Growth, Carcass and Meat Quality Attributes of Dairy-Beef Bulls and Steers Slaughtered at Eleven Months of Age

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Abstract

New Zealand dairy industry produces approximately 4.2 million calves annually but around half of these are processed within two weeks of birth as “bobby” calves. Bull calves retained for rearing for beef undergo a physical form of castration (usually using a rubber ring) and are raised as steers. Castration is painful and steers typically grow slower than bulls. The practice of processing bobby calves at a young age raises animal welfare concerns which threaten the dairy and beef industries’ social license to operate and has potential to impinge on New Zealand’s international market reputation and conceivably become a non-tariff barrier to trade. An alternative to early-life processing is to utilize the surplus calves in an accelerated beef production system with slaughter as a yearling. The objective of the study was to compare the growth, carcass and meat-quality attributes of Hereford x Friesian-Jersey bulls and steers slaughtered at 11 months of age. The study aimed to identify if there is need to castrate bulls in the yearling beef production system to optimize their growth, carcass and meat quality and whether proteolytic aging of the meat will affect meat quality attributes.

Hereford-sired bulls (n=17) and steers (n=16) born to dairy cows (Friesian and Friesian x Jersey) were raised on pasture as a single group until slaughter at 11 months and processed at Venison Packers Feilding Ltd in June 2019.

There was no difference in the growth rate of bulls compared to steers, with an average daily gain of 0.9 kg/day. The final live weight did not differ between bulls and steers at 306±7.1 and 303±6.9 kg respectively (P=0.773). There was no difference in carcass characteristics of bulls and steers (P>0.05), except that the top side weight was greater for bulls than steers (P=0.022) while intramuscular fat was greater for steers than bulls (P<0.001).

Although the ultimate pH was greater in bulls than steers (5.68±0.04, 5.55±0.04; P=0.036), both values were within normal range (pH between 5.4 and 5.7). There was no difference between bulls and steers for meat colour, shear force and myofibrillar fragmentation index (P>0.05). However, drip loss after 24 and 48 hours was greater in bulls than steers (P<0.05).

Aging did not influence meat tenderness (P=0.682) with both aged and unaged samples having shear force values less than 6 kgF. The low shear force values, usual beef colour values, and ultimate pH values in the ideal range indicates that meat from bulls and steers processed at 11 months of age will be acceptable for consumers of beef. The similarities in meat quality and carcass attributes for bulls and steers at 11 months of age indicates that they could be one category in a classification scheme.

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ADG	Average daily gain
AOAC	Association of official analytical collaboration
CW	Carcass weight
CM	Centimetres
DO	Dressing out
DMI	Dry matter intake
EMA	Eye Muscle Area
FOB	Free on board
g	Grams
hr	Hour
IMF	Intramuscular fat
kg	Kilogram
kgf	kilogram-force
km	Kilometres
LMY	Lean meat yield
LWG	Live weight gain
M:B	Muscle to bone ratio
MFI	Myofibrillar fragmentation index
mm	Millimetres
MT	Metric tonnes
NaCl	Sodium chloride
NZD	New Zealand Dollars
OECD	Organisation for economic Co-operation and development
WBSF	Warner-Bratzler shear-force

Chapter 1. Review of Literature

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1.1 Introduction

The New Zealand’s beef production system is pasture-based, and the supply of finished cattle has seasonal peaks and troughs to match the seasonal pasture supply with beef production reaching a summer peak between January and February for beef animals grown to weight on spring grass (Geenty & Morris, 2017). The pasture-based production system is low-cost and economically sustainable enabling the industry to be globally competitive (Morris and Kenyon, 2014). According to Geenty & Morris, (2017), approximately 13% of global beef production is traded internationally and New Zealand produces about 0.9% of the total but accounts for 6% of the traded meat volume. The total beef export from New Zealand was estimated to be 604,000 metric tonnes carcass weight for the year 2019 (Beef + Lamb NZ, 2020). The New Zealand beef production system involves raising and finishing steers and bulls and processing of beef and dairy cull cows, bobby calves and heifers (Beef + Lamb NZ, 2015). Nearly 70% of cattle slaughtered in New Zealand are of dairy origin contributing approximately 55% of beef product by weight (Morris, 2008; Beef + Lamb NZ, 2019), while most heifers and steers used for prime, or table beef are dairy-beef crossbreds that were born on a dairy farm (Beef + Lamb NZ, 2019). The dairy sector supplies dairy-beef bull beef calves, mainly Friesian bull calves and cross-bred steers and heifers to beef cattle farmers (Morris & Kenyon, 2014).

Although New Zealand beef industry is doing well on the international front in terms of export volume and value, the sector is facing potential scrutiny from the public for slaughtering young surplus calves (“bobby calves”) from the dairy industry that cannot be used as replacement stock (Jolly, 2016; Thomson, 2018). In the current scenario, the Friesian-Jersey and the Jersey calves tend to have limited use in the beef industry because of their low-genetic merit for beef production, and they tend to feature heavily in the bobby-calf slaughter (Geenty & Morris, 2017). The high number of surplus calves slaughtered coupled with the physical method of castration in New Zealand is now threatening the market reputation of dairy and beef industries’ social license to operate and New Zealand’s international market reputation because of animal welfare perceptions that are a potential non-tariff barrier to trade (Morris & Kenyon, 2014; Jolly, 2016; Thomson, 2018). However, good advice as to how and where the surplus calves are going to be raised has not been forth coming (Geenty & Morris, 2017).

Beef animals tend to take long on the farm before they attain the target weight and achieve the set carcass classification requirements for carcass weight, fat depth and muscling. The long durations of beef animals on the farm presents environmental concerns in relation to greenhouse gasses, water quality and soil properties. It is, therefore, important for the New

Zealand beef industry to work towards alleviating these concerns through alternative beef production systems where quality and value is considered more than quantity to help in the process of driving returns. Countries like Argentina are currently using the accelerated-cycle beef production system where animals are slaughtered when they are less than 14 months. The system can provide an opportunity for the beef industry to utilize the surplus calves from the dairy industry. This review examines beef production systems and structures in New Zealand in comparison to other parts of the world and the effect sex and age have on carcass characteristics and meat quality attributes to help in evaluating the potential for a yearling beef finishing system (bulls vs steers) in New Zealand. It will refer to various studies and use values from considered literature to make comparisons on carcass characteristics specifically: dressing-out percentage, lean and saleable meat yield, subcutaneous fat, intramuscular fat and eye muscle area. For meat quality attributes, the literature will specifically look into ultimate pH, tenderness, lean meat colour, fat colour, meat flavour, juiciness and water holding capacity.

1.2 Beef industry structure

1.2.1Types of beef production in New Zealand

In New Zealand, there are two main end uses of beef depending on the source. Prime beef or table beef is produced mainly from heifers and steers and small percentage of table cuts from bulls. Processing beef is produced from the older cows, bulls and the forequarters of steers and bulls (Geenty & Morris, 2017).

Beef farmers purchase weaners between the ages of 10 to 12 weeks old then feed the bulls targeting to achieve a 250 kg weight at 16 months with a target daily gain of 1 kg (Morris & Kenyon 2014). However, there are other beef farmers in New Zealand who will slaughter bulls at 2.5 years weighing approximately 350 kilograms carcass weight or more. Bulls grow 10-20% faster than heifers and steers and they are more flexible regarding sales time especially during dry seasons when pasture is a challenge (Peden, 2008; Morris & Kenyon 2014; Geenty & Morris, 2017).

Producers purchase steers and heifers as weaners at approximately 3 months old. Steers are ideally slaughtered weighing approximately 300 kilograms with 3 mm subcutaneous fat to meet the carcass classification requirement (Geenty & Morris, 2017). In New Zealand, slaughtering steers when less than 20 months is a practice aimed at saving the farmer the cost of keeping the animal through the second winter. However, steers can go through the second winter and then slaughtered weighing up to 400 kilograms (Peden, 2008; Geenty & Morris, 2017).

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Heifers are finished for both local trade and export market. However, heifers are lighter than steers at slaughter because they reach the 3mm fat at finishing with a lighter weight. Both heifers and steers undergo a complex grading system compared to bulls hence, they should be at their best at the time of slaughter (Geenty & Morris, 2017). Heifers are finished with a target weight of 235 kilograms mostly at 18 months or less (Morris & Kenyon 2014).

1.2.2 Global beef consumption

The global population is expected to grow by a further billion to reach 8.5 billion by 2030. According to (OECD, 2020), the global projection for beef and veal consumption will be 75,728 thousand tonnes by the year 2029. Many governments and private entities are looking for new innovations that can help in creating scalable food production. China, India and the Sub Sahara countries are projected to lead an increase in consumption of red meat (OECD 2020). Despite the contradicting perception towards red meat, meat importation in China is high. Interestingly, China is currently the highest importer of New Zealand beef with 113,460 metric tonnes carcass weight estimate during the first half of the year 2019 (Table 1.3).

1.3 Types of beef production systems in New Zealand

1.3.1 Breeding cattle (cows) on beef farms

Aberdeen Angus and Hereford cattle imported from Britain were the most popular breeds during the early days of New Zealand beef industry until 1970s when New Zealand imported over 20 exotic breeds from Europe. The importation was primarily to help in the crossing of the Friesian and the Jersey breeds. According to Geenty & Morris (2017), there are one million beef breeding cows in New Zealand with different breeds having different percentage contribution to the beef industry. Angus has the highest percentage contribution with 47 percent followed by Hereford at 14 percent and the cross of Hereford and Angus contributes 14 percent. Friesian crossbreds make up 4 percent of the beef cow herds; mixed breeds make up 15 percent while other breeds contribute the remaining 6 percent (Geenty & Morris, 2017). New Zealand beef farmers have a preference for Hereford and Angus because of their ability to adapt to the New Zealand hill country conditions (Morris *et al*., 2013; Morris & Kenyon 2014; Geenty & Morris, 2017). Utilizing breeds that are well adapted to the production system can have a positive impact in the productivity of the beef animals in terms of growth rate and carcass production (Geenty & Morris, 2017). Nogalski *et al*., (2018) demonstrated similar growth rates of cattle between 6-13 months old until slaughter age between 13 to 29 months among Hereford, Simmental, Limousin, Charolais and Angus breeds. However, a different experiment conducted in Europe by Albert *et al*. (2008), indicated that Angus bulls tend to have a faster growth rate between the ages of 9 and 15 months compared to Limousin, Charolais and Simmental. The Jersey breed tend to have a slower growth rate than the

Friesian at all ages while the Friesian-Jersey cross has an intermediate growth rate (Albert *et al*., 2008; Handcock *et al.,* 2019). Handcock *et al*., (2019) recorded greater weights in Friesian followed by Friesian-Jersey cross and then Jersey with 430kg, 417kg, and 388kg respectively at 22 months. Finally, there is no beef breed that can excel in all the beef traits, thus, the call for crossbreeding that allows for the use of both breed differences (additive) and heterosis (non-additive) traits (Geenty & Morris, 2017).

1.3.2 Beef Production calendar

In New Zealand, selection and mating takes place during spring enabling the breeding cows to match the calving dates with the start of spring pasture growth since 60-70% of the pasture occurs during spring through to early summer (Geenty & Morris, 2017). The weaning time for beef calves is specific to the farm mostly taking place when the calf has attained the set target weight. However, the minimum live weight gain target on hill country is 1.0 kg/calf/day although in New Zealand, this target is often not achieved, with calves weaned at 5-7 months weighing approximately 180 to 240kg (Geenty & Morris, 2017). In hill country, pasture tends to dry up in late summer or autumn and most farmers would wean the calves and place them on the available pasture while the cows are placed on hard rations to ease the grazing competition (Geenty & Morris, 2017).

1.3.3 Mature weights for different cattle breeds

Growth rate of cattle is essential in determining the finishing time and the amount of feed the animal requires to attain the slaughter weight (Freer *et al*. 2007). Cattle that have smaller body frames are classified as early maturing reaching lighter mature weights (Table 1.1; Freer *et al*., 2007; Geenty & Morris, 2017). The late maturing cattle have larger body frames reaching heavier mature weights later compared to the early maturing cattle (Table 1.1). The extent of the animal growth is determined by its defined genetically mature weight (Freer *et al*. 2007). Typically, Limousin, Friesian, Simmental and Charolais are late maturing while Hereford, Angus and Jersey are early maturing (Table 1.1; Freer *et al*. 2007).

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Table 1. 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	Bulls	Steers	Cows	Early or late maturing
Limousin	770	660	550	Late
Friesian	770	660	550	Late
Charolais	910	780	650	Late
Simmental	910	780	650	Late
Angus	700	600	500	Early
Hereford	700	600	500	Early
Jersey	560	480	400	Early

1.3.4 General management regimes and unique attributes of grass-fed systems in New Zealand

Beef animals in New Zealand are always farmed together with sheep complementing each other in terms of pasture management and the health status of the animal especially in hill country conditions (Geenty & Morris, 2017). The climatic conditions in New Zealand favours year-round cattle production with more than 95% of the cattle diet coming from grazed pasture and whole crops (Charteris *et al*., 1999; Morris, 2013; Geenty & Morris, 2017). The pasture-based system is an efficient, sustainable and relatively low-cost system that allows New Zealand to compete in the global market as a major exporter of fibre and food.

The New Zealand grassland system is divided into three categories: high, hill and flat based on the topography and elevation. The three categories tend to be similar in terms of area, but they significantly differ in terms of quantity of pasture each area is capable of producing as well as the type and the number of animals the regions can carry (Morris, 2013).

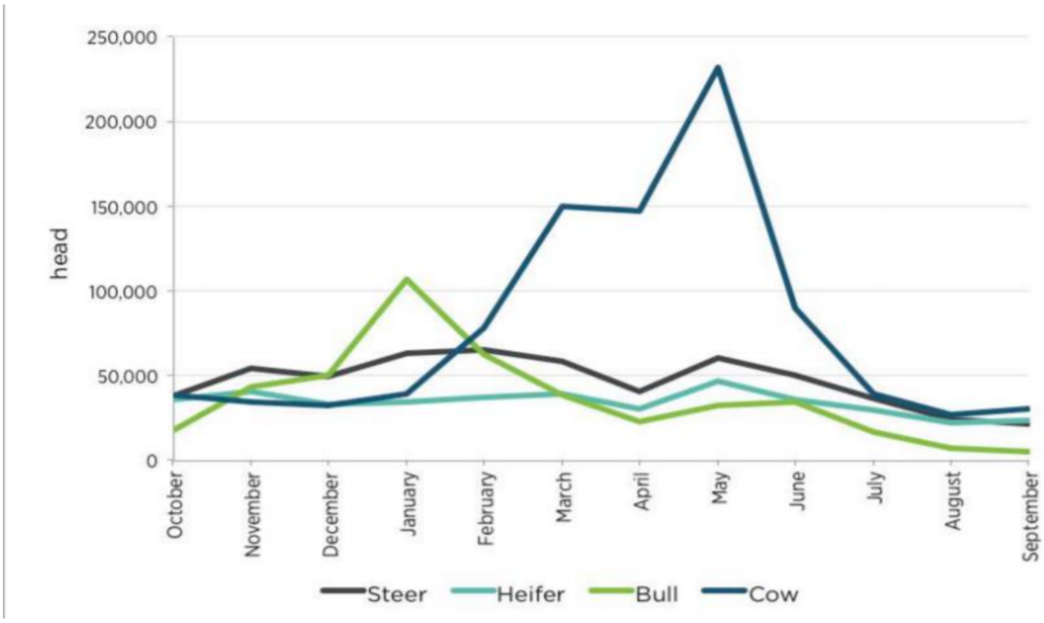
1.3.5 The land classes for pasture production in New Zealand

New Zealand has high hill country, hill country and the finishing and breeding farms (flat and rolling) as the main land classes for beef production. High hill country farms are large and mostly steep while the hill country has the smaller holdings of land but runs a slightly higher proportion of cattle with a stock unit of 43% (Charteris *et al*., 1999). High hill country farms consist of the low fertility grasses with a continuous erosion and reversion problem with 0.7 stock units per hectare of land (Charteris *et al*., 1999). The pastoral production of beef in these high hilly country areas tend to be unsustainable since the annual production of pastures is very low with approximately 2.0 tonnes of dry matter per hectare (Morris, 2013). Contrary, the annual production of pastures in hill country is slightly higher with 7.0 tonnes of dry matter per hectare with 7.5 stock unit per hectare (Morris. 2013). Moreover, the pastures in these conditions are high in quality having an increased percentage of good quality pastures like white clover and ryegrass (Beef + Lamb New Zealand., 2020). The finishing and breeding farms (flat and rolling) has the ability of producing pastures up to 11.0 tonnes dry matter per hectare and carries up to 14.0 stock unit per hectare (Morris, 2013). The lowest sheep to cattle ratio is found in these areas with a cattle stock unit of 46% (Charteris *et al*., 1999). The system has the highest proportions of cattle sales in relation to the opening stock numbers which shows the farms are interested in the finishing of stocks and not breeding (Morris, 2013; Geenty & Morris, 2017).

1.3.6 Cattle slaughter pattern

The pasture-based beef production system in New Zealand presents a challenge to the beef producers because of the seasonal pasture availability. The seasonal pasture growth leads to seasonality in annual kill and beef production (Figure 1.1; Beef + Lamb New Zealand, 2020).

Figure 1. 1 Cattle slaughter pattern by month (adapted from Geenty & Morris, 2017)



The peak adult kill for cull cows is in the month of May when dairy and beef cows are culled before the onset of winter (Figure 1.1; Geenty & Morris, 2017). The peak for bull grown to weight on spring grasses is between January and February although there is another autumn bull beef production peak in May and July before winter (Figure1.1; Geenty & Morris, 2017). The peak production pattern for steers follows a similar trend although less pronounced pattern to bull beef (Figure 1.1). Heifer production pattern is steady throughout the year with a small peak in May linked to the cull cows from the dairy herd (Figure 1.1). During winter, there are times the monthly kill for adult cattle can only be one-third of the peak months and in most cases, it is half the monthly average (Geenty & Morris, 2017). The peaks and ebbs in the numbers of animals sent for slaughter during the year leads to companies competing strongly for market share and having periods of strong competition for the procurement of animals especially during the time when the kill is about to ramp up (Morris, 2013; Morris and Kenyon *et al.*, 2014). Most farmers who can tailor their production to fit in the periods of maximum competition for their cattle tend to fetch high values for their animals (Morris, 2013).

1.4 New Zealand beef production

1.4.1 Processing numbers, volumes, and value

The number of beef animals in New Zealand has declined by 28% over the past few decades from a total of 5 million in the year 1994 to approximately 3,889,996 in 2019 (Table 1.2; statistics New Zealand, 2019). However, the total number of cattle has increased across New Zealand from a total of 8.9 million in 1994 to 10.4 million 2017 with beef animals being 3.9 million and dairy animals totalling to 6.5 million (Statistics New Zealand, 2019).

Beef production in New Zealand in the year 2018 was 671,507 tonnes of carcass weight equivalent and an increase in production was predicted for 2020 to 678,020 tonnes of carcass weight equivalent (Table 1.2; Statistics New Zealand, 2019). The big contributors to beef production in New Zealand are bulls and steers giving a combined total of 50 percent of total carcass weight equivalent with 157,011 and 170,515 tonnes of carcass weight equivalent respectively (Table 1.2; Statistics New Zealand 2019). The small contributor is calf slaughter with 29,573 tonnes of carcass weight equivalent (Table 1.2). Calf slaughter is forecast to drop further to 28,000 tonnes of carcass weight equivalent by the year 2020 (Table 1.2).

Table 1. 2 Type of cattle slaughtered in New Zealand from the year 2018 to 2019 and a forecast for 2020, including total tonnes of beef (Jones, 2019).

New Zealand Beef Production Table									
Marketing Year	**2018 Actual**			**2019 Estimated**			**2020 Forecasts**		
Category	**CW kgs/hd**	**Numbers to kill (1000's)**	**Total tons Beef**	**CW kgs/hd**	**Numbers to kill (1000's)**	**Total tons Beef**	**Est. CW kgs/hd**	**Numbers to kill (1000's)**	**Total tons Beef**
Cow Slaughter	198.6	990	196,496	199.0	970	193,030	199	970	193,030
Calf Slaughter	16.3	1,816	29,573	16.0	1,750	28,000	16.0	1,750	28,000
Heifer Slaughter	241.0	489	117,911	242.0	480	116,160	241	490	118,090
Steer slaughter	311.2	548	170,515	312.0	550	171,600	313	560	175,280
Bull Slaughter	299.8	524	157,011	300.0	543	162,750	303	540	163,620
Other Adult Cattle Sub Total	285.4	1,561	445,437	286.5	1,573	450,510	287	1,590	456,990
Total Slaughter	153.8	4,366	671,507	156.4	4,293	671,540	157.3	4,310	678,020

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1.4.2 Market overview for New Zealand beef

Beef industry plays a major role in the New Zealand primary sector with beef and veal exports contributing approximately $2.3 billion in a year (Statistics New Zealand, 2019). Moreover, there is an extra $0.5 billion from co-products like meat meal, tallow, hides, pet food, fats, and oils from beef. According to Geenty & Morris, (2017), approximately 13% of the global beef production is traded on the international basis. New Zealand produces about 0.9% of the total but accounts for 6% of the traded meat volume. The international beef trades have several sub-markets providing an opportunity for different countries with different unique production systems. Countries like New Zealand that do not have a developed feed-lot industries will supply grass-fed or minimal grain fed beef (Morris 2013; Geenty & Morris, 2017). Most of New Zealand’s beef exports are mainly directed to the grass-fed markets targeting the USA and Asian markets.

1.4.3 Markets for New Zealand beef by value

The total beef export from New Zealand is estimated to be 604,000 metric tonnes carcass weight for the year 2019 (Beef + Lamb NZ, 2020). The export market for New Zealand beef products includes the European Union, the Middle East, North America, and North Asia (Figure 1.2). European Union had the highest value ($ per tonne (NZD) of imported New Zealand beef in 2018, the average value of New Zealand beef exported to European Union was 17,000 Free on Board (FOB) $ Per Tonne (NZD) (Figure 1.2; Table 1.3). However, there was a decline in the average value of New Zealand beef export to the European Union in 2019 to 15,000 FOB $ Per Tonne (NZD) (Figure 1.2; Table 1.3). The Middle East provided the second highest return value per tonne for New Zealand beef with just over 10,000 FOB $ Per Tonne (NZD) in 2018 and close to 12,000 FOB $ Per Tonne (NZD) in 2019 (Figure 1.2). North America returns the lowest value at $6000 Per Tonne (NZD) in 2018 and $ 6500 Per Tonne (NZD) in 2019 (Figure 1.2). The average value of New Zealand beef exported to North Asia was approximately $8,000 Per Tonne (NZD) in 2018 and 2019 (Figure 1.2).

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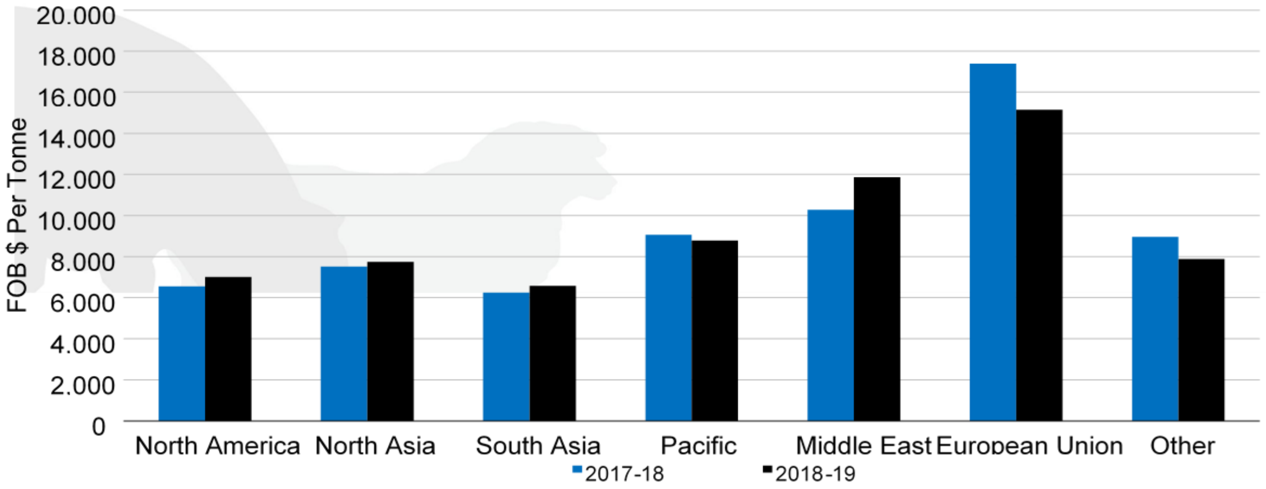
Figure 1. 2 Demonstrating New Zealand beef export and value (Free on Board) FOB $ Per Tonne) from the year 2017/18 and 2018/19 seasons (adapted from Beef + Lamb NZ, 2020).



1.4.4 Markets for New Zealand beef by volume

The greatest export volume of New Zealand beef is to China and USA. However, beef export to the US fell by 20% from 125,076 metric tonnes in 2018 to 93,624 metric tonnes in 2019 (Table 1.3). New Zealand beef export to China rose by 112% with China importing more than 113,460 metric tonnes of beef from New Zealand in 2019 from 58,354 metric tonnes in 2018 (Table 1.3). In 2019, China became the number one importer of beef from New Zealand with nearly half of the exported beef going to China while close to a quarter was exported to the United States (Table 1.3). Interestingly, Switzerland imported 2 metric tonnes (MT) of beef in 2018 but had the highest average free on-board price with $43,379 NZD/ MT (Table 1.3). In 2019 however, the quantity exported to Switzerland increased to 2,736 metric tonnes but the average free on-board price reduced to $7,296 NZD/ MT (Table 1.3).

Table 1. 3 Demonstrates the New Zealand beef export figures across the world from 2018 to 2019 (Jones, 2019; Beef + Lamb NZ, 2020).

New Zealand Beef Export Statistics (Year To Date: January – June)				
	2018		2019	
Partner Country	**Quantity (MT)**	**Average FOB Price NZD/MT**	**Quantity (MT)**	**Average FOB Price NZD/MT**
China	58,354	$6,808	113,460	$7,206
United States	125,076	$6,684	93,624	$7,365
European Union	1,300	$17,000	1,300	$15,000
Japan	8,533	$9,984	10,767	$9,324
Taiwan	13,526	$7,864	11,096	$8,256
Korea South	12,986	$5,824	8,594	$6,321
Canada	8,387	$6,438	6,442	$7,335
Australia	3,801	$8,927	3,986	$8,702
Netherlands	1,979	$19,619	1,789	$15,013
Switzerland	2	$43,379	2,736	$7,296
UAE	1,351	$11,749	1,403	$12,800
Rest of World	25,165	$8,253	20,739	$8,776
World Total	260,460	$152,529	$275,936	$113,394

MT - Metric tonnes
FOB- Free on board

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New Zealand exports beef to European Union market as a low volume but high value market. The high-quality beef is exported to the European Union at a 20% ad valorem duty (New Zealand meat board, 2006). Annually, New Zealand can export 1,300 tonnes (product weight) of high-quality beef to European Union (Table 1.3). Although China and USA are the main exports markets for New Zealand beef, they mainly take low value cuts and manufacturing beef while European Union takes the table cuts (prime beef). According to Beef + Lamb New Zealand (2020), the New Zealand red meat market to the European Union accounted for almost NZ$2 billion in trade in 2018.

On the domestic front, consumption of beef is estimated at 17.5 kilograms per capita which is equivalent to 80,000 Metric Tonnes carcass weight. New Zealand domestic beef consumption is between 10 to 12 percent of the total beef production which is an indicator of the New Zealand beef industry focus on exports (Morris 2013; Morris and Kenyon, 2014).

1.5 Role of dairy industry for beef production In New Zealand

1.5.1 Sources of Animals from the Dairy Industry

The New Zealand dairy industry is a major contributor to the beef industry with over 35% of the calves born from the dairy industry entering the beef industry each year (Morris and Kenyon 2014). The dairy composition is a combination of various breeds with the Friesian-Jersey cross having the highest percentage with 49.1%, Holstein Friesian with 32.7%, Jersey with 8.4% and Ayrshire 0.5% while the remaining 9.3% come from other breeds and crosses (Morris, 2013). Most beef producers in New Zealand prefer Friesian or beef-cross-Friesian for beef production especially bull beef production, rather than Friesian-Jersey cross or Jersey calves (Morris, 2013). The Jersey breed is mainly excluded from the beef industry because of its slow growth rate, light carcass and the yellow fat that makes it inferior in terms of grading at slaughter hence, fetching lower prices per kilogram carcass (Morris & Kenyon 2014; Geenty & Morris, 2017). The dairy industry is essential in beef production with nearly 70% of all cattle slaughtered in New Zealand are of the dairy origin (Morris, 2008) and most heifers and steers used for prime, or table beef are mainly dairy-beef crossbreds that are most likely been born from a dairy farm (Beef + Lamb NZ, 2019). The dairy sector supplies dairy-beef bull beef calves mainly Friesian bull calves and cross-bred steers and heifers to the beef cattle farmers (Morris & Kenyon, 2014). Friesian bulls that are kept and reared for beef production on beef farms make up 19% of the adult cattle slaughter (Morris, 2013).

There has always been a view that meat from the dairy breeds are of inferior eating quality compared to the meat from the British or the European breeds. However, the view is not supported by any experimental evidence apart from the fat colour (Geenty & Morris, 2017;

Muir *et al*., 2000). Interestingly, the dairy breeds are not genetically selected for beef production but there are very little differences in meat quality of different breeds of cattle that the consumer is unlikely to identify (Morris, 2013). However, smaller-sized breeds and slow growing breeds like Jersey have a negative impact on the productivity and profitability of the farmer because they tend to take more time in the farm, and they yield lighter carcasses resulting in low returns for beef farmers (Geenty & Morris, 2017).

1.6 Beef production finishing systems used overseas

1.6.1 Feedlot finishing system as used in North America

The feedlot system in North America is an intensive beef production system with the aim of fattening animals to reach the slaughter weight. The system is categorised into growing and finishing phases. The growing phase is typically 90 days after the arrival for feedlot calves (Endres *et al.,* 2018). The aim of the growing phase is to maximise on the growth while minimizing fat deposition through feeding of high forage but low grain ratio feeds (Endres *et al* 2018). The finishing phase is the last 100 days after growing phase. The finishing phase focuses on feeding high grain but low forage diets until the animals attain the prescribed finishing weight or fat cover before they are marketed for slaughter (Endres *et al.,* 2018).

1.6.2 Small holder beef production system in developing countries

The Smallholder (extensive) system of production is operated by virtually a single person mostly on the same piece of grazing land (Broom, 2019). The system is divided into agro-pastoral and pastoral system (Deblitz *et al*., 2005). The agro-pastoral system involves growing of food crops and keeping of animals mainly indigenous with a few crossbred a common practice in many developing countries (Broom, 2019). The pastoral system is regarded as low production but common in hardship areas like desert and meat is often regarded as the by-product of milk production (Broom, 2019). Animals in smallholder pastoral system mostly feed in groups a practice that can cause land degradation (Deblitz *et al*., 2005; Broom, 2019). Although the production cost in this system is low, the animals are most likely to suffer from mineral and protein deficiency with high risk of infections (Deblitz *et al*., 2005).

1.6.3 Yearling beef production in Argentina

Argentina in South America practices yearling beef production with cattle ranchers increasing their profitability by integrating the traditional cow-calf operations commonly practiced in the region with the grass-fed yearling finishing programmes (Guevara *et al*., 2012; Cid *et al*., 2011). The integration has led to the optimization of secondary production that is achieved through a more efficient use of vegetation and capitalizing on the faster growth rates of young cattle (Arelovich *et al*., 2011; Cid *et al*., 2011). According to Cid *et al*. (2011), a total of 2.4 million calves of British breeds mainly Hereford and Angus are raised in the Argentina pasture-based system across the country. The cattle are then slaughtered once they achieve a live weight of approximately 440 kg for steers and 320 kg for heifers mainly between 10-14 months (Cid *et al*., 2011).

1.6.4 Veal production in European Union countries

In Europe; Spain, Belgium, United Kingdom and Poland all practice yearling beef production where cattle are regularly slaughtered before or when they are one year of age. Unlike Argentina where animals are raised on pastures, in Europe they are mainly raised on milk, grains, and concentrates then slaughtered between 6 and 12 months (Domaradzki *et al*., 2017). The white veal and rosé veal production system are prominent in European countries. To obtain the white veal, the calves are fed on milk only diets and the calves are always penned to restrict their movement preventing reddening of the meat (Sans & de Fontguyon, 2009). Calves raised for rose veal are fed on milk and grass diets and then slaughtered between 6-8 months with the freedom to move around and mostly stay with the dam until slaughter time (Appleby *et al*., 2014).

1.7 Different sex classifications used for cattle

Cattle sex classification comprises of entire males (bull), castrated males (steer) and female (heifer/cow). However, beef heifers and steers are considered under one carcass classification. Cow carcases can either be prime with more than 3 mm fat or manufacturing with less than 3 mm fat (New Zealand Meat Classification Authority, 2004). In New Zealand, most bulls come from dairy industry and they grow 10-20% faster than heifers and steers (Geenty & Morris, 2017). Bulls are purchased at approximately 4 months as weaners and farmed for 14 to 18 months with a target carcass weight of 250 kilograms at 16 months (Geenty & Morris, 2017). However, with New Zealand pasture-based systems this may extend out to 24 months. Steers are purchased between 6 and 8 months as weaned beef calves while dairy-beef cross calves are purchased as weaners at 3 to 4 months and slaughtered ideally at 20 months weighing approximately 300 kilograms (Geenty & Morris, 2017). The slaughter of steers at 20 months is to avoid keeping them in the farm for a second winter. However, some steers will go through the second winter and slaughtered at 24-30 months although the age is not exact and depends mainly on when they achieve the right level of carcass classification and it can be anywhere between 24-36 months (Purchas, 2003). Heifers are mainly finished at 18 months weighing approximately 235 kilograms carcass weight and they are finished for both local and international market (Purchas, 2003). Steers and heifers are subject to a more complex grading system than bulls as they have to have 3mm of subcutaneous fat (or more) and sufficient muscling to achieve a convex shape (Geenty & Morris, 2017).

1.7.1 Welfare concerns of castration

Although castration of bulls has been practiced by farmers for centuries in the traditional beef production system where animals are slaughtered between 18 to 36 months with the aim of producing docile animals, modify carcass quality and control breeding, the practice is now raising animal welfare concerns. Intact males have been reported to be aggressive making it difficult to handle and can cause injuries to humans and destroy property (fences) and most importantly, affect the quality of meat. However, all the physical methods used in New Zealand to castrate bulls tend to cause pain and can have side effects. Surgical castration, use of burdizzo and rubber ring can lead to haemorrhages, oedema, excessive swelling or even tetanus. Fisher *et al*., (1996) observed a greater reduction in weight gain for animals that were surgically castrated. Although presence of testosterone in intact males is attributed to faster growth rates compared to castrated males (Kellaway, 1971), bulls and steers before puberty tend to demonstrate the same behavioural and growth characteristics (Mickan *et al*., 1976). Therefore, there is an opportunity to slaughter intact bulls in the pasture-based yearling beef production system since they may produce similar carcasses and meat quality as steers.

1.8 Beef carcass classification in New Zealand

The New Zealand meat classification authority system classifies beef carcasses into heifers, steers, bulls, and cows based on sex and maturity of the animal and further based on muscling and fat content (New Zealand Meat Classification Authority, 2004). There are three classes of carcass categorization based on the degree of muscling. Class one carcasses have the bulge at the hind quarters and the hock, and it is more desirable while type three has reduced muscling and it is less desirable. Bulls are graded separately from steers and heifers, which are grouped together (New Zealand Meat Classification Authority, 2004). Female cattle that are less than 3 years of age are categorised as heifers while more than 3 years are categorised as cows. Age is assessed by the number of permanent incisors with heifers having less than six while cows having six or more (New Zealand Meat Classification Authority, 2004). Heifers and steers tend to undergo a different growth pattern, but they are relatively young at the time of slaughter with the carcass having a similar conformation and composition at similar weights which allows them to grade in the same category as prime steer/heifer (New Zealand Meat Classification Authority, 2004).

1.8.2 Different meat products produced from different sexes of cattle

Cattle of different sexes produce different carcass and meat products. Some of the bull calves from the dairy industry are slaughtered at a young age for veal while others are slaughtered when they are between 18 to 22 months of age producing predominantly lean growth with minimal fat deposition suitable for processing beef compared to heifers and steers (Jolly, 2016; Purchas, 2003). Meat from bulls is mainly exported as frozen product (Geenty & Morris, 2017). Bull calves obtained from the beef breeding cow herds are castrated and raised as steers and provide prime beef that is mainly for export in chilled form (Geenty & Morris, 2017). The processing beef is obtained from the fore quarters of heifers and steers.

1.8.3 Carcass and meat quality characteristics

Observable and measurable carcass characteristics of beef animals are important in attributing value to beef. Carcass grading is done using post-mortem measurements of carcass muscling and fat depth because they act as indicators of meat quality and lean meat yield (Johnson *et al*., 1994). The classification of carcass helps in providing signals to farmers concerning the desirable composition and conformation for maximizing saleable meat yields making it the basis for saleable payment schedule for beef producers (Schreurs, 2012; Pike, 2019). Meat quality characteristics like colour, pH, tenderness, juiciness, flavour and water holding capacity play a vital role in attaining high standard of consumer satisfaction. A satisfied consumer is most likely to repurchase the product and when the eating quality is good, the meat is considered to have high value hence, fetching more money per kilogram of meat (Schreurs, 2012). Maintaining high standard levels of beef quality will also help in opening new export markets while maintaining the existing markets.

1.9 Influence of sex and age on carcass and meat quality attributes

1.9.1 Influence of sex on dressing out percentage

The average dressing-out percentage from considered literature (Table 1.4) was greater in bulls than steers with 57.43% and 56.44% respectively. However, it is hard to compare the dressing-out percentage among studies because of the different variations in gut weight, gut fill, fat content in non-carcass and carcass as well as hides and skins (Purchas, 2003 and Coleman *et al*., 2016).

Table 1. 4 Dressing-out percentage of bulls and steers from different breeds and age

Dressing out %		Breed	Age (Months)	Author
Bulls	Steers			
60.89	60.30	P	12-14	Blanco *et al*., 2020
61.1	59.4	H, A	14	Glimp *et al*, 1971
57.04	56.45	H x F	15	Pogorzelska *et al*., 2018a
58.8	57.0	H x F	15-18	Nogalski *et al*., 2018
63.7	63.7	A	16	Thomson *et al*., 2017
59.01	56.18	H x F	18	Pogorzelska *et al*., 2018b
59.44	58.9	F x L	18	Modzelewska *et al*., 2014
57.6	56.7	A x N	20	Mueller *et al*., 2019
51.3	48.3	H x F	29	Purchas *et al*., 1993
53.4	53.3	H x F	35	Venkata *et al*., 2015
60.9	60.6	C x A	12	Gerrard *et al*., 1987
50.07	48.50	Z x A	27	Aricetti *et al*., 2008
55.8	52.4	F	26	Mickan *et al* 1976
57.9	58.3	F	10-11	Nichols *et al*., 1964
54.3	54.8	-	26	Rodriguez *et al*., 2014
55.1	54.6	H x A	16-28	Purchas *et al*., 2002
60.0	60.0	Pi x H x A	12	Morgan *et al*., 1993
Average				
57.43	56.44			

Angus (A), Hereford(H), Charolais(C), Simmental (S), Limousin (L), Friesian (F), Nellore (N), Pirenaic (P), Zebu(Z), Red Poll (R), Pinzgauer (Pi)

1.9.2 Influence of age on Dressing-out percentage

The dressing out percentage increases as the animal grows and gets older (Pike, 2019). The average dressing out percentage for beef cattle between 13-19 months old was lower than the dressing out percentage of beef cattle older than 19 months with 54.34% and 54.48% respectively (Warren *et al*., 2008, Monsón *et al*., 2005, Albertí, *et al*., 2008, Chambaz *et al*., 2003, Thomson *et al*., 2017, Morris *et al*., 1992, Muir *et al*., 2001 Dalton & Everett, 1972, Pečiulaitienė *et al*., 2015, Barton *et al*., 1994, Callow, 1944, Coleman *et al*., 2016, Purchas and Grant 1995 and Barton and Pleasants 1997) . As the animal grows, they tend to deposit more muscle and fat into carcass increasing the dressing-out percentage. Young animals have a greater non-carcass component including gut fill and gut weight that influence the live weight compared to older animals where non-carcass components tend to grow relatively slowly than the overall animal leading to a decline in their contribution to live weight over time (Keane, 2011). However, different studies have demonstrated a contrary trend in young ruminants with animals between 0-12 months having greater dressing-out percentage than beef animals between 13-19 months with 54.48% and 54.34% respectively (Specht *et al*., 1994, Kirton *et al*., 1971, Brekke & Wellington, 1969, Butler-Hogg and Wood 1982, Domaradzki *et al*., 2017, Butler-Hogg and Wood 1982, Pike, 2019, Callow, 1944, Chambaz *et al*., 2003). Young ruminants often have greater or similar dressing-out percentage values compared with older beef animals because of their underdeveloped non carcass tissues (Specht *et al*., 1994).

1.9.3 Influence of sex on lean and lean meat yield, bone %, muscle to bone ratio and Eye Muscle Area (EMA)

From considered literature (Table 1.5), the average lean meat yield and average bone percentage was greater in bulls with 63.07% and 19.87% respectively compared to steers with 57.91% and 18.28%. The eye muscle area was greater in bulls than steers with an average of 74.90 and 66.28 respectively (Table 1.5). High testosterone level in bulls promotes muscular growth due to the increased levels of protein retention leading to high lean meat yield and high eye muscle area (EMA) in bulls than steers (Lee *et al*., 1990). The average muscle to bone ratio is greater in bulls than steers with 4.50 and 3.70 respectively (Table 1.5), an indicator of bulls having a greater saleable meat yield and lean meat yield when all other factors remain constant (Irshad *et al*., 2013).

Table 1. 5 Lean meat yield (LMY), bone percentage and fat percentage of bulls and steers from different breeds and age

Bulls				Steers				Breed	Age (Months)	Author
LMY%	**Bone%**	**M:B**	**EMA (cm^2)**	**LMY%**	**Bone%**	**M:B**	**EMA (cm^2)**			
74.4	16.3			67.1	15.8			P	13	Blanco *et al*., 2020
			83				68	H, A	14	Glimp *et al*, 1971
55.27	23.44			49.33	19.53			H x F	15	Pogorzelska *et al*., 2018
56.78	22.23			48.74	19.28			C x F	15-18	Nogalski *et al*., 2018
		5.7				4.8		H x S	16	Shahin *et al*., 1993
44.84	21.46			44.84	15.20			H x F	18	Pogorzelska *et al*., 2018
			84.7				65.4	A x N	20	Mueller *et al*., 2019
			76.3				70.7	H x F	29	Purchas *et al*., 1993
70.6			83.8	68.5			79.6	-	20-28	Bong *et al*., 2012
51.8	17.4			44.1	15.8				16-17	Bailey *et al*. 1966
60.5	21.3			52.9	20.0			H,S	16	Mandell*et al*.,1997
74.7	23.1	3.3	54.9	69.2	26.2	2.6	50.0	F	26	Mickan *et al*., 1976
65.1				61.6					35	Venkata *et al*., 2015
			64.41				64.70		27	Aricetti *et al*., 2008
	17.98				17.94			F	10-11	Nichols *et al*., 1964
			62.4				61.0	B	26	Rodriguez *et al*., 2014
77.3				73.3			-	H x A	16-28	Purchas *et al*., 2002
			87.9				69.4	H	17-18	Crouse *et al*., 1983
62.5	15.6			57.4	14.8			F,L	-	Steen *et al*., 1995
			76.7				67.7	RxPixH	12	Morgan *et al*., 1993
Average										
63.07	19.87	4.50	74.90	57.91	18.28	3.70	66.28			

Lean meat yield (LMY)
Breed: Angus (A), Brahman (B) Friesian (F), Hereford(H), Pirenaic(P), Nellore (N), Simmental (S), Charolais(C), Red Poll (R), Pinzgauer (Pi)

1.9.4 Influence of age on lean meat yield, bone percentage, meat to bone ratio and eye muscle area

As beef cattle grow, the muscle to bone ratio increases (Table 1.6), as a result of the relative growth rate of muscle which is higher than the growth rate of bones (Davies, 1989). From considered literature (Table 1.6), muscle to bone ratio increases with increase in age with an average of 2.9 for beef cattle older than 19 months and 3.7 for beef cattle between 13-18 months (Table 1.6). The higher muscle to bone ratio is equivalent to a higher lean meat yield and the saleable lean meat yield, other factors held constant. Animals of different ages differ in terms of lean and saleable meat. As cattle becomes older, the proportion of bones and muscles in the carcass decreases while the proportion of fat increases (Irshad, 2013). The value of carcass is influenced by the muscle to bone ratio at a particular fat level. The carcass that has a higher muscle to bone ratio is considered better because it equates to a higher saleable lean meat and good carcass conformation (Lawrie, 1998; Irshad, 2013). The eye muscle area increases as the animal grows older (Table 1.6). However, the deposition of muscles slows down when the animal gets older, and this mostly occurs at the inflexion point around 12 months as demonstrated in (Figure 1.3). The average lean meat yield percentage is greater for beef cattle older than 20 months with 62.43% compared to beef cattle between 0-12 months and 13-19 months with 60.36% and 61.81% respectively (Table 1.6).

Table 1. 6 Lean meat yield (LMY), bone percentage, meat to ratio and eye muscle area from different production types, breeds, and diets at a range of ages

Slaughter age in months	Production type	Breed	LMY%	Bone%	M:B Ratio	EMA (cm2)	Author
0-12							
4 days	Bobby Veal	F	58.8		1.9	13	Specht *et al*., 1994
6	Rose Veal	S	69	28.10			Miotello *et al*., 2009
6	Rose Veal	S	64.1	28.56			Miotello *et al*., 2009
6	Steer	A, H, M, S				41	Wolcott *et al*., 2001
8	Steer	H x F			4.6	53	Pike, 2019
10	Steer	H x F			5.1	56	Pike, 2019
10	Steer	F	56.9	22.9	2.5		Marti *et al*., 2013
11	Bulls	C, A				61	Maltin *et al*., 1998
12	Steer	A, H, M, S				50	Wolcott *et al*., 2001
12	Bulls	C, A				69	Maltin *et al*., 1998
12	Steer	H x AF				60	Coleman *et al*., 2016
12	Steer	H x F				65	Pike, 2019
12	Steer	F	53.0	20.2			Marti *et al*., 2013
13-19							
14	Steer	C x A, AF				70	Coleman, 2016
14	Bulls	C, A				74	Maltin *et al*., 1998
14	Steer	F	52.8	20.1	2.6		Marti *et al*., 2013
14	Bull	F	58.07	21.05			Monsón *et al*., 2005
14	Bull	L	68.47	16.94			Monsón *et al*., 2005
15	Bull	A	61.4	16.9			Albertí, *et al*., 2008
15	Bull	C	67.7	16.9			Albertí, *et al*., 2008
15	Bull	F	58.9	21.8			Albertí, *et al*., 2008
15	Bull	J	66.5	20.4			Albertí, *et al*., 2008
15	Bull	L	71.9	15.0			Albertí, *et al*., 2008
15	Bull	S	67.8	20.5			Albertí, *et al*., 2008
15	Steer	H x F	54.2	19.5			Nogalski *et al*., 2018
15	Bull	H x F	60.7	23.4			Pogorzelska *et al*., 2018
16	Bulls	C, A				75	Maltin *et al*., 1998
15	Bull and steer	C x F	53.20	21.99			Nogalski *et al*., 2018
18	Steer	H x F	48.1	15.2	3.2		Nogalski *et al*., 2018
18	Steer	C x A, AF				75	Coleman, 2016
18	Steer	H x AF				64	Coleman *et al*., 2016

18	Bull	H x F	61.0	21.5	2.8		Pogorzelska *et al*., 2018
18	Steer	F	64.81	19.4	3.3		Morris *et al*., 1992
18	Steer	B x F	64.81	17.9			Morris *et al*., 1992
18	Bull	A	71.61	24.5	2.9		Dalton & Everett, 1972
18	Bull and steer	C x F	52.32	21.99			Nogalski *et al*., 2018
18	Bull	F	70.11	25.9	2.7		Dalton & Everett, 1972
20+							
20	Steer	F	61	19			Bass *et al*., 1981
20	Steer	C	66	14.9			Pacheco *et al*., 2011
20	Steer	A	62	17			Bass *et al*., 1981
21	Steer & Bull	F				76	Morris *et al*., 1990
24	Steer	C x A, AF, AK, AJ				69	Coleman 2016
24	Steer	H x AF				73	Coleman *et al*., 2016
28	Steer	H			2.9		Berg & Butterfield, 1966
29	Steer	S x J				71	Purchas *et al*., 1992
30	Steer	H			4.4		Purchas *et al*., 2002a
30	Steer	F	60.71	22.7			Barton & Pleasants, 1997
Average							
0-12			60.36	24.940	3.5	52	
13-19			61.81	19.317	2.9	71.6	
20+			62.43	18.40	3.7	72.3	

Lean meat yield (LMY)
Breed: Angus (A), Brahman (B), Friesian (F), Hereford (H), Jersey (J)

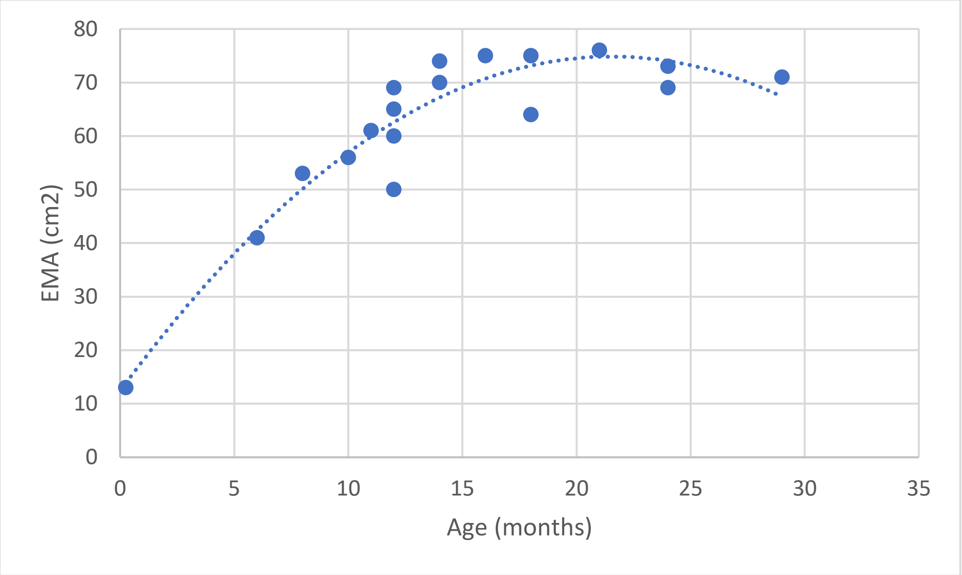


Figure 1. 3 Relationship between age and eye muscle area (EMA) for bulls and steers using considered literature data from Table 1.4. Line shown is a best fit polynomial regression (y = -0.1345x2 + 5.7952x + 12.403).

1.9.5 Influence of sex on Subcutaneous, Intramuscular and Fat percentage

Subcutaneous fat is essential in grading carcass as an indirect measure of carcass fat percentage (Schreurs, 2012). The average fat percentage from considered literature (Table 1.7) was greater in steers 27.82 than bulls 19.46 (Table 1.7) contributing to a lower lean meat yield (Table 1.5) hence, lower saleable meat yield for Steers. The intramuscular fat (IMF) percentage was greater for steers than bulls (Table 1.7), with an average of 4.41 and 2.76 respectively (Table 1.7). The same observation was made using ultrasound with bulls having lower intramuscular fat (IMF) than steers (Table 1.7); (Hassen *et al*., 1999; MacNeil *et al*., 2008). The average subcutaneous fat depth from considered literature was greater in steers than bulls with an average of 8.20 and 4.99 respectively (Table 1.7). The higher subcutaneous fat percentage in steers than bulls is associated with the absence of testosterone in steers that is responsible for sexual maturation leading to reduction in muscular development and slow growth while increasing fat deposition (Eichhorn *et al.,* 1985; Cafferky *et al*., 2019). Fatness has a positive association with palatability (Kirton, 1989; Coleman 2016) however, the increase in subcutaneous fat depth can be associated with the decrease in the saleable lean meat yield demonstrated in (Table 1.5). Finally, subcutaneous fat depth cannot be used to predict the total lean meat yield, but it is a good predictor of total fat content (Purchas, 2003).

Table 1. 7 Subcutaneous, intramuscular fat (IMF) and fat percentage of bulls, and steers at a range of cattle ages measured during slaughter.

Bulls			Steers			Breed	Age (Months)	Author
Subcutaneous fat (mm)	IMF%	Fat%	Subcutaneous fat (mm)	IMF%	Fat%			
	2.9			**3.1**			10-13	Field *et al*., 1966
7.5^{u}	1.0	9.8	9.2^{u}	1.5	16.6	P	12-14	Blanco *et al*., 2020
	4.10^{u}			5.52^{u}			14	Hassen *et al*., 1999
		15.90			26.26	H x F	15	Pogorzelska *et al*., 2018
		15.81			27.25	C x F	15-18	Nogalski *et al*., 2018
7.5^{u}	3.7^{u}		9.8^{u}	4.7^{u}			16	MacNeil *et al*., 2008
		23.6			29.4	H x S	16	Klastrup *et al*., 1984
		18.32			35.44	H x F	18	Pogorzelska *et al*., 2018
7.56	5.44		11.99	6.77		A x N	20	Mueller *et al*., 2019
		30.8			40.1		16-17	Bailey *et al*., 1966
	1.27			2.85		A,H,L,C	16-21	Cafferky *et al*., 2019
	3.0			11.0		K	20-28	Bong *et al*., 2012
5.7	2.41		9.3	4.94		H,S	16	Mandell *et al*., 1997
		17.4			26.6	H,S	16	Mandell *et al*., 1997
1.75	1.5		2.81	2.88		N x S	35	Venkata *et al*., 2015
1.90	3.80		3.47	5.77		Z x A	27	Aricetti *et al*., 2008
	2.67	18.01		4.10	21.18	F	10-11	Nichols *et al*., 1964
1.76	0.74		5.61	2.45		H x A	16-28	Purchas *et al*., 2002
8.1	6.94	19.8	12.1	8.91	25.8	H	17-18	Crouse *et al*., 1983
	1.8			1.9		A,H, Bs	13	Reagan *et al*., 1971
5.4	2.2	21.9	7.9	3.0	28.0	F,L,Bb	-	Steen *et al*., 1995
2.1	3.60		7.1	4.34		RxPixH	12	Morgan *et al*., 1993
7.4		22.7	10.9		29.4	A	12-24	Dikeman *et al*., 1986
Average								
4.99	2.76	19.46	8.20	4.41	27.82			

^{u} Measured on live animal using ultrasound

Breed: Angus (A), Brahman (B), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Simmental (S), Pirenaic (P), Nellore (N), Korean (K), Zebu (Z), Brown Swiss (Bs), Belgian Blue (Bb), Red Poll (R), Pinzgauer (Pi)

1.9.6 Influence of age on Subcutaneous, Intramuscular and fat percentage

From considered literature, deposition of subcutaneous fat increases with the increase in age (Table 1.8); (Figure 1.4), with beef animals older than 25 months having an average of 5.55mm of subcutaneous fat compared to beef animals between 0-12 and 13-24 months old with 1.40mm and 4.81mm respectively (Table 1.8). Most consumers associate Marbling or intramuscular fat with higher levels of palatability hence, playing a vital role in purchasing decisions. Intramuscular fat can only be visible after slaughter for subjective assessment. However, it can be measured chemically on lean meat or using ultrasound on live animal. Fat deposition in cattle increases as the animal grows (Table 1.8); (Figure 1.4) with beef animals between 13-24 months old having a greater fat percentage than beef animals between 0-12 months with an average fat percentage of 22.63% and 14.04% respectively (Table 1.8). (Figure 1.4) illustrates increasing fat deposition with age with a greater carcass fat depth variation in older animals from approximately 18 months based on considered literature in (Table 1.8). As the animal grows, the deposition of subcutaneous fat takes place before the deposition of the intramuscular fat (Irshad *et al*., 2013). This leads to greater deposition of intramuscular fat in older animals with animals between 13-24 months old having greater average intramuscular fat percentage than beef cattle between 0-12 months with 2.82% and 1.88% respectively (Table 1.8).

Table 1. 8 Subcutaneous, intramuscular (IMF) percentage and fat percentage from different production types, breeds, and diets at a range of cattle ages measured during slaughter.

Slaughter age in Months	Production type	Breed	Subcutaneous fat (mm)	IMF%	Fat%	Author
0-12						
4 days	Bobby Veal	F	< 1.0			Specht *et al*., 1994
5	Rosé veal	F	0.57	0.57		Yim & Hur, 2019
6	Rose Veal	S	0.96		2.90	Miotello *et al*., 2009
6	Rose Veal	S	0.73		7.36	Miotello *et al*., 2009
7	Rosé veal	F	0.65	0.65		Yim & Hur, 2019
8	Steers	H x F J		1		Pike, 2019
10	Steers	H x F J		2.3		Pike, 2019
10	Steer & Bull	F	1.6	1.6	19.6	Marti *et al*., 2013
12	Seers	H x F J		2.7		Pike, 2019
12	Steer	H x AF	3.1	2.7		Coleman *et al*., 2016
12	Steer & Bull	F	2.2	2.2	26.3	Marti *et al*., 2013
12	Steer	A		3.23		Chambaz *et al*., 2003
13-24						
14	Steer & Bull	F	3.0	3.0	27.0	Marti *et al*., 2013
14	Bull				15.42	Monsón *et al*., 2005
14	Steer	C x A, AF		2.9u		Coleman 2016
15	Bull	A			21.7	Albertí, *et al*., 2008
15	Steer	H x F			26.3	Nogalski *et al*., 2018
15	Bull	H x F			15.9	Pogorzelska *et al*., 2018
16	Steer	S		3.25		Chambaz *et al*., 2003
16	Bull	S		2.61		Nuernberg *et al*., 2005
17	steer	C		3.25		Chambaz *et al*., 2003
16 - 21	Steer & Bull	A		2.78		Cafferky *et al*., 2019
16 -21	Steer & Bull	H		2.16		Cafferky *et al*., 2019
16-21	Steer & Bull	L		2.13		Cafferky *et al*., 2019
16 - 21	Steer & Bull	C		2.05		Cafferky *et al*., 2019
16 - 21	Steer & Bull	S		2.41		Cafferky *et al*., 2019
18	steers	C x A, AF		3.6 u		Coleman *et al*., 2016
18	Steer	H x F			35.4	Nogalski *et al*., 2018
18	Bull	H x F			18.3	Pogorzelska *et al*., 2018
18	Steer	A	2.9			Muir *et al*., 2001
20	Steer & Bull	F	4.0			Morris *et al*., 1990
20	Steer	L		3.27		Chambaz *et al*., 2003

20	Steer	A			21	Bass *et al*., 1981
20	Bull	F		2.67		Nuernberg *et al*., 2005
23	Bull	S		1.51		Nuernberg *et al*., 2005
23	Steer	F	2.0			Barton *et al*. (1994)
23	steer	J	2.6			Barton *et al*. (1994
24	Bull	F		2.30		Nuernberg *et al*., 2005
24	Steer	H x AF	4.8 u	5.2 u		Coleman *et al*., 2016
25+						
25	Steer	C x A, AF	5.1	2.36		Coleman, 2016
27	Steer	A	3.3			Purchas & Morris (2007)
27	Steer	H	3.1			Purchas & Morris (2007)
29	Steer	H x F	4.8			Muir *et al*., 2000
30	Steer	F	5.0			Barton & Pleasants, 1997
33	steer	B		2.23		Wolcott *et al*., 2009
Average						
0-12			1.40	1.88	14.04	
13-24			3.69	2.76	22.63	
25+			4.26	2.30		

(u)Measured on live animal using ultrasound

Breed: Angus (A), Brahman (B), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Simmental (S),

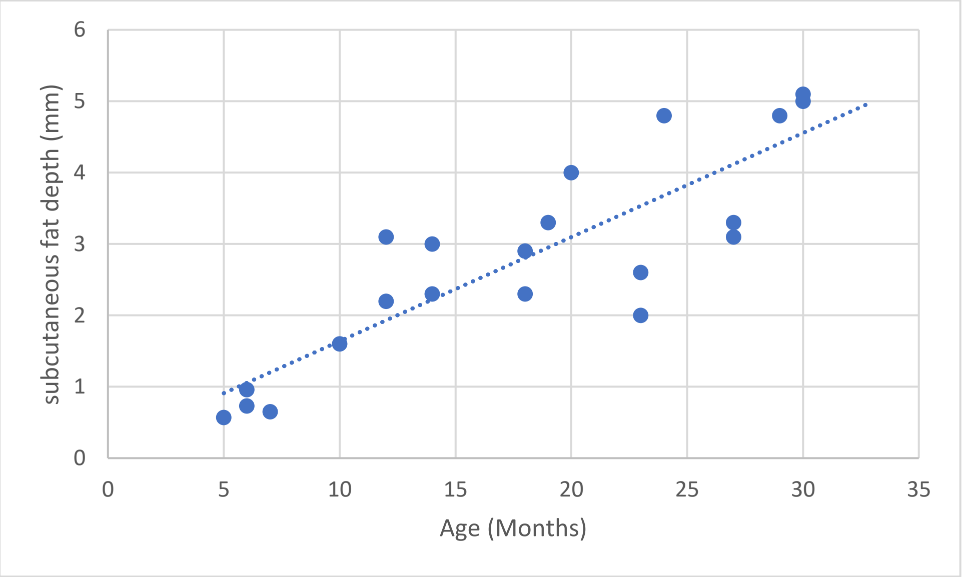


Figure 1. 4 Relationship between age and subcutaneous fat depth measured over the *Longissimus thoracic* muscle of bulls and steers using data from Table 1.8. Line shown is a best fit linear regression (y = 0.1458x - 0.1801)

1.10 Effect of age on meat quality characteristics

1.10.1 Influence of age on Ultimate pH

Different studies have reported no difference in ultimate pH among cattle of different ages (Bureš & Bartoň, 2012; Xie *et al*., 2012). However, another study has shown an increase in ultimate pH with increase in age although the difference is small and mostly lies within the normal ultimate pH range for beef cattle of between 5.3-5.7 (Lawrie, 1985). The increase in ultimate pH with increase in age could also be as a result of several pre slaughter factors (Muir *et al*., 2000; Du Plessis & Hoffman, 2007; Bures and Barton, 2012). However, dark coloured meat has been associated with an elevated ultimate pH (Sheath & McCall, 2003). Beef cattle 17-30 months had greater pH ranging from 5.49-6.18 (Chambaz *et al*., 2003, Wolcott *et al*., 2009; Bureš, *et al*., 2012, Xie *et al*., 2012, Coleman, 2016) compared to beef animals 12-16 months ranging from 5.53-5.57 (Chambaz *et al*., 2003, Bureš, *et al*., 2012, Cafferky *et al*., 2019) attributed to darker meat.

1.10.2 Influence of age on meat tenderness

Meat tenderness decreases as the slaughter age increases (Table 1.9), likely as a result of the decreased collagen solubility and increased collagen content known to occur with meat from older animals (Schonfeldt and Strydom, 2011). The average peak force (kg F) value was higher in beef cattle older than 21 months than beef cattle between 13-20 months and 0-12 months with 14.11, 9.22 and 4.19 kgF respectively (Table 1.9). The peak force values agreed with the sensory score whereby, the average sensory score for beef cattle above 21 months was lower with 32.64 while beef cattle between 13-20 months and 0-12 months had higher average sensory score of 50.96 and 66 respectively (Table 1.9). The reduction in tenderness is attributed to the development of the heat-stable collagen crosslinks that increases in concentration with the increase in age (Schonfeldt and Strydom, 2011).

Table 1. 9 Meat tenderness from different production types, breeds, and diets at a range of ages measured using sensory panels and Warner-Bratzler shear-force

Slaughter age (months)	Production type	Breed	Peak force (kg F)	Sensory score (1-100)	Days aged	Author
0-12						
2	White veal	H x A		78	0	Bouton *et al*., 1978
3	White Veal	F		57	0	Johnson *et al*., 1988
3	Veal	Q	2.94		0	Li *et al*., 2011
4	White Veal	F		69	6	Lensink *et al*., 2001
5	White Veal	F	2.40		7	Gottardo *et al*., 2005
6	Rose Veal	S	2.94			Miotello *et al*., 2009
6	Rose Veal	S	2.73			Miotello *et al*., 2009
6	White Veal	L	6.44		12	Domaradzki *et al*., 2017
7	White Veal	L	5.66		12	Domaradzki *et al*., 2017
8	steer	H x FJ	5.1			Pike, 2019
9	Rosé Veal	A		60	0	Bouton *et al*., 1978
9	Steer	Q	3.53		0	Li *et al*., 2011
10	Steer & Bull	F	4.8		7	Marti *et al*., 2013
10	Steer	H x FJ	4.6			Pike, 2019
11	White Veal	L	2.40		10	Domaradzki *et al*., 2017
12	Steer	Q	4.21		0	Li *et al*., 2011
12	Steer	H x FJ	5.6			Pike, 2019
12	Steer & Bull	F	5.3		7	Marti *et al*., 2013
13-20						
14	Steer & Bull	F	5.3		7	Marti *et al*., 2013
14	Bull	C x S		50	0	Bureš & Bartoň, 2012
14	Bulls	F	4.77		1	Monsón *et al*., 2005
14	Bulls	L	5.57		1	Monsón *et al*., 2005
15	Steer	H x F		70	0	Nogalski *et al*., 2018
15	Steer	Q	5.34		0	Li *et al*., 2011
15	Bull and steer	C x F	3.40			Nogalski *et al*., 2018
16	Steer	A	4.52	55	0	Bouton *et al*., 1978
16	Bulls	A	10.56			Thomson *et al*., 2017
16	Steer	A	9.46			Thomson *et al*., 2017

16	Bull	S	13.17			Nuernberg *et al*., 2005
16-23	Bull	S		63.6		Nuernberg *et al*., 2005
18	Steer	H x F		76	0	Nogalski *et al*., 2018
18	Bull and steers	C x F	3.51			Nogalski *et al*., 2018
18	Bull	C x S		54	0	Bureš & Bartoň, 2012
18	Bull	L	4.67			Xie *et al*., 2012
18	Bull	S	5.36			Xie *et al*., 2012
18	Bull	Q	5.29			Xie *et al*., 2012
19	Heifer	C x A			7	Coleman, 2016
19	Bull	L		51		Hoving-Bolink *et al*., 1999
20	Steer & Bull	H x F		9.85	7	Purchas & Grant, 1995
20	Steers	C	4.6			Pacheco *et al*., 2011
20	Steer & Bull	H x F		12.14	0	Purchas *et al*., 1997
20	Bull	F	11.06			Nuernberg *et al*., 2005
20-24	Bull	F		64.0		Nuernberg *et al*., 2005
21+						
22-25	Steer	H x A		9.42	7	Coleman *et al*., 2016
23	Bull	S	15.87			Nuernberg *et al*., 2005
24	Bull	F	14.34			Nuernberg *et al*., 2005
26	Steer	C x A		9.41	7	Coleman, 2016
27	Steer	H		29	6	Muir *et al*., 2000
27	Steer	H x F		32	6	Muir *et al*., 2000
27	Steer	F		64	6	Muir *et al*., 2000
27	Steer	A	12.13	52	6	Purchas & Morris, 2007
Average						
0-12			4.19	66		
13-20			6.44	50.56		
21+			14.11	32.64		

The sensory assessment was done on a scale of 1 (least tender) to 100 (most tender) by trained sensory panel

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Qinchuan (Q)

1.10.3 Influence of age on Lean Meat Colour

As the animal gets older, the myoglobin concentration (responsible for the red colour of meat) in the animal increases making the meat colour to become darker (Li *et al*., 2011). The average redness (a*) of beef was greater in beef cattle above 25 months with 19.32 compared to beef cattle between 0-12 and 13-24 months old with 10.41 and 17.76 respectively from considered literature (Table 1.10). Veal beef tends to be lighter in colour (Table 1.10) (Purchas, 1989) while beef from older cattle likely from 12 months is darker and redder (Table 1.10). The average lightness L* was higher in beef cattle between 0-12 months with 46.52 compared to beef cattle between 13-24 months and 25 months and above with 38.39 and 35.38 (Table 1.10). According to Bureš & Bartoň, (2012); Pogorzelska-Przybyłek *et al*., (2018), the difference in meat colour for animals of different ages can be observed when comparing animals with a large difference in age (Table 1.10).

Table 1. 10 Lean meat colour from different production types and breeds at different ages measured using chromometer.

Slaughter age	Production type	Breed	L* (lightness)	a* (redness)	b* (yellowness)	Author
0-12						
5 days	Bobby Veal	J	50.4	7.2	8.9	Biss *et al*., 1993
14 days	Bobby Veal	J	48.5	7.5	8.3	Biss *et al*., 1993
4	White Veal	F	58.7	11.2	8.5	Lensink *et al*., 2001
4	White Veal	F	58.5			Tarantola *et al*., 2003
5	White Veal	F	54.1	12.6	8.9	Gottardo *et al*., 2005
5	White Veal	F	61.0			Tarantola *et al*., 2003
6	Rose Veal	S	32.56	9.05	9.80	Miotello *et al*., 2009
6	Rose Veal	S	43.09	4.73	11.68	Miotello *et al*., 2009
6	Rosé Veal	F	42.8	11.3	6.6	Yim & Hur, 2019
6	White Veal	F	58.8	11.3		Tarantola *et al*., 2003
7	Rosé Veal	F	42.8	7.8	6.6	Yim & Hur, 2019
8	Rosé Veal	F	44.8		3.1	Yim & Hur, 2019
8	Steer	H x FJ	42.03	12.29	3.44	Pike, 2019
9	White Veal	L x S	40.1	8.7	7.5	Domaradzki *et al*., 2017
10	Steer	H x FJ	39.71	14.97	4.93	Pike, 2019
11	White Veal	L	43.2	9.4	8.8	Domaradzki *et al*., 2017
12	Steer	H x FJ	36.33	13.86	4.46	Pike, 2019
12	Steer	A	40.0	14.2	4.3	Chambaz *et al*., 2003
13-24						
14	Bull	S	42.6	29.2	11.4	Marenčić *et al*., 2018
14	Bull	C x S	43.2	13.7	13.9	Bureš & Bartoň, 2012
15-16	Bull	S	42.1	29.4	11.5	Marenčić *et al*., 2018
15	Steer	H x F	35.7	18.4	13.7	Nogalski *et al*., 2018
16	Bull	s	35.78			Nuernberg *et al*., 2005
16	Steer	S	37.3	14.3	4.1	Chambaz *et al*., 2003
16 - 21	Steer & Bull	A	41.89	14.37	11.15	Cafferky *et al*., 2019
16 -21	Steer & Bull	H	41.68	14.15	10.67	Cafferky *et al*., 2019
16- 21	Steer & Bull	L	42.66	14.31	11.41	Cafferky *et al*., 2019
16 - 21	Steer & Bull	C	42.52	14.56	11.6	Cafferky *et al*., 2019
16 - 21	Steer & Bull	S	42.27	14.27	11.12	Cafferky *et al*., 2019
17-18	Bull	S	41.6	29.4	11.5	Marenčić *et al*., 2018
17	Steer	C	39.5	14.2	4.7	Chambaz *et al*., 2003
18	Bull and steer	C x S	35.72	18.61	14.03	Nogalski *et al*., 2018
18	Bull	L	38.92	19.81	9.96	Xie *et al*., 2012
18	Bull	S	35.80	19.52	9.11	Xie *et al*., 2012
18	Steer	H x F	36.8	18.9	14.6	Nogalski *et al*., 2018
18	Bull and steer	C x S	36.18	18.81	15.41	Nogalski *et al*., 2018
18	Bull	Q	36.32	18.64	7.92	Xie *et al*., 2012
18	Bull	C x S	45.4	13.1	13.9	Bureš & Bartoň, 2012
19	Bulls	L	36.9	18.0	14.8	Hoving-Bolink *et al*., 1999
20	Steers	C		13.2		Pacheco *et al*., 2011
20	Bull & Steer	H x F	34.1	18.5	8.2	Purchas & Grant, 1995
20	Steer	L	38.1	14.7	4.9	Chambaz *et al*., 2003
20	Bull	F	33.08			Nuernberg *et al*., 2005
23	Bull	S	32.20			Nuernberg *et al*., 2005
22-25	Steer	H x A	38.9	14.2	4.2	Coleman *et al*., 2016
24	Bull	F	29.25			Nuernberg *et al*., 2005
25+						
26	Steer	C x A	38.2	15.5	4.4	Coleman, 2016
27	Steer	H	35.2	21.9	11.9	Muir *et al*., 2000
27	Steer	H x F	33.2	21.4	10.9	Muir *et al*., 2000
27	Steer	F	33.3	21.1	10.9	Muir *et al*., 2000
27	Steer	A	37.0	16.7	5.6	Purchas & Morris, 2007
Average						
0-12			46.52	10.41	7.10	
13-24			38.39	17.76	10.60	
25+			35.38	19.32	8.74	

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Qinchuan (Q),

1.10.4 Influence of age on subcutaneous fat colour

Fat colour plays a vital role in consumer beef acceptability. Some consumers consider yellow fat to come from inferior and older cattle, hence, white fat is more desirable (Dunne *et al*., 2009). However, the degree of yellow fat acceptability varies between markets. New Zealand beef industry experiences the yellow fat challenge because of the pasture-based beef production system (Nozière *et al*., 2006). The presence of the yellow fat-soluble pigments such as carotenoids from forage plants tend to cause yellow fat in pasture or forage fed cattle Dunne *et al*., 2009). The accumulation of carotenoid pigments is associated with older animals having an increased likelihood of yellow fat (Table 1.11) (Purchas, 2003). When averaging values across the literature beef animals from 0-24 months of age had lower b* (yellowness) values of 6.69 compared to beef animals above 25 months of age with values of 15.58 (Table 1.11).

Table 1. 11 Subcutaneous fat colour from different production types, breeds, and diets at a range of cattle ages measured using chronometer.

Slaughter age	Production type	Breed	L* (lightness)	a* (redness)	b* (yellowness)	Author
0-24						
18	Bull	L	78.4	3.4	7.3	Xie *et al*., 2012
18	Bull	S	35.8	3.4	6.9	Xie *et al*., 2012
18	Bull	Q	79.9	3.4	6.0	Xie *et al*., 2012
24	Steer	H x A	69.8	5.0	6.5	Coleman *et al*., 2016
25+						
26	Steer	C x A	62.4	8.8	13.2	Coleman, 2016
27	Steer	H	78.2	1.8	14.2	Muir *et al*., 2000
27	Steer	F	73.5	2.0	16.9	Muir *et al*., 2000
27	Steer	A	56.7	6.0	14.5	Purchas & Morris, 2007
27	Steer	H x F	55.8	5.0	15.6	Purchas & Morris, 2007
27	Steer	J x F	54.4	5.5	19.1	Purchas & Morris, 2007
Average						
0-24			65.96	3.81	6.69	
25+			63.50	4.85	15.58	

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Qinchuan(Q)

1.10.5 Influence of age on meat Flavour

The intensity of meat flavour increases with the increase in age, beef cattle between the ages of 0-12 months have a lower average flavour intensity score ranging between 48-54 out of 100 (Mandell *et al*., 2001, Lensink *et al*., 2001, Marti *et al*., 2013 and Campo *et al*., 1999) while for beef cattle older than 13 months the scores ranged between 50-66 (Beanaman *et al*., 1962; Taylor, 1982; Hoving-Bolink *et al*., 1999; Muir *et al*., 2000; Monsón *et al*., 2005; Resconi *et al*., 2010; Bureš & Bartoň, 2012, Marti *et al*., 2013; Purchas & Morris, 2007). This is attributed to intramuscular fat (marbling) of older animals (Marti *et al*., 2013). According to Thompson, (2004) and Moletta *et al*., (2014), intramuscular fat is associated with improved flavour, tenderness and juiciness of beef because it stores flavour compounds that are released during cooking, hence the positive effect on flavour. Animals older than 12 months have more flavour intensity with high gamey notes (Rodbotten *et al*. (2004). However, sex and diet can also affect meat flavour, hence, the observed variation in different studies, with animals within the same category and age having different flavour intensity (Young & West, 2001).

1.10.6 Influence of age on juiciness and Water-holding Capacity

Drip loss after 48 hours was lower in young beef cattle between 0-12 months with 3.20% than beef cattle between 13-20 months and 21 months and over with 5.87% and 8.23% respectively (Table 1.12). Young animals generally have a lower drip loss compared to the older animals because of the ability of protein to retain water (Bureš & Bartoň, 2012). However, cooking loss percentage was greater in young beef cattle between 0-12 months with 30.63% than beef cattle between 13-20 months and over 21 months with 26.57% and 26.00% respectively (Table 1.12). The subjective juiciness score increases with increase in age because of the increase in intramuscular fat as the animal ages (Table 1.12), that causes lubrication effect as a result of salivation (Purchas, 2003).

Table 1. 12 Drip loss, cooking loss expressed water and subjective juiciness scores from different production type at a range of cattle ages.

Slaughter age	Production type	Breed	Drip loss 48 hr (%)	Cooking loss (%)	Expressed water (cm2/g)	Subjective juiciness (Sensory Score)	Author
0-12							
1 day	Bobby Veal	J		38.3	42.2		Biss *et al*., 1993
5 days	Bobby Veal	J		39.1	42.6		Biss *et al*., 1993
21 days	Bobby Veal	J		38.5	44.6		Biss *et al*., 1993
3	Bobby veal	Q		39.19			Li *et al*., 2011
6	Rose Veal	S		26.17			Miotello *et al*., 2009
6	Rose Veal	S		31.59			Miotello *et al*., 2009
4	Rosé Veal	F	4.9	21.1		68	Mandell *et al*., 2001
4	White Veal	F	2.9	33.8			Lensink *et al*., 2001
5	Rose veal	F		29			Grigor *et al*., 2004
5	White Veal	F		29.3			Gottardo *et al*., 2005
5	White Veal	F	3.1	29.1			Tarantola *et al*., 2003
6	White Veal	F	2.4	27.2			Tarantola *et al*., 2003
7	White Veal	L	1.6	29.9			Domaradzki *et al*., 2017
8	White Veal	L	1.5	34.6			Domaradzki *et al*., 2017
8	Steer	H x FJ	5.7	28.7			Pike, 2019
9	White Veal	L x S	1.5	31.2			Domaradzki *et al*., 2017
10	Steer	H x FJ	4.1	27.8			Pike, 2019
11	White Veal	L	1.8	30.9			Domaradzki *et al*., 2017
12	Steer	H x FJ	6.4	26.5			Pike, 2019
12	Steer	A	2.5	20.6			Chambaz *et al*., 2003
13-20							
14	Bull	C x S	16.9			54	Bureš & Bartoň, 2012
15	Bull &steer	C x F	2.20	33.29			Nogalski *et al*., 2018
16	Steer	S	3.0	17.1			Chambaz *et al*., 2003
16-23	Bull	S				42.6	Nuernberg *et al*., 2005
16 - 21	Steer & Bull	A	2.15	30.15			Cafferky *et al*., 2019
16 -21	Steer & Bull	H	2.5	29.09			Cafferky *et al*., 2019
16- 21	Steer & Bull	L	2.97	29.09			Cafferky *et al*., 2019
16 - 21	Steer & Bull	C	3.22	29.66			Cafferky *et al*., 2019
16 - 21	Steer & Bull	S	2.52	30.59			Cafferky *et al*., 2019
17	Steer	C	3.6	15.8			Chambaz *et al*., 2003
18	Bull	L	9.57	26.99			Xie *et al*., 2012
18	Bull	S	10.29	29.38			Xie *et al*., 2012
18	Bull	C x S	12.1			58	Bureš & Bartoň, 2012
18	Bull and steer	C x F	2.27	34.53			Nogalski *et al*., 2018
18	Bull	Q	10.32	30.53			Xie *et al*., 2012
19	Bull	L			38		Hoving-Bolink *et al*., 1999
20	Steer	L	4.5	14.1			Chambaz *et al*., 2003
20	Bull & Steer	H x F		26.9			Purchas & Grant, 1995
20	Steer	C		21.4			Pacheco *et al*., 2011
20 -24	Bull	F				42.8	Nuernberg *et al*., 2005

21+							
24	Steer	H x A	8.1	24.3	31.7		Coleman *et al*., 2016
24	Steer & Heifer	C x A	8.7	26.4			Coleman, 2016
24	Steer & Heifer	C x AF	8.1	26.4			Coleman, 2016
26	Steer	H x A	8.0	26.9	31.2		Coleman 2016
27	Steer	H				57	Muir *et al*., 2000
Average							
0-12			3.20	30.63	43.13	68	
13-20			5.87	26.57	38.00		
21+			8.23	26.00	31.45	57	

The sensory assessment was done on a scale of 1 (minimum juiciness) to 100 (maximum juiciness) by trained sensory panel

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), (Q) Qinchuan

1.11 Effect of Sex on meat quality attributes

1.11.1 Influence of sex on beef ultimate pH

Bulls tend to have greater ultimate pH than steers ranging between 5.56-5.59 for bulls and 5.53-5.48 for steers for animals between 15-18 months (Bureš, *et al*., 2012, Nogalski *et al*., 2018 and Pogorzelska *et al*., 2018). According to Oliveira *et al*., (2012) and Mueller *et al*. (2019), pH higher than 6.0 is associated with pre-slaughter problems, breed and sex status of the animal. Depletion of glycogen reserves before slaughter is known to cause higher pH values mostly in bulls because of the higher testosterone levels that make bulls aggressive during slaughter (Lawrie, 1985). Although the bulls had higher ultimate pH than steers, both average values were within the normal range of 5.3-5.7 for cattle beef (Lawrie, 1985).

1.11.2 Influence of sex on meat tenderness

Sex affects tenderness sensory attributes of beef with bulls recording lower sensory score than steers with an average of 57.25 and 61.25 respectively from considered literature (Table 1.13). The average Warner-Bratzler shear-force (WBSF) values agreed with the sensory score with bulls having peak force value greater than steers with 5.50 and 4.69 respectively **(**Table 1.13) indicating beef from bulls was less tender compared to steers (Glimp *et al*., 1971 and Klastrup *et al*.,1984). The less tender meat in bulls result from the greater synthesis and activity of androgenic hormones that have a greater anabolic (muscle building) action in cattle (Mueller *et al*., 2019). The higher fat content in steers dilutes the muscle connective tissues leading to an increase in meat tenderness (Nishimura et al., 1999). However, Moran *et al*., (2017) did not observe any difference in meat tenderness for bulls and steers at 19 months.

Table 1. 13 Meat tenderness of bulls and steers measured using sensory panels and Warner-Bratzler shear-force

Bulls		Steers		Breed	Age (Months)	Author
Peak force (kg F)	Sensory score	Peak force (kg F)	Sensory score			
8.4		6.6		H, A	14	Glimp *et al*, 1971
10.6		9.5		A	16	Thomson *et al*., 2017
4.6	51	3.7	54	H x S	16	Klastrup *et al*., 1984
	63		69	A x N	26	Mueller *et al*., 2019
4.5		3.4		A,H,L,C,S	16-21	Cafferky *et al*., 2019
2.6		2.6		L x C	19	Moran *et al*., 2017
6.3		5.0		-	15-17	Arthaud *et al*., 1969
5.0		4.2		H,S	16	Mandell *et al*., 1997
5.4	58	5.2	53	-	15	Martin *et al*., 1971
5.0		5.2		B	26	Rodriguez *et al*., 2014
	55		41	H x A	16-28	Purchas *et al*., 2002
4.5	56	3.7	66	H	17-18	Crouse *et al*., 1983
4.2	55	3.0	71	A,H, Bs	13	Reagan *et al*., 1971
	54		59	A	22-23	Woodhams *et al*., 1965
4.9		4.2		RxPixHxA	12	Morgan *et al*., 1993
	66		77	A	12-24	Dikeman *et al*., 1986
Average						
5.50	57.25	4.69	61.25			

The sensory assessment was done on a scale of 1 (least tender) to 100 (most tender) by trained sensory panel
Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Nellore (N) Red Poll (R), Pinzgauer (Pi)

1.11.3 Influence of sex on Lean Meat and Fat Colour

The lightness, redness and yellowness values of meat, measured by chromameter, do not generally differ between bulls and steers (Table 1.14). There is no strong consensus on the effect that castration has on the colour of subcutaneous fat. Blanco *et al*., 2020, observed greater lightness (L*) and yellowness (b*) values for the subcutaneous fat of bulls compared to steers, while Moran *et al*., 2017, observed greater L* and b* values for the subcutaneous fat in steers than bulls.

Table 1. 14 Lean meat colour of bulls and steers measured using chronometer.

Bulls			Steers			Breed	Age (Months)	Author
L* (lightness)	a* (redness)	b* (yellowness)	L* (lightness)	a* (redness)	b* (yellowness)			
35.34	17.95	13.54	35.73	18.41	13.67	H x F	15	Pogorzelska *et al*., 2018
35.51	18.29	13.51	36.39	19.13	15.94	C x F	15-18	Nogalski *et al*., 2018
36.01	18.24	13.51	36.84	18.87	14.56	H x F	18	Pogorzelska *et al*., 2018
33.08			38.1			L, F	20	Chambaz *et al*., 2003; Nuernberg *et al*., 2005
30.0	11.8	9.9	32.0	11.7	12.9	A x N	20	Mueller *et al*., 2019
42.33	14.01	11.33	41.93	14.52	11.06	A,H,L,C,S	16-21	Cafferky *et al*., 2019
32.59	22.98	14.32	33.77	22.20	14.33	L x C	19	Moran *et al*., 2017
41.8	11.7	8.33	42.2	15.8	11.3	F	19-21	Nian *et al*., 2018
Average								
35.83	16.42	12.06	37.12	17.23	13.39			

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Nellore (N)

1.11.4 Influence of sex on Meat Flavour

The meat flavour intensity is generally similar for steers and bulls (Table 1.15) and so, castration status does not seem to be a driver of beef flavour intensity.

Table 1. 15 Meat Flavour from different production types, breeds, and diets at a range of cattle ages measured using sensory panel.

Bulls	Steers	Breed	Age (Months)	Author
65	66	H, A	14	Glimp *et al*, 1971
42	47	C x F	15-18	Nogalski *et al*., 2018
53	53	H x S	16	Klastrup *et al*., 1984
59	63	A x N	20	Mueller *et al*., 2019
50	52	L X C	19	Moran *et al*., 2017
58	61	H,S	16	Mandell *et al*., 1997
54	47	-	15	Martin *et al*., 1971
41	42	B	26	Rodriguez *et al*., 2014
54	56	H	17-18	Crouse *et al*., 1983
56	65	A,H, Bs	13	Reagan *et al*., 1971
58	58	A	22-23	Woodhams *et al*., 1965
56	58	RxPixHxA	12	Morgan *et al*., 1993
32	33	A	12-24	Dikeman *et al*., 1986
Average				
52.15	53.92			

The flavour intensity was assessed by a panel on a scale of 1 as the low intensity to 100 as the greatest intensity. Breed: Angus(A), Brown Swiss (B), Charolais(C), Friesian (F), Hereford(H), Limousin (L), Simmental (S), Nellore(N), Red Poll (R), Pinzgauer (Pi)

1.11.5 Influence of sex on Juiciness and Water-holding Capacity

The juiciness of meat is partly determined by the water content and the meat's ability to hold and release water. Water holding capacity is objectively assess through drip loss, cooking loss and expressed loss or subjectively through sensory evaluation of juiciness (Table 1.16; Muir *et al*., 2000; Purchas and Zou, 2008). The cooking loss was similar between bulls than steers with average percentage obtained from the literature of 27.63% and 26.09% respectively (Table 1.16). The sensory score for juiciness tends to be greater in steers than bulls (Table 1.16). Drip loss percentage was greater in bulls than steers, with an average of 2.48% and 2.24% respectively (Table 1.16). However, Cafferky *et al*., (2019) recorded higher drip loss percentage for steers than bulls with 3.41% and 2.73% respectively for animals slaughtered between 16-21 months. According to Cheng *et al*., (2008) a decrease in the muscular glycogen reserve due to stress tends to increase the ultimate pH leading to a high-water holding capacity. In addition, a fast decrease in pH coupled with high muscle temperature leads to denaturation of protein and shrinkage of myofibrillar hence, reduced water holding capacity (Micklander *et al*., 2005; Cheng *et al*., 2008). So, sex differences in water holding and juiciness are more likely being driven indirectly by pH.

Table 1. 16 Drip loss, cooking loss, expressed water and subjective juiciness scores of bulls and steers of different breeds and age.

Bulls			Steers			Breed	Age (Months)	Author
Drip loss 48 hr (%)	**Cooking loss (%)**	**Sensory Score (juiciness)**	**Drip loss 48 hr (%)**	**Cooking loss (%)**	**Sensory Score (juiciness)**			
2.16	34.78		1.81	34.07		H x F	15	Pogorzelska *et al*., 2018
2.48	34.46	45	1.99	33.36	48	C x F	15-18	Nogalski *et al*., 2018
	31.6			29.5		H x S	16	Klastrup *et al*., 1984
2.55	35.17		1.75	32.13		H x F	18	Pogorzelska *et al*., 2018
		60			66	A x N	20	Mueller *et al*., 2019
2.73	30.4		3.41	29.25			16-21	Cafferky *et al*., 2019
	26.71			24.31		L x C		Moran *et al*., 2017
	22.2			17.6		H,S	16	Mandell *et al*.,1997
		57			50	-	15	Martin *et al*., 1971
		41			42	B	26	Rodriguez *et al*., 2014
	27.7	46		26.4	48	H x A	16-28	Purchas *et al*., 2002
	28.1	58		25.7	59	H	17-18	Crouse *et al*., 1983
	10.40	56		11.50	62	A,H, Bs	13	Reagan *et al*., 1971
		56			57	A	22-23	Woodhams *et al*., 1965
	22.4	51		23.2	51	RxPixHx A	12	Morgan *et al*., 1993
		68			74	A	12-24	Dikeman *et al*., 1986
Average								
2.48	27.63	53.80	2.24	26.09	55.70			

The sensory assessment was done on a scale of 1 (minimum juiciness) to 100 (maximum juiciness) by trained sensory panel

Breed: Angus (A), Charolais (C), Friesian (F), Hereford (H), Jersey (J), Limousin (L), Simmental (S), Red Poll (R), Pinzgauer (Pi)

Chapter 2. Research questions and objectives

Chapter 2. Research questions and objectives

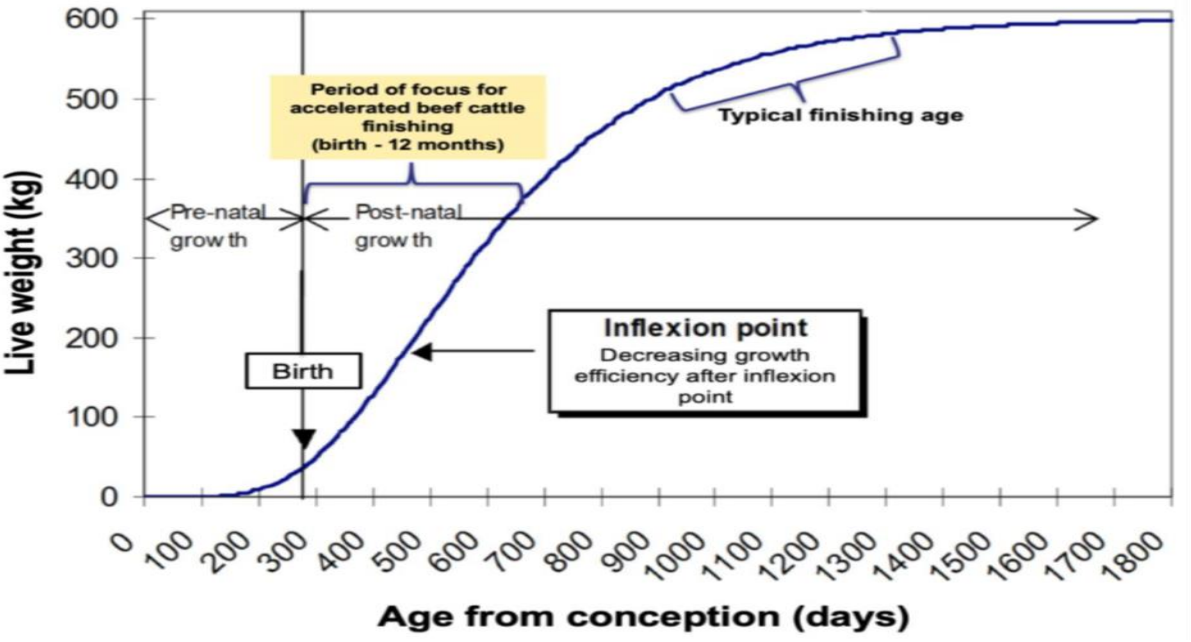
2.1 Potential for yearling beef production in New Zealand

The high number of calves produced from the dairy industry that cannot be used as replacement stock provides an opportunity for the beef industry to use the surplus dairy origin calves as sources of beef. Although the beef industry has been using these surplus calves for veal to a limited extent and for by-products, the public is now raising concerns regarding the slaughter of the surplus calves. The concerns raised by the public on animal welfare presents a risk to the beef industry in terms of imposing compliance and a social license to operate. New Zealand beef production industry relies heavily on natural pastures and beef animals are mainly finished between 24 and 36 months of age. However, if the goal is to finish all surplus calves from the dairy industry for beef, the constraints of land and feed availability makes it unfeasible to take the cattle through to 24-36 months of age (Pike, 2019). Restricted availability of land especially prime beef finishing land is partially a consequence of the conversion to dairy, driven by high returns from dairy, of approximately one million hectares of the beef finishing hill country since the year 1990 (Geenty & Morris, 2017). Therefore, the dairy-beef industry requires an alternative end points for the surplus calves. New Zealand pasture-based beef production system offers an alternative use of the surplus calves utilising a shortened production system where calves are slaughtered at approximately12 months of age (as yearling) allowing a greater turnover of animals compared to the beef production system. Such a system will provide a good opportunity for the beef industry to capitalize on the high number of surplus calves from the dairy industry and reduce the bobby calf slaughter (Pike, 2019).

The physiology of cattle allows accelerating growth within the first year of growth under optimal conditions until inflexion when the animal is 12 months (Figure 1.5). Feed conversion is very efficient during the initial stages of the accelerating growth as demonstrated by the Hereford steers with their feed conversion efficiency increasing from 0.05 kgLWG/kgDMI for steer that were slaughtered at 30 months to 0.14 kgLWG/kgDMI for steers that were slaughtered at one year (Marti *et al*., 2013; Vickers & Stewart, 2016). A similar observation was made by Marti *et al*. (2013), on Holstein bulls where feed conversion efficiency increased from 0.19 kgLWG/kgDMI for bulls slaughtered at 14 months to 0.23 kgLWG/kgDMI for bulls slaughtered at 10 months.

Chapter 2. Research questions and objectives

Figure 1. 5 Demonstrates the sigmoidal growth curve of a cattle (adapted from Fitzhugh, 1976)



After 12 months, cattle enter a decelerating growth phase (inflexion point) going towards maturity because of the fat deposition and maintenance requirements (Figure 1.5; Pike, 2019). Therefore, slaughter of cattle at the ages of 18 to 36 months means the cattle have undergone a period of naturally slowed growth (Figure 1.5) making the cattle less efficient. To ensure efficient utilization of the limited resources like land and pasture and counteract the environmental concerns of keeping animals over multiple winters (McGee 2015), processing animals for beef production at 12 months is a better alternative. According to (Morris and Kenyon, 2014; Pike, 2019), processing animals at one year reduces the possibility of the animals pugging or damaging the fragile soils hence, minimizing environmental concerns.

The animal welfare concerns raised on the slaughter of surplus calves of dairy-origin makes it important to investigate alternative methods of utilization. The slaughter of calves at a young age imposes threat to New Zealand's market reputation for both dairy and beef industries because of animal welfare perceptions suggesting a potential non-tariff barrier to trade and in the future could represent an impediment to the farmers social license to operate. However, the surplus calves from dairy industry have potential for greater use in a yearling beef production system.

In New Zealand, the beef industry has been relying heavily on prime beef from cattle finished between 18-36 months of age. Argentina in South America has shown quality-beef can be obtained from the yearling beef production system. The utilization of surplus calves from the dairy industry in a New Zealand pasture-based yearling beef production system is novel but is regarded as having potential benefits for utilising more cattle for beef production. The New

Zealand dairy-beef finishing system uses steers however, in a yearling system, puberty may not be reached, and this suggests that bulls can be used which eliminates the need for castration.

In New Zealand, steers slaughtered at 18-36 months of age are used for chilled, prime products while bull slaughtered at similar ages are used for manufacturing beef products. It is unknown whether the separation of the systems based on sex and end product is required for yearlings.

1.10.12 Important traits for pasture-based yearling beef production

The traits that may pose a challenge in young animals include fatness and dressing-out percentage. Fatness increases with the increase in age hence, improving meat palatability. In addition, steers tend to have greater fat percentage compared to bulls in older animals greater than 12 months. Dressing-out percentage tends to increase with age as older animals deposit more muscle and fat into carcass while young animals have the non-carcass components. On the other hand, there are traits that are advantageous to young animals including lean meat and saleable lean meat yield, tenderness, water holding capacity and meat colour. Lean and saleable lean meat yield decreases as the animal ages due to increase in fat proportion in older animals. Meat tenderness decreases with increase in age while older bulls tend to have a darker meat colour compared to young bulls. Consumers prefer tender meat with good meat colour that appeals to the eyes. Young animals tend to have a greater water holding capacity because of the ability of protein to retain water. Greater ability of meat to retain water means that the meat can be stored without affecting juiciness. Therefore, the choice of cattle for this system (steers vs bulls) at yearlings stage should be ones that are most likely to get fat enough to pass the minimum standards required, and most likely to capitalise on the most advantageous traits to make a super delicious product.

Chapter 2. Research questions and objectives

Research objectives, questions, and hypothesis

The objectives of the study in this thesis was to compare the growth rates, carcass characteristics and meat quality attributes of dairy-beef bulls and steers at 11 months. The study aimed to identify if there is need to castrate bulls in the yearling beef production system for growth, carcass and meat quality and whether proteolytic aging of the meat will differentially affect meat quality attributes. Therefore, the research questions include:

- What are the growth rates of dairy-beef bulls compared to steers when finished at 11 months in a pasture-based beef production system?
- What are the carcass and the meat quality attributes of bulls compared to steers finished at 11 months in a pasture-based beef production system?
- Is there the need for castration of bulls in a yearling pasture-based beef production system?

It is hypothesised that when compared at the yearling age (11 months), bulls and steers will perform the same in terms of growth rates, carcass characteristics and meat quality attributes.

Chapter 3. Materials and Methods

3.1 Animals and Management

Thirty-three Hereford-sired bull calves born in spring 2018 to Friesian and Friesian-Jersey cows at Massey University's Dairy 4 farm were selected for this experiment. Calves were reared by a commercial calf rearer. The calves were unrecorded, so the sires were unknown. Calves were randomly assigned to be bulls or steers, and steers were castrated using a rubber ring approximately 6 weeks after birth. Calves were weaned at 3 months of age and moved to Massey University's Tuapaka farm near Palmerston North (latitude 40° 20' south, longitude 175° 43' east) from late October 2018 to mid-November 2018. Both bulls and steers were managed as a single group throughout the experiment.

The feeding regime for the calves aimed to achieve the target live weight gain of 1 kg/day. Between November and January, calves were grazed on herb-clover forage crop consisting of red clover (*Trifolium pratense*), chicory (*Cichorium intybus*), plantain (*Plantago lanceolata*) and white clover (*Trifolium repens*) supplemented with 0.5 kg/head/day of Sharpes Earlywean Calf Pellets (16% crude protein). Calves grazed on Hunter Brassica (*Brassica campestris*) in February 2019 before moving to ryegrass- white clover pasture from early March until slaughter in June. Calves were drenched with oral anthelmintic (coopers Alliance) at monthly intervals.

Bulls and steers were transported on 5th June 2020 to Feilding Venison Packers Limited abattoir (20 km from farm). The animals were slaughtered on 6th June 2020 approximately 24 hours after transportation and processed following standard commercial dressing procedures. The dressed carcasses were hung in a chiller overnight at 4ºC and boned into commercial cuts 24 hours after slaughter.

3.2 Measurements

Since calves arrived on different dates, the arrival live weights were recorded. Thereafter, the start live weight was recorded after the arrival of all the calves. Live weight was recorded directly off feed every 2 weeks from start of the experiment at Tuapaka farm until slaughter, with the final live weight obtained immediately prior to transportation to the abattoir (24 hours before slaughter).

Carcass characteristics were assessed on the live animal on the 23rd of May using ultrasound by a commercial operator (Austins Ultrasound Limited) to measure: P8 fat depth over the *Gluteus medius* muscle on the rump, Rib fat depth measured between 12th and 13th rib of the *Longissimus thoracis* where the eye muscle (*Longissimus thoracis*) was deepest, and the transverse area of the *Longissimus thoracis* muscle (eye muscle area; EMA) between the 12th and the 13th rib.

The weight of each half of the carcass was recorded prior to the carcasses entering the chiller at the processor. The carcass weight for each animal was obtained by adding the weight of the left and the right sides of the carcass. The dressing-out percentage was calculated by dividing the hot carcass weight by live weight measured on farm and expressing as a percentage. After chilling and prior to boning-out, the length of the carcass was measured from the distal end of the tarsal bone to the mid-point of the cranial edge of the first rib (Purchas and Morris 2007). The mean length of the two carcass sides was used as the carcass length of each carcass.

At boning out, the topside (*Semimembranosus* and *Adductor*), silverside (*Biceps femoris, Semitendinosus*), and knuckle (*Quadriceps*) were obtained from the left side of each carcass and weighed (Figure 1; Pike, 2019). The left femur bone was also collected and the weight and length of the femur and the weight of the topside, silverside and knuckle measured at the Massey University Meat Laboratory. The sum of weight of the five main muscles surrounding the femur (muscles within the silverside, topside and knuckle) and the femur length were used to calculate muscularity (Purchas, Davies, & Abdullah, 1991; Purchas *et al*., 2002a; Purchas, Fisher, Price, & Berg, 2002b) using the formula developed by (Purchas *et al*., 1991) as;

$$Muscularity = \frac{\left[\sqrt{\frac{(Five\ muscle\ weight\ (g))}{\text{Femur length (cm)}}}\right]}{\text{Femur length (cm)}}$$

The weight of the five muscles surrounding the femur within the silverside, topside and the knuckle cuts divided by femur weight were used to calculate Muscle to bone ratio (M:B) (Purchas *et al*., 2002b) using the formula;

$$M{:}B\ = \frac{Five\ muscle\ weight\ (g)}{\text{Femur weight (g)}}$$

The striploin (*Longissimus lumborum*) was collected and vacuum packed from the left side of each carcass during boning for meat quality analysis (Figure 3.1). After boning out, the caudal half of the striploin from each carcass was aged at 1^0C for 21 days and then frozen at -20^0C for seven days and the cranial half of the striploin was frozen at -20^0C for 28 days.

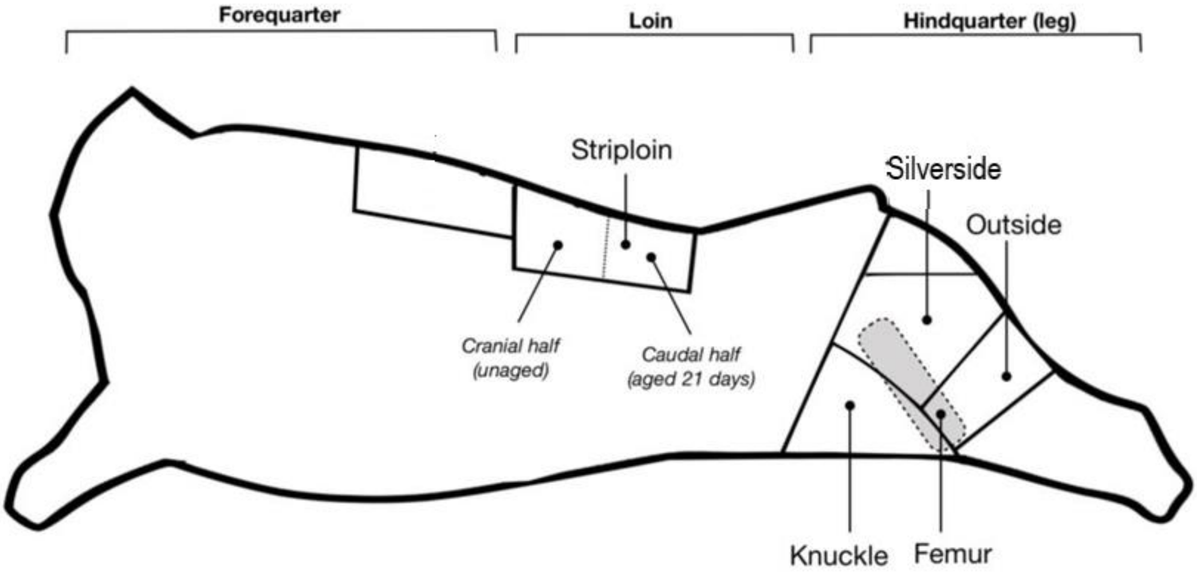
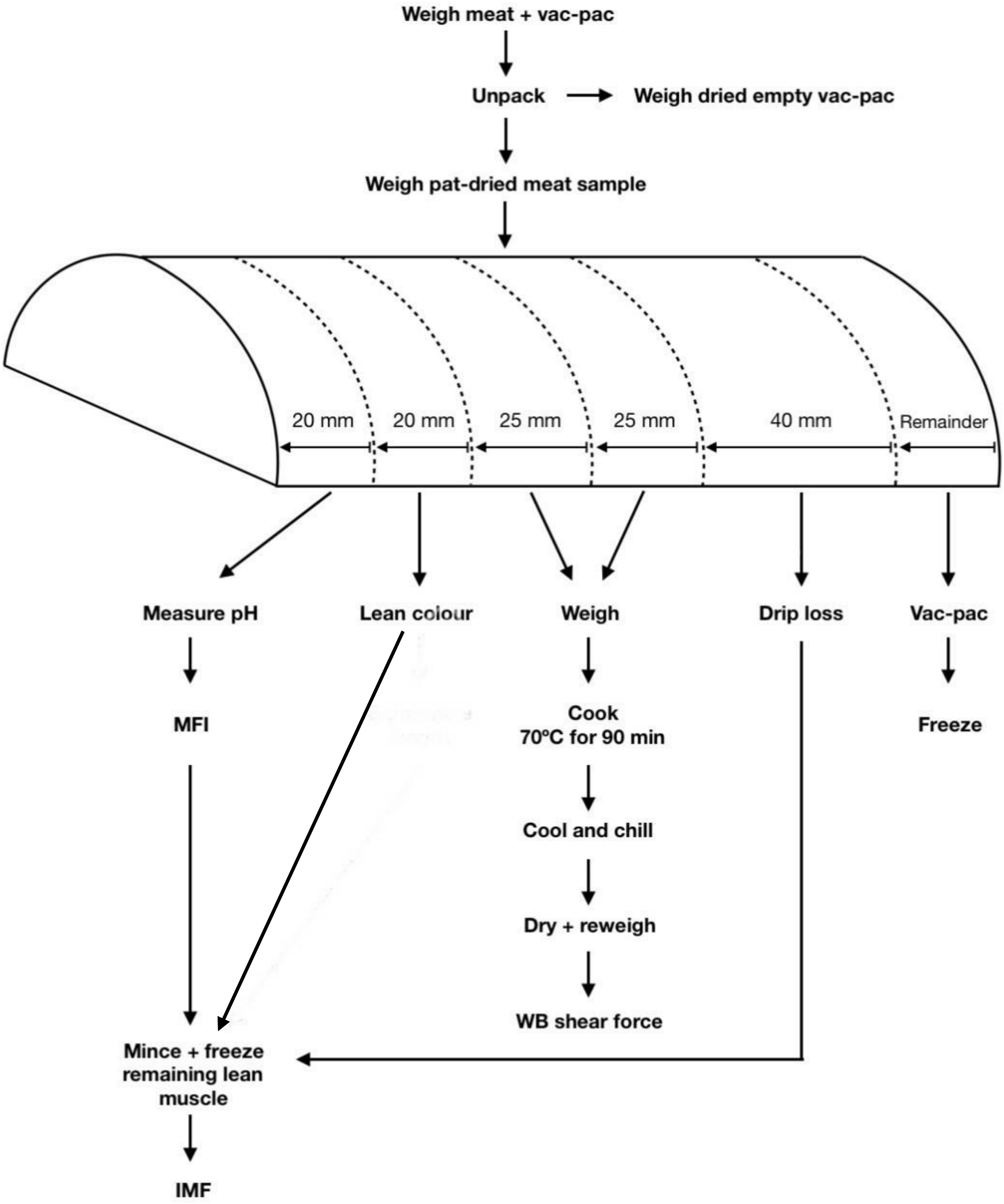


Figure 3. 1 Beef cuts and bone location collected at boning from the left side of the carcass (Adapted from (Pike, 2019))

3.3 Meat Quality

The striploin was cut into five steaks as indicated in Figure 3.2. The first 20 mm steak was used for measurement of pH then MFI. The second 20 mm steak was used to measure meat colour. For the measurement of cooking loss and Warner-Bratzler shear force, the two 25 mm steaks from the centre of the striploin were weighed and placed in the plastic bag for cooking. A steak of 40 mm was created, and the cross-sectional area of the steak was traced. The traced area was then measured using a planimeter (Placom KP-90N, Tokyo, Japan). The 40 mm steak was then trimmed to make a 40 x 40 x 40 mm cube to assess drip loss while the remaining lean muscle from the 20 mm and 40 mm steaks were used for intramuscular fat analysis. The remaining striploin was vacuum packed and frozen but, not used for any analysis (Figure 3.2).

Figure 3. 2 Portioning of the beef striploin (*Longissimus lumborum*) for meat quality analysis (adapted from Pike, (2019)).



MFI: myofibrillar fragmentation index

IMF: Intramuscular fat

3.3.1 Ultimate pH

The ultimate pH was measured on a 20mm steak from the striploin using a pH spear (Eutech Instruments, Singapore). Measurements were taken at three points across the transverse internal cut of the striploin from medial to distal. The three measurements obtained were averaged to obtain the ultimate pH for each striploin sample. The pH spear was calibrated with the standard buffers of pH 4.01, 7.0 and 10.01.

3.3.2 Lean meat colour

The lean meat colour was measured using Minolta Chroma Meter (CR-200; Konica Minolta, Mahwah, NJ, USA) calibrated to a standard white tile supplied by the manufacturer. Measurements were taken on a transverse cut surface of a 20 mm striploin steak that had been exposed to air for 30 minutes. The L* (lightness), a* (redness) and b* (yellowness) values were measured (Illuminant D65, 8 mm diameter aperture, 0° viewing angle) at three points from the medial to the distal across the striploin through a polycarbonate petri dish.

3.3.3 Tenderness

Two 25 mm steaks were cooked in a water bath at 70°C for 90 minutes, cooled to room temperature and then chilled at 1ºC for at least four hours for assessment of Warner-Bratzler shear force (Purchas & Aungsupakorn, 1993). To calculate the cooking loss, the two steaks were weighed before and after cooking. A cork borer was used to make cylindrical cores of 13 mm diameter cut parallel to the direction of the muscle fibre that were used to measure the Warner-Bratzler peak shear force with V-shaped blade (TMS-Pilot, Food Technology Corporation, Virginia, USA). Shears were made perpendicular to the direction of the muscle fibres (Purchas & Aungsupakorn, 1993). Six replicates were measured per sample and averaged to get the peak shear force for each sample.

MFI assessed the proportion of muscle that pass through a filter following a standard homogenisation procedure (Purchas *et al*., 1997). Finely diced lean muscle from striploin approximately 5 g (±0.1 g) was added to 50 mL of physiological saline (0.85% NaCl) with 5 drops of antifoam and then homogenised for two 30-seconds periods (Ultra-Turrax, 18 mm diameter shaft, and one - third speed). The obtained homogenised mixture was rapidly poured through a pre-weighed stainless-steel mesh filters (231 μm) and allowed to drip for three hours after which, the filters were dried for 40 hours at 30ºC and reweighed. MFI values range from 100% when all the fragments pass through the filter to 78% when no fragments pass through the filter (Purchas, Hartley, Xun, & Grant, 1997) and is calculated as:

$$\mathrm{MFI\%} = 100 - \frac{(\text{weight of dried sample retained on filter (g)} \times 100)}{\text{weight of muscle sample (g)}}$$

3.3.4 Water holding capacity

Water loss from freezing then thawing (thaw loss) was measured using the weight of the packing and the thawed meat in vacuum pack before unpacking and the weight of the dried packing and dried meat separately then calculated as:

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

Cooking loss was established by measuring the 25 mm steak before and after cooking. Cooking loss was calculated as:

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

Drip loss was assessed using the 40 mm cube that was weighed and suspended on a metal hook and placed in a plastic bag at 1°C. The cube was then blotted dry and reweighed after 24 and 48 hours. Drip loss was calculated as the original weight minus the weight at 24 and 48 hours and the value expressed as a percentage of the original weight.

3.3.5 Intramuscular Fat

The remaining lean muscle from the 40 mm and the 20 mm steaks after meat quality tests, was trimmed of external connective tissue, finely minced (Kenwood MG450 with 3 mm hole-plate), vacuum packed and frozen for fat content analysis using the ether extraction procedure (AOAC 911.36) at the Massey University Nutrition Laboratory.

3.4 Statistical Analysis

General and mixed models were used to analyse data in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Live weight measurements were analysed using mixed models allowing for repeated measures with treatment group (bull versus steer) and age at measurement included as a fixed effect and animal fitted as a random effect. General linear models were used to analyse the ultrasound, carcass and meat quality attributes and included treatment group as a fixed effect. Models for meat quality analysis included sex treatment and ageing treatment as a fixed effect. For the meat quality measurements, ultimate pH was included as a linear covariate but was removed where it was not significant in the model. For carcass characteristics carcass weight was used as a covariate in the model when it was significant and removed from the model when it was not significant, and the model was rerun.

Chapter 4. Results

4.1 Live Animal Measurements

There was no difference in arrival weight (kg), start weight (kg), and the final weight (kg) (P>0.05; Figure 4.1) for bulls and steers. The average daily gain (kg/day) from arrival to start and start to slaughter did not differ for bulls and steers demonstrating the same growth pattern (P>0.05; Table 4.1; Figure 4.1).

Table 4. 1 (±SEM) Live weight and growth characteristics of Hereford x Friesian-Jersey bulls and steers from 3 months to slaughter age at 11 months.

	Sex		P-value
	Bulls	***Steers***	**(sex)**
Arrival weight (kg)	99±2.3	103±2.2	0.220
Start weight (kg)	128±5.1	134±5.0	0.423
Final weight (kg)	306±7.1	303±6.9	0.773
Average daily gain ADG^1 (kg/day)	1.33±0.01	1.43±0.01	0.505
Average daily gain ADG^2 (kg/day)	0.91±0.02	0.86±0.02	0.124

The arrival weight was taken on the arrival day with calves arriving on different dates
The start weight was taken two weeks after all calves had arrived on the farm.
Final weight was taken on farm 24 hours before slaughter.
ADG^1 was calculated from arrival date to the start of the experiment for bulls and steers (bulls n=17; steers n=16).
ADG^2 was calculated from start date of the experiment to slaughter for bulls and steers (bulls n=17; steers n=16)

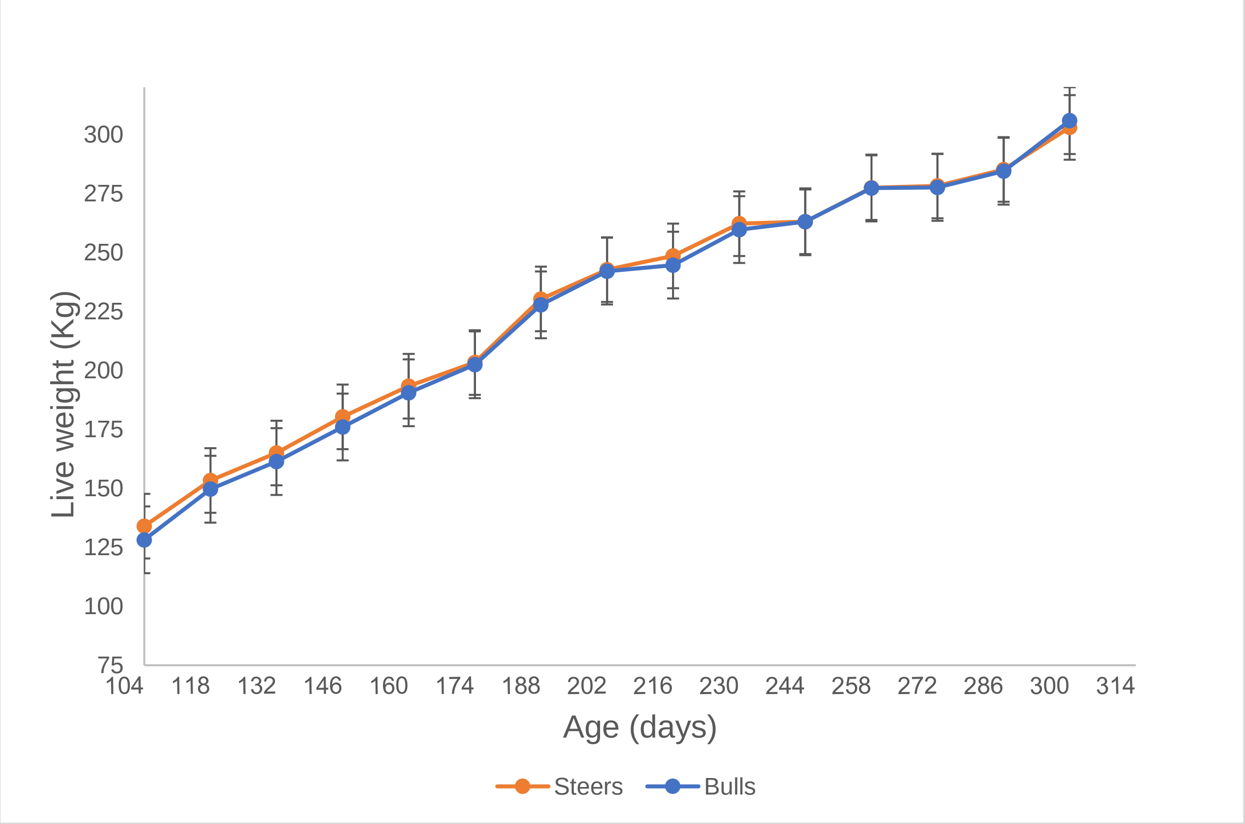


Figure 4. 1 Mean unfasted live weight from approximately three months to 11 months of age for Hereford x Friesian-Jersey (bulls n=17; steers n=16). Points are least squares means, with standard error bars.

4.2 Carcass characteristics

There was no difference in carcass characteristics of bulls and steers (P>0.05; Table 4.2), except that the top side weight was greater for bulls than steers while intramuscular fat was greater for steers than bulls (P<0.05; Table 4.2). Carcass weight was significant as a covariate for knuckle weight, topside and silverside (P<0.05; Table 4.2).

Table 4. 2 Means (± SEM) for carcass characteristics for bulls as steers from Hereford x Friesian-Jersey slaughtered at 11 months.

Carcass characteristics	Sex		P-value		
	Bulls	Steers	Sex	CW covariate	CW coefficient
Hot carcass weight (kg)	146±3.8	144±3.7	0.697		
Dressing-out (%)	47.7±0.4	47.5±0.3	0.638		
Muscling					
Knuckle weight (g)	3009±55.4	2914±53.7	0.231	<.0001	16.3±2.6
Topside weight (g)	4762±56.8	4570±55.1	**0.022**	<.0001	33±2.7
Silverside weight (g)	2806±70.4	2783±68.3	0.820	<.0001	23.9±3.3
Striploin traverse area (cm^2)	48.72±2.7	46.34±2.6	0.535	NS	
Muscularity	0.45	0.44	0.776	NS	
M:B ratio	6.0±0.4	5.8±0.4	0.636	NS	
Femur bone					
Femur length (mm)	338.2±22.5	339.2±21.8	0.975	NS	
Femur weight (g)	1832±135.1	1896±131.1	0.737	NS	
Fat					
Ultrasound Rump fat	2.13±0.10	2.29±0.10	0.248	NS	
Ultrasound Rib fat	1.75±0.11	1.82±0.10	0.619	NS	
Intramuscular fat (%)	0.29±0.05	0.55±0.05	**<.001**	NS	

NS: Indicates effect was not significant and removed from the model
CW: Carcass weight,
Rump fat: P8 fat measurement
Rib fat:12 – 13 rib measurement

4.3 Meat quality attributes

4.3.1 Effect of sex

The ultimate pH was greater in beef from bulls than from steers (P=0.036; Table 4.3). For water holding capacity, cooking loss was greater for bulls than steers (P=0.032; Table 4.3), but there was no difference between bulls and steers for thaw loss (P=0.441; Table 4.3). Drip loss after 24 hours was greater in bulls than steers (P=0.002; Table 4.3) with the same observation made for drip loss after 48 hours (P<0.001; Table 4.3). There was no difference between bulls and steers for all the meat colour attributes, shear force and MFI (P>0.05; Table 4.3).

Table 4. 3 Means (±SEM) for Meat quality attributes of bulls and steers *Longissimus lumborum* (striploin) muscle samples

Meat quality Attributes	**Sex**		**p values**		**pH coefficient**
	Bulls	**Steers**	**Sex**	**pH covariate**	
Ultimate pH	5.68±0.04	5.55±0.04	**0.036**		
Tenderness					
MFI	97.42±0.7	97.07±0.7	0.722	NS	
WB Peak force (kgF)	5.01±0.21	4.64±0.20	0.213	NS	
Water-holding capacity					
Cooking loss (%)	28.29±0.48^{b}	26.80±0.46^{a}	**0.032**	<.0001	-7.43 ±1.34
Thaw loss (%)	1.89±0.18	2.09±0.18	0.441	<.001	-1.90 ±0.51
Drip loss24 (%)	5.24±0.42^{b}	3.33±0.40^{a}	**0.002**	<.001	-4.74 ±1.17
Driploss48 (%)	6.96±0.45^{b}	4.40±0.44^{a}	**<.001**	<.001	-6.18 ±1.26
Meat colour					
L* (Lightness)	34.66±0.33	34.04±0.32	0.191	<.0001	-7.43 ±0.92
a* (Redness)	12.86±0.28	13.12±0.27	0.503	<.0001	-6.08 ±0.77
b* (Yellowness)	6.25±0.20	6.16±0.19	0.731	<.0001	-4.93 ±0.55

^{ab}values within a row for both sex treatments with different superscripts are significantly different (P<0.05)
NS: Indicates effect was not significant and removed from the model
WB: Warner-Bratzler shear force
MFI: myofibrillar fragmentation index

4.3.2 Effect of Post-mortem Ageing with no interaction of sex and ageing

There was no effect of aging on ultimate pH (P=0.239; Table 4.4). There was less cooking loss for the unaged than aged samples (P=0.026; Table 4.4), but there was no difference between aged and unaged for thaw loss and drip loss after 24 or 48 hours (P>0.05; Table 4.4). Aged beef samples had higher lightness, redness, and yellowness values (P<0.01; Table 4.4). The shear force and myofibrillar fragmentation index values did not differ between aged and unaged beef samples (P>0.05; Table 4.4).

Table 4. 4 Means (±SEM) for Meat quality attributes of aging *Longissimus lumborum* (striploin) muscle samples from 11-month-old steers and bulls

Meat quality Attributes	**Aging**		**p values**		**pH coefficient**
	unaged	**aged**	**Aging**	**pH covariate**	
Ultimate pH	5.57±0.04	5.65±0.04	0.239		
Tenderness					
MFI	97.80±0.7	96.7±0.7	0.287	NS	
WB Peak force (kgF)	4.88±0.21	4.76±0.21	0.682	NS	
Water-holding capacity					
Cooking loss (%)	26.80±0.5	28.28±0.5	**0.026**	<.001	-7.11 ±1.30
Thaw loss (%)	2.10±0.18	1.88±0.18	0.377	<.001	-1.93 ±0.50
Drip loss24 (%)	4.60±0.43	3.91±0.43	0.273	.003	-3.57 ±1.22
Drip loss48 (%)	5.91±0.49	5.37±0.49	0.441	<.001	-4.72 ±1.37
Meat colour					
L* (Lightness)	33.67±0.30	35.01±0.30	**0.003**	<.0001	-7.51 ±0.85
a*(Redness)	12.13±0.22^{a}	13.85±0.22^{b}	**<.0001**	<.0001	-6.71 ±0.62
b*(Yellowness)	5.70±0.17^{a}	6.71±0.17^{b}	**<.0001**	<.0001	-5.18 ±0.47

NS: Indicates pH covariate was not significant and removed from the model
WB: Warner-Bratzler shear force.
MFI: myofibrillar fragmentation index

Chapter 5. Discussion

The objective of this study was to compare the growth rates, carcass characteristics and objective meat quality attributes of dairy-origin bulls and steers slaughtered at 11 months in a pasture-based beef production system. The aim was to identify if there is need to castrate bulls in a yearling beef production system for growth, carcass and meat quality and to secondly consider if proteolytic aging will differentially affect quality attributes of meat from 11-month-old bulls compared to steers.

5.1 Growth characteristics

Since the animals arrived on different dates, the arrival weight was measured. However, there was no difference in arrival weight between bulls and steers hence, did not affect the start and the final weights. There was no difference in the growth rates of bulls and steers between 3 to 11 months which was consistent with literature (Kellaway, 1971; Mickan, Thomas, & SPike,r, 1976; Schoonmaker *et al*., 2002; Nogalski *et al*., 2018a). However, other studies have recorded greater growth rates in bulls than steers that are older than 12 months and this is attributed to the bull attaining puberty and testosterone increasing growth rate compared to steers (Bailey *et al*., 1966; Purchas *et al*., 2002). The current study recorded growth rates of 0.91 and 0.86 kg/day for bulls and steers respectively which was greater than studies by (Mickan *et al*., 1976; Purchas & Grant, 1995) that recorded average daily gains of between 0.73-0.80 kg/day for bulls and 0.65-0.72kg/day for steers from approximately 3 months to 20 months. The difference of 0.05kg in daily gains between the bulls and steers is consistent with literature (Schoonmaker *et al*., 2002; Nogalski *et al*., 2018a) that recorded an average difference of 0.04 kg/day.

Bulls tend to record greater daily gains due to higher testosterone levels. However, the observed similarity in the final weight in the current study could indicate that puberty was not yet attained, and testosterone had minimal influence in the growth rates of bulls until slaughter age at 11 months. Mickan *et al*., (1976) observed behavioural changes in bulls from 11 months attributed to the onset of puberty. Contrary, Kellaway (1971) observed changes in growth rates from 7 months with bulls demonstrating slightly higher average daily gain than steers. Although there are variations among studies regarding the age when bulls start showing superiority in daily gains which might indicate that between the studies bulls are attaining puberty at different ages, the current study demonstrates that yearling bulls and steers in the pasture-based beef production system have the same growth patterns and therefore, for growth characteristics there is no need to castrate bulls in this system.

5.2 Carcass characteristics

Bulls and steers slaughtered at 11 months produced the same carcasses with the same weight and similar characteristics. There was a difference in topside weight where bulls produced greater top side weight than steers. However, there was minimal variation in the topside weights within the bull and steer groups which created a statistical difference although the numerical difference in average topside weight was small at only 0.19 kg.

Bulls and steers at 11 months produced similar dressing-out percentage of 47.7% and 47.6% respectively which was lower than in the study by Marti *et al*., (2013) that recorded dressing-out percentage for 12-month-old bulls and steers of 53.9% and 53.2%, respectively. The higher dressing-out percentage for bulls and steers in (Marti *et al*., 2013) is attributed to a concentrate-based diet.

The muscle to bone ratio, striploin transverse area and muscularity indicate similar lean meat yield for bulls (6.0) and steers (5.8) at 11 months. However, 16-month-old bulls had a higher muscle to bone ratio of 5.7 than steers at 4.8 (Shahin, Berg, & Price, 1993). The higher muscle to bone ratio in bulls than steers at 16 months is attributed to high testosterone levels that promotes increased muscle deposition leading to a higher lean meat yield (Lee *et al*., 1990). The similar muscle to bone ratio in the current study indicates bulls and steers at 11 months will yield similar amounts of saleable meat.

Consumers tend to use visual cues for initial evaluation of meat quality with specific interest in muscle colour, fat colour and visible fat: lean content (Fiorentini *et al*., 2012). Fat on the carcass can also contribute to the weight of the carcass and the weight of meat cuts as part of the saleable meat yield. For the carcass classification of steer in New Zealand a minimum of 3mm of rib fat is required to achieve the premium prices associated with a “Prime” classification and up to 10mm of subcutaneous fat is allowed before trimming will occur. Subcutaneous fat above 10 mm is not desired as it reduces the saleable meat yield. Intramuscular fat has a positive association with palatability (Kirton, 1989). Steers had greater intramuscular fat compared to bulls with 0.55% and 0.29% respectively which was consistent with studies (Field *et al*., 1966; Reagan *et al* 1971; Blanco *et al* 2020) that recorded an average intramuscular fat percentage for 10-14-month-old bulls and steers of 1.9% and 2.2%, respectively. However, Bong *et al*., (2012) recorded greater intramuscular fat for 20-28-month-old steers than bulls with 11% and 3% respectively, attributed to lack of testosterone in steers increasing intramuscular adipogenesis, lipolysis and lipogenesis hence, accumulation of lipids in steers. Although there was a statistical difference in the current study, all meat samples had intramuscular fat percentage that was less than 2.2% indicating a marbling score that is practically devoid of intramuscular fat (Lonergan *et al*., 2018). Steers and bulls in the current study had the same subcutaneous rump fat and rib fat content when measured by ultrasound. Purchas. *et al*., (2002) observed higher rib fat content in steers than bulls slaughtered between 16 to 26 months-of-age with rib fat depths of 5.61 and 1.76 respectively compared to the current study with 1.82 and 1.75 respectively. Steers tend to deposit more fat compared to bulls as testosterone production in bulls promotes lean rather than fat growth (Eichhorn*et al*., 1985; Cafferky *et al*., 2019) however, the results from the current study indicate that up to 11 months of age the deposition of fat is not different between bulls and steers. For these young cattle the subcutaneous fat depth was low (below 3mm) and so, utilising current classification systems for older steers is likely to disadvantage the value of the yearling carcass.

5.3 Effect of sex and slaughter age on meat quality attributes

Although bulls had a greater ultimate pH than steers, the average difference was only 0.13 pH and all meat sample had a pH which was within the range for good beef quality (pH between 5.4 and 5.7); (Purchas, 2010). Although there was a statistical difference in pH, the absolute difference was unlikely to have an appreciable difference on the meat quality characteristics (Purchas. *et al*., 2002; Modzelewska-Kapitula *et al*., 2019). Bulls have been attributed as producing meat with higher ultimate pH due to testosterone producing a temperament and pre-slaughter behaviours that increase the risk of depleting muscle glycogen concentration at slaughter (Bureš & Bartoň, 2012; Martin *et al*., 2018; Nogalski *et al*., 2018a; Pogorzelska-Przybyłek*et al*., 2018). Bulls and steers before puberty tend to show the same growth and behavioural characteristics (Kellaway, 1971; Mickan *et al*., 1976), the slightly higher pH value for bulls at 11 months could be an indicator of the onset of puberty for some of the bulls in study which was increasing testosterone levels and potentially eliciting behaviours that influenced some glycogen depletion pre-slaughter (Cross, Schanbacher, & Crouse, 1984).

The objective meat quality measures for tenderness indicate that meat from bulls and steers at 11 months is tender, with no difference observed between the meat samples from each group. Consumers designate shear force values above 10kgF as tough while values below 8 kgF are considered tender (Bickerstaffe *et al*., 2001). The values for both bulls and steers were all below 6kgF indicating that meat from bulls and steers at 11 months have acceptable meat tenderness. Meat from bulls has been associated with lower tenderness sensory scores and greater shear force values (11.68kgF) when compared to meat from steers (8.46kgF) when they are slaughtered at an age older than 14 months (Purchas *et al*., 2002). Similarly, 13-17-month-old steers had meat that was more tender than bulls (Field, Nelms, & Schoonover, 1966). The less tender meat in older bulls is from greater activity of androgenic hormones that have a greater anabolic (muscle building) action in cattle and also preslaughter behaviours that result in meat with a high pH (Mueller *et al*., 2019). The greater fat content that dilutes the muscle fibres and their associated connective tissues has also been implicated as contributing to more tender meat of steers compared to bulls (Field, Nelms, & Schoonover, 1966). Cross *et al*., (1984) reported increased collagen synthesis in bulls than steers close to puberty at around 12 months resulting to increased proportion of immature collagen and less cross-linking leading to an increased proportion of collagen solubilized during cooking which could further be a factor associated with a lack of difference in tenderness between yearling bulls and steers.

Cooking loss and drip loss was greater in bulls than steers, which has been observed in studies comparing meat from 15-22-month-old steers and bulls (Pogorzelska-Przybyłek *et al*., 2018; Nogalski *et al*., 2018b; Cafferky *et al*., 2019). However, a study by Mueller *et al*., (2019) recorded higher cooking loss for beef from 20-month-old steers than bulls. Likewise, Cafferky *et al*., (2019) recorded greater drip loss for steers than bulls that were older than 16 months with 2.73% and 3.41% respectively. Contrary to these findings, Miguel *et al*., (2014) observed no difference in cooking loss for bulls and steers that were 24-28-month-old. Cooking loss mainly occurs through the release of the water bound to protein. The greater levels of intramuscular fat in steers is an indicator of a lower lean protein proportion leading to steers losing less water (Ahnström *et al*.,2012; Ueda *et al*., 2007). This agrees with Pike, (2019) who recorded an increase in intramuscular fat for steers at 12 months compared to steers at 8 and 10 months leading to a decline in cooking loss at 12 months.

There was no difference between the meat samples from bulls and steers for meat colour attributes which was consistent with Moran *et al* 2017; Cafferky *et al*., 2019 and Nogalski *et al*., 2018b) that observed no difference between meat colour of bulls and steers slaughtered between 15 and 21 months.

5.4 Post-mortem Ageing

The ultimate pH was similar for aged and unaged beef however, other studies have found the aging process to alter the pH of meat (Franco *et al*., 2012; Pike, 2019; Modzelewska-Kapitula *et al*., 2019). Pike, (2019) observed a higher pH value for aged than unaged beef but, the difference was numerically small and did not have a noticeable effect on the other meat quality attributes. A study by Franco *et al*., (2012) reported an increase in pH with an increase in aging time attributed to proteolytic enzyme that caused changes in charges of proteins within the meat (Boakye & Mittal, 1993) although, the increase differed between dietary treatments.

There was no difference in the shear force or MFI values between aged and unaged beef samples which was inconsistent with other studies that recorded improved meat tenderness (lower shear force) through ageing (Hanzelková *et al*., 2011; Modzelewska-Kapitula *et al*., 2019; Yim & Hur, 2019). Most previous studies consider beef from cattle that are 24-36 months old at slaughter but in this study, young animals that were slaughtered at 11 months of age were assessed and it is likely that the young age is providing a tender meat product without the need for ageing and that ageing is only of benefit for increasing tenderness of meat from older animals where proteolytic enzymes can work on cross-linked collagen to have an effect on tenderness.

There was no difference for aged and unaged beef samples for thaw loss and drip loss but cook loss was greater for aged than unaged samples. In contrast (Hiner, Madsen, & Hankins, 1946; Pike, 2019) observed a decrease in drip loss with post-mortem ageing. However, the increase in cooking loss as a result of post-mortem ageing was observed in 15-16 months old cattle (Shanks *et al*., 2002) but not observed in the study of Pike, (2019). Ageing alters meat protein structure leading to muscle degradation and shrinkage associated with water expulsion (Kristensen & Purslow, 2001).

Beef colour is vital in consumer acceptability with bright red meat having a higher consumer acceptability than darker meat (Jeremiah *et al*. 1972). The unaged meat samples recorded lower values for meat colour attributes (lightness, redness and yellowness) than the aged meat samples which was in agreement with previous studies (Bruce, Stark, & Beilken, 2004; Lagerstedt, Lundström, & Lindahl, 2011; Vitale *et al*., 2014; Pike, 2019;). Increase in meat lightness after ageing is attributed to proteolysis that changes the 3D molecular structure and increase the extracellular space which then allows light to be reflected and scattered (Hughes *et al*., 2014). The increase in redness and yellowness of beef with ageing is attributed to muscle degradation during ageing leading to a decline in water holding capacity which then leads to an increase in reflectance (Warriss & Brown, 1987; Bruce *et al*., 2004).

5.5 Limitations

The growth, carcasses and the meat quality attributes of bulls and steers in the current study could not be directly compared with dairy-origin bulls and steers at the traditional finishing age of between 18-36 months of age because they were not included as control. Also, the primary aim of the study was to compare bulls and steers at 11 months of age. However, the comparisons to previous studies with the range of slaughter age over twelve months of age were made. Future research should consider comparing dairy-beef bulls and steers from the eleven months slaughter treatment with older animals to fully elucidate the age effect in interaction with sex class.

Only objective meat quality attributes were assessed. However, further investigation into subjective meat quality attributes by a sensory panel could provide further insights into how the meat products of yearling cattle are perceived. A consumer sensory panel would have helped in deeper understanding of the general consumer acceptability and whether the product can obtain premium prices.

5.6 Future research

The higher growth rates of more than 0.8kg/day on pasture-based beef production system is indicative of proper feeding but could also be indicative of positive dairy influence on growth rates although the carcass weights were lighter than the traditional pasture-based beef production system where steers and bulls are slaughtered at 18-36 months. The muscularity indexes for bulls and steers indicates lower meat yields per animal compared to cattle slaughtered at 18-36 months of age, therefore, there is potential to investigate the potential of increasing the stocking rate and whether it could achieve similar meat yields per hectare.

The main challenge the pasture-based yearling beef production system faces is the lack of cattle on-farm when the pasture growth rates are at maximum since the animals are brought in at three months in November and slaughtered before they attain 12 months of age. However, complimentary livestock classes like breeding cattle and sheep, when included in a yearling beef production system may increase feed availability for breeding cattle and sheep during spring when pasture supply is high. To better understand the economic feasibility of the proposed yearling beef production system compared with the traditional beef production system, it is important to undertake a modelling exercise. It will include identifying the break-even point (cents/kg) for profitability given the feed and the non-feed costs for the 11month slaughter age of bulls and steers. The scope can also extend to investigate whether finishing yearling bulls and steers could allow for an increased stocking rate compared to the traditional beef production system that slaughter animals between 18-36 months. Young animals tend to have less feed demand per head which may enable the stock to graze more intensively leading to attainment of similar carcass yields on per hectare basis when compared to the traditional system where animals are slaughtered when they are between 18-36 months (Hunt *et al*., 2019).

The meat quality result has highlighted how this product differ from the traditional slaughter age of over 18 months and veal meat making it necessary to develop and identify markets for the new product. To maximize returns, the products should target high-end retail such as upscale supermarkets and restaurants. It is, therefore, important to conduct market research to determine the demand for the new product and understand how to attain the greatest premium.

New Zealand beef classification does not have a classification system for light beef carcasses from young animals and it considers these carcasses as “lightweight” with poor attributes for saleable meat yield. The light beef carcasses are classified as manufacturing beef implying lower returns on a cents/kg basis with carcasses having lower fat deposition and graded under fat classes “L” (light, patchy fat cover) or ‘A’ (devoid of fat) that receive lower schedule prices (Pike, 2019). The combination results in very low returns for the producers and would not be a sustainable production class (Hunt *et al*., 2019). It is, therefore, important to have a separate classification system that reflects the market demand for the yearling beef products using data from this study.

5.7 Conclusions and Implications

There are very few and only small differences between bulls and steers in terms of growth rates, carcass characteristics and meat quality attributes. Meat obtained from bulls and steers at 11 months is very tender, associated with red meat colour and likely to be of high eating quality and therefore, it can target premium markets. Beef obtained from bulls and steers slaughtered at 11 months can be classed and processed together under one category or classification. This will offer farmers flexibility on whether to castrate or, not to castrate, bulls. In principle, if a farmer is rearing calves for yearling beef production system, there is no need to castrate the bull calves offering potential benefits for animal welfare in terms of the concerns that have been implicated with the process of castration.

Ageing affected cooking loss and the meat colour attributes. However, the values were numerically small and unlikely to be noticeable by consumers in terms of visual appearance. The results indicate that it is not necessary to age the meat from bulls and steers slaughtered at 11 months to achieve a desirable level of tenderness and ensure high ratings of eating quality. This may save cost for processors and allow the product to reach the market quicker.

The objective meat quality attributes for bulls and steers slaughtered at 11 months indicated good meat and eating quality. The meat tenderness, water holing capacity, pH and meat colour is indicative that this system is worthy of further exploration as an alternative use for surplus dairy calves.

Chapter 6. References

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