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# Carcass Characteristics, Meat Quality, and Fat Deposition of Beef Steers Finished on Alternative Summer Forages

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

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# Abstract

The use of forages alternative to perennial ryegrass-based swards offers a potential mechanism by which farmers can maximise animal performance and beef quality. Forage crops are able to provide high quality feed to livestock at critical times of the year when pasture supply and quality is low. This allows animals to maintain high growth rates and achieve target carcass traits in a timely manner. Forage crops also offer a potential method to manipulate beef tissue characteristics, fatty acid profile, and eating quality to produce beef of higher quality or with more favourable characteristics, that consumers are willing to pay a premium for.

This thesis presents a collection of studies that compared the carcass traits, beef quality, fatty acid profile, and sensory properties of beef steers finished on chicory, raphanobrassica, and a traditional ryegrass-based pasture. The findings of three studies (completed in 2020, 2021, and 2022) were analysed separately and as a combined dataset. In each study, a group of steers were finished on each forage treatment (chicory, raphanobrassica, or pasture), then slaughtered and processed. Carcass traits were measured, and a striploin sample was collected for assessment of meat quality and fatty acid profile. A consumer panel was used to assess sensory properties (overall liking, tenderness, juiciness, and flavour intensity). Simple linear regressions and stepwise models were used to assess relationships between variables.

Overall, the beef produced from the steers across the three studies had good meat and eating quality. In the combined dataset, forage treatment had no effect on carcass traits, meat quality, or fatty acid profile of beef steers. Within each study, forage treatment had significant effects on various carcass traits, meat quality attributes, and fatty acid concentrations and ratios, although these effects were not consistently observed across studies. Sensory analysis indicated that consumers preferred beef from steers finished on chicory, compared to that of steers finished on raphanobrassica or pasture. Moderate relationships were found between intramuscular fat (IMF) concentration and carcass weight, and IMF and marbling score. Strong relationships were found between concentrations of fatty acids (saturated, monounsaturated, and polyunsaturated) and IMF.

These findings demonstrated that chicory and raphanobrassica could be used as summer finishing forages to produce beef of similarly high quality to that of steers grazed on standard pastures.

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# Chapter 1

## Introduction

# Chapter One: Introduction

The New Zealand beef industry makes a significant contribution to the New Zealand economy, generating $4.8 billion in export revenues in 2025, which is set to increase to $5.6 billion by 2027 (Ministry of Primary Industries, 2025b). New Zealand beef production is reliant on a seasonal pasture-based system, which allows it produce high quality beef in an affordable manner (Morris & Martín, 2023; Smeaton, 2003). Despite competing land use (Moot & Davison, 2021), New Zealand beef production systems have the potential to produce more beef more efficiently, while improving meat quality, allowing the industry to increase in value (Morris, 2013a).

As with most livestock production in New Zealand, beef production is primarily pasture based (Morris & Martín, 2023; Smeaton, 2003). Seasonal variations in weather conditions lead to a seasonal pattern of pasture production. As a result, there are periods of the year when pasture supply does not meet cattle demands, and supplementary feed must be provided to ensure that maintenance and growth requirements are met (Morris, 2022; Smeaton, 2003). Forage crops, such as herbs, legumes, and brassicas can be used to provide high quality feed that can be grazed during predicted periods of pasture deficit (Morris, 2022; Valentine & Kemp, 2022). They are becoming an increasingly popular option for wintering beef cattle (Morris, 2022; Morris & Kenyon, 2014b), and for use over summer and autumn, to support growing and finishing cattle (Smeaton, 2003).

Increasing consumer interest in the quality and health benefits of their food offers a potential method by which New Zealand beef producers and processors can increase the value of their product, to maintain or increase market share (Fowler et al., 2019; Morris, 2013b). Beef quality is difficult to manipulate, as it is affected by a wide range of factors pre- and post-mortem (Purchas, 1989, 2007). It has been well documented that beef cattle nutrition can be manipulated to modify beef composition, fatty acid profile, and overall quality (Muir et al., 1998; Ponnampalam et al., 2024). The use of alternative forages, each with a unique nutrient profile, offers a potential way to improve meat quality and health properties of beef, and may prove to be an effective method by which beef producers and processors can maximise the quality and value of their product.

This thesis will investigate the effects of two summer forage crops: chicory (*Chicorium intybus*) and raphanobrassica (*Raphanus sativus* L. x *Brassica oleracea* L.), on the carcass traits, meat quality attributes, fatty acid profile, and sensory characteristics of beef steers finished on them, compared to steers finished on a standard ryegrass based pasture.

# Chapter 2

## Literature Review

# Chapter Two: Literature Review

## 2.1 New Zealand Beef Industry

### 2.1.1 Industry Overview

As of June 2025, there were 3,833,000 beef cattle in New Zealand (Statistics New Zealand, 2026). Approximately 70% of the New Zealand beef herd is located in the North Island (Beef and Lamb NZ, 2023; Morris & Martín, 2023). The New Zealand dairy industry also makes a significant contribution to the beef industry, directly through the supply of bobby calves and cull cows (van Selm et al., 2021) and indirectly through the supply of bull calves and progeny from dairy beef crosses, which are raised and finished in beef systems (Beef and Lamb NZ, 2023; Charteris et al., 1998; Martín, 2021; Morris & Kenyon, 2014b; Pike, 2019).

Over the 2024/25 season, a total of 4,225,371 cattle were slaughtered (Ministry of Primary Industries, 2025a). Of this, 561,812 were heifers, 622,490 were steers, 893,603 were cows, 431,203 were bulls, 1,716,082 were bobby calves (4-14 days old), and 181 were vealers (Ministry of Primary Industries, 2025a), as seen in Figure 2.1. This produced a total carcass weight of 685,826,931kg, with an average carcass weight of 162.31kg (Ministry of Primary Industries, 2025a).

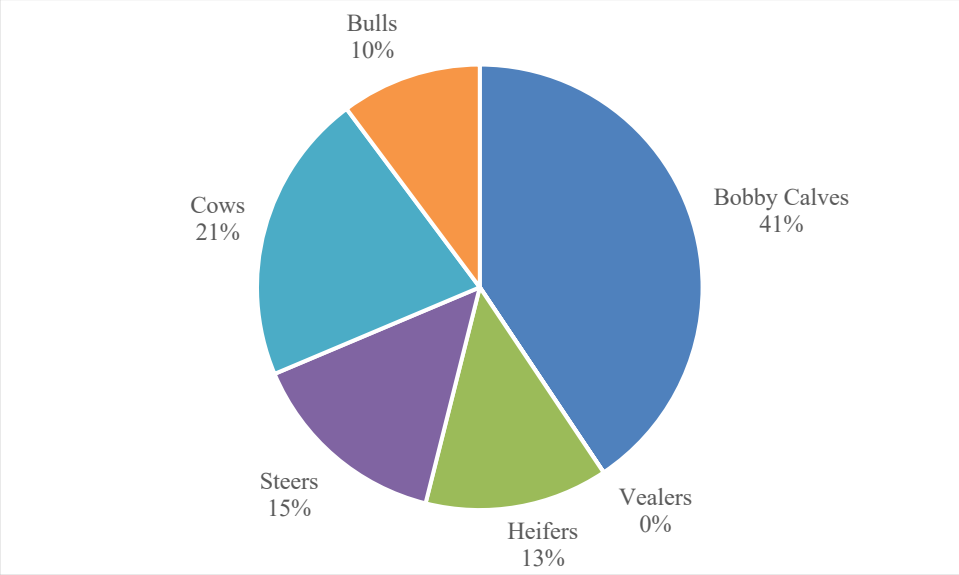


**Figure 2.1: Breakdown of New Zealand cattle slaughtered in year ending September 2025 (Ministry of Primary Industries, 2025a).**

### 2.1.2 Markets

Over the 2024/2025 season, approximately 90% of beef produced in New Zealand was exported (Meat Industry Association, 2025a). Beef export destinations are broken down in Table 2.1, in terms of value and volume. Over the 2023/24 season, the United States accounted for 39% of export volume and 43% of export value, and China for 25% of export volume though only 17% of export value (Meat Industry Association, 2025b). This

highlights the difference in values of beef cuts. Typically, beef is either marketed as high quality prime or table cuts, or as lower quality processing or ingredient beef (Charteris et al., 1998; Hodgson et al., 2019; Morris, 2013a). The United States represents a high value market, as their proportion of export volume is lower than their proportion of export value. Alternatively, China represents a commodity market with lower value cuts, as their proportion of export volume is greater than their proportion of export value.

**Table 2.1: Destination, volume, and value of New Zealand beef exports in 2025 (Meat Industry Association, 2025b).**

| Country | Export volume | | Export value | |
|---|---|---|---|---|
| | Tonnes | % | NZ$ million | % |
| United States | 173,056 | 39 | 2,146.9 | 43 |
| China | 112,246 | 25 | 876.3 | 17 |
| Canada | 36,590 | 8 | 422.1 | 8 |
| Japan | 25,968 | 6 | 317.4 | 6 |
| United Kingdom | 21,116 | 5 | 277.7 | 6 |
| Korea | 16,670 | 4 | 154.1 | 3 |
| Taiwan | 13,591 | 3 | 179.8 | 4 |
| Philippines | 9,401 | 2 | 65.2 | 1 |
| European Union | 5,965 | 1 | 150.8 | 3 |
| Other | 33,005 | 7 | 426.1 | 9 |
| Total | 447,608 | 100 | 5016.4 | 100 |

## 2.2 New Zealand Beef Cattle Production

### 2.2.1 Management Systems

Beef cattle in New Zealand are typically born to beef breeding cows, typically on hill or high country in extensive pastoral systems (Beef and Lamb NZ, 2023; Morris, 2013a, 2013b; Morris, 2022; Morris & Martín, 2023). These systems are often run alongside a sheep/lamb rearing operation, as beef and sheep production often complement each other in terms of pasture management and animal health issues (Morris, 2013b; 2022), allowing for them to be economically farmed within the same enterprise. Beef cattle that are destined for slaughter are often finished on more intensive lowland farms, using high quality pastures and forages to support faster growth rates and greater levels of fat deposition (Hodgson et al., 2019; Morris, 2013a). This allows cattle to reach sufficient liveweights and fat levels to receive a favourable carcass classification, maximising the financial return of the farmer. Meat from steers and heifers finished in intensive fattening/finishing systems typically enters the higher value and quality prime beef supply chain, rather than the lower value and quality processing (or manufacturing) supply chain (Hodgson et al., 2019; Morris, 2013a).

### 2.2.2 Dairy Beef

The dairy industry contributes directly to beef production through the supply of cull dairy cows and bobby calves, and indirectly through the bull finishing system, in which excess dairy origin bull calves are reared and finished for beef production (Geenty & Morris,

2017; Gleeson, 2003; Hodgson et al., 2019; Morris, 2013a; Morris & Kenyon, 2014b). These calves are typically Friesian bulls, or calves from dairy beef crosses, in which a dairy dam is bred with a beef sire (such as Friesian Hereford crosses- 'white faces'), producing progeny that perform better in beef finishing systems.

### 2.2.3 Cattle Classes

Finishing systems rear and finish steers and heifers destined for beef production. Morris and Martín (2023) estimate that 50% of steers are slaughtered at 18-24 months of age, with the rest carried through a second winter to be at slaughtered 27-34 months of age. Heifers are typically slaughtered at 18-24 months of age (Morris & Martín, 2023). In the 2024/25 season the average carcass weight of steers and heifers were 317.09kg and 252.27kg respectively (Ministry of Primary Industries, 2025a).

### 2.2.4 Breeds

New Zealand's national beef herd is comprised of a range of breeds, though the Angus is 'numerically' the most important (Morris & Martín, 2023). The national beef herd make up is as follows: 33% Angus, 10% Hereford, 11% Hereford x Angus, 21% mixed (Angus and Hereford crosses to other breeds), 18% Holstein Friesian, and 7% other (Beef and Lamb NZ, 2023; Morris & Martín, 2023) (Figure 2.2).

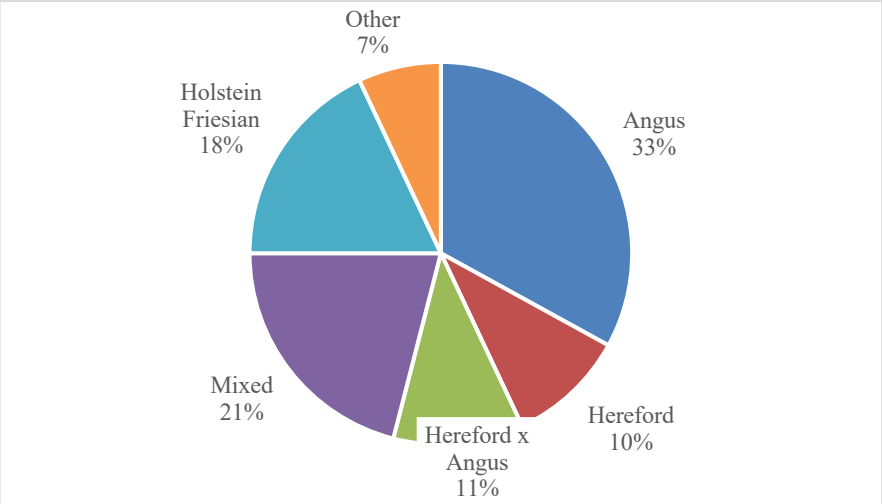


**Figure 2.2: Breakdown of breeds within the New Zealand beef herd (Morris & Martín, 2023).**

### 2.2.5 Feeding Systems

As with most livestock production in New Zealand, beef production is reliant on pasture production (Morris & Martín, 2023), which makes up over 95% of the diet for beef cattle, sheep, and deer (Hodgson et al., 2019). New Zealand pastures typically consist of a perennial ryegrass (*Lolium perenne)* and white clover (*Trifolium repens*) (Kemp et al., 2010; Morris & Kenyon, 2014a). As a result of the seasonal nature of pasture production, pasture deficits reliably occur in winter and pasture surpluses in spring. Consequently, beef production in New Zealand also follows a seasonal pattern (Garmyn et al., 2018; Hodgson et al., 2019; Johnson, 1989; Morris, 2013a; Morris & Martín, 2023), with 85-90% of slaughter occurring between November and June (Morris, 2013a), and production

peaking from January to May (Garmyn et al., 2018; Hodgson et al., 2019). Pasture quality can vary considerably and is influenced by many factors such as management practises, species present, sward renewal programmes, fertilizer use, climatic conditions, and soil type (Wróbel et al., 2023).

Supplementary feed is used on farm to fill pasture deficits and meet cattle energy demands (Morris, 2022). Conserved pasture (hay or silage), made on farm or brought in, is the most used supplement on beef farms in New Zealand (Morris, 2022). Beef producers are also increasingly using forage crops, such as chicory (*Chicorium intybus*), lucerne (*Medicago sativa)*, brassicas (*Brassicaseae*), and fodder beet (*Beta vulgaris*), to fill predicted periods of pasture deficit (Morris, 2022; Morris & Kenyon, 2014b; Smeaton, 2003).

## 2.3 New Zealand Carcass Classification

### 2.3.1 Purpose/objectives of Carcass Classification

Carcass classification occurs after slaughter and identifies carcasses with similar retail and processing traits (Schreurs, 2012). The payment schedule is largely based on carcass classification, with the price received by farmers varying based on carcass weight, fat depth, and carcass shape (muscling) (Schreurs, 2012). As a result, meat processors and marketers use the price schedule to signal to farmers what carcass traits, composition, and conformation are most in demand, which varies in response to seasonal supply and demand, exchange rates, tariffs, and climatic events (Schreurs, 2012). Kirton (1989) also describes carcass classification as the 'common language' processers, producers, wholesalers, and retailers use to facilitate carcass trading. The true value of a beef carcass is determined by the quantity of lean saleable beef, the beefs quality, and the value of co-products obtained from the carcass (Purchas, 2003). This is reflected in carcass classification systems, in which farmers are rewarded for carcasses with greater lean meat yields and favourable fat levels, which are associated with minimal changes in processing costs (Schreurs, 2012). Alternatively, farmers are penalized for lower yielding carcasses with leaner or overly fat meat, destined for use as manufacturing beef, and for damaged or bruised carcasses (Bown et al., 2016).

### 2.3.2 Carcass Classification Criteria

Currently, New Zealand beef carcasses are classified by age, sex, fat content, and muscling (Martín, 2021). The New Zealand Meat Classification Authority (2004) defines steers as castrated males and heifers as females with no more than six permanent incisors. Steers and heifers are placed into the same class, as carcass composition differences are minimal when they are slaughtered at similar carcass weights (Kirton, 1989).

#### 2.3.2.1 Fat Depth and Carcass Weight

All beef cattle are placed into fat classes, based on their subcutaneous fat depth over the eye muscle at the 12th rib and the carcasses fat content as a whole (New Zealand Meat Classification Authority, 2004). Farmers are penalized for excessive fat depths by a

reduction in price per kg of carcass weight, as it decreases the saleable meat yield as a proportion of the carcass weight (Kirton, 1989; Purchas, 2003), though a certain level of fat is desirable in retail cuts. Steer and heifer fat classes are as follows: no ('nil') fat is assigned an 'A' grade, under 3mm of fat is assigned a 'L' grade, 3-10mm of fat is assigned a 'P' grade, 11-16mm of fat is assigned a 'T' grade, and 17mm of fat or more is assigned a 'F' grade, as demonstrated in Figure 2.3 (New Zealand Meat Classification Authority, 2004).

| Steer and Heifer | | | |
|---|---|---|---|
| Fat Cover Description | Fat Class | Fat Depth | Weight Ranges |
| Deviod | A | Nil | 145-159.5kg |
| | | | 160-195kg |
| | | | 195.5-220kg |
| Light, patchy | L | Under 3mm | 220.5-245kg |
| | | | 245.5-270kg |
| | | | 270.5-295kg |
| | | | Over 295kg |
| Light to medium | P | 3-10mm | 145-159.5kg |
| | | | 160-195kg |
| | | | 195.5-220kg |
| | | | 220.5-245kg |
| | | | 245.5-270kg |
| Heavy | T | 11-16mm | 270.5-295kg |
| | | | 295.5-320kg |
| | | | 320.5-345kg |
| | | | Over 345kg |
| Excessive | F | 17mm and over | 145-159.5kg |
| | | | 160-270kg |
| | | | 270.5-295kg |
| | | | Over 295kg |
| Number of muscling classes: 3 | | | |

**Figure 2.3: Fat depths and weight ranges for steers and heifers (New Zealand Meat Classification Authority, 2004).**

Steers and heifers in the 'P' grade receive the greatest return ($/kg), as they fall within the desirable fat range, while carcasses over or under this are penalized for having too much or too little fat (Pike, 2019). Within each fat grade farmers are rewarded for heavier carcasses, as they are paid per kg of carcass weight, making carcass weight the most important attribute for payment purposes (Martín, 2021). Steers and heifer carcasses can also be penalized for having excessively yellow fat, and may be downgraded to manufacturing beef (Kirton, 1989).

### 2.3.2.2 Muscularity

Beef Cattle are also classified into a muscularity class, based on muscling over the hindquarter (New Zealand Meat Classification Authority, 2004). Muscularity can be used as an indicator for the muscle to bone ratio and saleable meat yield, with greater muscularity indicating a greater saleable meat yield (Kirton & Morris, 1989; Pike, 2019; Purchas, 2003). Carcasses are assigned a muscling score of 1-3, with highly muscled carcasses assigned a '1', and poorly muscled carcasses a '3' (New Zealand Meat Classification Authority, 2004). As muscling score serves as an indicator for saleable

meat yield, farmers are rewarded, through greater schedule prices per kg of carcass weight, for highly muscled carcasses (1), and penalized, through lower schedule prices per kg of carcass weight, for poorly muscled carcasses (3) (Martín, 2021; Pike, 2019).

### 2.3.3 Specialized Markets and Carcass Classification Schemes

Other carcass characteristics schemes are used overseas, or by specific processors, and consider different sets of criteria. A New Zealand meat processing company, Silver Fern Farms, has an additional classification system- the Silver Fern Farms Eating Quality System®. This rates beef on six scientific criteria that influence the quality of meat (Silver Fern Farms, 2025). These criteria are ultimate pH, marbling, ossification, rib fat/total rib fat, meat colour, and fat colour (Silver Fern Farms, 2025). These attributes are assessed by accredited master graders and are used as a guarantee to consumers that they are purchasing high quality beef.

## 2.4 Beef Production on Alternative Forages

Alternative forage crops are an effective tool farmers can use to provide high quality feed to livestock at certain times of the year, when pasture supply and quality are typically low. The provision of high-quality forage crops can improve cattle growth performance, allowing farmers to meet liveweight targets sooner or achieve heavier liveweights at a set slaughter date, which can also influence carcass composition and characteristics. The effect of alternative forage crops on beef production are not always consistent and vary considerably as a result of a range of other factors.

### 2.4.1 Growth Rates

In the literature, growth rates of beef cattle varied considerably with forage type, ranging from 0.34-1.18kg/d, 0.45-1.16kg/d, 0.75-1.21kg/d, 0.80-1.28kg/d, 0.29-0.98kg/d, 0.72-1.27kg/d, and 0.45kg/d for cattle grazed on pastures, chicory, herb mixes, lucerne, kale, brassica mixes, and fodder beet, respectively (Table 2.2). This demonstrates the large range of factors that also significantly affect growth rates, and may have varied considerably between trials, such as age, cattle class, breed, and mature size (Kirton & Morris, 1989).

Table 2.2 shows that high quality herbs and legumes, such as chicory and lucerne, can be used to support high growth rates in cattle. Chicory was able to support relatively high growth rates in beef cattle, with the greatest rates of 1.13-1.16 kg/d reported by American studies (Parish et al., 2012; Schmidt et al., 2013), though cattle grazed on lucerne performed even better, with growth rates of 1.22kg/d or more (de Clifford et al., 2014; Schmidt et al., 2013). Similarly high growth rates have been reported for beef cattle grazed on herb mixes/legumes (Pettigrew et al., 2017). Beef cattle growth response to brassica varieties is similarly varied, with cattle grazed on kale (*Brassica oleracea*) producing growth rates as low as 0.29kg/d (Barry et al., 1981) and as high as 0.98kg/d (Rugoho et al., 2014), with brassica mixes supporting growth rates as high as 1.27kg/d (Bakker et al., 2021b).

**Table 2.2: Summary of the effects of alternative forages on cattle growth rates.**

| Source | Country | Breed | Trial Duration | Average Daily Gain (kg/day) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pasture | Chicory | Herb mix | Lucerne | Kale | Brassica mix | Fodder beet |
| Clark et al. (1990) | New Zealand | Friesian bull calves | 1 month | 0.62[1] | 0.62 | | | | | |
| Clark et al. (1990) | New Zealand | Friesian bulls | 1 month | 1.10[1] | 0.45 | | | | | |
| Fraser et al. (1988) | New Zealand | Friesian bull calves | 20 days | | 0.88 | | | | | |
| Marley et al. (2014) | United Kingdom | Belgian bull x dairy steers | 1 grazing season | 1.10[2] | | 1.04[3] | | | | |
| Parish et al. (2012) | United States | British-Continental steers | 56 days | 1.18[4] | 1.16 | | | | | |
| Schmidt et al. (2013) | United States | Angus steers | 2 years | 0.76[5] | 1.13 | | 1.28 | | | |
| Handcock et al. (2015) | New Zealand | Friesian x Jersey dairy heifers | 63 days | 0.53[1] | | 0.75[6] | 0.80 | | | |
| de Clifford et al. (2014) | New Zealand | Friesian x Jersey dairy heifers | 42 days | 0.57 | | 0.78[7] | 1.22 | | | |
| Pettigrew et al. (2017) | New Zealand | Friesian bull calves | Over summer | 1.06[8] | | 1.21[9] | | | | |
| Duckett et al. (2013) | United States | Angus steers | 3 years | 1.11 | | | 1.15 | | | |
| Barry et al. (1981) | New Zealand | Friesian x Angus steers | 24 weeks | 0.34 | | | | 0.29 | | |
| Rugoho et al. (2014) | New Zealand | Friesian x Jersey | 47 days | 1.00[10] | | | | 0.98 | | |
| Bakker et al. (2021b) | United States | Angus based steers | 44 days | | | | | | 1.27[11] | |
| Cox-O'Neill et al. (2017) | United States | Composite steers | 65 days | | | | | | 0.72[12] | |

***Table 2.2 continues onto page 14***

*Table 2.2 continued from page 13*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Maciel et al. (2022) | United States | Angus steers | 70 days | 1.16[13] | | | | | 0.85[14] | |
| Maciel et al. (2022) | United States | Angus steers | 70 days | 1.16[13] | | | | | 1.06[15] | |
| Harris et al. (2021) | New Zealand | Friesian x Jersey dairy heifers | 112 days | | | | | 0.46 | | 0.45 |
| Range | | | | 0.34-1.18 | 0.45-1.16 | 0.75-1.21 | 0.80-1.28 | 0.29-0.98 | 0.72-1.27 | 0.45 |

[1] Perennial ryegrass and clover; [2] Perennial ryegrass;[3] Chicory and perennial ryegrass mix; [4] Annual ryegrass; [5] Bermuda grass; [6] 70% chicory, 20% plantain, 10% white clover; [7] Chicory, plantain, red, and white clover, supplemented with pasture silage/bailage; [8] Italian ryegrass and white clover; [9] Chicory, plantain, red, and white clover; [10] Italian ryegrass; [11] Turnips, forage rape, radish, and annual ryegrass; [12] Oats, radish, and turnips; [13] Perennial mix; [14] Mix of forage rape and greenfeed oat; [15] Mix of two forage rapes, greenfeed oat, annual ryegrass, and field pea.

### 2.4.2 Carcass Traits

There is notably less literature available that outlines the effects of forage herbs and brassicas on carcass characteristics in cattle. The available literature is summarized in Table 2.3. As with growth rates, carcass characteristics are also significantly influenced by a range of other factors (Kirton & Morris, 1989) and were found to vary considerably between trials.

Most studies presented in Table 2.3 reported very minor differences in carcass characteristics between cattle grazed on alternative forages. Both Marley et al. (2014) and Bakker et al. (2021b) reached similar conclusions, finding that beef carcass characteristics did not significantly differ between cattle finished on pasture, chicory or brassica fed cattle. Overall, the limited studies available show that alternative forages have an inconsistent or little effect on carcass characteristics, producing carcasses that meet similar market standards to those produced on pasture.

**Table 2.3: Summary of the effects of alternative forages on carcass characteristics in cattle.**

| Source | Forage Variety | Country | Breed | Trial Duration | Carcass Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Carcass weight (kg) | Dressing out (%) | Fat thickness (mm) | Ribeye area ($cm^2$) | Marbling score* |
| Schmidt et al. (2013) | Chicory | United States | Angus steers | 2 years | 307.1 | 60.41 | 7.6 | 73.5 | 433 |
| Marley et al. (2014) | Herb mix[1] | United Kingdom | Belgian blue x dairy steers | 2 grazing seasons | 353.7 | 56 | | | |
| Duckett et al. (2013) | Lucerne | United States | Angus steers | 3 years | 480 | 54.8 | 5.4 | 64.6 | 410 |
| Schmidt et al. (2013) | Lucerne | United States | Angus steers | 2 years | 322.9 | 60.86 | 7.7 | 78.2 | 450 |
| Schmidt et al. (2013) | Pasture[2] | United States | Angus steers | 2 years | 326.8 | 57.60 | 5.6 | 79.1 | 455 |
| Duckett et al. (2013) | Pasture[3] | United States | Angus steers | 3 years | 479 | 53.4 | 5.4 | 63.5 | 402 |
| Langlie (2020) | Pasture[4] | United States | Angus & Angus x Simmental steers | 55 days | 354 | | 11.8 | 82.6 | 617 |
| Maciel et al. (2022) | Pasture[5] | United States | Angus steers | 70 days | 276.3 | 56.8 | 6.6 | 68.8 | 436 |
| Garmyn et al. (2018) | Pasture | New Zealand | Beef steers | 92 days | 280.7 | | 5.0 | 71.6 | 404 |
| Langlie (2020) | Brassica mix[6] | United States | Angus & Angus x | 55 days | 344 | | 12.2 | 78.5 | 601 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Simmental steers | | | | | | |
| Bakker et al. (2021b) | Brassica mix[7] | United States | Angus based steers | 44 days | 385 | | 9.3 | 88.1 | 469 |
| Maciel et al. (2022) | Brassica mix[8] | United States | Angus based steers | 70 days | 276.3 | 53.3 | 6.6 | 67.7 | 434 |
| Maciel et al. (2022) | Brassica mix[9] | United States | Angus based steers | 70 days | 286.3 | 55.7 | 6.4 | 71.1 | 448 |
| Garmyn et al. (2018) | Fodder beet | New Zealand | Beef steers | 92 days | 278.4 | | 5.7 | 69.5 | 415 |
| Range | | | | | 275-480 | 53-61 | 3.9-12.2 | 63-88 | 299-617 |

* USDA numeric marbling score; 300: slight, 400: small, 500: modest, 600: moderate.

[1] Chicory and perennial ryegrass mix; [2] Bermuda grass; [3] Bluegrass, orchard grass, tall fescue, and white clover; [4] Perennial pasture mix, consisting of quack grass, orchard grass, smooth bromegrass, red clover, and lucerne; [5] Perennial mix; [6] Oats, bulb turnips, leafy turnip, and radish; [7] Turnips, rapeseed, radish, and ryegrass; [8] Mix of forage rape and greenfeed oat; [9] Mix of two forage rapes, greenfeed oat, annual ryegrass, and field pea.

### 2.4.3 Mechanism

Although growth rates of cattle on alternative forages vary considerably, in certain favourable conditions alternative forages have the potential to match and surpass the growth rates achieved by cattle on pastures. Ultimately, an animal's performance on a certain forage is driven by the forages feeding value, which is determined by its nutrient value and voluntary feed intake (Waghorn et al., 2022). Forages with high nutritive value that promote high intake levels support greater levels of animal production, by increasing the rate of protein and muscle deposition, leading to greater growth rates. Additionally, forage type and the rate of growth also influence the relative proportions of muscle, bone, and fat, and the specific depots in which fat is deposited (i.e. carcass composition).

Although the nutritional composition and value of each forage varies considerably, averages taken from Dairy NZ (Table 2.4) show the average nutritive value of chicory and forage brassicas relative to that of pasture. Chicory proves to be of greater nutritive value than pasture (both high and low quality), with greater energy content, adequate protein content, and lower fibre levels. The range of brassicas prove to be of greater nutritive value than low quality pasture, with greater energy, similar protein levels, and lower fibre levels, though little difference is observed when brassicas are compared to high quality pasture.

**Table 2.4: Average nutritional composition of pasture and forage crops (Dairy NZ, 2021).**

| Feedstuff | Dry matter (%) | Metabolisable energy (MJ/Kg) | Crude protein (% DM) | Non-detergent fibre (% DM) | Soluble sugars and starch (% DM) | Fat (% DM) |
|---|---|---|---|---|---|---|
| High quality pasture | 12-18 | 11.5-12.5 | 18-35 | 35-45 | 7-25 | 3-6 |
| Low quality pasture | 20-30 | 9.0-10.0 | 10-15 | 50-65 | 7-10 | 4 |
| Chicory | 8-19 | 12.5-13.0 | 20-26 | 30-38 | | |
| Kale | 11-15 | 11.0-13.5 | 12-18 | 20-35 | 35-40 | 2.1 |
| Swedes | 9-12 | 11-13 | 12-20 | 16-30 | 45-50 | |
| Turnips | 9-11 | 12.0 | 12-18 | 27 | 17 | 2.0 |
| Lucerne | 24 | 11.0 | 30.0 | 30 | | 2.5 |
| Fodder beet | 14-20 | 12.0-12.5 | 9-14 | 11-16 | 60-65 | |

Both chicory and brassicas have a greater ratio of readily fermentable carbohydrates (soluble sugars and pectin) to structural carbohydrates compared to standard perennial ryegrass and white clover New Zealand pastures. This generally leads to more rapid rumen degradation and clearance, greater voluntary feed intake, and greater feeding value (Barry, 2013). Chicory's lower protein to readily fermentable carbohydrates ratio (Barry, 1998) allows it to have improved protein utilisation and reduced nitrogen wastage.

Cattle grazed on brassica forages show a lower growth response then would be expected, which Barry (2013) attributes to the presence of secondary plant compounds, which negatively affect the metabolism and performance of cattle consuming them. Brassicas contain a number of secondary compounds which negatively affect livestock performance, such as S-methyl-cysteine sulphoxide and glucosinolates (Barry, 2013; de Ruiter et al., 2009), which may account for the observed lower than expected animal performance on them, despite their high yields and quality. That said, plant breeding and improved awareness of the importance of transitioning periods (de Ruiter et al., 2009, 2022) may allow for improved growth performance.

Barry (1998) also noted that chicory has a greater organic matter digestibility than perennial ryegrass, and notes that particle breakdown during rumination is much faster for chicory. This may be a result of chicory's high ratio of readily fermentable to structural carbohydrates, as more structural support is offered by pectin rather than fibre, and pectin degrades rapidly in the rumen relative to fibre (Barry, 1998). Additionally, animals grazing chicory have been found to have a faster rumen fractional outflow rate, for both solids and liquids, showing that chicory is rapidly degraded and cleared from the rumen compared to perennial ryegrass (Barry, 1998). Barry (1998) also notes the seasonal variation in nutritive values of pastures and forages and concludes that the nutritional advantages of chicory over ryegrass are greatest over the summer autumn period. Additionally, Barry (1998) found that voluntary feed intake is generally greater for livestock grazing chicory rather than pasture, particularly during summer, and concludes that the greater feeding value of chicory is a result of the greater voluntary feed intake and apparent digestibility.

Although animals often perform better on high quality pasture, forage crops still play a significant role in New Zealand beef production as they are able to provide greater quality and quantities of forage during critical times of the year when pasture supply and quality is predictably low. The use of alternative forage crops allows farmers to maximize cattle growth and carcass performance during periods in which they would be otherwise limited.

# 2.5 Beef Quality

## 2.5.1 Beef Quality Attributes

As perceptions of meat quality varies from consumer to consumer, and with the occasion of consumption, meat quality is often difficult to define (Purchas, 2007). As a result, meat quality is often considered as a number of separate components, which can each be studied and measured (Purchas, 2007).

### 2.5.1.1 Beef Colour

Colour is considered an important indicator of meat quality by retail customers (Young & West, 2001), influencing purchasing decisions more than any other quality attribute (Bekhit et al., 2019; Cornforth, 1994; Tapp III et al., 2011). Bright red meat is often

considered attractive or fresh, and off coloured (not red) meat is considered unwholesome, not fresh, or spoilt (Bekhit et al., 2019; Cornforth, 1994; Muir et al., 1998). Beef quality is also influenced by fat colour, with yellow fat deemed undesirable in some markets, as it is often associated with older diseased cattle (Muir et al., 1998). Meat colour can be measured subjectively, via visual assessments, or objectively, with instruments such as chromameters and spectrophotometers, which produce CIE $L^*$, $a^*$, and $b^*$ values, representing lightness, redness-greenness, and yellow-blueness respectively (Bekhit et al., 2019).

#### 2.5.1.2 Beef Juiciness and Water Holding Capacity

Juiciness is a sensory trait, and can be defined as 'the impression of moisture and lubrication when meat is chewed in the mouth', and can be split into two components (Warner, 2023). The first accounts for the initial impression of wetness produced from the first chews, and the second for the impression of juiciness from sustained chewing (Warner, 2023; Winger & Hagyard, 1994). Juiciness is a uniquely subjective property (Warner, 2023; Winger & Hagyard, 1994). Winger and Hagyard (1994) note that the only 'reliable and consistent' way to measure meat juiciness is via sensory tests, and Honikel and Hamm (1994) conclude that juiciness cannot be expressed by via physical measurements.

Juiciness is partially determined by the water holding capacity (WHC) of meat (Warner, 2023), and can be defined as the ability of fresh meat to retain its own water (Pearce et al., 2011). Poor WHC often leads to lower cook yields, dry/less juicy meat, and may also affect the colour, taste, and tenderness of the meat (Warner, 2023). Drip and cooking losses can be used as an indicator of WHC (Honikel & Hamm, 1994; Warner, 2023).

#### 2.5.1.3 Beef Tenderness

Tenderness is often considered the most important meat quality attribute by the consumer (Chrystall, 1994; Muir et al., 1998). Tenderness is also made up of two components: a myofibrillar (muscle) component and a connective tissue (collagen) component (Muir et al., 1998). Tenderness can be defined as the 'resistance to shear or the hardness of the meat', and is an attribute of texture (Chrystall, 1994). Tenderness can be measured subjectively through sensory panels (Chrystall, 1994; Hopkins & Ertbjerg, 2023), or via objective mechanical and chemical measures (Chrystall, 1994; Purchas, 2014). This is most commonly done using the Warner-Bratzler shear force device (Chrystall, 1994; Hopkins & Ertbjerg, 2023), which measures the force required to pull a blade through a cylindrical core of meat placed within an opening on the blade (Purchas, 2014).

#### 2.5.1.4 Beef Flavour

Flavour can be defined as a combination of a foods taste, smell, chemical irritation, and temperature (Beauchamp & Brand, 1994). Many sensations influence the flavour of meat, though it is the combination of taste and smell that is considered unique, and most important (Flores, 2023). Flavour profile cannot be measured by instrumental means, though specific compounds associated with flavour can be monitored by instrumental/objective methods, such as chromatography, high-performance liquid

chromatography or piezo electric crystals mass balance measurements (Bett & Grimm, 1994). More commonly, flavour is subjectively assessed via a panel of tasters (Caul, 1957), which can be split into overall difference tests and attribute difference tests (Bett & Grimm, 1994).

#### 2.5.1.5 Nutritive Value of Beef

Meat is a key source of protein and fat for many people, and makes a significant nutritional contribution to many people's diet (Lupton & Cross, 1994; Wood, 2023). Protein in meat serves as an important source of amino acids, including nine essential amino acids which the body cannot synthesise itself, which support and play a key role in many bodily functions (Wood, 2023). Meat is also a source of fat, which is a key source of energy, essential fatty acids, and fat-soluble vitamins (Wood, 2023).

Fatty acids can be categorised as saturated (SFA), which have no double bonds; monounsaturated (MUFA), which have one double bond; or polyunsaturated (PUFA), which have two or more double bonds (Wood & Enser, 2017). Additionally, PUFA can be classified as omega 3 (n-3) or omega 6 (n-6) fatty acids, depending on the position of the first double bond from the methyl end of the fatty acid chain (Schmitz & Ecker, 2008).

High intakes of dietary SFA are associated with increased risk of cardiovascular disease in humans, as it causes an increase in low density lipoprotein (LDL) cholesterol (Calder, 2015; Wood & Enser, 2017). Alternatively, dietary MUFA and PUFA are known to lower LDL cholesterol, and are associated with a lower risk of cardiovascular disease (Calder, 2015; Wood & Enser, 2017), and are as such recognised as beneficial (Wood, 2023). The overconsumption of n-6 fatty acids relative to n-3 fatty acids also contributes to a greater risk of cardiovascular disease (Wood & Enser, 2017). Meat with well-balanced fatty acids profiles and greater concentrations of certain favourable PUFA are generally seen as higher quality, due to the beneficial impacts they have on consumers health.

### 2.5.2 Effects of Alternative Forages on Beef Quality

This review will focus mainly on the effect of forage diets on beef colour (Table 2.5), juiciness (Table 2.6), tenderness (Table 2.7), flavour (Table 2.8), and nutritive value (Table 2.9), as these attributes are most considered throughout the literature. It is important to note that differences in beef quality may not be solely attributed to nutritional factors, as beef quality is influenced by a range of other factors, such as age, and weight at slaughter, genetics, breeds, sex, pre slaughter stress, use of growth promotants, season/daylength, climate, post mortem processing, and storage techniques (Purchas, 1989, 2007).

As most of the work investigating the effect of forage brassicas on beef quality has taken place in cover cropping systems in the United States, using mixes containing multiple brassicas and/or other species, it is difficult to attribute any differences in beef quality to a single brassica species. Cover crops are typically grown in between conventional/cash crops, and take advantage of close growing crops to protect soil quality and improve soil health and productivity (Quintarelli et al., 2022). Additionally, a lot of the American

studies use C4 grass-based pastures which are typically lower quality than temperate C3 grass-based pastures (Coleman et al., 2004), which are commonly used in New Zealand.

### 2.5.2.1 Beef Colour

Lean meat colour is reported in Table 2.5 and varied from 37.0 to 48.3 for lightness ($L^*$), 10.6-25.6 for redness ($a^*$), and 8.5-16.1 for yellowness ($b^*$). This shows slight variation in the colour characteristics of beef from each trial. The most variation occurs on the red green axis ($a^*$) with beef from cattle grazing turnips, lucerne, bermuda grass, chicory, cow pea, pearl millet, and mixed pasture (Duckett et al., 2013; Schmidt et al., 2013) seemingly producing redder meat ($a^*$>23+) than cattle on other pastures (Daly et al., 1999; Dunne et al., 2006; Langlie, 2020). Cover crops show quite a varied response, with Bakker et al. (2021a) reporting notably redder meat than Langlie (2020). Interestingly, beef from both pasture and cover crops grazed cattle in Langlie's (2020) trial were considerably yellower ($b^*$>15+) than beef from all other trials ($b^*$<13).

Similarly, there was slight variations in fat colour with lightness ($L^*$) ranging from 63.3-78.6, redness ($a^*$) from 2.2-12.1, and yellowness ($b^*$) from 11.4-26 (Table 2.5). Notably, fat from cattle on mixed pasture (Duckett et al., 2013) had lighter fat than all other trials, fat from cattle grazing New Zealand pasture (Daly et al., 1999) was notably less red, fat from cattle grazing Irish pastures (Dunne et al., 2006) was notably less yellow than other trials, and fat from turnip grazed cattle (Rodríguez-Pereira et al., 2025) was darker than fat in all other trials. Duckett et al. (2013), Schmidt et al. (2013) and Langlie (2020) all concluded that there were no significant differences found between lean muscle and fat colour between cattle on different dietary treatments within the same trial.

#### 2.5.2.1.1 Mechanism

Meat colour is largely determined by the protein myoglobin (purple-red), and its exposure to oxygen, which leads to its oxidation to oxymyoglobin (bright red) or metmyoglobin (brown) (Cornforth, 1994; Faustman et al., 2023; Muir et al., 1998; Young & West, 2001). Muir et al. (1998) concludes that there is 'little information' available on the effect of diet on meat colour. Faustman et al. (2023) does report that diet can influence the concentration of myoglobin in the muscles, with diets high in iron leading to greater myoglobin concentrations, which would have an influence on the subsequent meat colour. Myoglobin also varies with muscle type, age, and environmental conditions (Faustman et al., 2023), and Muir et al. (1998) notes that variations in lean muscle colour are generally associated to age differences, with younger cattle more likely to have improved/superior meat colour. Forage diets can be used to improve cattle growth rates, allowing cattle to reach a set slaughter weight at a younger age, which may improve beef colour.

Beef fat colour is also affected by diet, with carotenoids from pasture-based diets accumulating in the fat, leading to yellow fat, which is undesirable in many markets and can lead to carcass downgrading, penalties, and even rejection (Walker et al., 1990; Yang et al., 1992). Variation in fat colour and yellowness may be a result of different carotenoid content between forages. Greater levels of fat, as a result of different planes of nutrition, will also influence the colour and perceived quality of the meat.

**Table 2.5: Summary of the effects of alternative forages on beef colour.**

| Source | Forage Variety | Country | Breed | Trial Duration | Lean Muscle Colour | | | Subcutaneous Fat Colour | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $L^*$[1] | $a^*$[2] | $b^*$[3] | $L^*$[1] | $a^*$[2] | $b^*$[3] |
| Schmidt et al. (2013) | Chicory | United States | Angus cross steers | 2 years | 37.61 | 25.60 | 9.68 | 72.48 | 9.01 | 23.94 |
| Schmidt et al. (2013) | Lucerne | United States | Angus cross steers | 2 years | 38.22 | 25.40 | 9.77 | 72.50 | 6.90 | 21.82 |
| Duckett et al. (2013) | Lucerne | United States | Angus cross steers | 3 years | 40.89 | 24.15 | 10.05 | 72.62 | 9.91 | 18.34 |
| Schmidt et al. (2013) | Cow Pea | United States | Angus cross steers | 2 years | 37.11 | 24.72 | 9.25 | 69.85 | 11.72 | 23.67 |
| Schmidt et al. (2013) | Pearl Millet | United States | Angus cross steers | 2 years | 37.45 | 24.24 | 9.07 | 72.33 | 10.85 | 22.84 |
| Duckett et al. (2013) | Pearl Millet | United States | Angus cross steers | 3 years | 39.77 | 24.02 | 10.05 | 72.75 | 9.91 | 18.80 |
| Duckett et al. (2013) | Pasture[4] | United States | Angus cross steers | 3 years | 39.94 | 23.28 | 9.48 | 78.57 | 8.91 | 18.58 |
| Langlie (2020) | Pasture[5] | United States | Angus and Angus x Simmental steers | 55 days | 45.43 | 13.75 | 15.39 | | | |
| Daly et al. (1999) | Pasture[6] | New Zealand | Angus cross steers | 9 weeks | 40.6 | 10.6 | 8.5 | 69.4 | 2.2 | 26.1 |
| Dunne et al. (2006) | Pasture | Ireland | Charolais x Limousine/Friesian heifers | 120 days | 37.23 | 14.13 | | | | 11.46 |
| Schmidt et al. (2013) | Pasture[7] | United States | Angus cross steers | 2 years | 37.98 | 24.28 | 8.96 | 71.15 | 10.02 | 22.14 |
| Rodríguez-Pereira et al. (2025) | Brassica mix[8] | Chile | Holstein-Friesian steers | 76 days | 38.8 | 25.9 | 13.0 | 63.3 | 10.9 | 13.8 |
| Rodríguez-Pereira et al. (2025) | Brassica mix[9] | Chile | Holstein-Friesian steers | 76 days | 40.2 | 26.4 | 13.7 | 63.5 | 12.1 | 14.0 |
| Langlie (2020) | Brassica mix[10] | United States | Angus and Angus x Simmental steers | 55 days | 48.27 | 13.88 | 16.07 | | | |
| Bakker et al. (2021a) | Brassica mix[11] | United States | Angus based steers | 44 days | 41.59 | 24.53 | 9.82 | | | |
| Range | | | | | 37-48.3 | 10.6-25.6 | 8.5-16.1 | 63-78.6 | 2.2-12.1 | 11.4-26 |

***Table 2.5 continues onto page 25***

***Table 2.5 continues from page 24***

[1] CIE $L^*$: Lightness (100: white, 0: black); [2] $a^*$: Red-green axis (+ve: values: red, -ve: green); [3] $b^*$: Yellow-blue axis (+ve: yellow, -ve: blue); [4] Bluegrass, orchard grass, tall fescue, and white clover; [5] Perennial pasture mix, consisting of quack grass, orchard grass, smooth bromegrass, red clover, and lucerne; [6] Perennial rye grass and white clover; [7]Bermuda grass; [8] 50% bulb turnips, 35% pasture hay, and 15% rolled corn; [9] 70% bulb turnips, 26% pasture hay, and 4% rolled corn; [10] Greenfeed oats, turnips leafy turnip, and radish; [11] Annual ryegrass, radish, trophy rape seed, and purple top turnip.

#### 2.5.2.2 Beef Juiciness and Water Holding Capacity

A range of measurements were produced to describe the variations in juiciness and water holding capacity seen between cattle grazing different forage diets (Table 2.6). Cooking losses ranged from 17.6% to 22.3%. Interestingly, cooking losses reported by Bakker et al. (2021b) were notably lower than cooking losses reported by Langlie (2020), despite both studies looking at the effect of cover crop mixes on beef quality. Cooking losses for cattle grazed on pasture (Langlie, 2020) and lucerne (Lafreniere et al., 2020) were found to be intermediate to the two cover cropping trials.

Juiciness was also reported through a range of sensory trials (Table 2.6). Although each trial uses a different scale, trials can be compared to see if beef from certain forages was extremely juicy, moderately juicy or not juicy at all. Most trials reported moderate juiciness, with sensory scores around the centre of the scale. Juiciness varied between samples from the same forages used in different trials, with Langlie (2020) reporting relatively lower juiciness for pasture fed cattle compared to that of Duckett et al. (2013) and Garmyn et al. (2018). Langlie (2020) also reported relatively lower juiciness for cattle grazed on cover crops, compared to that of Bakker et al. (2021b). Garmyn et al. (2018) reported relatively greater juiciness for pasture and fodder beet diets. Similarly, Duckett et al. (2013), Langlie (2020) and Rodríguez-Pereira et al. (2025) all found no significant differences in juiciness scores between alternative forage treatments.

##### 2.5.2.2.1 Mechanism

Juiciness and WHC are complex meat quality attributes, affected by a range of pre- and post-mortem factors. While juiciness and WHC should be positively correlated, sensory assessments of juiciness often contradict this (Winger & Hagyard, 1994). Similar to the findings reported in Table 2.6, Smith et al. (1977) found that diet had no effect on juiciness when steers were adjusted to a constant weight or fat endpoint, mirroring the conclusions of Muir et al. (1998). Warner (2023) notes that juiciness, as perceived by sensory assessments, improves with increased intramuscular fat (IMF) content, which has similarly been noted by early studies by Blumer (1963) and Barbella et al. (1939). Although fat deposition and IMF concentrations increase with age, Powell (1991) and Riley et al. (1986) both found that bovine age had no significant effects on juiciness, though Pearson (1966) found that older fatter cattle had slightly improved juiciness. Ultimately, the main prospect for improving beef juiciness via the use of forage diets is in their potential to improve growth rates and fat deposition, producing cattle that are fatter at slaughter, which may have improved juiciness.

**Table 2.6: Summary of the effects of alternative forages on beef juiciness.**

| Source | Forage Variety | Country | Breed | Trial Duration | Cooking Losses (%) | Sensory Characteristics | |
|---|---|---|---|---|---|---|---|
| | | | | | | Juiciness | Scale |
| Duckett et al. (2013) | Lucerne | United States | Angus cross steers | 3 years | | 5.14 | 1-8[a] |
| Lafreniere et al. (2020) | Lucerne | Canada | Angus, Hereford, and Angus x Herefords steers | 2 years | 20.4 | 6.04 | 0-10<br>0: very little juiciness<br>10: very high juiciness |
| Duckett et al. (2013) | Pearl Millet | United States | Angus cross steers | 3 years | | 4.94 | 1-8[a] |
| Duckett et al. (2013) | Pasture[1] | United States | Angus cross steers | 3 years | | 4.78 | 1-8[a]<br>1: extremely dry, 8: extremely juicy |
| Langlie (2020) | Pasture[2] | United States | Angus & Angus x Simmental steers | 55 days | 20.2 | 8.8 | 0-20[b]<br>0: none<br>20: extremely juicy |
| Garmyn et al. (2018) | Pasture | New Zealand | Beef steers | 92 days | | 66.3 (21d PM)<br>71.1 (35d PM) | 0-100[c] |
| Rodríguez-Pereira et al. (2025) | Brassica mix[3] | Chile | Holstein-Friesian steers | 76 days | | 4.39 | 0-10[d]<br>0: absence<br>10: max intensity |
| Rodríguez-Pereira et al. (2025) | Brassica mix[4] | Chile | Holstein-Friesian steers | 76 days | | 4.60 | 0-10[d] |
| Langlie (2020) | Brassica mix[5] | United States | Angus & Angus x Simmental steers | 55 days | 22.3 | 9.0 | 0-20[b] |

***Table 2.6 continues onto page 28***

*Table 2.6 continued from page 27*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bakker et al. (2021b) | Brassica mix[6] | United States | Angus based steers | 44 days | 17.6 | 97.28 | 0-185<br>0: extremely juicy<br>185: extremely dry |
| Garmyn et al. (2018) | Fodder beet | New Zealand | Beef steers | 92 days | | 69.7 (21d PM)<br>70.8 (35d PM) | 0-100[c] |

d PM= days postmortem.

[a, b, c, d]: studies with the same superscript use the same scale.

[1] Bluegrass, orchard grass, tall fescue, and white clover; [2] Perennial pasture mix: quack grass, orchard grass, smooth brome grass, red clover, and lucerne; [3] 50% bulb turnips, 35% pasture hay, and 15% rolled corn; [4] 70% bulb turnips, 26% pasture hay, and 4% rolled corn; [5] Greenfeed oats, bulb turnips, leafy turnips, and grazing radish; [6] Annual ryegrass, grazing radish, forage rape, and bulb turnip..

### 2.5.2.3 Beef Tenderness

Objective measurements, derived from the Warner-Bratzler shear force test, produce a range of tenderness values, from 2.10-3.96kgF, with most values around 2.5-2.7kgF (Table 2.7). The shear force reported by Lafreniere et al. (2020) for beef from cattle on lucerne (3.96kgF) was relatively greater than all other values, indicating tougher beef than all other trials, including the lucerne treatment in Duckett et al. (2013). Both Warner-Bratzler shear forces reported by Langlie (2020) were relatively lower (more tender) than those of other studies, particularly that of perennial pasture grazed cattle (2.10kgF). Similarly, Duckett et al. (2013) and Langlie (2020) both found no difference in Warner-Bratzler shear force between alternative forage treatments.

Tenderness was also measured subjectively, via sensory tests in a number of trials (Table 2.7). Tenderness was similar across trials, scoring just above the median of each trials scale for overall tenderness, initial tenderness, and texture liking. Beef from cattle grazed on lucerne had more favourable tenderness scores than beef from cattle grazed on other forages, (Duckett et al., 2013; Lafreniere et al., 2020). Bakker et al. (2021b) reported a relatively low tenderness score for beef from cover crop grazed cattle, which indicates more tender beef on that particular scale. Similarly, Duckett et al. (2013), Langlie (2020), and Rodríguez-Pereira et al. (2025) all found no significant differences in overall tenderness, texture liking, or toughness scores between alternative forage treatments.

#### 2.5.2.3.1 Mechanism

Although Dransfield (1994) concludes that variations in animal production systems have ‘relatively little’ effect on tenderness, on-farm management decisions can influence beef tenderness and quality. Hopkins and Ertbjerg (2023) note that tenderness typically decreases with age, as a result of greater collagen cross-linking, which decreases collagen solubility and produces tougher/less tender meat. Additionally, Fishell et al. (1985) found that cattle with faster growth rates had more tender beef, which Muir et al. (1998) attributes to the greater rate of protein turnover, which results in greater concentrations of proteolytic enzymes in the muscle postmortem (Ponnampalam et al., 2024).

Hopkins and Ertbjerg (2023) also note that the amount of IMF present influences meat tenderness, which is influenced by the animals age at slaughter, with older/mature animals having larger fat depots. Additionally, this is influenced by feeding levels, with high intakes leading to nutrient overflow into all fat depots, including IMF. Similarly, Muir et al. (1998) describe a ‘clear positive correlation’ between meat tenderness, and fatness, and Dransfield (1994) found that marbling accounts for approximately 10% of the variation in tenderness. Like juiciness, New Zealand beef farmers may be able to make slight improvements in beef tenderness via the use of alternative forage crops, as they can be used to improve growth rates and fat deposition, producing heavier and fatter cattle by a set slaughter weight or age.

**Table 2.7: Summary of the effects of alternative forages on beef tenderness.**

| Source | Forage Variety | Country | Breed | Trial Duration | Warner Bratzler Shear Force (kgF) | Sensory Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Initial tenderness | Overall tenderness | Texture liking | Toughness | Scale |
| Duckett et al. (2013) | Lucerne | United States | Angus cross steers | 3 years | 2.63 (14d PM)<br>2.52 (28d PM) | 6.04 | 6.14 | | | 1-8[a] |
| Lafreniere et al. (2020) | Lucerne | Canada | Angus, Hereford, and Angus x Herefords steers | 2 years | 3.96 | | 6.34 | | | 0-10<br>0: extremely tough<br>10: very tender |
| Duckett et al. (2013) | Pearl Millet | United States | Angus cross steers | 3 years | 2.70 (14d PM)<br>2.61 (28d PM) | 5.73 | 5.75 | | | 1-8[a] |
| Duckett et al. (2013) | Pasture[1] | United States | Angus cross steers | 3 years | 2.64 (14d PM)<br>2.67 (28d PM) | 5.33 | 5.4 | | | 1-8[a]<br>1: extremely tough<br>8: extremely tender |
| Langlie (2020) | Pasture[2] | United States | Angus and Angus x Simmental steers | 55 days | 2.10 | | | 74/120 | 6.1/20 | 0-120[b]<br>0: Worst imaginable 120: greatest imaginable<br>0-20[c]<br>0: none<br>20: extremely tender |
| Garmyn et al. (2018) | Pasture | New Zealand | Beef steers | 92 days | | | 61.2 (21d PM)<br>68.0 (35d PM) | | | 0-100[d] |

***Table 2.7 continues onto page 31***

*Table 2.7 continued from page 30*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mithcell et al. (1991) | Pasture | Australia | | | | 5.25 | | | 1-8: extremely tough to extremely tender |
| Rodríguez-Pereira et al. (2025) | Brassica mix[3] | Chile | Holstein-Friesian steers | 76 days | | 6.41 | | | 0-10[e]<br>0: absence<br>10: max intensity |
| Rodríguez-Pereira et al. (2025) | Brassica mix[4] | Chile | Holstein-Friesian steers | 76 days | | 6.52 | | | 0-10[e] |
| Langlie (2020) | Brassica mix[5] | United States | Angus and Angus x Simmental steers | 55 days | 2.29 | | 71/120 | 6.7/20 | 0-120[b]<br>0-20[c] |
| Bakker et al. (2021b) | Brassica mix[6] | United States | Angus based steers | 44 days | | 68.24 | | | 0: extremely tender,<br>185: extremely tough |
| Garmyn et al. (2018) | Fodder beet | New Zealand | Beef steers | 92 days | | 63.2 (21d PM)<br>67.5 (35d PM) | | | 0-100[d] |

d PM= days postmortem.

[a, b, c, d]: studies with the same superscript use the same scale.

[1] Bluegrass, orchard grass, tall fescue, and white clover; [2] Perennial pasture mix: quack grass, orchard grass, smooth brome grass, red clover, and lucerne; [3] 50% bulb turnips, 35% pasture hay, and 15% rolled corn; [4] 70% bulb turnips, 26% pasture hay, and 4% rolled corn; [5] Greenfeed oats, bulb turnips, leafy turnips, and grazing radish; [6] Annual ryegrass, grazing radish, forage rape, and bulb turnip.

#### 2.5.2.4 Beef Flavour

Flavour was mainly quantified through subjective panel tests, looking at beef flavour intensity, off flavour intensity, flavour liking, and overall liking (Table 2.8). Lafreniere et al. (2020) reported a considerably greater beef flavour intensity for cattle grazing lucerne than Duckett et al. (2013), who reported similar beef flavour intensity for cattle grazing lucerne and pearl millet, although found that beef from pasture grazed cattle had a significantly less intense beef flavour. Lafreniere et al. (2020) reported a considerably less intense off flavour in beef from lucerne grazed cattle, compared to Duckett et al. (2013), who found similar off flavour intensity between cattle grazed on lucerne, pasture, and pearl millet, as did Langlie (2020) between pasture and cover crop grazed cattle.

Both flavour and overall liking were mostly scored just above the centre of each scale. Flavour liking reported by Mithcell et al. (1991) for cows grazed on Australian pastures was notably greater than that of cows on other pastures, reported by Garmyn et al. (2018) and Langlie (2020). Flavour liking was considerably different between cattle grazed on cover crops, with Bakker et al. (2021b) reporting notably lower scores than Langlie (2020). Similarly, both Langlie (2020) and Rodríguez-Pereira et al. (2025) reported no significant difference in beef flavour between alternative forage treatments, though Duckett et al. (2013) did find beef from cattle grazed on lucerne and pearl millet to score significantly greater for beef flavour compared to beef from pasture grazed cattle.

##### 2.5.2.4.1 Mechanism

Beef flavour is affected by a wide range of factors. Flores (2023) notes that flavour intensity increases with age, which is a result of changes in age-related flavour precursors, and the increased fat deposition associated with older animals, which contains fat soluble flavour precursors. Beef flavour is also significantly influenced by the release of volatile flavour compounds, the type and concentration of which is dependent on the initial fatty acid profile (Ponnampalam et al., 2024), which is influenced by an animals diet. Similarly, Muir et al. (1998) describes how different feed types can alter flavour precursors, such as fatty acids, though concludes that different feeding treatments did not generate differences large enough to produce detectable flavour differences between cattle slaughtered at similar weights and fat covers. Alternative forages can alter the fat deposition, fatness, and age of cattle at slaughter, which have implications on ultimate beef flavour, producing unique flavour compounds, which can influence beef flavour, though flavour differences may be minor.

**Table 2.8: Summary of the effects of alternative forages on beef flavour and overall liking.**

| Source | Forage Variety | Country | Breed | Trial Duration | Sensory Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Beef flavour intensity | Off flavour intensity | Flavour liking | Overall liking | Scale |
| Duckett et al. (2013) | Lucerne | United States | Angus cross steers | 3 years | 3.94 | 2.77 | | | 1-8[a] |
| Lafreniere et al. (2020) | Lucerne | Canada | Angus, Hereford, and Angus x Herefords steers | 2 years | 6.37 | 1.06 | 6.05 | 5.78 | 0-10<br>0: weak flavour detected/ unacceptable/ undesirable<br>10: intense detected/ acceptable/desirable |
| Duckett et al. (2013) | Pearl Millet | United States | Angus cross steers | 3 years | 3.82 | 2.94 | | | 1-8[a] |
| Duckett et al. (2013) | Pasture[1] | United States | Angus cross steers | 3 years | 3.56 | 2.94 | | | 1-8[a]<br>1: extremely bland<br>8: extremely intense |
| Langlie (2020) | Pasture[2] | United States | Angus and Angus x Simmental steers | 55 days | | 4.2/20 | 76/120 | 74/120 | 0-120[b]<br>0: worst imaginable<br>120: greatest imaginable<br>0-20[c]<br>0: none<br>120: extremely tender |
| Garmyn et al. (2018) | Pasture | New Zealand | Beef steers | 92 days | | | 66.3 (21d PM)<br>66.6 (35d PM) | 60.5 (21d PM)<br>67.9 (35d PM) | 0-100[d] |
| Mithcell et al. (1991) | Pasture | Australia | | | | | 5.85 | | 1-8: dislike extremely to like extremely |

***Table 2.8 continues onto page 34***

*Table 2.8 continued from page 33*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rodríguez-Pereira et al. (2025) | Brassica mix[5] | Chile | Holstein-Friesian steers | 76 days | | 5.54 | | 0-10[e]<br>0: absence<br>10: max intensity |
| Rodríguez-Pereira et al. (2025) | Brassica mix[6] | Chile | Holstein-Friesian steers | 76 days | | 5.33 | | 0-10[e] |
| Langlie (2020) | Brassica mix[7] | United States | Angus and Angus x Simmental steers | 55 days | 5.1/20 | 74/120 | 74/120 | 0-120[b]<br>0-20[c] |
| Bakker et al. (2021b) | Brassica mix[8] | United States | Angus based steers | 44 days | | 80.85 | | 0: extremely bland beef flavour<br>185: extremely intense beef flavour |
| Garmyn et al. (2018) | Fodder beet | New Zealand | Beef steers | 92 days | | 62.0 (21d PM)<br>65.3 (35d PM) | 62.3 (21d PM)<br>66.0 (35d PM) | 0-100[d] |

d PM= days postmortem.

[a, b, c, d]: studies with the same superscript use the same scale.

[1] Bluegrass, orchard grass, tall fescue, and white clover; [2] Perennial pasture mix: quack grass, orchard grass, smooth brome grass, red clover, and lucerne, [3] 50% bulb turnips, 35% pasture hay, and 15% rolled corn; [4] 70% bulb turnips, 26% pasture hay, and 4% rolled corn; [5] Greenfeed oats, bulb turnips, leafy brassica, and grazing radish; [6] Annual ryegrass, grazing radish, forage, and bulb turnip.

### 2.5.2.5 Nutritive Value of Beef

The fatty acid profile of each sample varied between each trial, as seen in Table 2.9, with SFA concentration ranging from 39-51g/100g, MUFA from 35-41g/100g, n-3 PUFA from 0.8-4.4g/100g, n-6 PUFA from 1.8-7.6g/100g, the PUFA:SFA ratio of 0.05-0.25, and the n-6:n-3 ratio of 1.29-2.45. The SFA concentration reported by Leheska et al. (2008) for pasture fed cattle were considerably greater than SFA concentrations from any other trial, and their PUFA concentration (n-3 and n-6) were notably lower than PUFA concentrations recorded in any other trials. As a result, the PUFA:SFA ratio reported by Leheska et al. (2008) was considerably lower than all other reported values. Lafreniere et al. (2020) also reported notably greater n-3 and n-6 PUFA concentrations than other trials, and as a result had a greater PUFA:SFA ratio compared to all other trials. Both Schmidt et al. (2013) and Duckett et al. (2013) found no significant differences in the concentration of SFA, MUFA, PUFA (n-3 and n-6), or that ratio of SFA to PUFA in beef from cattle grazed on alternative forages. Schmidt et al. (2013) did find that beef from cattle grazed on chicory and pearl millet had a significantly greater n-6 to n-3 ratio than cattle grazing cow pea, lucerne, or bermuda grass, though Duckett et al. (2013) observed no significant differences between n-6 to n-3 ratios of beef from cattle grazed on alternative forages.

#### 2.5.2.5.1 Mechanism

Forage diets have a direct impact on the nutritive value of the meat/beef, as they alter the fatty acid profile of the beef. Meat from ruminant production (beef, lamb, chevon) is typically relatively high in SFA and low in PUFA, as rumen biohydrogenation saturates dietary PUFA, producing SFA and some intermediate MUFA, in the *trans* arrangement rather than the *cis* arrangement (Ponnampalam et al., 2024; Wood, 2023; Wood & Enser, 2017). Wood and Enser (2017) describe how dietary changes can be used to effectively reduce the concentration of SFA, increase the concentration of PUFA and supply specific fatty acids with proven health benefits. The replacement of SFA with PUFA or MUFA decreases total cholesterol and LDL cholesterol, improving blood lipid profiles (Mensink et al., 2003), which lowers the risk of associated cardiovascular illnesses.

Certain fatty acids are also associated with specific consumer health benefits. Specific n-3 long chained PUFA, such as eicosapentaenoic acid and docosahexaenoic acid, exert a range of activities that can influence cancer/tumour cell initiation, proliferation, and viability (Calder, 2015). Additionally, conjugated linoleic acid has also been identified as a substance that can potentially reduce the risk of cancer, as well as influence the onset and severity of atherosclerosis, obesity, bone density loss, and diabetes (McGuire & McGuire, 2011). Forage diets can be used to alter and improve the fatty acid profile of grazing beef cattle (Duckett et al., 2013; Rodríguez-Pereira et al., 2025; Wood & Enser, 2017), increasing the concentration of PUFA relative to SFA, and deposition of specific beneficial fatty acids, all of which have associated benefits to consumers health.

**Table 2.9: Summary of the effects of alternative forages on the fatty acid profile of beef.**

| Source | Forage Variety | Country | Breed | Trial Duration | SFA (g/100g) | MUFA (g/100g) | n-3 PUFA (g/100g) | n-6 PUFA (g/100g) | Ratio of PUFA:SFA | Ratio of n-6:n-3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Schmidt et al. (2013) | Chicory | United States | Angus cross steers | 2 years | 43.42 | 37.46 | 2.52 | 5.37 | 0.18 | 2.11 |
| Duckett et al. (2013) | Lucerne | United States | Angus cross steers | 3 years | 45.21 | 35.42 | 2.92 | 3.79 | 0.15 | 1.30 |
| Schmidt et al. (2013) | Lucerne | United States | Angus cross steers | 2 years | 43.59 | 39.67 | 2.19 | 4.14 | 0.14 | 1.88 |
| Lafreniere et al. (2020) | Lucerne | Canada | Angus, Hereford, and Angus x Herefords steers | 2 years | 47.6 | 40.5 | 4.38 | 7.56 | 0.25 | 1.71 |
| Schmidt et al. (2013) | Cow Pea | United States | Angus cross steers | 2 years | 44.46 | 38.08 | 2.38 | 4.22 | 0.14 | 1.80 |
| Schmidt et al. (2013) | Pearl Millet | United States | Angus cross steers | 2 years | 41.54 | 39.50 | 1.96 | 4.41 | 0.14 | 2.26 |
| Duckett et al. (2013) | Pearl Millet | United States | Angus cross steers | 3 years | 44.45 | 37.05 | 2.39 | 3.08 | 0.12 | 1.29 |
| Duckett et al. (2013) | Pasture[1] | United States | Angus cross steers | 3 years | 44.45 | 35.76 | 2.65 | 3.46 | 0.14 | 1.30 |
| Leheska et al. (2008) | Pasture[2] | United States | | | 50.9 | 39.2 | 0.88 | 1.85 | 0.05 | 2.45 |
| Mithcell et al. (1991) | Pasture | Australia | | | 39.1 | 40.8 | | | | |
| Schmidt et al. (2013) | Pasture[3] | United States | Angus cross steers | 2 years | 43.12 | 39.20 | 1.91 | 3.60 | 0.12 | 1.90 |
| Range | | | | | 39-51 | 35-41 | 0.8-4.4 | 1.8-7.6 | 0.05-0.25 | 1.29-2.45 |

[1] Bluegrass, orchard grass, tall fescue, and white clover; [2] Native and cut grasses, and forages; [3] Bermuda grass.

## 2.6 Conclusions and Research Objectives

Although the literature found that forage diets have little effect on beef carcass characteristics and meat quality, the system differences in beef production for overseas studies means that forage effects on carcass and meat quality in the New Zealand beef production system context needs consideration, in particular investigating specific forages available for use by New Zealand beef producers.

Additionally, with an eye on maintaining market share for New Zealand beef and ensuring consumer satisfaction, research is needed to determine how and why different forage diets affect specific carcass characteristics and beef quality attributes. This would include a consideration of fatty acids that are deposited by cattle grazing specific forages (such as chicory or brassicas) as meat fatty acids can influence human health and the flavour profile of beef.

With this in mind, the following research question will be considered:

- **How does the carcass traits, meat quality, fatty acid profile, and sensory characteristics of beef differ between steers finished on alternative forage crops compared to pasture?**

Overall, forage crops have a varied impact on beef cattle growth rates, carcass characteristics, and beef quality. A range of literature is available to support this, though more studies could be performed to confirm these findings in a modern New Zealand beef production system using commercially available forage products including the novel product, raphanobrassica. Alternative forage crops do offer the potential to improve cattle growth rates during key times of the year when pasture supply and quality may otherwise limit animal performance. Additionally, the use of alternative forages offers potential for improvements and variations in beef colour, juiciness, tenderness, and flavour, with potential for larger improvements to be made around the nutritive value of beef, via improved fatty acid profiles and properties. This poses a viable method for New Zealand beef farmers to produce a high-quality, high-value product, which is in demand internationally.

# Chapter 3

## Methods and Materials

# Chapter Three: Methods and Materials

## 3.1 Animals and Management

Three separate studies were run over three separate summers (Table 3.1), each looking at the carcass traits, beef quality, and fatty acid profiles of beef steers finished on three summer forage treatments: chicory (*Chicorium intybus)* cv 'Puna II', raphanobrassica (*Raphanus sativus* L. x *Brassica oleracea* L.) cv 'Pallaton Raphno®', and pasture. The first study ran in early 2020, the second in early 2021, and the third from late 2021 through to early 2022 (referred to as the 2022 study). The studies took place at Marshdale Farm in Oxford (Canterbury, New Zealand) and at Ngai Tahu farm in Eyrewell (Canterbury, New Zealand). All animal procedures were carried out with the approval of the Massey University Animal Ethics Committee (MUAEC 20/44).

**Table 3.1: Overview of summer forage finishing studies completed in the summers of 2020, 2021, and 2022.**

| Study Year | Location | Number of Steers in Each Forage Treatment | | | Breed | Duration | Slaughter Date |
|---|---|---|---|---|---|---|---|
| | | Chicory | Raphano brassica | Pasture | | | |
| 2020 | Marshdale (crops) and Ngai Tahu (pasture) | 10 | 10 | 10 | Angus steers | 27/01/2020 - 16/02/2020 (20 days)[1] | 17/02/2020 |
| 2021 | Marshdale | 12 | 13 | 12 | Angus steers | 21/01/2021 - 08/03/2021 (46 days) | 09/03/2021 |
| 2022 | Marshdale | 12 | 14 | 14 | Hereford x Friesian steers | 23/12/2021 - 09/03/2022 (48 days) | 10/03/2022 |

[1] The planned duration of forty days grazing in 2020 was shortened due to study constraints imposed during a Covid lockdown.

### 3.1.1 The 2020 Study

The experimental design consisted of three 3ha plots, one for each forage type. The chicory and raphanobrassica plots were sown at Marshdale farm, on November 1st 2019, at a sowing rate of 8kg/ha. The pasture treatment utilized a pre-established pasture at Ngai Tahu farm, consisting of an Italian ryegrass (*Lolium multiflorum*), red clover (*Trifolium pratense*), and white clover (*Trifolium repens*) mix.

Thirty spring born Angus steers (approximately 17-18 months of age) were selected from a line of steers at Ngai Tahu on January 15th 2020 and assigned to each forage treatment to obtain an equal start weight, with 10 steers in each treatment group. Steers in the chicory and raphanobrassica treatment groups underwent a transition period, from January 24th to January 31st 2020. During the seven day transition period, steers were given controlled access to their respective forage crops, allowing them to adjust to the

change in diet. Steers grazed the crops during the day and then returned to pasture overnight. Additionally, all steers (including those in the pasture treatment group) were offered lucerne baleage (*ad libitum*) throughout this period to ensure an appropriate transition.

Steers were break fed on each plot, with break sizes which offered an allowance of 14kg dry matter (DM)/steer/day. Following the transition period, lucerne baleage allowance was reduced to 3kgDM/steer/day, representing 20% of their total daily feed allocation on a DM basis, to ensure adequate effective fibre intake. Fresh water was always available to all steers.

The final liveweight of steers finished on Marshdale farm was recorded on February 14th 2020, and those on Ngai Tahi farm on February 16th 2020. All steers were trucked together to Alliance Pukeuri (Oamaru, Otago, New Zealand) on February 16th 2020, and slaughtered on February 17th 2020.

### 3.1.2 The 2021 Study

In the 2021 study, all forage plots were located at Marshdale farm and were each 5ha in size. Chicory and raphanobrassica were sown on November 1st 2020, at a sowing rate of 8kg/ha. The pasture treatment utilized a pre-established pasture (established in 2019), containing a perennial ryegrass (*Lolium perenne*) and white clover mix (Request AR37 ryegrass and Tribute white clover).

Spring born Angus steers ($n$=37, approximately 17-18 months of age) were again purchased from Ngai Tahu, with 12 steers allocated to each the chicory and pasture treatments, and 13 to the raphanobrassica treatment. Differences in stocking rates between forage treatments were to account for the differences in forage quantity available. Steers on forage crop treatments underwent a transition period, from January 21st to January 26th 2021, managed according to the protocol used in the 2020 study. On each plot steers were break fed based on a feed allowance of 12kgDM/steer/day, with an additional 4-5kgDM of lucerne baleage/steer/day. Fresh water was always available to all steers.

All steers were weighed on March 8th 2021 and then transported in Alliance Pukeuri for slaughter on March 9th 2021.

### 3.1.3 2022 Study

In the 2022 study all forage plots were located at Marshdale farm and were each 5ha in size. Chicory and raphanobrassica were sown between October 16th and 28th 2021, at a sowing rate of 8kg/ha. The pasture treatment utilized a pre-established pasture (established 2019), containing a perennial ryegrass and white clover mix.

Dairy-cross steers (Hereford x Friesian) ($n$=40, approximately 17-18 months of age) were purchased from a vendor in Outram (Otago, New Zealand) with 12 steers allocated to the chicory treatment, and 14 to each of the raphanobrassica and pasture treatments. Steers on forage crop treatments underwent a seven day transition period, starting December

23rd 2021, managed according to the protocol used in the 2020 and 2021 study. On each plot steers were break fed, based on a feed allowance of 12kgDM/steer/day, with an additional 4-5kgDM of lucerne baleage/steer/day. Fresh water was always available to all steers.

All steers were weighed on March 9th 2022, and transported to Alliance Pukeuri for slaughter on March 10th 2022.

## 3.2 Slaughter and Carcass Measurements

Following the finishing period, all steers were transported to Alliance Pukeuri for slaughter. Steers were held overnight, slaughtered the following day, and processed according to commercial dressing procedures. Hot carcass weight was recorded, allowing for dressing out percentages to be calculated as hot carcass weight divided by the live weight measured on farm (x100). Dressed carcasses were chilled and stored overnight at 4ºC. At boning, the striploin (*M. longissimus lumborum*) was collected from each steer for further analysis.

Additionally, in the 2020 study carcasses were assessed subjectively in-chiller for marbling score, meat colour score, and fat colour score according to the Aus-Meat beef carcass evaluation scheme (AUS-MEAT, 2017). Subcutaneous fat depth was also measured, using a ruler, at the 13th rib, over the deepest part of the eye muscle. None of these in-chiller assessments were repeated in the 2021 study, though marbling score was assessed in chiller in the 2022 study (Table 3.2).

**Table 3.2: Total number of observations for each trait in each trial year.**

| | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|
| Carcass weight (kg) | 30 | 37 | 40 | 107 |
| Slaughter weight (kg) | 29 | 37 | 40 | 106 |
| Dressing out (%) | 29 | 37 | 40 | 106 |
| Intramuscular fat concentration (%) | 30 | 37 | 34 | 101 |
| Marbling score | 30 | 0 | 40 | 70 |
| Objective meat quality attributes | 30 | 37 | 35 | 102 |
| Fatty acid profile | 30 | 37 | 15 | 82 |

## 3.3 Meat Quality Attributes

Striploin samples collected after slaughter were vacuum packed and chilled at 0 ± 1ºC then transported to Massey University (Palmerston North, Manawatu, New Zealand), and stored at 4 ºC for 14 days to age, then transferred to -20 ºC for storage until analysis. In the 2020 and 2021 study, a sample from every steer was collected and assessed. In the 2022 study samples were collected from 10 steers from the chicory treatment, 12 from the pasture treatment, and 13 from the raphanobrassica treatment (35 in total) (Table 3.2).

The meat quality tests were only performed on internal subsamples, the ends of the striploin sample were not used. Two 2.5cm wide steaks and one 3cm wide steak were then cut, transverse across the sample.

### 3.3.1 Ultimate pH

Ultimate pH was measured on one of the 2.5cm steaks, with a pH spear (Eutech Instruments, Singapore). The pH was measured at three points across the subsample (from medial to lateral), and an average was used for analysis. Standard buffers were used to calibrate the pH spear, at pH 4.01, 7.0, and 10.01, at 10ºC.

### 3.3.2 Lean Meat Colour

Following 30 minutes of exposure to air, the first steak was also used to measure CIE $L^*$, $a^*$, and $b^*$ values, with a calibrated Minolta CR-200 chromameter (Illuminant D65, 8mm diameter aperture, 0º viewing angle; CR-200; Konica Minolta, Mahwah, NJ, USA). Three replicates were taken for each value across the subsample, from which an average was calculated. From these values, chroma, and hue angle were calculated to represent the degree of colour saturation and brownness respectively, using the following two equations:

$$Chroma = (a*^2 + b*^2)^{0.5}$$

$$Hue\ Angle(°) = atan2(b*, a*) \times \frac{180}{\pi}$$

### 3.3.3 Cooking Loss

The second 2.5cm steak was weighed, then placed into a plastic bag and cooked via immersion in a water bath at 70ºC for 90 minutes. Following cooking, samples were rested at room temperature, then chilled for four hours. Following chilling, each subsample was dried and reweighed to calculate cooking loss, using the following equation:

$$Cooking\ loss\ (\%) = \frac{Weight\ loss\ after\ cooking\ (g)}{Initial\ weight\ (g)} \times 100$$

### 3.3.4 Shear Force

These cooked subsamples were then used to assess shear force. Peak load (kgF) was measured, as the maximum force required to shear 13mm diameter cylindrical cores. Peak area (kgF) was also measured, as the area under the load curve. Six cores were collected from the cooked subsample using a corer to cut along the grain of the muscle, allowing shears to be made perpendicular to the muscle fibres direction. Each core was sheared once with a TMS-Pilot Texture Analyzer (Food Technology Corporation, USA), with a V-shaped blade at a 20mm/s blade speed. The TL-Touch texture software (version 1.18-408) was used to record the peak force required to shear through each core, measured in kilograms of force (kgF). An average was calculated from the values from six cores.

### 3.3.4 Drip Loss

The remaining 3cm steak was used to measure drip loss. This subsample was cut into cubes (3 x 3 x 3cm), each cube was then weighed and hung on a metal hook inside of a plastic bag, and chilled at 4°C for 48 hours. Following this period the cubes were dried with paper towels and weighed, allowing drip loss to be calculated as follows:

$$Drip\ Loss = \frac{Weight\ loss\ after\ 48\ hours\ (g)}{Initial\ weight\ (g)} \times 100$$

### 3.3.5 Intramuscular Fat Content

Any remaining sample of the striploin was trimmed of subcutaneous fat and visible connective tissue, then finely minced (Kenwood MG450 with 3 mm hole-plate), vacuum packed, and then frozen. Minced samples were then sent to the Massey University Nutrition Laboratory to measure intramuscular fat (IMF) content, via a Soxhlet extraction procedure (AOAC 911.36).

## 3.4 Fatty Acid Profiles

Subsamples collected from the striploin were sent to AgResearch Grasslands for analysis. The analysis for fatty acids was done following the procedure of Bermingham et al. (2021). The method follows the procedure where subsamples are weighed, internal standard added (3mg of tri C11 in Toulene), followed by toluene and 5% sulphuric acid in methanol. Samples are then incubated (70 °C for 2 h). Once cooled saturated NaCl solution in distilled water was added then centrifuged at 1000x g for 10min, with an aliquot taken for gas chromatography flame ionisation detection (GCFID of fatty acid methyl esters).

## 3.5 Sensory Attributes

The evaluation of eating quality and sensory attributes of beef samples from each forage was completed by the Food Experience and Sensory Testing (FEAST) laboratory, at Massey University. In July 2022, 133 untrained consumers were recruited in Palmerston North (Manawatu, New Zealand) to participate in the study. Participant selection was based on participants meeting the following criteria: aged 18-65 years old, not pregnant or lactating during the trial, no allergies or intolerance to beef, and were regular consumers of red meat, including beef.

The FEAST laboratory ran 12 sessions in total, with four sessions a day, over three consecutive days. Each session had 10 to 12 participants attend, and each participant attended one session. In each session participants ranked overall liking, tenderness, juiciness, and flavour of beef samples from steers grazed on each of the three forage treatments. Each participant received three subsamples, one from each forage treatment, for each question. Samples were received in a different order for each question, according

to a Williams square design. Cook times were staggered throughout the session so that rest time was the same for each question. Participants evaluated samples in individual sensory booths, under controlled conditions with white light. Participants had access to filtered water and unsalted gluten-free crackers to cleanse their palate between each sample. Each participant was asked to rank each sample (1-3) for each of the four attributes (overall liking, tenderness, juiciness, and flavour intensity). Rankings of one indicated the least and three the most liked/tender/juicy/flavour intensity (Table 3.3).

**Table 3.3: Consumer rankings of sensory properties of beef samples.**

| | Score | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| Overall Liking | Least liked | Intermediate | Most liked |
| Tenderness | Least tender | Intermediate | Most tender |
| Juiciness | Least juicy | Intermediate | Most juicy |
| Flavour Liking | Least flavour intensity | Intermediate | Most flavour intensity |

Two days prior to each session, vacuum packed samples of striploin were thawed at 4°C for 24 hours. One sample was used from each treatment for each question in the session, with 12 samples required per session. Sensory analysis was only performed on samples from the 2022 study. One day prior to the session the samples were boned out and had any connective tissue removed, then were repackaged into individual vacuum packs. The 12 loins were then *sous vide* cooked for 1 hour at 58°C, then refrigerated overnight.

On the day of the session, samples were removed from the refrigerator 90 minutes prior to cooking. Five minutes before cooking, samples were taken out of vacuum packs and patted dry with paper towels, then left to rest for five minutes. Each sample had a thermocouple inserted into its centre, then were subsequently grilled in a clamshell hot plate (Roband Aluminium Grill Station 8 Slice Smooth Plates WGSA815S, Nisbets, Auckland), that had been pre-heated for 2.5 minutes at 150°C. Samples were grilled until they reached an internal temperature of 65°C, indicating a medium degree of doneness. After resting, samples were cut lengthwise into seven 1cm thick slices, and cut in half cross ways, using a cutting grid. Each of the 14 subsamples weighed approximately 4 grams. Each subsample was then individually wrapped in aluminium foil that had been pre-coded with a three-digit code and stored in a sample warmer at 50°C until serving.

## 3.6 Statistical Analysis

Data was analysed using the Statistical Analysis Software (SAS), version 9.4 (SAS 9.4, SAS institute Inc., Carey, NC, USA). Linear mixed-effects models were used to assess the effect of alternative forage treatments on carcass traits, meat quality attributes, and fatty acid profiles. Forage treatment was included as a fixed effect, and individual steer were set as random effects. When analysing meat quality attributes, ultimate pH was included as a covariate to account for variation in colour traits (CIE $L^*$, $a^*$, $b^*$, chroma, and hue angle), shear force traits (peak area and load) and water holding capacity (drip

and cooking losses). The concentration of IMF was also included as a covariate to account for the variation in fatty acid concentrations and ratios. When combining the data of each separate trial, study year nested within forage treatment was included as a random effect to account for variation associated with study year within each treatment.

Simple linear regressions were run in SAS to investigate the relationships between variables. Stepwise regressions were also run in SAS, using the PROC GLMSELECT command, to determine which variables contribute to the prediction of IMF, concentrations of fatty acids (SFA, MUFA, and PUFA), and for shear force values. Prediction of IMF considered study year, forage treatment, carcass weight, liveweight at the start of the finishing period, and marbling score. The prediction of fatty acid concentrations considered study year, forage treatment, IMF concentration, and carcass weight, and the prediction of shear force values considered study year, forage treatment, IMF concentration, carcass weight, and pH. Variables were added to or removed from the stepwise models based on Akaike Information Criterion (AIC). Sensory data collected by FEAST was analysed using a Friedman Analysis in Microsoft Excel (version 16.0), allowing for randomised block analysis of rank data, as described by Meilgaard et al. (1999).

# Chapter 4

## Results

# Chapter Four: Results

## 4.1 Effect of Forage Treatments

### 4.1.1 Carcass Traits

In the 2020 study, steers on pasture had a greater dressing out percentage than steers grazed on chicory or raphanobrassica treatments ($p<0.05$, Table 4.1). Meat colour score was greater in steers grazed on chicory compared to steers grazed on pasture or raphanobrassica ($p<0.05$, Table 4.1). Forage type had no effect on liveweight at slaughter, carcass weight, intramuscular fat (IMF) concentration, marbling score, or fat colour score ($p>0.05$, Table 4.1), though tended to affect fat depth with fat depth of raphanobrassica fed steers tending to be greater than pasture fed steers ($p=0.089$, Table 4.1).

**Table 4.1: Least square means (±SEM) of carcass traits of beef steers finished on chicory, raphanobrassica, or pasture, in the 2020 study.**

| | Chicory | Raphanobrassica | Pasture | P value |
|---|---|---|---|---|
| *n* | 10 | 10 | 10 | |
| Liveweight at slaughter (kg)[1] | 642.4 ±8.8 | 640.0 ±8.3 | 625.2 ±8.3 | 0.312 |
| Carcass weight (kg) | 328.3 ±5.3 | 327.0 ±5.3 | 334.9 ±5.3 | 0.538 |
| Dressing out (%)[1] | 51.30 ±0.46b | 51.08 ±0.46b | 53.57 ±0.46a | 0.001 |
| Marbling score | 3.00 ±0.33 | 2.40 ±0.33 | 1.90 ±0.33 | 0.280 |
| Meat colour score | 2.60 ±0.23a | 1.40 ±0.23b | 1.90 ±0.23b | 0.002 |
| Fat colour score | 2.00 ±0.20 | 2.30 ±0.20 | 1.80 ±0.20 | 0.199 |
| Fat depth (mm) | 11.10 ±0.74 | 11.90 ±0.74 | 9.60 ±0.74 | 0.089 |
| Intramuscular fat (%) | 4.57 ±0.83 | 3.85 ±0.83 | 3.82 ±0.83 | 0.772 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).
[1] *n* chicory treatment = 9, *n* raphanobrassica treatment = 10, *n* pasture treatment = 10.

In the 2021 study, steers grazed on pasture had a lower carcass weight than steers grazed on chicory and a lower dressing out percentage than steers grazed on chicory or raphanobrassica ($p<0.05$, Table 4.2). Forage treatment had no effect on liveweight at slaughter and IMF concentration ($p>0.05$, Table 4.2).

**Table 4.2: Least square means (±SEM) of carcass traits of beef steers finished on chicory, raphanobrassica, or pasture, in the 2021 study.**

| | Chicory | Raphanobrassica | Pasture | P value |
|---|---|---|---|---|
| *n* | 12 | 13 | 12 | |
| Liveweight at slaughter (kg) | 548.2 ±7.8 | 539.4 ±7.5 | 539.7 ±7.8 | 0.664 |
| Carcass weight (kg) | 285.6 ±4.1a | 281.9 ±3.9ab | 271.0 ±4.1b | 0.044 |
| Dressing out (%) | 52.13 ±0.37a | 52.26 ±0.37a | 50.24 ±0.35b | <0.001 |
| Intramuscular fat (%) | 2.77 ±0.31 | 2.75 0.37 | 2.67 ±2.75 | 0.971 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).

Forage treatment had no effect on any of the measured carcass traits ($p>0.05$, Table 4.3) in the 2022 study.

**Table 4.3: Least square means (±SEM) of carcass traits of beef steers finished on chicory, raphanobrassica, or pasture, in the 2022 study.**

| | Chicory | Raphanobrassica | Pasture | P value |
|---|---|---|---|---|
| *n* | 12 | 14 | 14 | |
| Liveweight at slaughter (kg) | 671.8 ±11.0 | 675.4 ±10.2 | 679.1 ±10.2 | 0.888 |
| Carcass weight (kg) | 340.2 ±6.3 | 344.9 ±5.8 | 341.9 ±5.8 | 0.859 |
| Dressing out (%) | 50.64 ±0.55 | 51.09 ±0.51 | 50.34 ±0.51 | 0.591 |
| Marbling score | 3.08 ±0.37 | 2.79 ±0.34 | 2.43 ±0.34 | 0.435 |
| Intramuscular fat (%)[1] | 6.79 ±0.79 | 6.61 ±0.66 | 7.21 ±0.69 | 0.815 |

[1] *n* chicory treatment = 10, *n* raphanobrassica treatment = 13, *n* pasture treatment = 12.

When considering data for all studies combined, forage treatment had no effect on any carcass traits ($p>0.05$, Table 4.4). The random effect of year (nested within forage treatment) affected carcass weight and slaughter weight ($p<0.05$, Table 4.4). The random effect of year had no effect on marbling score ($p=0.486$, Table 4.4).

**Table 4.4: Least square means of carcass traits of beef steers finished on chicory, raphanobrassica, or pasture, over all three studies (2020, 2021, and 2022).**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treat-ment | Year (forage) |
| Liveweight at slaughter (kg)[1] | 620.8 ±39.7 | 618.3 ±39.6 | 614.7 ±39.6 | 0.994 | 0.044 |
| Carcass weight (kg)[2] | 318.0 ±19.5 | 317.9 ±19.5 | 315.9 ±19.5 | 0.996 | 0.045 |
| Dressing out (%)[2] | 51.36 ±0.71 | 51.48 ±0.71 | 51.36 ±0.71 | 0.990 | 0.070 |
| Marbling score[3] | 3.04 ±0.29 | 2.62 ±0.29 | 2.21±0.29 | 0.123 | 0.486[*] |
| Intramuscular fat (%)[4] | 4.69 ±1.24 | 4.41 ±1.23 | 4.57 ±1.23 | 0.987 | 0.056 |

[1] *n* chicory treatment = 34, *n* raphanobrassica treatment = 37, *n* pasture treatment = 36.
[2] *n* chicory treatment = 33, *n* raphanobrassica treatment = 37, *n* pasture treatment = 36.
[3] *n* chicory treatment = 22, *n* raphanobrassica treatment = 24, *n* pasture treatment = 24.
[4] *n* chicory treatment = 31, *n* raphanobrassica treatment = 36, *n* pasture treatment = 34.
[*] As marbling score was not recorded in all studies, the criteria for a nested model was not met, so the random effect of just year is reported instead.

## 4.1.2 Meat Quality Attributes

In the 2020 study, pH was similar across forage treatments ($p=0.336$, Table 4.5). Ultimate pH, when included as a covariate, influenced meat colour values (CIE $L^*$, $a^*$, $b^*$, chroma, and hue angle) and shear force values (peak area and load) ($p<0.05$, Table 4.5), but did not affect water losses (drip and cooking loss) ($p>0.05$, Table 4.5). Colour values and water losses were not affected by forage treatment ($p>0.05$, Table 4.5). Shear force values were greater in beef from raphanobrassica compared to chicory and pasture ($p<0.05$, Table 4.5).

**Table 4.5: Meat quality attributes of the striploin of beef steers finished on chicory, raphanobrassica, or pasture, in the 2020 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | **Chicory** | **Raphano-brassica** | **Pasture** | **Treatment** | **pH covariate** |
| *n* | 10 | 10 | 10 | | |
| pH | 5.46 ±0.03 | 5.41 ±0.03 | 5.43 ±0.03 | 0.336 | |
| *L** | 39.23 ±0.86 | 40.72 ±0.95 | 38.71 ±0.83 | 0.398 | 0.002 |
| *a** | 19.73 ±0.36 | 18.92 ±0.40 | 19.45 ±0.35 | 0.399 | <0.001 |
| *b** | 11.21 ±0.28 | 11.08 ±0.31 | 10.92 ±0.27 | 0.763 | <0.001 |
| Chroma | 22.71 ±0.43 | 21.93 ±0.47 | 22.28 ±0.41 | 0.547 | <0.001 |
| Hue angle (°) | 29.40 ±0.45 | 30.29 ±0.50 | 29.30 ±0.44 | 0.320 | <0.001 |
| Peak load (kgF) | 4.70 ±0.13b | 5.27 ±0.14a | 4.76 ±0.13b | 0.013 | <0.001 |
| Peak area (kgF) | 19.39 ±0.50b | 21.47 ±0.56a | 19.36 ±0.49b | 0.009 | <0.001 |
| Drip loss (%) | 5.20 ±0.76 | 4.08 ±0.74 | 4.98 ±0.84 | 0.759 | 0.271 |
| Cooking loss (%) | 21.95 ±0.60 | 22.87 ±0.67 | 22.52 ±0.58 | 0.486 | 0.382 |

a,b values with different superscript within the same row are different from each other (LSD, p<0.05).

In the 2021 study, pH was greater in the beef of pasture grazed steers than chicory grazed steers (p=0.024, Table 4.6). As a covariate, pH affected *a**, *b**, chroma, and hue angle (p<0.05, Table 4.6), but did not affect *L**, shear force values, or water losses (p>0.05, Table 4.6). Additionally, *a**, *b**, and chroma were greater in chicory steers compared to pasture or raphanobrassica grazed steers (p<0.05, Table 4.6), with hue angle tending to be greater for the meat from chicory fed steers (p<0.10, Table 4.6). Forage type had no effect on *L** values, shear force values, or water losses (p>0.05, Table 4.6).

**Table 4.6: Meat quality attributes of the striploin of beef steers finished on chicory, raphanobrassica, or pasture, in the 2021 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | **Chicory** | **Raphano-brassica** | **Pasture** | **Treatment** | **pH covariate** |
| *n* | 12 | 13 | 12 | | |
| pH | 5.47 ±0.01b | 5.49 ±0.01ab | 5.53 ±0.01a | 0.024 | |
| *L** | 37.82 ±0.67 | 36.79 ±0.52 | 36.03 ±0.65 | 0.134 | 0.160 |
| *a** | 18.40 ±0.33a | 17.31 ±0.26b | 17.17 ±0.33b | 0.033 | 0.001 |
| *b** | 9.46 ±0.25a | 8.71 ±0.19b | 8.32 ±0.24b | 0.008 | <0.001 |
| Chroma | 20.69 ±0.39a | 19.38 ±0.30b | 19.09 ±0.39b | 0.016 | <0.001 |
| Hue angle (°) | 27.22 ±0.46 | 26.67 ±0.36 | 25.82 ±0.45 | 0.084 | 0.003 |
| Peak load (kgF) | 4.91 ±0.25 | 4.67 ±0.20 | 5.52 ±0.25 | 0.234 | 0.010 |
| Peak area (kgF) | 21.02 ±0.90 | 20.38 ±0.70 | 21.55 ±0.88 | 0.403 | 0.015 |
| Drip loss (%) | 2.90 ±0.70 | 2.98 ±0.54 | 4.05 ±0.68 | 0.445 | 0.985 |
| Cooking loss (%) | 23.76 ±0.57 | 24.17 ±0.44 | 23.83 ±0.55 | 0.895 | 0.807 |

a,b values with different superscript within the same row are different from each other (LSD, p<0.05).

In the 2022 trial, pH was greater in beef from chicory grazed steers compared to beef from pasture and raphanobrassica (p=0.039, Table 4.7). As a covariate, pH influenced drip loss, *b**, and chroma (p<0.05, Table 4.7), and tended to affect *a** values and peak area (p<0.10, Table 4.7). Forage type had no effect on colour values, shear force values, or water losses in the 2022 study (p>0.05, Table 4.7).

**Table 4.7: Meat quality attributes of the striploin of beef steers finished on chicory, raphanobrassica, or pasture, in the 2022 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treatment | pH covariate |
| *n* | 10 | 13 | 12 | | |
| pH | 5.62a ±0.01a | 5.58 ±0.01b | 5.58 ±0.01b | 0.039 | |
| *L** | 38.37 ±0.81 | 37.84 ±0.64 | 38.59 ±0.65 | 0.468 | 0.173 |
| *a** | 17.70 ±0.47 | 18.15 ±0.37 | 18.30 ±0.37 | 0.811 | 0.052 |
| *b** | 9.74 ±0.35 | 10.11 ±0.28 | 10.12 ±0.28 | 0.734 | 0.043 |
| Chroma | 20.21 ±0.56 | 20.78 ±0.45 | 20.91 ±0.45 | 0.786 | 0.043 |
| Hue angle (°) | 28.73 ±0.40 | 29.13 ±0.32 | 28.89 ±0.32 | 0.741 | 0.254 |
| Peak load (kgF) | 4.52 ±0.30 | 4.93 ±0.24 | 4.60 ±0.24 | 0.432 | 0.232 |
| Peak area (kgF) | 18.30 ±1.10 | 20.13 ±0.87 | 19.24 ±0.88 | 0.271 | 0.062 |
| Drip loss (%) | 3.88 ±1.22 | 2.61 ±0.97 | 5.08 ±0.98 | 0.315 | 0.019 |
| Cooking loss (%) | 21.97 ±0.69 | 23.34 ±0.55 | 22.79 ±0.55 | 0.157 | 0.754 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).

In the combined analysis across all study years, pH influenced all colour and shear force values ($p<0.05$, Table 4.8) but had no effect on water losses ($p>0.05$, Table 4.8). Forage treatment had no effect on any of the meat quality attributes ($p>0.05$, Table 4.8). Ultimate pH, *b**, and hue angle were affected by the random effect of year nested within forage treatment ($p<0.05$, Table 4.8).

**Table 4.8: Meat quality attributes of the striploin of beef steers finished on chicory, raphanobrassica, or pasture, over all three studies (2020, 2021, and 2022).**

| | Least Square Means (±SEM) | | | P values | | |
|---|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treat-ment | Year (forage) | pH |
| *n* | 32 | 36 | 34 | | | |
| pH | 5.52 ± 0.05 | 5.49 ± 0.05 | 5.51 ± 0.05 | 0.935 | 0.049 | |
| *L** | 38.17 ± 0.92 | 38.23 ± 0.91 | 37.85 ± 0.91 | 0.951 | 0.079 | 0.001 |
| *a** | 18.46 ± 0.65 | 18.19 ± 0.64 | 18.24 ± 0.64 | 0.951 | 0.065 | <0.001 |
| *b** | 10.00 ± 0.75 | 9.94 ± 0.75 | 9.76 ± 0.75 | 0.973 | 0.049 | <0.001 |
| Chroma | 21.01 ± 0.92 | 20.74 ± 0.92 | 20.71 ± 0.92 | 0.968 | 0.057 | <0.001 |
| Hue angle (°) | 28.32 ± 1.03 | 28.54 ± 1.03 | 27.96 ± 1.03 | 0.924 | 0.049 | <0.001 |
| Peak load (kgF) | 4.66 ± 0.33 | 4.86 ± 0.32 | 4.87 ± 0.32 | 0.884 | 0.102 | 0.003 |
| Peak area (kgF) | 19.55 ± 1.45 | 20.36 ± 1.45 | 20.13 ± 1.45 | 0.920 | 0.077 | <0.001 |
| Drip loss (%) | 4.6 ± 0.6 | 3.3 ± 0.6 | 4.5 ± 0.6 | 0.355 | 0.268 | 0.661 |
| Cooking loss (%) | 22.67 ±0.56 | 23.53 ±0.55 | 23.05 ±0.55 | 0.581 | 0.114 | 0.292 |

### 4.1.3 Fatty Acid Profiles

In the 2020 study, IMF concentration influenced the concentration of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA), and the ratio of PUFA to SFA ($p<0.05$, Table, 4.9). When compared at an equal IMF concentration forage treatment had no effect on the concentration of SFA, MUFA, or PUFA, or the omega 6 (n-6) to omega 3 (n-3) ratio ($p>0.05$, Table 4.9). Beef from pasture grazed steers had a greater ratio of PUFA to SFA than that of chicory or raphanobrassica grazed steers ($p=0.024$, Table 4.9).

**Table 4.9: Concentration of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) (mg/100g raw meat), and ratios of PUFA to SFA and omega 6 (n-6) fatty acids to omega 3 (n-3) fatty acids from striploin samples of steers finished on chicory, raphanobrassica, or pasture, in the 2020 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treatment | IMF[1] covariate |
| *n* | 10 | 10 | 10 | | |
| SFA | 17.30 ±0.80 | 16.48 ±0.80 | 16.84 ±0.79 | 0.763 | <0.001 |
| MUFA | 16.29 ±0.63 | 16.34 ±0.63 | 15.91 ±0.62 | 0.948 | <0.001 |
| PUFA | 1.76 ±0.04 | 1.65 ±0.04 | 1.70 ±0.04 | 0.548 | <0.001 |
| PUFA : SFA | 0.11 ±0.01b | 0.11 ±0.01b | 0.14 ±0.01a | 0.024 | <0.001 |
| n-6 : n-3 | 1.10 ±0.03 | 1.02 ±0.03 | 1.08 ±0.03 | 0.159 | 0.372 |

[1] Intramuscular fat concentration.

In the 2021 study, IMF concentration affected the concentration of SFA, MUFA, and PUFA, and the ratio of PUFA to SFA ($p<0.05$, Table 4.10). The concentration of PUFA in beef from steers in the chicory treatment was greater than that of steers in the pasture or raphanobrassica treatments ($p=0.001$, Table 4.10). The ratio of n-6 to n-3 fatty acids was greater in the beef of pasture and chicory grazed steers compared to raphanobrassica grazed steers ($p<0.001$, Table 4.10). Forage treatment had no effect on SFA and MUFA concentration, or on the PUFA to SFA ratio in the beef ($p>0.05$, Table 4.10).

**Table 4.10: Concentration of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) (mg/100g raw meat), and ratios of PUFA to SFA and omega 6 (n-6) fatty acids to omega 3 (n-3) fatty acids from striploin samples of steers finished on chicory, raphanobrassica, or pasture, in the 2021 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treatment | IMF[1] covariate |
| *n* | 12 | 13 | 12 | | |
| SFA | 11.54 ±0.53 | 11.09 ±0.51 | 11.54 ±0.53 | 0.206 | <0.001 |
| MUFA | 10.84 ±0.46 | 10.68 ±0.44 | 10.42 ±0.46 | 0.889 | <0.001 |
| PUFA | 1.94 ±0.03a | 1.76 ±0.03b | 1.85 ±0.03b | 0.001 | 0.001 |
| PUFA : SFA | 0.18 ±0.01 | 0.17 ±0.01 | 0.18 ±0.01 | 0.873 | 0.001 |
| n-6 : n-3 | 1.22 ±0.03a | 1.09 ±0.03b | 1.27 ±0.03a | <0.001 | 0.308 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).
[1] Intramuscular fat concentration.

In the 2022 study, IMF concentration influenced the concentration of SFA, MUFA, and the ratio of PUFA to SFA ($p<0.05$, Table 4.11), and tended to affect the concentration of PUFA ($p=0.10$, Table 4.11). Beef from steers grazed on chicory or pasture had a greater PUFA to SFA ratios than that of raphanobrassica grazed steers ($p=0.047$, Table 4.11). Forage treatment tended to have an effect on the concentration of SFA, MUFA, and PUFA ($p<0.10$, Table 4.11).

**Table 4.11: Concentration of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) (mg/100g raw meat), and ratios of PUFA to SFA and omega 6 (n-6) fatty acids to omega 3 (n-3) fatty acids, from striploin samples of steers finished on chicory, raphanobrassica, or pasture, in the 2022 study.**

| | Least Square Means (±SEM) | | | P values | |
|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treatment | IMF[1] covariate |
| *n* | 5 | 5 | 5 | | |
| SFA | 24.05 ±1.99 | 29.29 ±1.98 | 22.57 ±2.01 | 0.073 | 0.007 |
| MUFA | 29.43 ±2.29 | 24.82 ±2.32 | 33.03 ±2.29 | 0.078 | 0.004 |
| PUFA | 1.89 ±0.06 | 1.91 ±0.06 | 1.71 ±0.07 | 0.094 | 0.010 |
| PUFA : SFA | 0.08 ±0.004a | 0.07 ±0.004b | 0.08 ±0.004a | 0.047 | 0.036 |
| n-6 : n-3 | 1.14 ±0.05 | 1.15 ±0.05 | 2.22 0.05 | 0.481 | 0.609 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).
[1] Intramuscular fat concentration.

When combining the data across all three study years, IMF concentration (as a covariate) affected the concentration of SFA, MUFA, and PUFA, and the ratio of PUFA to SFA ($p<0.001$, Table 4.12). Forage treatment had no effect on the concentration of SFA, MUFA, or PUFA, or on the ratios of PUFA to SFA, and n-6 to n-3 fatty acids ($p>0.05$, Table 4.12). The effect of year nested within forage treatment tended to influence the concentration of MUFA and PUFA, and the ratio of n-6 to n-3 fatty acids ($p<0.10$, Table 4.12).

**Table 4.12: Concentration of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) (mg/100g raw meat), and ratios of PUFA to SFA and omega 6 (n-6) fatty acids to omega 3 (n-3) fatty acids from striploin samples of steers finished on chicory, raphanobrassica, or pasture, over all three studies (2020, 2021, and 2022).**

| | Least Square Means (±SEM) | | | P values | | |
|---|---|---|---|---|---|---|
| | Chicory | Raphano-brassica | Pasture | Treat-ment | Year (forage) | IMF[1] |
| *n* | 27 | 28 | 27 | | | |
| SFA | 15.70 ±1.03 | 16.75 ±1.02 | 15.19 ±1.02 | 0.584 | 0.142 | <0.001 |
| MUFA | 16.78 ±2.15 | 18.10 ±2.14 | 15.24 ±2.14 | 0.662 | 0.062 | <0.001 |
| PUFA | 1.82 ±0.12 | 1.72 ±0.12 | 1.71 ±0.12 | 0.771 | 0.054 | <0.001 |
| PUFA : SFA | 0.14 ±0.01 | 0.13 ±0.01 | 0.14 ±0.01 | 0.705 | 0.149 | <0.001 |
| n-6 : n-3 | 1.16 ±0.05 | 1.09 ±0.05 | 1.19 ±0.05 | 0.329 | 0.074 | 0.223 |

[1] Intramuscular fat concentration.

## 4.1.4 Sensory Characteristics

Consumers found that beef samples from steers finished on chicory were more favourable (ranked higher) than beef samples from steers finished on pasture for all attributes ($p<0.05$, Table 4.13). Beef from steers finished on chicory ranked higher than raphanobrassica finished steers for overall liking, juiciness, and flavour intensity ($p<0.05$, Table 4.13) but were equally ranked for tenderness. Consumers ranked the sensory attributes of beef samples from pasture and raphanobrassica fed steers equally. This indicates that chicory fed steers have more juicy and flavourful beef that was liked more

overall compared to pasture and raphanobrassica fed steers, and more tender beef than pasture fed steers.

**Table 4.13: Mean scores for each sensory attribute (overall liking, tenderness, juiciness, and flavour intensity) of beef samples from steers grazed on chicory, raphanobrassica, or pasture in the 2022 study.**

| | Chicory | Raphanobrassica | Pasture | P-Value |
|---|---|---|---|---|
| Overall liking | 2.301a | 1.932b | 1.767b | <0.001 |
| Tenderness | 2.203a | 2.008ab | 1.789b | 0.003 |
| Juiciness | 2.301a | 1.932b | 1.767b | <0.001 |
| Flavour intensity | 2.301a | 1.932b | 1.767b | <0.001 |

a,b values with different superscript within the same row are different from each other (LSD, $p<0.05$).

The distribution of consumer scores for overall liking of steers fed pasture and raphanobrassica were similar (Figure 4.1). Although a similar number of consumers ranked each forage as the most liked, a greater number of consumers ranked beef from chicory fed steers as intermediate, and a lower number of consumers ranked beef from chicory fed steers as the least liked.

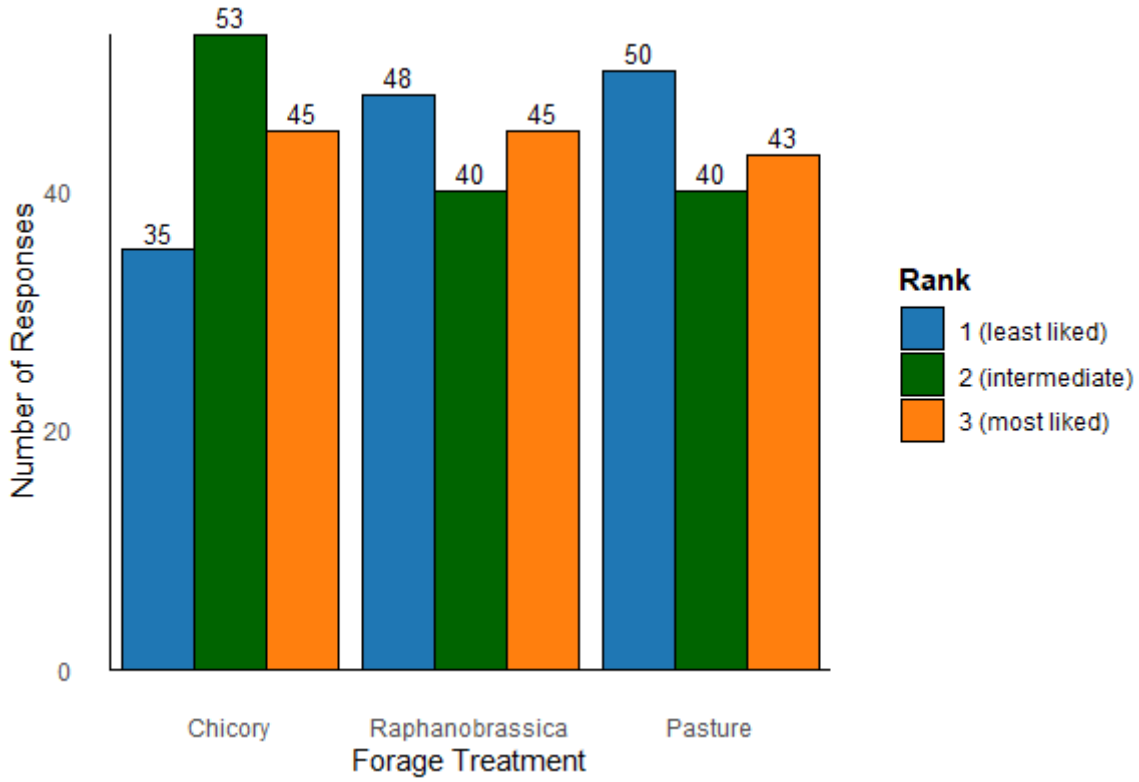


**Figure 4.1: Consumer ranking of overall liking of beef samples from steers grazed on chicory, raphanobrassica, or pasture, in the 2022 study.**

The distribution of scores from chicory and pasture grazed beef showed opposing patterns (Figure 4.2), with beef from chicory fed steers more often ranked as the most tender (rank of 3), while beef from pasture fed steers was most often ranked as the least tender (rank of 1). The distribution of ranks for beef from raphanobrassica fed steers were relatively equal, with a similar number of consumers ranking it as least, intermediate, or most tender.

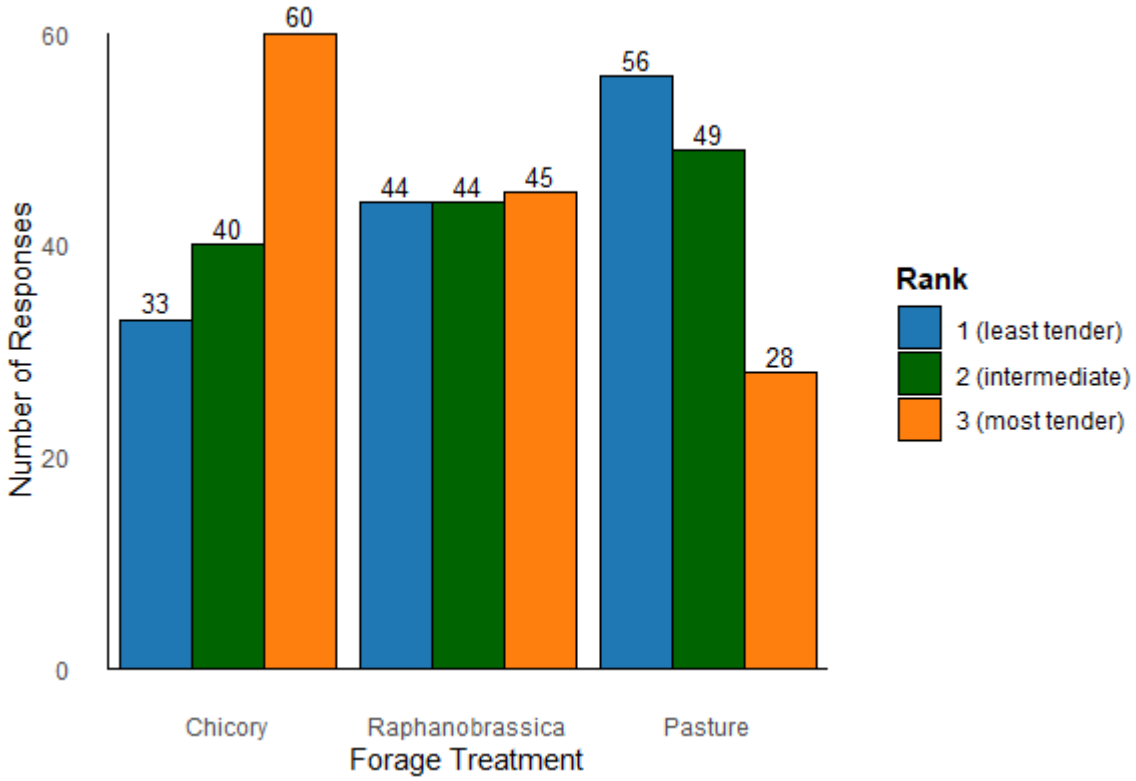


**Figure 4.2: Consumer ranking of tenderness of beef samples from steers grazed on chicory, raphanobrassica, or pasture, in the 2022 study.**

Consumers rankings for juiciness were like those of tenderness, with beef from steers fed chicory most often ranked as the most juicy (rank of 3), and beef from pasture fed most often ranked as the least juicy (rank of 1) (Figure 4.3). Although consumers found no difference in juiciness of beef from pasture and raphanobrassica fed steers, the allocation of ranks for raphanobrassica was relatively equal, compared to chicory and pasture distributions.

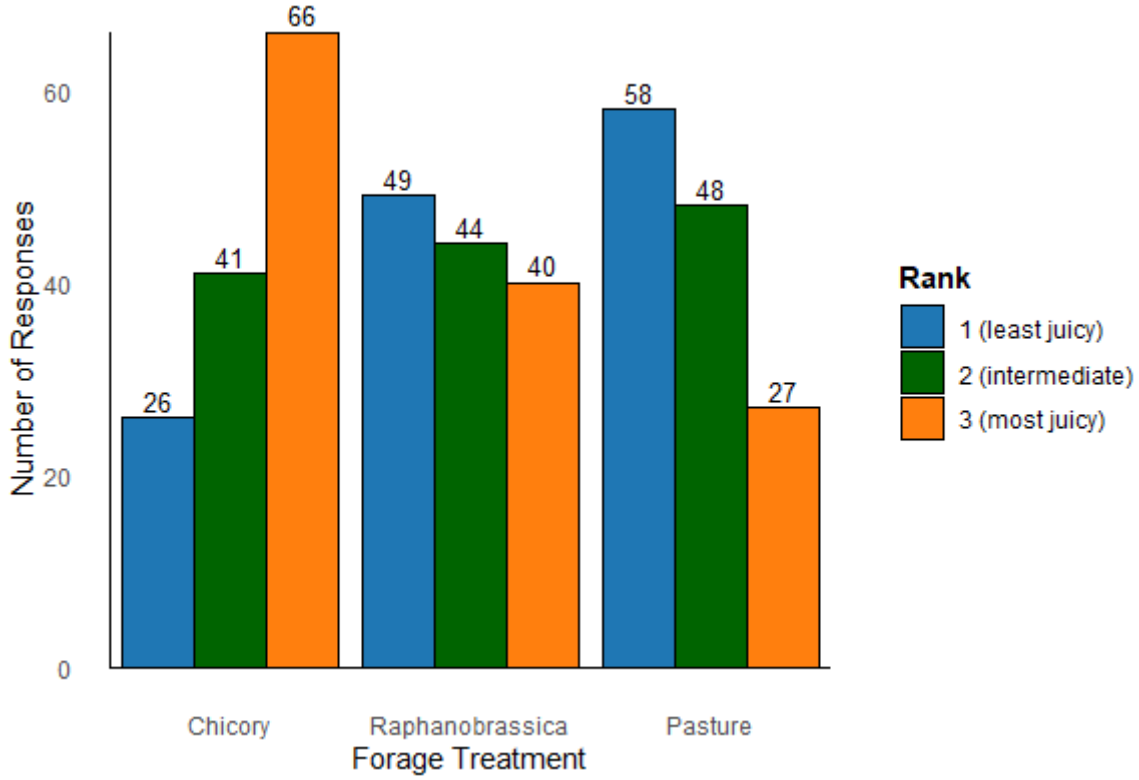


**Figure 4.3: Consumer ranking of juiciness of beef samples from steers grazed on chicory, raphanobrassica, or pasture, in the 2022 study.**

Beef from raphanobrassica fed steers was more frequently ranked as having the greatest flavour intensity (rank of 3) than beef from pasture and chicory fed steers (Figure 4.4). More consumers ranked flavour intensity of beef from pasture or chicory fed steers as intermediate compared to beef from steers fed raphanobrassica. Beef from chicory fed steers received more higher and intermediate ranks than that of beef from pasture fed steers and pasture received more lower ranks than that of chicory for flavour intensity. Consumers were relatively dichotomous with regards to the flavour intensity of raphanobrassica, with many consumers ranking it as the most or least flavourful, and fewer ranking it as intermediate.

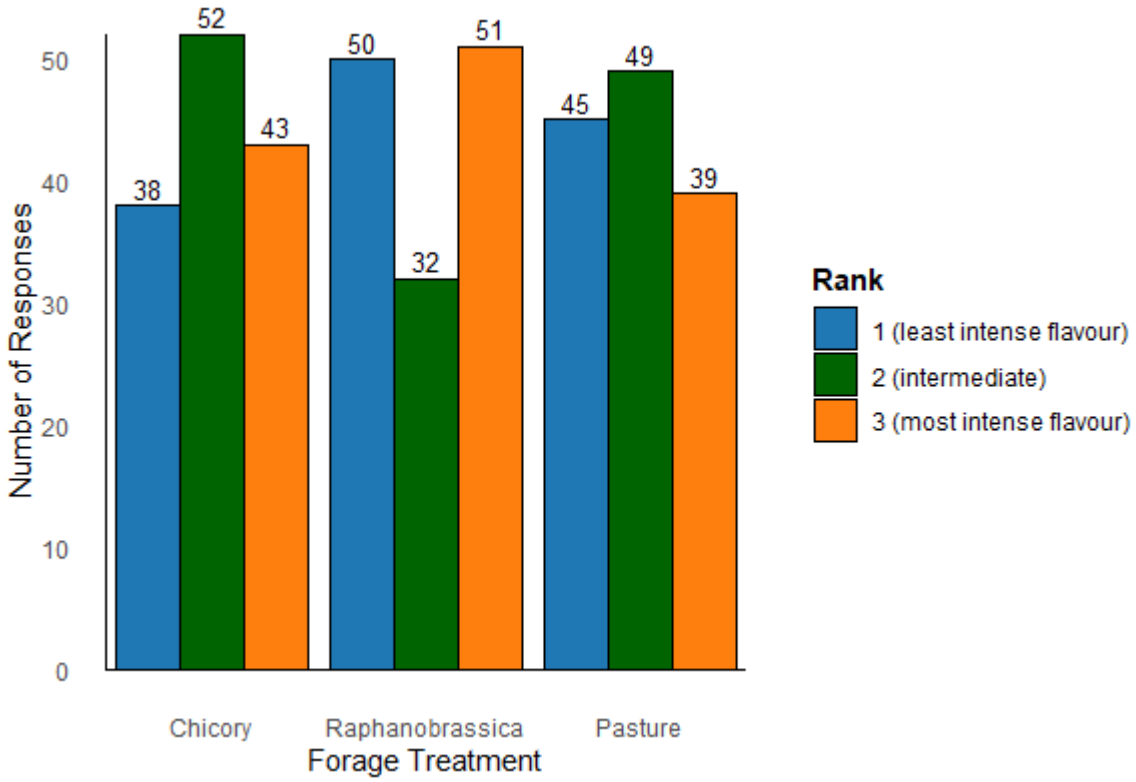


**Figure 4.4: Consumer ranking of flavour intensity of beef samples from steers grazed on chicory, raphanobrassica, or pasture, in the 2022 study.**

## 4.2 Regressions and Relationships

### 4.2.1 Simple Linear Regressions

Marbling score and carcass weight had a positive relationship with IMF ($p<0.05$, Figure 4.5, Table 4.14). The IMF accounted for 86-87% of the variation of SFA and MUFA, and for 33% of the variation in PUFA ($p<0.05$, Figure 4.5, Table 4.14). Ultimate pH had no relationship with shear force, either as a linear ($p>0.05$, Figure 4.5, Table 4.14), or quadratic relationship (data not shown).

**Table 4.14: Summary of simple linear regressions relating carcass and fat characteristics.**

| Variables | $R^2$ | RMSE* | Prediction Equation | P value |
|---|---|---|---|---|
| IMF[1] and marbling score | 0.357 | 2.25 | IMF = 2.53 + 1.16 (MS) | <0.001 |
| IMF[1] and CWT[2] | 0.259 | 2.31 | IMF = 8.58 + 0.04 (CWT) | <0.001 |
| SFA[3] and IMF[1] | 0.873 | 2.97 | SFA = 2.58 + 3.35 (IMF) | <0.001 |
| MUFA[4] and IMF[1] | 0.864 | 3.40 | MUFA = 1.35 + 3.68 (IMF) | <0.001 |
| PUFA[5] and IMF[1] | 0.327 | 1.44 | PUFA = 1.57 + 0.06 (IMF) | <0.001 |
| Peak load and pH | 0.007 | 0.77 | PL = 0.70 + 0.74 (pH) | 0.398 |

*Root mean square error.
[1]Intramuscular fat concentration (%).
[2]Carcass weight (kg).
[3]Saturated fatty acid concentration (mg/100g raw meat).
[4]Monounsaturated fatty acid concentration (mg/100g raw meat).
[5]Polyunsaturated fatty acid concentration (mg/100g raw meat).

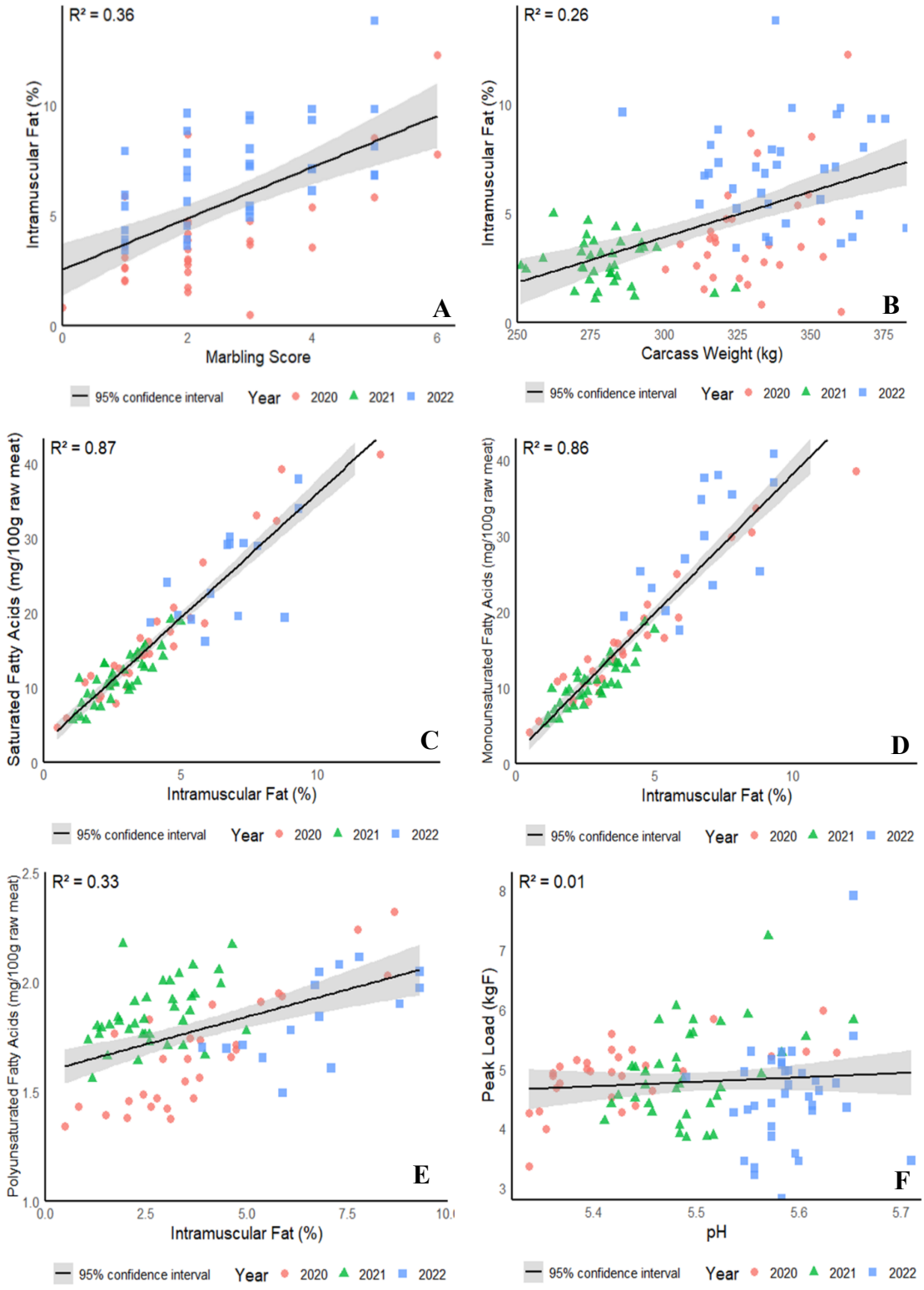


**Figure 4.5: Relationships from beef samples collected from steers finished on chicory, raphanobrassica, or pasture, between intramuscular fat (IMF), carcass traits, and fatty acid composition across all studies (2020, 2021, and 2022). Panels: (A) marbling score vs IMF, (B) carcass weight v IMF, (C) IMF v saturated fatty acids, (D) IMF v monounsaturated fatty acids, (E) IMF v polyunsaturated fatty acids, (F) pH vs peak load.**

### 4.2.2 Stepwise Regressions

Forage treatment, carcass weight, and start liveweight did not contribute to the stepwise model predicting IMF concentration. Together, marbling score and year accounted for 54.79% of the variation in IMF concentration, with marbling score accounting for most of this variation (35.70%) (Table 4.15).

**Table 4.15: Stepwise regression predicting intramuscular fat concentration (%) from marbling score and study year.**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | Marbling score | 0.3570 | 0.3570 | 0.3466 |
| 2 | Study year | 0.1909 | 0.5479 | 0.5331 |

Intramuscular fat concentration was the only variable retained in the model predicting SFA, explaining 87.31% of the observed variation (Table 4.16). Although year of study and forage treatment did not contribute to the SFA prediction model, they both contributed to the prediction of MUFA and PUFA, with study year contributing 3.79% and 33.32%, and forage treatment contributing 0.61% and 5.35% to the variation in MUFA and PUFA, respectively (Table 4.17 and 4.18). Intramuscular fat content also explained 86.44% and 32.69% of the variation in MUFA and PUFA respectively (Table 4.17 and 4.18). Carcass weight did not contribute to any of the prediction models for SFA, MUFA, and PUFA.

**Table 4.16: Stepwise regression predicting saturated fatty acid concentration (mg/100g of raw meat) from intramuscular fat (IMF) concentration (%).**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | IMF concentration | 0.8731 | 0.8731 | 0.8715 |

**Table 4.17: Stepwise regression predicting monounsaturated fatty acid concentration (mg/100g of raw meat) from intramuscular fat (IMF) concentration (%), study year, and forage treatment.**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | IMF concentration | 0.8644 | 0.8644 | 0.8715 |
| 2 | Study year | 0.0379 | 0.9023 | 0.8986 |
| 3 | Forage treatment | 0.0061 | 0.9084 | 0.0038 |

**Table 4.18: Stepwise regression predicting polyunsaturated fatty acid concentration (mg/100g of raw meat) from intramuscular fat (IMF) concentration (%), study year, and forage treatment.**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | IMF concentration | 0.3269 | 0.3269 | 0.3185 |
| 2 | Study year | 0.3332 | 0.6601 | 0.6471 |
| 3 | Forage treatment | 0.0535 | 0.7136 | 0.6947 |

In the stepwise model for peak load and area, IMF, pH, and study year contributed 5.53%, 3.03%, and 9.67%, respectively to the peak load model (Table 4.19), and 3.02%, 3.74% and 9.05% respectively to the peak area model (Table 4.20). Additionally, carcass weight contributed 10.60% to the model for peak area (Table 4.20). Forage treatment did not contribute to either shear force prediction models.

**Table 4.19: Stepwise regression predicting peak load (kgF), from intramuscular fat (IMF) concentration, pH, and study year.**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | IMF concentration | 0.0553 | 0.0553 | 0.0458 |
| 2 | pH | 0.0303 | 0.0856 | 0.0669 |
| 3 | Study year | 0.0967 | 0.1823 | 0.1483 |

**Table 4.20: Stepwise regression predicting peak area (kgF), from carcass weight, intramuscular fat (IMF) concentration, pH, and study year.**

| Step | Variable | Partial $R^2$ | Model $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | Carcass weight | 0.1060 | 0.1060 | 0.0970 |
| 2 | IMF concentration | 0.0302 | 0.1362 | 0.1186 |
| 3 | pH | 0.0374 | 0.1736 | 0.1484 |
| 4 | Study year | 0.0905 | 0.2641 | 0.2253 |

# Chapter 5

## Discussion

# Chapter Five: Discussion

This study aimed to investigate the effects of the alternative forages of chicory and raphanobrassica compared to ryegrass-based pastures on the carcass traits, meat quality attributes, fatty acid profile, and sensory characteristics of steers. This was done using studies performed over three years (2020-2022). When considering the individual studies, no significant results showed the same pattern consistently over the three studies. This was also seen in the analysis of the combined dataset, which found no differences in any of the measured traits. Certain results, such as dressing out percentage, pH, and the PUFA to SFA ratio were significant in multiple studies, though showed differing patterns, indicating that factors other than forage species may be influential if they are not held constant between studies.

## 5.1 Carcass Characteristics

Different study years showed some variation in carcass traits. The greater carcass weight of chicory fed steers in the 2022 study may be associated with greater feeding value of chicory compared to pasture (Table 2.4, Dairy NZ (2021)), however this superior feeding value was not evident in other study years suggesting seasonal effects were working differently on the feeding value of each forage.

Interestingly, the dressing out percentage of pasture fed steers was greater in the 2020 study and lower in the 2021 study, compared to that of steers finished on chicory or raphanobrassica. Dressing out percentages have been known to be influenced by levels of gut fill that can differ with different forages (Duckett et al., 2013; Maciel et al., 2022; Somasiri et al., 2015). Carcasses from livestock grazed on forage crops are often associated with less gut fill compared to ryegrass-based swards, because of the forages greater feeding value and digestibility that allows for a faster rumen outflow rate, leading to higher dressing out percentages (Phillips, 2025). However, this effect on carcass characteristics seen in individual years was not observed in the combined dataset. Dressing out percentages may also have been influenced by time off feed prior to slaughter, which may have varied between study years. Future considerations of forage effects on dressing out percentages may need to consider controlling time off feed or recording times of feed, to be able to make suitable conclusions.

Although no differences in intramuscular fat (IMF) concentration were detected in the present study, other studies have shown that variations in forage diet can affect IMF concentration (Subiabre et al., 2024). The mean range of IMF concentration reported in the present study (4.4-4.7%) can be considered above average, in comparison to IMF concentrations in beef from steers finished on traditional pastures of similar age and weight, which are noted as having an IMF% between 1.3-5.7% (Coleman et al., 2023; Martín et al., 2022). This potentially reflects a greater digestibility and metabolisable energy content of the finishing diets used across the three study years compared to other

studies. The influence of forage metabolisable energy on driving IMF deposition, independent of other factors, warrants further investigation.

When considering the variation that can occur from season-to-season or year-to-year in grazing systems for beef cattle, these findings indicate that forage treatments used during finishing period (between 20 and 48 days) may not manipulate or alter carcass weights, intramuscular fat (IMF) concentration, slaughter weight, or marbling score of beef steers. Other factors, such as the quantity of feed, may be more important to consider than forage type.

## 5.2 Meat Quality Attributes

As with carcass traits, the combined analysis over all three study years found no effects of forage treatment on any of the measured meat quality attributes, although some differences were observed in some of the study years.

Forage treatments had an effect on ultimate pH, with pH in pasture grazed beef greater than chicory grazed beef in the 2021 study, but lower than chicory grazed beef in the 2022 study. Ultimate pH is determined by the relative concentration of glycogen in the muscle at the time of slaughter, which is mainly affected by pre-slaughter stresses and nutrition (Carrasco-García et al., 2020; Loudon et al., 2019). It is possible that the greater pH observed in the pasture treatment in the 2021 study may be a result of the lower feeding value of the pasture treatment, which may have reduced muscle glycogen concentrations at the time of slaughter, subsequently leading to greater postmortem pH. However, results between studies were inconsistent, and all measured pH were within the expected range of 5.4-5.7 for beef meat when standard postmortem biochemistry has occurred (Young et al., 2005). The pH values of beef produced from each forage across all studies indicate acceptable and high-quality beef, with no incidence of dark-cutting (Young et al., 2005). The studies by Duckett et al. (2013), Rodríguez-Pereira et al. (2025), and Schmidt et al. (2013) also found no difference in ultimate pH of beef from cattle grazed forage diets alternative to pasture and also had a pH within the 5.4-5.7 range associated with typical post-mortem muscle.

Slight variations in tenderness and colour were observed in the 2020 and 2021 studies, respectively. Although beef from chicory was redder, yellower, and more saturated/intense, the difference between CIE $L^*$, $a^*$, and $b^*$ values were relatively small, and are unlikely to affect consumers subjective purchasing decisions (Phillips, 2025). Ultimately, any differences detected in meat quality attributes from beef from different forage treatments were small and not observed consistently across different years, with each forage able to produce beef of similarly acceptable high quality.

## 5.3 Fatty Acid Deposition

There were no forage treatment effects on the concentration of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA), and similar findings have been reported by other studies (Duckett et al., 2013; Marley et al., 2017; Schmidt et al., 2013). In both the 2020 and 2022 studies, beef from pasture fed steers had a greater ratio of polyunsaturated fatty acids (PUFA) to SFA than that of pasture fed beef. Interestingly, no differences in SFA or PUFA concentration were observed in either these study years, although a trend towards significance was detected in the 2022 study.

Differences in fatty acid concentration and ratios are likely a result of differences in the fatty acid content of each forage. Phillips (2025) found that chicory and pasture had a greater total PUFA and n-3 concentration than raphanobrassica, and that chicory had a greater n-6 concentration than pasture and raphanobrassica. The greater PUFA concentration of pasture compared to raphanobrassica could account for the greater ratio of PUFA to SFA found in the beef, observed in the 2020 and 2022 studies. The effect of forage treatment grazed by the steers was not observed when analyzing the combined dataset, suggesting that any changes in fatty acid concentration in beef are variable and dependent on multiple factors. The strong relationship of SFA and MUFA concentration with IMF from regression analysis suggests that fatty acid concentration in beef is more related to the amount of fat deposited rather than forage treatment.

## 5.4 Sensory Traits

For the assessment of overall liking by the consumer panel, each treatment received similar allocations of the highest score (rank of 3), although chicory received notably less of the lowest ranking (rank of 1). The mean overall liking rank was driven by what consumers like less (i.e. consider to be bad/lower quality) rather than what they enjoy. Although no differences were found in the objective measures of tenderness (shear force values) and juiciness (drip and cooking losses), consumers did rank beef from chicory fed steers as more tender than pasture fed, and beef from chicory fed steers juicier than beef from steers fed pasture or raphanobrassica. The distributions for both tenderness and juiciness are relatively similar, indicating that consumers may have not been able to separately distinguish tenderness and juiciness, hence the industry terminology of ‘succulence’ which takes into account aspects of both tenderness and juiciness. Consumers perception of beef from chicory fed steers as having greater juiciness and tenderness than beef from other forage treatments likely contributed to the chicory treatment’s greater overall liking. Thompson (2004) found high correlations ($r>0.86$) between all sensory attributes, showing that individual results are confounded by other sensory attributes. Differences in tenderness, juiciness, and flavour are often attributed to differences in IMF concentration (Miller, 1994), however there were no differences in IMF concentration of beef from steers in different forage treatments in the 2022 study, which was the source of beef for the sensory evaluation in this study.

Consumers were dichotomous in their ranking of the flavour-intensity associated with raphanobrassica, showing a distinctive high- or low-ranking pattern. Similar results were seen in sensory analysis of lamb grazed on raphanobrassica (Phillips, 2025). The ranking of beef from chicory and pasture grazed steers were distributed more to favorable ranks, indicating that a more acceptable flavour is associated with beef from steers fed these forages.

Similar studies (Bakker et al., 2021b; Duckett et al., 2013; Langlie, 2020; Rodríguez-Pereira et al., 2025) found that forage treatment had no effect on sensory characteristics of beef. Bakker et al. (2021b) concluded that any dietary effects on sensory traits were 'dissipated' by a common finishing period, indicating that any potential effects of finishing diet on sensory properties of beef are likely subtle. Additionally, Phillips (2025) found no difference in the sensory characteristics of lamb finished on pasture, chicory, and raphanobrassica. As sensory analysis was only completed on the samples from the 2022 study, it would be valuable to perform sensory analysis on beef samples from other years, to determine whether this effect is consistent over different years and for cattle on forages for a longer period.

## 5.5 Regressions and Relationships

As IMF is a late maturing tissue (Pethick et al., 2004; Vernon, 1981), IMF concentrations typically increase with age. Age, slaughter weight, and subsequent carcass weight act in the same way to be driver of IMF concentration, as more mature, heavier animals are associated with greater IMF concentrations (Pethick et al., 2004). Additionally, Duckett et al. (1993) and Lorenzen et al. (1993) found that increases in slaughter weight and carcass weight lead to increases in IMF concentration and marbling score, respectively. As a subjective measure of IMF concentration, marbling score is often found to represent a high proportion of the variation in IMF concentration, as high as 88% (Stewart et al., 2024), although in this study only marbling score only accounted for 36% of the variation in IMF.

The present study found high $R^2$ between IMF and SFA/MUFA concentrations and a moderate $R^2$ between IMF and PUFA concentrations. Similarly, Realini et al. (2021) reported an $R^2$ of 0.99 between IMF and both SFA and MUFA concentrations in lamb meat, and a lower $R^2$ of 0.63 between IMF and PUFA concentration. These findings explain the large contribution of IMF in each of the stepwise models of SFA, MUFA, and PUFA concentration. The relationship between IMF and PUFA concentration was weaker than that of IMF and SFA, or MUFA, although carcass weight contributed relatively more to the PUFA prediction model. Overall, the fatty acid composition seems to be driven by the extent of growth that the steer achieved and the parallel deposition of IMF.

## 5.6 Implications

The use of alternative forages to pasture (chicory and raphanobrassica) had no adverse effects on carcass traits, beef quality, and fatty acid profile. These crops can be used by beef producers to finish beef steers resulting in similar carcass traits, beef quality, and fatty acid profiles to steers finished on pasture swards. This means that beef producers can incorporate these alterative forages into the finishing diets/swards to produce beef that is of similarly high quality to that which is achieved on pasture.

There was a subtle preference for chicory finished beef by the consumer sensory panel. This would not affect the income of New Zealand beef producers as meat quality and sensory traits are not part of carcass classification for cattle and subsequent farmer payment in New Zealand. The difference in ranking between the forages being only small suggests that all finishing forages tested will produce beef that will generally be equally acceptable to consumers. Thus, beef producers can focus on utilising chicory and raphanobrassica over the summer finishing period, when pasture supply and quality is typically low, to maintain high growth rates, reach target slaughter weights sooner, or achieve greater slaughter weights.

## 5.7 Limitations

A primary limitation of this study is the relatively small sample size used in each year. Each treatment group was relatively small (10-14 steers) compared to similar studies. Larger treatment groups would have reduced the influence of individual animal variation and increased the statistical power to detect any true differences between treatment groups. Additionally, a consistent and longer finishing period may have provided more consistent and observable effects between treatment groups and different study years.

The average liveweight of steers at the beginning of each study also varied considerably (2020: 623.9kg, 2021: 512.0kg, 2022: 595.3kg). This reflects the potential role for steers used in each year being at relatively different percentages of mature liveweight, which likely impacted growth rates and tissue deposition, impacting carcass traits, meat quality, and fatty acid profiles. Additionally, steers used in the 2022 study used dairy beef steers (Hereford x Friesian), rather than Angus steers, sourced from a different vendor than the previous two studies. These dairy beef steers genetic makeup would have been considerably different to that of the Angus steers, altering their growth patterns. If cattle of similar liveweights, maturity levels, and genetics had been used in each study, more consistent forage treatment effects may have been observed between study years.

The study is also limited to the climatic conditions typical of the Canterbury region, which may not be representative of all regions in New Zealand. Different environmental climatic conditions between regions causes variations in pasture supply and quality, with summer pastures in Canterbury often found to be of greater quality than pastures from Northern regions of New Zealand (e.g. Waikato) (Litherland et al., 2002). The use of forage crops compared to summer pastures in warmer northern regions, such as the Waikato, may

cause greater differences in growth rates, carcass traits, meat quality attributes, and beef fatty acid profile, as the pasture will likely be of a lower quality.

In the first study (2020) the pasture treatment group was located on a different farm than all other treatment groups, which may also have impacted forage crop growth rates and animal performance. The pasture treatment in the 2020 study also consisted of Italian ryegrass, which is associated with more seedhead and greater fibre levels over summer compared to perennial ryegrass. This difference in pasture composition and quality between years may also have affected the results. Varying climatic conditions between study years will also have impacted the findings, potentially confounding any forage treatment effects. The provision of lucerne balage in each study may have reduced forage treatment intake, which may have limited the potential for any forage effects to be expressed. Furthermore, the findings of this study are limited to the forage crops chicory and raphanobrassica in stand-alone swards, and to pastures consisting of Italian ryegrass, red, and white clover pastures, or perennial ryegrass and white clover pastures. The effects of other alternative forages, their use in mixed swards, and pastures with differing compositions on beef production in New Zealand requires more research.

It also would have been valuable to consistently record all the same variables in each year, to provide more statistical power to the analysis of some variables. Some carcass traits (such as marbling score) were not recorded in each study year. Analysis of the nutrient profile of each forage would also have been valuable, but was not performed due to the commercial limits of the studies, which focused on forage effects on carcass and meat rather than forage quality. However, having the nutritive value information may have helped to explain the mechanism by which the forages were having their effect and so, measuring the feed chemical composition would be vital for any further studies performed to understand how forages affect carcass traits and meat quality.

Additionally, consumer sensory analysis could have been completed on beef samples from each study year, to determine if the observed differences in sensory properties was consistent over different studies or only observed in 2022. A consideration of alternative sensory techniques that go beyond ranking may also be valuable to pick up additional information or be more sensitive to the sensory perception of the beef from the different forage treatments.

# Chapter 6

## Conclusion

# Chapter Six: Conclusion

This project sought to investigate the effects of alternative summer forages on beef production, from paddock to plate. To achieve this, three studies were combined, each comparing the carcass traits, meat quality attributes, and fatty acid concentrations of beef steers finished on the summer forages, chicory and raphanobrassica, compared to steers finished on a typical ryegrass and white clover pasture. Additionally, one study also included the analysis of the sensory characteristics of beef, to ascertain how each forage affected the carcass traits, eating quality, and fatty acid composition of the final product.

Ultimately, forage treatment had no effects on the carcass traits, meat quality attributes, or fatty acid concentrations of the beef steers finished on them. This showed that beef from steers finished on each summer forage was of the same quality, meeting the same high standards as beef produced on typical New Zealand pastures. A consumer panel did find that the sensory characteristics (overall liking, tenderness, juiciness, and flavour intensity) of beef from steers finished on chicory were subtly more favourable than the beef from steers finished on pasture.

The results of these studies indicate that New Zealand beef producers can utilise these summer forage crops for finishing cattle, to produce beef of similarly high quality while maintaining cattle growth rates when pasture supply or quality is low, allowing them to finish animals faster or to heavier slaughter weights. Further in-depth studies to consider the sensory and fatty acid composition aspects of beef from cattle finished on different forages may be of interest if New Zealand were to adopt a classification or grading system that rewards farmers for meat of superior eating quality or with specific quality attributes.

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