0.856
Day	**<0.001**	**<0.001**	0.390	**<0.001**
Breed*day	0.511	0.810	0.671	0.933
Winter trial	NS	**0.004**	NS	NS
Birthdate	**<0.001**	**0.006**	NS	**0.011**

[ab] Differing superscript values within a column within breed-cross or age indicate significant differences (P<0.05)
NS Indicates the effect was not significant and removed from the model

3.1.2. Steers

At weaning (193 days of age) the C-AA steers were lighter at weaning than the other breed-crosses (The ultrasound measurements of eye muscle area, fat depth C, P8 fat depth and intramuscular fat were similar for all breed-crosses (**Error! Not a valid bookmark self-reference.**, P>0.05). Ultrasound measurements of eye muscle area, fat depth C and P8 fat depth were greater at 553 days than 415 days of age (**Error! Not a valid bookmark self-reference.**, P<0.001). There was no difference in intramuscular fat at 415 versus 553 days of age (**Error! Not a valid bookmark self-reference.**).

Table 13, Figure 6, P<0.05). The growth rate of the C-AJ steers decelerated so that at the end of the wintering experiment at 302 days of age, the C-AA and C-AJ steers were lighter than the C-AF steers (The ultrasound measurements of eye muscle area, fat depth C, P8 fat depth and intramuscular fat were similar for all breed-crosses (**Error! Not a valid bookmark self-reference.**, P>0.05). Ultrasound measurements of eye muscle area, fat depth C and P8 fat depth were greater at 553 days than 415 days of age (**Error! Not a valid bookmark self-reference.**, P<0.001). There was no difference in intramuscular fat at 415 versus 553 days of age (**Error! Not a valid bookmark self-reference.**).

Table 13, Figure 6, P<0.05). There were no differences among the breed-crosses in growth rate from weaning until slaughter and in the final live weight of the steers at 783 days of age (The ultrasound measurements of eye muscle area, fat depth C, P8 fat depth and intramuscular fat were similar for all breed-crosses (**Error! Not a valid bookmark self-reference.**, P>0.05). Ultrasound measurements of eye muscle area, fat depth C and P8 fat depth were greater at 553 days than 415 days of age (**Error! Not a valid bookmark self-reference.**, P<0.001). There was no difference in intramuscular fat at 415 versus 553 days of age (**Error! Not a valid bookmark self-reference.**).

Table 13, Figure 8). There were no differences in age among breed-crosses during this experiment (Table 14).

After the completion of the wintering trial, at 302 days until 407 days of age, the C-AA steers were lighter than C-AF steers (Figure 8, P<0.05). There were no differences in live weight among breed-crosses from 407 days of age until slaughter at 783 days of age (Figure 8).

The height of the steers increased 171 mm between 302 and 553 days of age (P<0.001). The C-AF steers (1263±7 mm) were taller than C-AJ (1234±6 mm) and C-AA (1219±6 mm) steers (P<0.05). The C-AK steers (1244±9 mm) were intermediate to the C-AF and C-AJ steers (P>0.05). Height was influenced by birthdate (P=0.021) so that for every day older the heifer was, height increased 0.69±0.20 mm. Height was also influenced by winter trial treatment (P=0.001) in that the heifers in the set-stocked treatment were the tallest as opposed to those on the break-fed (-3.88±9.19 mm), feed-pad (-11.69±9.23) and oats (-28.83±9.49) treatments.

Body condition score increased between days of measurement (Figure 9, P<0.001). The C-AJ steers had lower body condition score than the other breed-crosses at 241 days of age, but increased body condition compared to other breeds between 423 and 553 days of age (Figure 9). The C-AA steers had the greatest increase in body condition score to achieve the greatest body condition score of 3.5 at 553 days of age (Figure 9, P<0.05). There were no breed-cross differences in body condition score at 302 and 423 days of age (Figure 9, P>0.05).

The C-AJ steers had smaller ultrasound eye-muscle areas compared with the other breed crosses (Table 15, P=0.04). The C-AA steers had a greater fat depth (C and P8) than other breed-crosses (Table 15, P<0.05). All breed-crosses had a similar proportion of ultrasound-measured intramuscular fat in the eye muscle (Table 15). Steers had a greater eye-muscle area, greater fat depth over the rib and rump sites and a greater intramuscular fat percentage at 553 days of age than at 415 and 723 days (Table 15, P<0.01).

Table 14: Growth characteristics from weaning until slaughter, for Charolais (C-) sired steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows. Values are least squares means ± standard error of the mean. Age presented is an average age of all cattle.

	Breed-cross				**P-Value**
	C-AA	C-AF	C-AK	C-AJ	Breed-cross
	17	11	7	15	
Weaning weight (kg)	238.8 ±4.6^{a}	267.0 ±5.7^{b}	257.0 ±7.2^{b}	256.1 ±4.9^{b}	See Figure 8
End of wintering trial weight (kg)	300.5 ±6.3^{a}	327.6 ±7.8^{b}	316.7 ±9.7^{ab}	305.7 ±6.7^{a}	See Figure 8
ADG weaning until final weight (g/day)	648.7 ±10.0	659.4 ±12.1	636.9 ±16.4	645.5 ±10.4	See Figure 8
Final weight (kg)	650.0 ±10.4	662.0 ±12.5	640.3 ±17.0	640.5 ±10.7	0.585
Age at slaughter (d)	783.9 ±4.2	782.5 ±5.2	782.9 ±6.5	775.0 ±4.4	0.486

^{abc} Differing superscript values within a row represent breeds which are significantly different ($P<0.05$)

Figure 8: Un-fasted live weight for Charolais (C-) sired steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows from weaning at 193 days of age until slaughter. Points are least squares means, with standard error bars. P-values are presented within the figure. Age presented is an average age of all cattle.

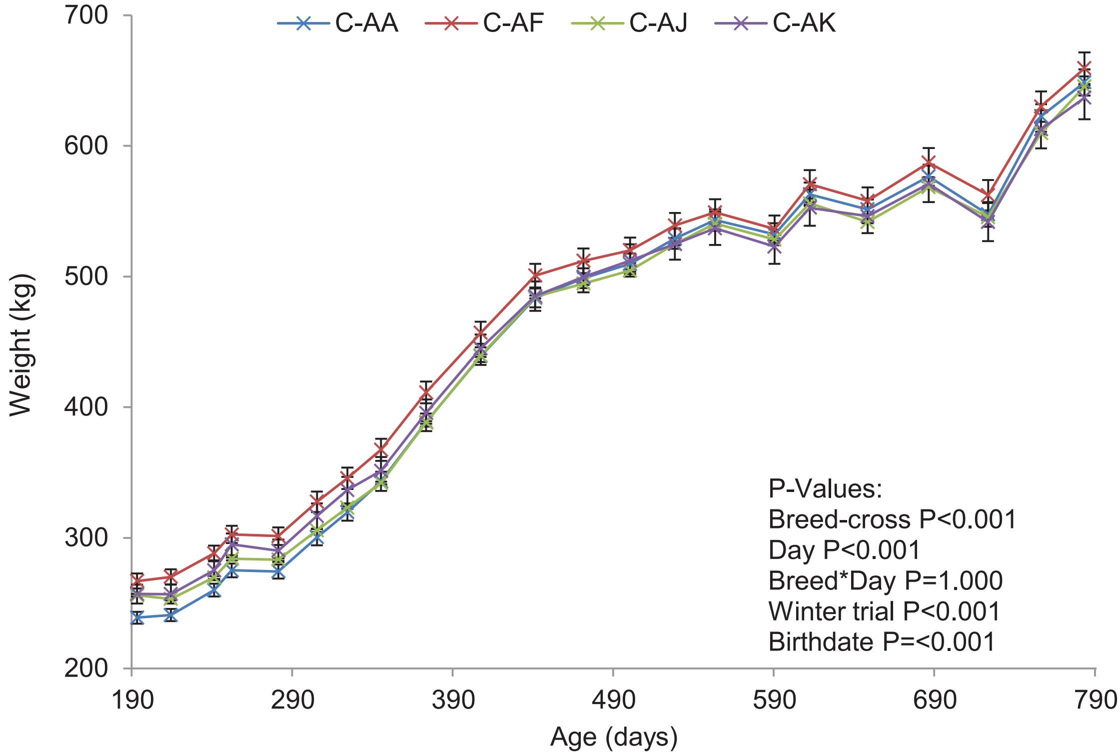


Figure 9: Body condition score for Charolais sired (C-) steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows measured at 241, 302, 423 and 553 days of age. Points are least squares means, with standard error bars. P-values are presented within the figure. Age presented is an average age of all cattle.

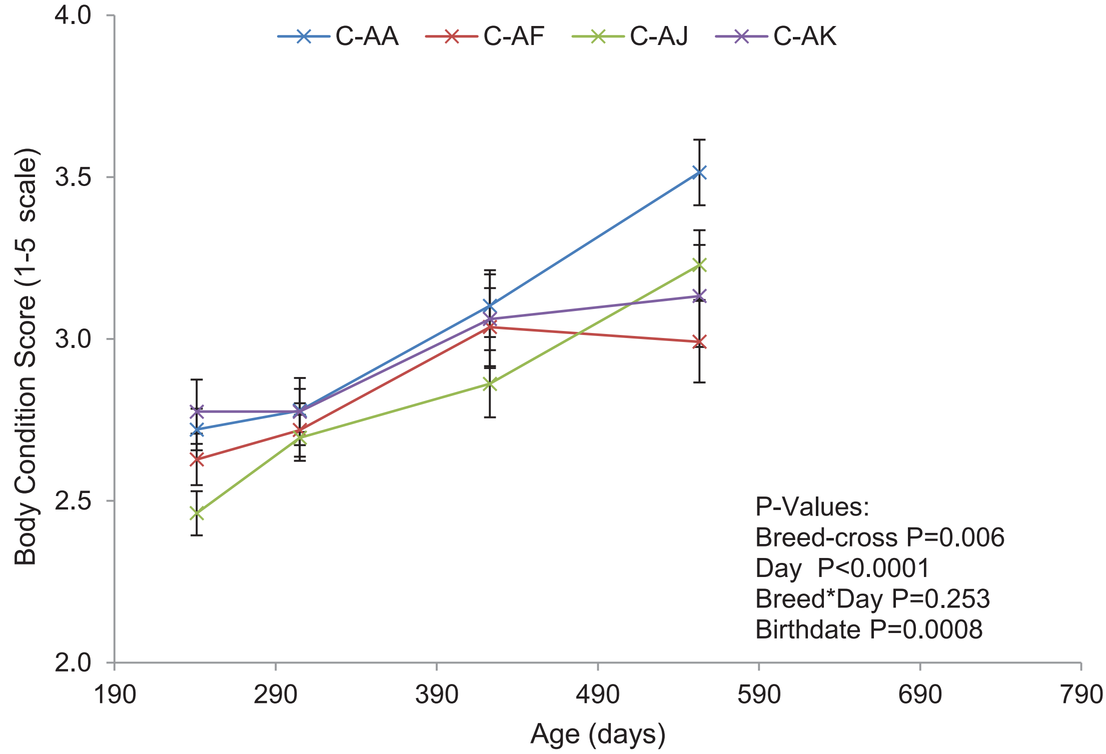


Table 15: Ultrasound carcass characteristics for Charolais sired (C-) steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, measured at 415, 553 and 723 days of age. Values are least squares means ± standard error. Age presented is an average age of all cattle.

	EMA (cm^2)	Fat depth C (mm)	IMF (%)	P8 fat depth (mm)
Breed				
C-AA	71.0 ±0.8	2.8 ±0.1[b]	3.3 ±0.2	4.2 ±0.1[b]
C-AF	72.0 ±1.0	2.2 ±0.1[a]	3.0 ±0.2	3.8 ±0.2[ab]
C-AK	72.3 ±1.2	1.9 ±0.2[a]	2.9 ±0.3	3.4 ±0.2[a]
C-AJ	69.9 ±0.9	2.0 ±0.1[a]	3.0 ±0.2	3.5 ±0.2[a]
Age (days)				
415	69.8 ±0.8[a]	2.0 ±0.1[a]	2.9 ±0.2[a]	3.5 ±0.1[b]
553	75.7 ±0.8[b]	2.7 ±0.1[b]	3.6 ±0.2[b]	5.1 ±0.2[c]
723	68.6 ±0.9[a]	1.9 ±0.1[a]	2.6 ±0.2[a]	2.6 ±0.1[a]
P-Values[1]				
Breed-cross	0.302	**<0.001**	0.686	**0.008**
Day	**<0.001**	**<0.001**	**0.009**	**<0.001**
Breed*day	0.934	0.491	0.391	0.948
Birthdate	**<0.001**	**<0.001**	**0.006**	**<0.001**

[abc] Differing superscript values within a column within an effect type indicate significant differences (P<0.05)

3.2. Carcass characteristics

All steers and heifers were graded as prime with a muscling score of 2 (P2) during commercial grading. Most heifers had a visual fat colour score of 2.5 or 3 (1-8 scale), and one C-AA heifer had a fat colour of 2 and one C-AJ heifer had fat colour of 3.5. All steers had a fat colour of 2 or 2.5. No animals were downgraded due to yellow fat colour.

Steers had longer, heavier carcasses with a greater fat depth C than heifers and greater percentage of intramuscular fat in the *Longissimus lumborum* muscle sample (Table 16, P<0.01). C-AA steers had a greater dressing-out percentage than C-AF and C-AJ steers (Table 16, P=0.008).

There were no differences among breed-crosses for carcass weight, length, eye muscle area, fat depth C, LL muscle area, LL muscle density or intramuscular fat percentage (Table 16, P>0.05). There was an interaction among breed and sex for fat depth C as C-AA steers had a greater fat depth the C-AK steers, but this was not evident for the heifers (Table 16, P=0.027).

Table 16: Carcass weight, dressing-out percentage, carcass length, eye muscle area (EMA) and fat depth C measured on the carcass at slaughter, and *Longissimus lumborum* muscle area and density measured during meat quality testing from Charolais sired (C-) heifers and steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, slaughtered at an average age of 574 and 784 days old respectively. Values are least squares means ± standard error of the mean.

	Breed-cross				Sex		P-Values			
	C-AA	C-AF	C-AK	C-AJ	Heifer	Steer	Breed-cross	Sex	Breed *sex	Carcass Weight
n	33	22	16	32	53	50				
Carcass weight (kg) [1]	291.6 ±3.6	296.3 ±4.4	288.7 ±5.2	282.1 ±3.6	238.8 ±2.9[a]	340.4 ±3.1[b]	0.083	**<0.001**	0.740	-
Dressing-out % [2]	53.1 ±0.3[b]	51.9 ±0.4[a]	52.0 ±0.5[ab]	51.5 ±0.3[a]	-	-	**0.008**	-	-	-
Carcass length (mm)	2239 ±8	2262 ±10	2251 ±12	2258 ±9	2218 ±13[a]	2287 ±14[b]	0.277	**0.007**	0.470	**<0.001**
EMA (cm^2)	80.9 ±2.0	84.0 ±2.5	84.4 ±2.8	83.2 ±2.0	84.4 ±3.0	81.9 ±3.3	0.672	0.682	0.531	**0.012**
Fat depth C (mm)	4.8 ±0.3	4.1 ±0.3	3.8 ±0.4	4.1 ±0.3	3.3 ±0.2[a]	5.1 ±0.2[b]	0.136	**<0.001**	**0.027**	NS
n	32	22	16	32	53	49				
LL muscle area (cm^2)	76.2 ±1.9	79.3 ±2.3	81.8 ±2.7	79.7 ±2.3	80.6 ±2.8	77.9 ±3.1	0.330	0.622	0.891	**0.001**
Density (g/cm^3)	1.03 ±0.02	0.99 ±0.03	1.00 ±0.03	1.04 ±0.02	1.02 ±0.02	1.02 ±0.02	0.464	0.958	0.901	NS
Intramuscular fat %	1.88 ±0.10	1.92 ±0.13	2.14 ±0.15	2.21 ±0.10	1.71 ±0.08[a]	2.36 ±0.09[b]	0.100	**<0.001**	0.066	NS

[1] Adjusted for age P=0.003
[2] Dressing out percentage not calculated for Heifers, values are for steers only, n: C-AA=17, C-AF=11, C-AK=7, C-AJ=15
[ab] Differing superscripts within a row represent breeds or sex type which are significantly different (P<0.05)
A hyphen indicates the effect was not fitted in the model
NS Indicates the effect was not significant and removed from the model

3.3. Meat quality

3.3.1. Ultimate pH

The spear pH and pH by homogenate were not different among breed-crosses (Table 17). Measurement of pH by spear method found steers to have a higher pH than heifers (Table 17, P<0.001), whereas the measurement by homogenate found heifers to have a higher pH than steers (Table 17, P=0.017).

3.3.2. Tenderness and related attributes

There were no differences between the beef from heifers and steers or the breed-crosses for Warner Bratzler work done, MFI and sarcomere length (Table 17). Beef from steers had a greater Warner Bratzler peak force and initial yield shear force than samples from heifers (Table 17, P<0.01).

3.3.3. Lean meat and subcutaneous fat colour

When measured by chromameter there were no differences in the lightness, redness or yellowness of meat among the breed-crosses (Table 17). Heifers and steers had meat of similar lightness and yellowness (Table 17), but steers had redder meat than heifers (Table 17, P<0.001). Steers had redder, yellower and darker fat than heifers when measured by chromameter (Table 17, P<0.001).

There was no difference among breed-crosses for lightness values (Table 17). The fat from C-AK cattle was redder than fat from C-AA and C-AF breed cattle (Table 17, P=0.026). The fat from C-AJ cattle was yellower than fat from C-AA cattle while C-AF and C-AK were intermediate (Table 17, P=0.035).

3.3.4. Water-holding measures

There was no difference in expressed juice, cooking and thaw loss and driploss at 24 and 48 hours among breed-crosses (Table 17, P>0.05).

Steers had greater thaw loss compared to heifers (Table 17, P<0.001). There were no differences between heifers and steers for expressed juice, cooking loss and driploss at both 24 and 48 hours (Table 17).

Table 17: Meat quality characteristics analysed on aged *Longissimus lumborum* muscle samples from Charolais sired (C-) heifers and steers from Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows, slaughtered at an average age of 574 and 784 days old respectively. Values are least squares means ± standard error of the mean.

	Breed				Sex		P-Values			
	C-AA	C-AF	C-AK	C-AJ	Heifers	Steers	Breed-cross	Sex	Breed *Sex	Ultimate pH
n	32	22	16	32	53	49				
Ultimate pH										
Spear method	5.64 ±0.02	5.62 ±0.02	5.58 ±0.03	5.61 ±0.02	5.56 ±0.01^{a}	5.67 ±0.02^{b}	0.252	**<0.001**	0.355	NS
Homogenate method	5.61 ±0.02	5.58 ±0.02	5.55 ±0.03	5.57 ±0.02	5.61 ±0.02^{b}	5.55 ±0.02^{a}	0.395	**0.017**	0.127	NS
Warner Bratzler (kgF)										
Peak force	9.04 ±0.31	9.27 ±0.37	8.32 ±0.44	8.85 ±0.31	8.33 ±0.27^{a}	9.42 ±0.28^{b}	0.417	**0.009**	0.117	**0.050**
Initial yield	2.83 ±0.07	2.71 ±0.08	2.64 ±0.10	2.63 ±0.07	2.48 ±0.05^{a}	2.92 ±0.06^{b}	0.196	**<0.001**	0.187	NS
Work done	2.70 ±0.08	2.72 ±0.10	2.51 ±0.12	2.62 ±0.08	2.65 ±0.07	2.63 ±0.08	0.547	0.614	0.215	**0.004**
MFI (%)	96.5 ±0.6	98.3 ±0.8	97.8 ±0.9	97.4 ±0.7	98.1 ±0.5	97.0 ±0.6	0.308	0.157	0.436	NS
Sarcomere length (µm)	1.86 ±0.02	1.87 ±0.03	1.82 ±0.03	1.86 ±0.02	1.86 ±0.02	1.85 ±0.02	0.724	0.587	0.278	NS
Meat colour										
Lightness (*L**)	37.7 ±0.4	37.4 ±0.5	39.2 ±0.6	37.9 ±0.4	37.9 ±0.3	38.2 ±0.4	0.125	0.445	0.677	NS
Redness (*a**)	14.4 ±0.2	14.6 ±0.3	14.7 ±0.3	14.9 ±0.2	13.7 ±0.2^{a}	15.5 ±0.2^{b}	0.325	**<0.001**	0.436	**<0.001**
Yellowness (*b**)	4.0 ±0.2	4.2 ±0.2	4.4 ±0.2	4.3 ±0.2	4.0 ±0.1	4.4 ±0.1	0.571	0.070	0.752	**0.018**
Fat colour										
Lightness (*L**)	65.8 ±0.5	64.9 ±0.5	64.7 ±0.6	65.3 ±0.5	67.9 ±0.4^{b}	62.4 ±0.4^{a}	0.465	**<0.001**	0.136	NS
Redness (*a**)	7.3 ±0.4^{b}	7.3 ±0.4^{b}	5.7 ±0.5^{a}	6.3 ±0.4^{ab}	4.5 ±0.3^{a}	8.8 ±0.3^{b}	**0.026**	**<0.001**	0.154	NS
Yellowness (*b**)	11.7 ±0.3^{a}	12.0 ±0.4^{ab}	12.6 ±0.5^{ab}	13.0 ±0.3^{b}	11.5 ±0.3^{a}	13.2 ±0.3^{b}	**0.035**	**<0.001**	0.055	NS
Water holding measures										
Expressed juice (cm^2/g)	31.3 ±0.5	30.1 ±0.6	30.7 ±0.5	30.8 ±0.7	30.6 ±0.4	31.2 ±0.4	0.875	0.260	0.867	NS
Driploss 24h (%)	7.0 ±0.5	6.4 ±0.6	6.0 ±0.7	6.3 ±0.5	6.6 ±0.4	6.2 ±0.4	0.562	0.464	0.424	**0.008**
Driploss 48h (%)	8.7 ±0.6	8.1 ±0.7	8.1 ±0.8	8.3 ±0.6	8.6 ±0.5	8.0 ±0.5	0.877	0.441	0.328	**0.004**
Thaw loss (%)	2.5 ±0.3	2.5 ±0.3	3.2 ±0.4	2.3 ±0.3	1.7 ±0.2^{a}	3.6 ±0.2^{b}	0.264	**<0.001**	0.937	**<0.001**
Cooking loss (%)	26.4 ±0.3	26.4 ±0.4	27.0 ±0.4	26.3 ±0.3	26.2 ±0.2	26.9 ±0.3	0.537	0.077	0.344	NS

^{ab} Differing superscripts within a row represent breeds or sexes which are significantly different ($P<0.05$)
NS Indicates effect was not significant and removed from the model

4. Discussion

The objectives of this study were to investigate the effect of breed-cross on growth, carcass characteristics and meat quality attributes for Charolais-sired progeny of beef and beef-cross-dairy cows, namely Angus, Angus-Friesian, Angus-KiwiCross, and Angus-Jersey grown in a New Zealand pastoral production system. This study also aimed to determine if any breed effects differed between heifer and steer cattle.

4.1. Growth characteristics

The C-AA cattle were lighter than the beef-cross-dairy cattle at weaning. Differences among breed-crosses in the weaning weights of both the heifers and steers are likely reflective of the differences in milk production of the dams. The milk production of the straight-bred Angus cow, was less than that of the beef-cross-dairy breed cows used to produce the cattle used in this experiment (Roca Fraga *et al.*, 2013, Hickson *et al.*, 2015a). The differences among breed-crosses are consistent with weaning weights from previous calves born to the same dams as used in the present experiment (Law *et al.*, 2013, Vazquez *et al.*, 2013).

Despite being heavier at weaning, the C-AJ and C-AK heifers were slower growing than the C-AA heifers, although there was no difference in the final live weight among breed-crosses. The Jersey-cross cattle being slower growing than Angus and Friesian cattle is supported by literature in which straight-bred and first-cross Jersey cattle grew slower than straight-bred and first-cross Angus and Friesian cattle (Long *et al.*, 1979, Baker *et al.*, 1990, Alberti *et al.*, 2008). There were no differences in the overall growth rate from the steers, and despite the C-AA steers being lighter at weaning, there were no differences in the final live weight.

4.2. Carcass characteristics

Although the C-AA heifers were shorter than the C-AF and C-AK heifers, there was no difference in the body condition scores of the different breed-crosses throughout the experiment indicating that although growth rates were different (reflecting the different sizes and mature extents of the animals) the level of tissue deposition on the frame of the animals was relatively constant across the breed-crosses. This could be due to the fact that the breed-crosses were only ¼ different genetically and had similar management conditions.

The C-AA steers had greater body condition at 553 days of age, likely due to the greater subcutaneous fat depths (C and P8 sites) measured by ultrasound during the experiment. The incidence of greater body condition from the C-AA is likely in part reflective of the shorter stature of the C-AA steers and the lack of differences in weight of the steers from 407 days of age until the end of the experiment. The results from the current experiment are not consistent with the differences among breed-cross in previous progeny from the same cows used in this experiment, in which there were no differences in fat depth C and body condition score among breed-crosses (Vazquez *et al.*, 2013).

The cattle were in the best condition at 553 days of age. The steers, although still gaining weight, lost body condition between 553 and 723 days of age as indicated by the decreased eye muscle area, fat depth and intramuscular fat. The decreased body condition is likely to be reflective of the dry winter and spring with restricted feed availability, so although the steers were gaining weight until slaughter, this was not enough to regain the tissue mobilised and impacted on the fat depths and EMA.

Generally there were no differences in carcass characteristics among breed-crosses. Dressing out percentage in the present experiment was the only trait which differed among breed-crosses and was greater for C-AA steers compared to the C-AF and C-AJ steers. Several previous authors have reported greater dressing out percentages for beef-breeds compared with dairy-breed cattle (Morris *et al.*, 1990, Barton and Pleasants, 1997, Purchas and Morris, 2007, Alberti *et al.*, 2008, Schreurs *et al.*, 2014, Collier *et al.*, 2015), which has been attributed to partitioning of fat into non-carcass in dairy compared with beef breeds (Barton and Pleasants, 1997, Muir *et al.*, 2000). The lack of difference between the C-AA and C-AK steers is likely to be partly a consequence of the lower number of C-AK steers and the large variation in dressing out percentage. The similarities among breed-crosses for carcass length, EMA and LL muscle area are not consistent with literature reports for straight breed and first crosses among Angus, Jersey and Friesian cattle (Purchas and Barton, 1976, Morris *et al.*, 1990, Barton *et al.*, 1994, Burke *et al.*, 1998, Purchas and Morris, 2007, Purchas and Zou, 2008), although carcass length and the measures of muscle area were adjusted for carcass weight in the present experiment. The similarity between the breed crosses for carcass length, EMA and LL muscle area when the measurements were adjusted to an equal carcass weight, suggests that carcass characteristics are driven by the size and weight of the animal at slaughter (Morris *et al.*, 1990, Burke *et al.*, 1998).

The differences in carcass weight, length, fat depth C and proportion of intramuscular fat between heifers and steers could be attributed to the steers being seven months older, and that the steers were heavier at slaughter which agrees with literature that older animals have greater proportions of fat (Arthuad *et al.*, 1977, Irshad *et al.*, 2013) and that the steers were at a phase where the steers were maturing and this was associated with more fat in growth. Both heifers and steers were at the lower end of ‘P’ grade fatness, so there is potential to fatten the cattle more before slaughter. This has the potential to decrease the dressing out percentage through increased deposition of non-carcass fat.

It was hypothesised that the C-AA cattle grow faster than the other breed-crosses (Young *et al.*, 1978, Long *et al.*, 1979, Baker *et al.*, 1990, Alberti *et al.*, 2008). This was seen with the heifers but not with steers, and dressing-out percentage as seen with the steers. Also that the C-AA cattle will have greater eye muscle area (Koch *et al.*, 1976, Morris *et al.*, 1990, Wheeler *et al.*, 2004) which was not evident in this experiment, and a greater fat depth C (Koch *et al.*, 1976, Morris *et al.*, 1990, Barton and Pleasants, 1997, Wheeler *et al.*, 2004), which was evident in this experiment. The dairy-cross cattle did have yellower fat which was supported by the literature (Morgan and Everitt, 1969, Walker *et al.*, 1990, Muir *et al.*, 2000). It was also hypothesised that the Jersey-cross breed-crosses would have more tender meat (Morgan and Everitt, 1969, Walker *et al.*, 1990, Muir *et al.*, 2000) but there were no breed-cross differences in the tenderness of the meat.

Dressing-out percentage could not be calculated for heifers and so it cannot be speculated whether the steers had a greater dressing out percentage. It was also hypothesised that steers would have greater fat depth C than heifers, due to being older at slaughter (Arthuad *et al.*, 1977, Irshad *et al.*, 2013), which was evident in this experiment. It was also hypothesised that steers would have redder meat, yellower fat (Morgan and Everitt, 1969, Koch *et al.*, 1976, Seideman *et al.*, 1984, Purchas, 1989, Renerre, 1990, Dubeski *et al.*, 1997, Muir *et al.*, 2000, Chambaz *et al.*, 2003, Bures and Barton, 2012) and decreased tenderness and juiciness (Purchas, 1989, Moloney *et al.*, 2001, Purchas *et al.*, 2002a, Chambaz *et al.*, 2003, Destefanis *et al.*, 2003, Lucero-Borja *et al.*, 2014) than heifers due to being older at slaughter, which was also found in this study.

4.3. Meat Quality

There were no differences among breed-cross for any meat quality characteristics, apart from fat colour. The C-AJ steers had yellower fat than the C-AA steers, which is consistent with published literature that dairy breeds have a tendency for yellower fat, and more so Jersey cattle than other breeds (Morgan and Everitt, 1969, Walker *et al.*, 1990, Burke *et al.*, 1998, Purchas, 2003, Purchas and Morris, 2007). Although there was a difference in the fat colour, when carcasses were graded at slaughter none were penalised for yellow fat8 reflecting the sensitivity of the chromameter for detecting differences in colour, but the difference in b*-values are unlikely to be detected by the human eye and therefore, not of concern for beef producers. As beef-cross-dairy cattle were ¼ Jersey at most, it is unsurprising that the effect is diluted. Comparison of cross-breed cattle for meat production has been noted to produce little difference in meat quality when animals are slaughtered at a similar weight or level of finish (Purchas and Barton, 1976, Barton and Pleasants, 1993, Burke *et al.*, 1998, Muir *et al.*, 2000, Schreurs *et al.*, 2014).

There was a difference in the pH between heifers and steers, and the two methods of measuring pH found different results. The spear pH method found steers to have a greater pH, whereas, the homogenate method found a higher pH from heifers. However, the high precision of the tests (Solomon, 1987) means that, although statistically different, the differences between heifers and steers are unlikely to have biological significance. The differences between the two tests were unexpected, and may be due to human error rather when measuring meat quality.

Generally the steers produced meat that had higher shear force values than the heifers, which is consistent to the literature (Purchas and Aungsupakorn, 1993, Purchas, 2000, Purchas *et al.*, 2002a, Lucero-Borja *et al.*, 2014). It is likely that the greater age of the steers was influencing the shear force values. Steers also had redder meat, and redder, darker and yellower fat than the heifers. The higher incidence of yellower fat from steers compared to heifers reflects the steers being older at slaughter and on a pasture diet for longer (Morgan and Everitt, 1969, Koch *et al.*, 1976, Seideman *et al.*, 1984, Kirton and Morris, 1989, Purchas, 1989, Renerre, 1990, Dubeski *et al.*, 1997, Muir *et al.*, 2000, Chambaz *et al.*, 2003).

4.4. Limitations

The design of this experiment was such that sex and age at slaughter were confounded by the fact that heifers were slaughtered almost seven months earlier than the steers. As this experiment was designed to reflect commercial reality, heifers are typically slaughtered earlier than steers, the cattle in this experiment were managed to reflect this. The heifers and steers were managed separately and the heifers were preferentially fed.

Due to Mendelian sampling of the mother’s genetics, offspring from the crossbreed cows will have inherited differing proportions of the grandparent breeds. The effect of this is that the beef-cross-dairy progeny vary in their percentage of Jersey, Friesian and Angus genes. However, over a large enough sample size, the genetics of the breed-crosses will average out to 50% Charolais, 25% Angus and 25% Angus (C-AA), Friesian (C-AF), Jersey (C-AJ), or KiwiCross (C-AK). Similarly, the KiwiCross-cross cattle would average 12.5% Friesian and 12.5% Jersey. There were a smaller number of cattle born to Angus-KiwiCross cows than other breed-crosses, due to fewer Angus-KiwiCross cows used than other breed-crosses. The relatively low number of animals in this group increased the likelihood that this group was biased towards either Friesian or Jersey.

The wintering experiment was a potential issue. Each of the feeding treatments was balanced for breed-cross, sex and initial live weight. By balancing the feeding treatments, and that the experimental period was for a relatively short period, and well in advance of slaughter, the wintering trial was unlikely to have a major impact on the results from this experiment.

The cattle were grazed during a drought in the summer of 2012-2013 and 2013-2014, and a dry winter during 2014, so the cattle were slower growing and were in poorer condition due to feed restrictions. This would have limited the deposition of fat over the period, and if energy intake was restricted enough, body condition will be mobilised for maintenance energy requirements.

There were no body condition scores taken on the steers after the heifers were slaughtered. The results from the ultrasound scanning at 723 days of age show that the steers lost condition represented by decreased fat depths and eye muscle area between when the heifers and steers were slaughtered. Body condition scores would have given a record illustrating that visually, they did lose considerable condition.

No final live weight was measured for the heifers and so a calculation of dressing-out percentage was not possible. A measurement of dressing-out percentage would have shown if there were any differences in the dressing-out percentage from steers and heifers, and if the differences seen among the steer breed-crosses were consistent with the heifers.

4.5. Implications

At the level of the beef cow, the Angus-cross-dairy cow is more efficient than the straight-bred Angus cow for production of a weaned calf (Hickson *et al.*, 2012, Law *et al.*, 2013, Roca Fraga *et al.*, 2013). However for finishing of cattle for meat production, Angus progeny are superior to the dairy-cross breeds in terms of growth, dressing-out percentage and carcass weight (Vazquez *et al.*, 2013, Schreurs *et al.*, 2014, Collier *et al.*, 2015). As the Angus progeny are more suitable for the finishing system than the dairy-cross progeny, the Angus-cross progeny would be worth more to the finisher, and warrant a higher price per kg for the weaned calves. However, an increased price for the Angus-cross calves may not outweigh the extra production from beef-cross-dairy calves at the level of the beef cow.

The Angus-cross cattle in this study had a greater dressing out percentage for the same carcass weight and had deeper fat depth C (signalling level of finish) as the beef-cross-dairy breed cattle, despite being lighter at weaning and growing at a similar rate. Therefore, a beef finishing farm purchasing weaned Angus-cross cattle would be more profitable than one purchasing beef-cross-dairy breeds, as the Angus-cross cattle would reach a desired level of finish faster and would be slaughtered sooner than the beef-cross-dairy breeds.

4.6. Future Research

Results from this study indicate differences in carcass characteristics and meat quality attributes between steers and heifers, although the sex effect was confounded by the steers being older at slaughter. Therefore, research into investigating the differences in growth, the carcass performance and meat quality between heifers and steers is warranted, and could be achieved by managing all cattle together and slaughtering them at the same point to focus on just the sex effect.

As the proportion of KiwiCross cows in the dairy industry is increasing, more exploration into the performance of these cows and their progeny in the beef industry is warranted. Particularly research into the straight-bred and first-cross beef breeding cow, and the finishing performance of straight-bred, first-cross and second-cross cattle, with larger numbers of the KiwiCross breed than were in the current experiment.

Previous research has considered the pre-weaning and post-weaning systems of beef production separately. Combining the research into an evaluation of the beef breeding and finishing systems as a whole is a necessary next step for research into beef-cross-dairy cows in New Zealand. As the weaning weight of Angus-cross calves is lower than beef-cross-dairy calves, but the post weaning growth and dressing out percentage is greater, an investigation into the effect of increasing the price per kg of weaned Angus-cross calves relative to the dairy-cross calves is warranted. This would be to investigate whether the increased price outweighs the extra production from the beef-cross-dairy calves at the level of the beef cow.

4.7. Conclusions

The C-AA cattle were the lightest at weaning, but caught up to be heavier than the Jersey- and KiwiCross-cross cattle and similar in weight to the Friesian-cross cattle at slaughter, making the C-AA cattle the best choice for purchase on a per kg basis at weaning. The Jersey-cross cattle were slower growing, and lost the live weight advantage from weaning over the Angus-cross cattle early on in the experiment. As there were differences in the dressing-out percentage between breeds, the beef producer needs to adjust live weight expectations for different breeds to achieve a target carcass weight.

Although the Jersey-cross cattle were slower growing, and the C-AJ steers had a lesser dressing-out percentage, the Jersey-cross cattle were no different to the other breed-crosses in terms of final live weight or carcass weight and the eye muscle area, fat depth and intramuscular fat proportion. There were also no yellow fat penalties for the Jersey-cross carcasses signifying that the Jersey-cross cattle were comparable to the C-AA. Although there were differences among breed-crosses, on a price per kg weaning weight basis the C-AA cattle would be superior.

The C-AA cattle are more suited to a finishing system than beef-cross-dairy breeds, but the dairy-cross cows are efficient calf producers, and the beef-cross-dairy cattle did not differ in the carcass weight, and were similar in eye muscle area, fat depth and intramuscular fat. There were few differences in the meat (eating) quality of the breed-crosses. To the beef production industry as a whole the beef-cross-dairy breeding cow provides progeny which are competitive to straight-bred beef for beef finishing and meat production, and provide a means of increasing the export quantity of New Zealand beef.

Reference List

Aass, L., Fristedt, C.-G. & Gresham, J. D. 2009. Ultrasound prediction of intramuscular fat content in lean cattle. *Livestock Science,* 125**,** 177-186.

Akbas, Y., Alcicek, A., Onenc, A. & Gungor, M. 2006. Growth curve analysis for body weight and dry matter intake in Friesian, Limousin x Friesian and Piedmontese x Friesian cattle. *Archives Animal Breeding,* 49**,** 329-339.

Alberti, P., Panea, B., Sanudo, C., Olleta, J. L., Ripoll, G., Ertjerg, P., Christensen, M., Gigli, S., Failla, S., Concetti, S., Hocquette, J. F., Jailler, R., Rudel, S., Renand, G., Nute, G. R., Richardson, R. I. & Williams, J. L. 2008. Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. *Livestock Science,* 114**,** 19-30.

Arthuad, V. H., Mandigo, R. W., Koch, R. M. & Kotula, A. W. 1977. Carcass composition, quality and palatability attributes of bulls and steers fed different energy levels and killed at four ages. *Journal of Animal Science,* 44**,** 53-64.

Arthur, P. F., Hearnshaw, H., Johnston, D. & Stephenson, P. D. 1995. Evaluation of Angus, Charolais and Hereford as terminal sire breeds on Hereford and first-cross cows. II. Carcase characteristics and retail yield of progeny. *Australian Journal of Agriculture Research,* 46**,** 1245-1258.

Bailey, C. M., Probert, C. L. & Bohman, V. R. 1966. Growth rate, feed utilization and body composition of young bulls and steers. *Journal of Animal Science,* 25**,** 132-137.

Baker, R. L., Carter, A. H., Morris, C. A. & Johnson, D. L. 1990. Evaluation of eleven cattle breeds for crossbred beef production: Performance of progeny up to 13 months of age. *Animal Production,* 50**,** 63-77.

Barton, R. A., Donaldson, J. L., Barnes, F. R., Jones, C. F. & Clifford, H. J. 1994. Comparison of Friesian, Friesian-Jersey cross and Jersey steers in beef production. *New Zealand Journal of Agricultural Research,* 37**,** 51-58.

Barton, R. A. & Pleasants, A. B. 1993. Fat colour and meat colour in different breeds of steers in five consecutive years raised on pasture and slaughtered at 30 months of age. *Proceedings of the New Zealand Society of Animal Production,* 53**,** 389-391.

Barton, R. A. & Pleasants, A. B. 1997. Comparison of the carcass characteristics of steers of different breeds and pre-weaning environments slaughtered at 30 months of age. *New Zealand Journal of Agricultural Research,* 40**,** 57-68.

Bass, J. J., Baker, R. L., Carter, A. H. & Ackerley, L. R. 1975. Comparison of the growth and carcass composition of purebred Angus and crossbred Hereford-Angus and Friesian-Angus steers. *New Zealand Journal of Experimental Agriculture,* 3**,** 207-211.

Beef + Lamb NZ. 2015a. *Compendium of New Zealand Farm Facts* [Online]. Wellington, New Zealand: Beef and Lamb NZ. Available: www.beefandlambnz.com/Documents/Information/Compendium%20of%20New%20Zealand%20farm%20facts.pdf [Accessed 29 July 2015].

Beef + Lamb NZ. 2015b. *Mid-Season Update 2014-15* [Online]. Wellington, New Zealand Beef and lamb NZ. Available: www.beefandlambnz.com/Documents/Information/Mid-Season%20Update%202014-15.pdf [Accessed 29 July 2015].

Bendall, J. R. 1973. Post mortem changes in muscle. *In:* Bourne, G. H. (ed.) *The Structure and Function of Muscle.* New York, NY: Academic Press, 243-309.

Blanco, M., Jurie, C., Micol, D., Agabriel, J., Picard, B. & Garcia-Launay, F. 2013. Impact of animal and management factors on collagen characteristics in beef: a meta-analysis approach. *Animal,* 7, 1208-1218.

Blumer, T. N. 1963. Relationship of marbling to the palatability of beef. *Journal of Animal Science,* 22, 771-778.

Bouton, P. E., Harris, P. V. & Shorthose, W. R. 1975. Changes in shear parameters of meat associated with structural changes produced by aging, cooking and myofibrillar contraction. *Journal of Food Science,* 40, 1122-1126.

Breedplan. 2015. *BREEDPLAN EBV's "the traits explained"* [Online]. Available: breedplan.une.edu.au/tips/BREEDPLAN%20-%20The%20Traits%20Explained.pdf [Accessed 15/04/2015.

Bures, D. & Barton, L. 2012. Growth performance, carcass traits and meat quality of bulls and heifers slaughtered at different ages. *Czech Journal of Animal Science,* 57, 34-43.

Burke, J. L., Purchas, R. W. & Morris, S. T. 1998. A comparison of growth, carcass and meat characteristics of Jersey- and Friesian- cross heifers in a once bred heifer system of beef production. *New Zealand Journal of Agricultural Research,* 41, 91-99.

Burnham, D. L. 2000. *Investigations into variation in growth performance of cattle at pasture.* Masters in Applied Science (Animal Science), Massey University.

Burnham, D. L., Purchas, R. W. & Morris, S. T. 2005. Relationships between on-farm and pre-slaughter behaviour, and growth and meat quality for bulls and steers. *Proceedings of the New Zealand Society of Animal Production,* 65, 261-265.

Butler-Hogg, B. W. & Wood, J. D. 1982. The partition of body fat in British Friesian and Jersey steers. *British Society of Animal Production,* 35, 253-262.

Butler, O. D. 1957. The relation of conformation to carcass traits. *Journal of Animal Science,* 16**,** 227-233.

Calkins, C. R. & Hodgen, J. M. 2007. A fresh look at meat flavor. *Meat Science,* 77**,** 63-80.

Campo, M. M., Santolaria, P., Sanudo, C., Lepetit, J., Olleta, J. L., Panea, B. & Alberti, P. 2000. Assessment of breed type and aging time effects of beef meat quality using two different texture devices. *Meat Science,* 55**,** 371-378.

Carter, A. H. 1975. Evaluation of cattle breeds for beef production in New Zealand. *Livestock Production Science,* 2**,** 327-340.

Chambaz, A., Scheeder, M. R. L., Kreuzer, M. & Dufey, P.-A. 2003. Meat quality of Angus, Simmental, Charolais and Limousin compared at the same intramuscular fat content. *Meat Science,* 63**,** 491-500.

Collier, K. J. D., Hickson, R. E., Schreurs, N. M., Martin, N. P., Kenyon, P. R. & Morris, S. T. 2015. Growth rate and carcass characterisitcs of Simmental- and Angus-sired steers born to Angus and Angus-cross-dairy cows. *Proceedings of the New Zealand Society of Animal Production,* 75**,** 15-19.

Conroy, S. B., Drennan, M. J., McGee, M., Keane, M. G., Kenny, D. A. & Berry, D. P. 2010. Predicting beef carcass meat, fat and bone proportions from carcass conformation and fat scores or hind quarter dissection. *Animal,* 4**,** 234-241.

Cook, A. 2014. *The hunt for the missing billion: NZ's dairy beef opportunity*. Kellogg rural leaders programme 2014.

Cundiff, L. V. 1970. Experimental results on crossbreeding cattle for beef production. *Journal of Animal Science,* 30**,** 694-705.

Dairynz. 2014. *New Zealand Dairy Statistics 2013-2014* [Online]. Hamilton, New Zealand: Livestock Improvement limited & DairyNZ limited.

Available: http://www.dairynz.co.nz/media/1327583/nz-dairy-statistics-2013-2014-web.pdf [Accessed 24 April 2015].

Daly, C. C. 2000. Live animal contribution to beef tenderness. *Proceedings of the New Zealand Society of Animal Production,* 60**,** 103-106.

Destefanis, G., Brugiapaglia, A., Barge, M. T. & Lazzaroni, C. 2003. Effect of castration on meat quality in Piedmontese cattle. *Meat Science,* 64**,** 215-218.

Drennan, M. J., McGee, M. & Keane, M. G. 2008. The value of muscular and skeletal scores in the live animal and carcass classification scores as indicators of carcass composition in cattle. *Animal,* 2**,** 752-760.

Dubeski, P. L., Aalhus, J. L., Jones, J. L., Robertson, W. M. & Dyck, R. S. 1997. Meat quality of heifers fattened to heavy weights to enhance marbling. *Canadian Journal of Animal Science,* 77**,** 635-643.

Freer, M., Dove, H. & Nolan, J. V. 2007. Energy. *In:* Freer, M., Dove, H. & Nolan, J. V. (eds.) *Nutrient requirements of domesticated ruminants.* Collingwood, Australia: CSIRO publishing, 1-61.

Garrick, D. J. & Lopez-Villalobos, N. 1998. Tomorrow's cows - some kiwi cows of the future. *Proceedings of the Ruakura Farmers' Conference,* 50**,** 39-44.

Glimp, H. A., Dikeman, M. E., Tuma, H. J., Gregory, K. E. & Cundiff, L. V. 1971. Effect of sex condition on growth and carcass traits of male hereford and angus cattle. *Journal of Animal Science,* 33**,** 1242-1247.

Gorraiz, C., Beriain, M. J., Chasco, J. & Insausti, K. 2002. Effect of aging time on volatile compounds, odor, and flavor of cooked beef from Pirenaica and Friesian bulls and Heifers. *Journal of Food Science,* 67**,** 916-922.

Gregory, K. E., Cundiff, L. V., Koch, R. M., Dikeman, M. E. & Koohmaraie, M. 1994. Breed effects and retained heterosis for growth, carcass and meat traits in advanced generations of composite populations of beef cattle *Journal of Animal Science,* 74**,** 833-850.

Gregory, K. E., Laster, D. B., Cundiff, L. V., Koch, R. M. & Smith, G. M. 1978. Heterosis and breed maternal and transmitted effects in beef cattle. II. growth rate and puberty in females. *Journal of Animal Science,* 47**,** 1042-1053.

Hamm, R. 1986. Functional Properties of the Myofibrillar System and Their Measurements. *In:* Bechtel, P. J. (ed.) *Muscle as Food.* Orlando, FL: Academic Press, 135-199

Hansen, S., Therkildsen, M. & Byrne, D. V. 2006. Effects of a compensatory growth strategy on sensory and physical properties of meat from young bulls. *Meat Science,* 74**,** 628-643.

Hickson, R. E., Back, P. J., Coleman, L. W., Lopez-Villalobos, N., Kenyon, P. R. & Morris, S. T. 2015a. Composition of milk sampled from beef-cross-dairy cows unaccustomed to milking. *Proceedings of the New Zealand Society of Animal Production,* 75**,** 260-262.

Hickson, R. E., Laven, R. L., Lopez-Villalobos, N., Kenyon, P. R. & Morris, S. T. 2012. Postpartum anoestrous interval in first lactation beef and dairy-beef crossbred cows. *Animal Production Science*, 52, 478-482.

Hickson, R. E., Lopez-Villalobos, N., Kenyon, P. R. & Morris, S. T. 2014. Breed effects and heterosis for productivity traits at first calving of Angus, Holstein Friesian, Jersey and crossbred beef cows. *Animal Production Science,* 54**,** 1381-1387.

Hickson, R. E., Zhang, I. L. & Mcnaughton, L. R. 2015b. Birth weight of calves born to dairy cows in New Zealand. *Proceedings of the New Zealand Society of Animal Production,* 75**,** 257-259.

Homer, D. B., Cuthbertson, A., Homer, D. L. M. & Mcmenamin, P. 1997. Eating quality of beef from diffeerent sire breeds. *Animal Science,* 64**,** 403-408.

Hopkins, D. L. 1989. Relaibility of three sites for measuring fat depth on beef carcasses. *Australian Journal of Experimental Agriculture,* 29**,** 165-168.

Hopkins, D. L. & Geesink, G. H. 2009. Protein degradation, postmortem and tenderization *In:* Du, M. & Mccormick, R. J. (eds.) *Applied Muscle Biology and Meat Science.* Boca Raton, Florida: CRC Press, 149-174.

Huuskonen, A., Pesonen, M., Kamarainen, H. & Kauppinen, R. 2013. A comparison of the growth and carcass traits between dairy and dairy x beef breed crossbred heifers reared for beef production. *Journal of Animal and Feed Sciences,* 22**,** 188-196.

Irshad, A., Kandeepan, G., Kumar, S., Ashish Kumar, A., Vishnuraj, M. R. & Shukla, V. 2013. Factors influencing carcass composition of livestock: A review. *Journal of Animal Production Advances,* 3**,** 177-186.

Johnson, E. R. 1987. Marbling fat in beef. *Meat Science,* 20**,** 267-279.

Johnson, E. R., Taylor, D. C., Priyanto, R. & Meehan, D. P. 1994. The value of eye muscle area in predicting carcass muscle *Proceedings of the Australian Society of Animal Production,* 19**,** 68-70.

Juarez, M., Aldai, N., Lopez-Campos, O., Dugan, M. E. R., Uttaro, B. & Aalhus, J. L. 2012. Beef texture and Juiciness. *In:* Hui, Y. H. (ed.) *Handbook of meat and meat processing.* Boca Raton, FL: Taylor and Francis Group, LLC, 177-206.

Keane, M. G. & Moloney, A. P. 2009. A comparison of finishing systems and duration for spring-born Aberdeen Angus x Holstein-Friesian and

Belgian Blue x Holstein-Friesian steers. *Livestock Science,* 124, 223-232.

Kempster, A. J. & Owen, M. G. 1981. A note on the accuracy of an ultrasonic technique for selecting cattle of different breeds for slaughter at equal fattness. *Animal Production,* 32, 113-115.

Kirton, A. H. 1989. Principles of classification and grading. *In:* Purchas, R. W., Butler-Hogg, B. W. & Davies, A. S. (eds.) *Meat Production and Processing.* Hamilton, New Zealand: New Zealand Society of Animal Production Inc, 143-158.

Kirton, A. H. & Morris, C. A. 1989. The effect of mature size, sex and breed on patterns of change during growth and development. *In:* Purchas, R. W., Butler-Hogg, B. W. & Davies, A. S. (eds.) *Meat Production and Processing.* Hamilton, New Zealand: New Zealand Society of Animal Production Inc, 73-86.

Kirton, A. H. & Pickering, F. S. 1967. Factors associated with differences in carcass conformation in lamb. *New Zealand Journal of Agricultural Research,* 10, 183-200.

Koch, R. M., Dikeman, M. E., Allen, D. M., May, M., Crouse, J. D. & Campion, D. R. 1976. Characterization of biological types of cattle III. Carcass composition, quality and palatability. *Journal of Animal Science,* 43, 48-62.

Koutsidis, G., Elmore, J. S., Oruna-Concha, M. J., Campo, M. M., Wood, J. D. & Mottram, D. S. 2008. Water-soluble precursors of beef flavour: I. Effect of Diet and Breed. *Meat Science,* 79, 124-130.

Lage, I. N. K., Paulino, P. V. R., Pires, C. V., Villela, S. D. J., Duarte, M. S., Filho, S., C, V., Paulino, M. F., Maia, B. A., Silva, L. H. P. & Teixeira, C. R. V. 2012. Intake, digestibility, performance, and carcass traits of beef cattle of different gender. *Tropical Animal Health and Production,* 44, 361-367.

Lambe, N. R., Ross, D. W., Navajas, E. A., Hyslop, J. J., Prieto, N., Craigie, C., Bünger, L., Simm, G. & Roehe, R. 2010. The rediction of carcass composition and tissue distribution oin beef cattle using ultrasound scanning at the start and/or end of the finishing period. *Livestock Science,* 131**,** 193-202.

Laster, D. B., Smith, G. M., Cundiff, L. V. & Gregory, K. E. 1979. Characterization of biological types of cattle (cycle II) II. Postweaning growth and puberty of heifers. *Journal of Animal Science,* 43**,** 500-508.

Laster, D. B., Smith, G. M. & Gregory, K. E. 1976. Characterization of biological types of cattle. IV. Post weaning growth and puberty of heifers. *Journal of Animal Science,* 43.

Law, N. L., Hickson, R. E., Lopez-Villalobos, N., Kenyon, P. R. & Morris, S. T. 2013. Efficiency of beef breeding cows that vary in liveweight and milking potential. *Proceedings of the New Zealand Society of Animal Production,* 73, 11-16.

Little, C. L., Hickson, R. E., Martin, N. P., Beausoleil, N. J., Cockrem, J. F., Kenyon, P. R., Horne, D. & Morris, S. T. 2015. Beef cattle wintering systems: effects on cattle and pasture. *Proceedings of the New Zealand Society of Animal Production,* 75**,** 167-171.

Locker, R. H. 1989. Muscle into Meat. *In:* Purchas, R. W., Butler-Hogg, B. W. & Davies, A. S. (eds.) *Meat Production and Processing.* Hamilton, New Zealand: New Zealand Society of Animal Production Inc, 173-184.

Long, C. R., Stewart, T. S., Cartwright, T. C. & Baker, J. F. 1979. Charactrization of cattle of a five breed diallel: II. Measures of size, condition and growth in heifers. *Journal of Animal Science,* 49**,** 432-447.

Lucero-Borja, J., Pouzo, L. B., De La Torre, M. S., Langman, L., Carduza, F., Corva, P. M., Santini, F. J. & Pavan, E. 2014. Slaughter weight, sex and age effects on beef shear force and tenderness. *Livestock Science,* 163**,** 140-149.

Maltin, C. A., Sinclair, K. D., Warriss, P. D., Grant, C. M., Porter, A. D., Delday, M. I. & Warkup, C. C. 1998. The effects of age at slaughter, genotype and finishing system on the biochemical properties, muscle fibre type characteristics and eating quality of bull beef from suckled calves. *Animal Science,* 66**,** 341-348.

Mandell, I. B., Gullett, E. A., Wilton, J. W., Allen, O. B. & Osborne, V. R. 1997a. Effects of diet, breed and slaughter endpoint on growth performance, carcass composition and beef quality traits in Limousin and Charolais steers. *Canadian Journal of Animal Science,* 77**,** 23-32.

Mandell, I. B., Gullett, E. A., Wilton, J. W., Kemp, R. A. & Allen, O. B. 1997b. Effects of gender and breed on carcass traits, chemical composition and palatability attributes in Hereford and Simmental bulls and steers. *Livestock Production Science,* 49**,** 235-248.

McCormick, R. J. 2009. Collagen. *In:* Du, M. & McCormick, R. J. (eds.) *Applied muscle biology and meat science.* Boca Raton, Flodira: CRC Press, 129-148.

McDowell, L. R. 1989. *Vitamins in animal nutrition,* San Diego, CA, Academic Press, Inc.

McGee, M., Keane, M. G., Neilan, R., Moloney, A. P. & Caffrey, P. J. 2007. Body and carcass measurements, carcass conformation and tissue distribution of high dairy genetic merit Holstein, standard dairy genetic merit Friesian and CharolaisxHolstein-Friesian male cattle. *Irish Journal of Agricultural and Foor Research,* 46**,** 129-147.

Menchaca, M. A., Chase, C. C. J., Olson, T. A. & Hammond, A. C. 1996. Evaluation of growth curves of Brahman cattle of various frame sizes. *Journal of Animal Science,* 74**,** 2140-2151.

Moloney, A. P., Mooney, M. T., Kerry, J. P. & Troy, D. J. 2001. Producing tender and flavoursome beef with enhanced nutritional characteristics. *Proceedings of the Nutrition Society,* 60**,** 221-229.

Morgan, J. H., L. & Everitt, G. C. 1969. Yellow fat colour in cattle. *New Zealand Journal of Agricultural Science,* 4**,** 10-18.

Morgan, J. H. L., Pickering, F. S. & Everitt, G. C. 1969. Some factors affecting yellow fat colour in cattle. *Proceedings of the New Zealand Society of Animal Production,* 29**,** 164-175.

Morris, C. A., Baker, R. L., Carter, A. H., Cullen, N. G., Amyes, N. C. & Hickey, S. M. 1993. Evaluation of two-breed composites alongside Angus or Hereford controls for growth, reproduction, maternal, and carcass traits. *New Zealand Journal of Agricultural Research,* 36**,** 327-340.

Morris, C. A., Baker, R. L., Carter, A. H. & Hickey, S. M. 1990. Evaluation of eleven cattle breeds for crossbred beef production: Carcass data from males slaughtered at two ages. *Animal Production,* 50**,** 79-92.

Morris, C. A., Daly, C. C., Cullen, N. G. & Hickey, S. M. 2001. Correlations among beef carcass composition and meat quality traits from a genetic marker trial. *Proceedings of the New Zealand Society of Animal Production,* 61**,** 96-99.

Morris, S. T. 2008. *A review of beef cross dairy bred cattle as beef breeding cows* [Online]. Available: http://www.beeflambnz.com/ [Accessed 15 November 2012].

Morris, S. T. 2013. Presidential Address 2012: The New Zealand beef cattle industry. *Proceedings of the New Zealand Society of Animal Production,* 73**,** 1-4.

Morris, S. T. & Kenyon, P. R. 2014. Intensive sheep and beef production from pasture - A New Zealand perspective of concerns, opportunities and challenges. *Meat Science,* 98**,** 330-335.

Morris, S. T., Kenyon, P. R. & Burnham, D. L. 2002. A comparison of two scales of body condition scoring in Hereford x Friesian beef breeding cows. *Proceedings of the New Zealand Grassland Association,* 64**,** 121-123.

Morris, S. T., Parker, W. J., Purchas, R. W. & McCutcheon, S. N. 1992. Dairy crossbreeding alternatives to improve New Zealand beef production. *Proceedings of the New Zealand Grassland Association,* 54**,** 19-22.

Muir, P. D., Deaker, J. M. & Bown, M. D. 1998. Effects of forage- and grain-based feeding systems on beef quality: A review. *New Zealand Journal of Agricultural Research,* 41**,** 623-635.

Muir, P. D., Wallace, G. J., Dobbie, P. M. & Bown, M. D. 2000. A comparison of animal performance and carcass and meat quality characteristics in Hereford, Hereford x Friesian, and Friesian steers grazed together at pasture. *New Zealand Journal of Agricultural Research,* 43**,** 193-205.

Neville, W. E. J., Mullinix, B. G. J. & Mccormick, W. C. 1984. Grading and rotational crossbreeding of beef cattle. III. Postweaning and carcass traits of steers. *Journal of Animal Science,* 58**,** 47-56.

New Zealand Meat. 2004. *Guide to Beef Carcass Classification* [Online]. Wellington, New Zealand. Available: http://www.interest.co.nz/files/rural/beefgrade.pdf [Accessed 2 December 2014].

Peachey, B. M., Purchas, R. W. & Duizer, L. M. 2002. Relationships between sensory and objective measures of meat tenderness of beef m. longissimus thoracis from bulls and steers. *Meat Science,* 60**,** 211-218.

Pethick, D. W., Harper, G. S. & Oddy, V. H. 2004. Growth, development and nutritional manipulation of marbling in cattle: a review. *Australian Journal of Experimental Agriculture,* 44**,** 705-715.

Pfuhl, R., Bellmann, O., Kuhn, C., Teuscher, F., Ender, K. & Wegner, J. 2007. Beef versus dairy cattle: a comparison of feed conversion, carcass composition, and meat quality. *Archives Animal Breeding,* 50**,** 59-70.

Purchas, R. W. 1989. On-farm factors affecting meat quality characteristics. *In:* Purchas, R. W., Butler-Hogg, B. W. & Davies, A. S. (eds.) *Meat Production and Processing.* Hamilton, New Zealand: New Zealand Society of Animal Production Inc, 159-171.

Purchas, R. W. 1990. An assessment of the role oh pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Science,* 27**,** 129-140.

Purchas, R. W. 2000. An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Science,* 27.

Purchas, R. W. 2003. Factors affecting carcass composition and beef quality. *In:* Smeaton, D. C. (ed.) *Profitable beef production: A guide to beef production in New Zealand.* New Zealand Beef Council, 124-152.

Purchas, R. W. 2012. Carcass Evaluation. *In:* Hui, Y. H. (ed.) *Handbook of meat and meat processing.* 2nd ed. Boca Raton, FL: Taylor and Francis Group, LLC.

Purchas, R. W. & Aungsupakorn, R. 1993. Further Investigations into the relationship between ultimate pH and tenderness for beef samples from bulls and steers. *Meat Science,* 34**,** 163-178.

Purchas, R. W. & Barton, R. A. 1976. The tenderness of meat of several breeds of cattle raised under New Zealand pastoral conditions. *New Zealand Journal of Agricultural Research,* 19**,** 421-428.

Purchas, R. W., Barton, R. A. & Hunt, I. R. 1992a. Growth and carcass characteristics of crossbred steers out of Jersey cows. *New Zealand Journal of Agricultural Research,* 35**,** 393-399.

Purchas, R. W., Burnham, D. L. & Morris, S. T. 2002a. Effects of Growth Potential and Growth Path on Tenderness of Beef Longissimus muscle from Bulls and Steers. *Journal of Animal Science,* 80**,** 3211-3221.

Purchas, R. W., Fisher, A. V., Price, M. A. & Berg, R. T. 2002b. Relationships between beef carcass shape and muscle to bone ratio. *Meat Science,* 61**,** 329-337.

Purchas, R. W. & Grant, D. A. 1995. Liveweight gain and carcass characterictics of bulls and steers farmed on hill country. *New Zealand Journal of Agricultural Research,* 38**,** 131-142.

Purchas, R. W., Hartley, D. G., Xun, Y. & Grant, D. A. 1997. An evaluation of the growth performance, carcass characteristics, and meat quality of Sahiwal-Friesian cross bulls. *New Zealand Journal of Agricultural Research,* 40**,** 497-506.

Purchas, R. W. & Morris, S. T. 2007. A comparison of carcass characteristics and meat quality for Angus, Hereford x Friesian, and Jersey x Friesian steers. *Proceedings of the New Zealand Society of Animal Production,* 67**,** 18-22.

Purchas, R. W., Morris, S. T. & Grant, D. A. 1992b. A comparison of characteristics of the carcasses from Friesian, Piedmontese x Friesian, and Belgian Blue x Friesian bulls. *New Zealand Journal of Agricultural Research,* 35**,** 401-409.

Purchas, R. W. & Zou, M. 2008. Composition and quality differences between the longissimus and infraspinatus muscles for several groups of pasture-finished cattle. *Meat Science,* 80**,** 470-479.

Renand, G., Picard, B., Touraille, C., Berge, P. & Lepetit, J. 2001. Relationships between muscle characteristics and meat quality traits of young Charolais bulls. *Meat Science,* 59**,** 49-60.

Renerre, M. 1990. Review: Factors involved in the discolouration of beef meat. *International Journal of food science and technology,* 25**,** 613-630.

Roca Fraga, F. J., Hickson, R. E., Lopez-Villalobos, N., Kenyon, P. R. & Morris, S. T. 2013. Lactational performance of straightbred Angus cows and three Angus-dairy-cross genotypes. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics,* 20**,** 142-146.

Ruiz De Huidobro, F., Miguel, E., Onega, E. & Blaquez, B. 2003. Changes in meat quality characteristics of bovine meat during the first 6 days post mortem. *Meat Science,* 65**,** 1439-1446.

Schonfeldt, H. C. & Strydom, P. E. 2011. Effect of age and cut on tenderness of South African beef. *Meat Science,* 87**,** 206-218.

Schreurs, N. M., Garcia, F., Jurie, C., Agabriel, J., Micol, D., Bauchart, D., Listrat, A. & Picard, B. 2008. Meta-analysis of the effect of animal maturity on muscle characteristics in different muscles, breeds, and sexes of cattle. *Journal of Animal Science,* 86**,** 2872-2887.

Schreurs, N. M., Hickson, R. E., Coleman, L. W., Kenyon, P. R., Martin, N. P. & Morris, S. T. 2014. Quality of meat from steers born to beef-cross-dairy cows and sired by Hereford bulls. *Proceedings of the New Zealand Society of Animal Production,* 74**,** 229-232.

Seideman, S. C., Cross, H. R., Smith, G. C. & Durland, P. R. 1984. Factors associated with fresh meat color: A review. *Journal of Food Quality,* 6**,** 211-237.

Siebert, B. D., Pitchford, W. S., Malau-Aduli, A. E. O., Deland, M. P. B. & Bottema, C. D. K. 1999. Breed and sire effects on fatty acid composition of beef fat. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics,* 13**,** 389-392.

Smith, D. R., Wright, D. R. & Muir, P. D. 1996. Variation in meat pH in steers and association with other carcass attributes: analysis of a commercial database. *Proceedings of the New Zealand Society of Animal Production,* 56**,** 187-192.

Smith, G. M., Laster, D. B., Cundiff, L. V. & Gregory, K. E. 1976. Characterization of biological types of cattle II. Postweaning growth and feed efficiency of steers. *Journal of Animal Science,* 43**,** 37-47.

Smith, T. P. L., Casas, E., Rexroad, C. E., Knappes, S. M. & Keele, J. W. 2000. Bovine CAPN1 maps to a region of BTA29 containing a quantitative trait locus for meat tenderness. *Journal of Animal Science,* 78**,** 2589-2594.

Solomon, M. B. 1987. Comparison of Methods Used for Measuring pH in Muscle Tissue. *Journal of Food Science,* 52**,** 1428-1429.

Taylor, D. C., Johnson, E. R. & Knott, L. 1996. The accuracy of rump p8 fat thickness and twelfth rib fat thickness in predicting beef carcass fat content in three breed types. *Proceedings of the Australian Society of Animal Production,* 21**,** 193-195.

Troy, D. J. & Kerry, J. P. 2010. Consumer perception and the role of science in the meat industry. *Meat Science,* 86**,** 214-226.

Vazquez, C. G., Hickson, R. E., Morris, S. T., Lopez-Villalobos, N., Kenyon, P. R. & Garcia-Muniz, J. G. 2013. Post-weaning growth in beef and dairy crossbred steers. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics,* 20**,** 467-470.

Walker, P. J., Warner, R. D. & Winfield, C. G. 1990. Sources of variation in subcutaneous fat colour of beef carcasses. *Proceedings of the Australian Society of Animal Production,* 18**,** 416-419.

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.

Warren, H. E., Scollan, N. D., Enser, M., Hughes, S. I., Richardson, R. I. & Wood, J. D. 2008. Effects of breed and a concentrate or grass silage diet on beef quality in cattle of 3 ages. 1: Animal performance, carcass quality and muscle fatty acid composition. *Meat Science,* 78**,** 256-269.

Wendt, A., Thompson, V. F. & Goll, D. E. 2004. Interaction of calpastatin with calpain: a review. *Journal of Biological Chemistry,* 385**,** 465-472.

Wheeler, T. L., Cundiff, L. V., Shackelford, S. D. & Koohmaraie, M. 2004. Characterization of biological types of cattle (Cycle VI): Carcass, yield, and longissimus palatability. *Journal of Animal Science,* 82**,** 1177-1189.

Wheeler, T. L., Cundiff, L. V., Shackelford, S. D. & Koohmaraie, M. 2005. Characterization of biological types of cattle (Cycle VII): Carcass, yield, and longissimus palatability traits. *Journal of Animal Science,* 83**,** 196-207.

Wheeler, T. L., Cundiff, L. V., Shackelford, S. D. & Koohmaraie, M. 2010. Characterization of biological types of cattle (Cycle VIII): Carcass yield, and longissimus palatability traits. *Journal of Animal Science,* 88**,** 3070-3083.

Wilson, L. L., Ziegler, J. H., Watkins, J. L., Thompson, C. E. & Purdy, H. R. 1969. Influence of sex and sire upon growth and carcass traits of beef cattle. *Journal of Animal Science,* 28**,** 607-611.

Wood, J. D., Enser, E., Fisher, A. V., Nute, G. R., Richardson, R. I. & Sheard, P. R. 1999. Manipulating meat quality and composition. *Proceedings of the Nutrition Society,* 58.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sherad, P. R., Richardson, R. I., Hughes, S. I. & Whittington, F. M. 2008. Fat deposition, fatty acid composition and meat quality: A review. *Meat Science,* 78**,** 343-358.

Yancey, E. J., Dikeman, M. E., Hachmeister, K. A., Chambers, E. & Milliken, G. A. 2005. Flavor characterization of top-blade, top-sirloin, and tenderloin steaks as affected by pH, maturity, and marbling. *Journal of Animal Science,* 83**,** 2618-2623

Young, L. D., Laster, D. B., Cundiff, L. V., Smith, G. M. & Gregory, K. E. 1978. Characterization of biological types of cattle. IX. Postweaning growth and puberty of three-breed cross heifers. *Journal of Animal Science,* 47**,** 843-852.