

The effect of breed and days on feed on feedlot performance,  
ultrasound and meat quality traits, and dissected body composition  
of British, European and *Bos indicus* steers



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### **Statement of Originality**

This is to certify that the content of the present thesis is my own work and has not been submitted for any other tertiary degrees or purpose.

I certify that the intellectual content of the present thesis is the product of my own work, and all assistance received in preparing the present thesis and all sources have been acknowledged.

Jillian Elizabeth McCowen Burgess

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Jillian Elizabeth McCowen Burgess

### **Acknowledgement of AI Use**

During the preparation of the present thesis the author used Chat GPT (GPT-4o) for the purposes of conducting additional literatures searches to ensure the accuracy of statements regarding research gaps in existing literature. This was conducted after a comprehensive manual search has been completes by the author.

The author confirms that no text was modified by generative AI during the preparation of the present thesis. The author takes full responsibility for the submitted thesis and ensure the work is their own and has used generative AI within the parameters of use.

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## **Preface**

Each experimental chapter of the present thesis is formatted to be published in peer-reviewed scientific journals following the submission of the present thesis.

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## **List of Abbreviations**

The following abbreviated terms have been used throughout the thesis:

ADF: Acid detergent fibre

ADG: Average daily gain

B\_CCW: Bone as a percentage of cold carcass weight

B\_EBW: Bone as a percentage of empty bodyweight

BCS: Body condition score

BL: Blade and front leg

BSR: Brisket and spareribs

BW: Bodyweight

CB: Carcass bone

CC: Carcass components

CCW: Cold carcass weight

CF: Carcass fat

CL: Carcass lean

CP: Crude protein

DM: Dry matter

DMI: Dry matter intake

DOF: Days on feed

EBV: Estimated Breeding Value

EBW: Empty bodyweight

EE: Ether extract

EMA: Eye muscle area

F\_CCW: Fat as a percentage of cold carcass weight

F\_EBW: Fat as a percentage of empty bodyweight

FCR: Feed conversion ratio

GIT: Gastrointestinal tract

HCW: Hot carcass weight

IMF: Intramuscular fat

KPH: kidney, pelvic and heart

L\_CCW: Lean as a percentage of cold carcass weight

L\_EBW: Lean as a percentage of empty bodyweight

LMY: Lean meat yield

LR: Loin and Rump

MBW: Metabolic bodyweight

MSA: Meat Standards Australia

NC: Neck and chuck

NCB: Non carcass bone

NCC: Non-carcass components

NCF: Non carcass fat

NCL: Non carcass lean

NDF: Neutral detergent fibred

RFI: Residual feed intake

RG: Residual gain

SBW: Shrunken bodyweight

WSR: Wholesale ribset

## Thesis Abstract

The global population is rapidly growing, increasing protein requirements and thus, driving the beef feedlot industry to optimise efficiency and productivity. Accurately determining the time of slaughter to achieve the optimal carcass endpoint of cattle is integral to achieving the maximum carcass yield and minimising feed and fat wastage. Whole body and carcass composition of feedlot cattle is affected by several factors including diet, breed, and feeding length, amongst others, which in turn determine the optimal carcass endpoint. Physical dissection is used to determine whole body and carcass composition, but such data is limited due to the immense labour, infrastructure and cost. The literature review revealed that existing prediction models for animal growth and nutrition utilise decades old data with narrow breed diversity (e.g. British breeds), thus the accuracy of these models for modern beef genetics are unknown. Therefore, there is a need of detailed animal performance and body composition data of growing feedlot cattle to understand the rate of muscle and fat deposition in different depots of the main biotypes of cattle. This information is essential to target and achieve market specifications and optimise carcass value. The general objective of the present thesis was to determine the effect of breed and days on feed (DOF) on the feedlot performance, feed efficiency, whole body and carcass composition, and carcass yield and quality. The general hypothesis was that breed and DOF affect all aspects outlined in the general thesis objective.

A serial slaughter factorial experimental design with Angus ( $n = 30$ ; initial BW of  $361 \pm 5.3$  kg), Brahman ( $n = 30$ ;  $355 \pm 5.3$  kg), and Charolais ( $n = 29$ ;  $317 \pm 5.3$  kg) steers were inducted into the feedlot and fed for up to 200 DOF. Animals were transitioned onto a finisher diet over a 21-day period, with real time feed intake measured by electronic feeders. Six steers of each breed ( $n = 18$ ) were randomly selected for slaughter every 50 days, ultrasound of muscle and fat, and BW were recorded prior to transportation for slaughter. At

slaughter, all non-carcass components (NCC) were collected, cleaned, and bone, lean and fat tissues dissected and weighed. Carcasses were chilled at 3-4 °C and graded 16-24 hours post slaughter, then broken down into six wholesale primal cuts, and finally the bone, lean and fat tissues of these carcass components (CC) were dissected and weighed.

Chapter 3 aimed to determine the effect of breed, DOF and their interaction on feedlot performance, dry matter intake (DMI) and feed efficiency. Breed affected all variables ( $P < 0.05$ ) except residual feed intake (RFI) corrected by ultrasound fat ( $P > 0.05$ ). In contrast, DOF only affected shrunk BW, and body condition score, DMI, average daily gain (ADG), and gain to feed ratio ( $P > 0.05$ ). The breed  $\times$  DOF interaction only affected final shrunk BW, residual gain, and RFI corrected by subcutaneous fat ( $P < 0.05$ ). Both Angus and Brahman steers had greater initial BW and body condition score (BCS) compared to Charolais steers ( $P < 0.05$ ). However, final shrunk BW was not different between breeds at 50 DOF and it was lowest in Brahman afterwards ( $P < 0.05$ ). The DMI and ADG was slowest and feed conversion ratio highest in Brahman compared to Angus and Charolais steers ( $P < 0.05$ ). Charolais steers were the most efficient with the lowest RFI and greatest RG ( $P < 0.05$ ). This chapter highlighted the need for breed and DOF to be considered in prediction models of growth and nutrition, and notably when making management decisions such as sorting animals into feeding and marketing programs to optimise productivity, profitability and minimise feed wastage.

The objective of Chapter 4 was to determine the effect of breed and DOF on meat quality traits through ultrasound scanning and carcass grading. The breed  $\times$  DOF interaction affected all ultrasound and grading variables ( $P < 0.05$ ) except meat standards Australia (MSA) marbling, ultrasound kidney fat and dressing percentage ( $P > 0.05$ ). Ultrasound scanning showed that Angus had the greatest rib, P8, and kidney fat at 200 DOF ( $P < 0.05$ ) but no differences between breeds existed at 0 DOF ( $P < 0.05$ ). In contrast, Angus had the greatest

marbling ( $P < 0.05$ ) but similar eye muscle area to Charolais at carcass grading, with the differences between breeds becoming greater over time ( $P > 0.05$ ). Breed and DOF affected body and carcass composition measured with ultrasound and carcass grading with differences between breeds increasing with DOF. Therefore, prediction models and sorting animals into feeding programs should consider both factors to produce uniform carcasses at slaughter and optimise productivity and profitability.

Chapter 5 studied the effect of breed and DOF on the whole body and carcass composition through physical dissection. Breed  $\times$  DOF affected the proportion of dissected bone, lean and fat from empty body weight (EBW), NCC and CC ( $P < 0.05$ ). The EBW of Charolais steers had lower fat proportion compared to Angus and Brahman at 0 DOF but both Charolais and Brahman steers had lower fat at 200 DOF. Angus had greater fat in both NCC and CC compared to the other breeds ( $P < 0.05$ ). At 200 DOF, Charolais had the greatest CC lean ( $P < 0.05$ ) as a proportion of empty BW (EBW), Brahman intermediate, and Angus the least ( $P < 0.05$ ), whereas the opposite was observed for CC fat ( $P < 0.05$ ). Breed and DOF affects tissue composition both as %EBW and cold carcass weight (CCW). Therefore, such interaction should be considered when determining the optimal carcass endpoint of each breed.

Chapter 6 investigated the effect of breed and DOF on the proportion and tissue composition of six wholesale primal cuts including the neck and chuck (NC), blade and front leg (BL), brisket and spareribs (BSR), wholesale ribset (WSR), loin and rump (LR) and butt. Breed and DOF as main factors affected all primal and tissue weights as %CCW ( $P < 0.05$ ), except NC was not affected by breed ( $P > 0.05$ ). As a %CCW, Angus had greater BSR, WSR and LR compared to the other breeds, whereas Charolais had greater BL and butt ( $P < 0.05$ ). Brahman steers had intermediate LR and butt, but lower BSR and WSR compared to Angus, and lower BL compared to Charolais as %CCW ( $P < 0.05$ ). Angus had the greatest

proportion of fat, Charolais the greatest lean and Brahman intermediate in most primal cuts as %CCW ( $P < 0.05$ ), except similar butt fat, and WSR, BSR, LR and BL lean compared to Angus ( $P > 0.05$ ). The effect of breed and DOF demonstrated differences in allometric growth patterns of body parts and tissues. This information can be used by processors to forecast lean meat yield and value of primal cuts and could be used to adjust pricing grids.

Results from the present thesis demonstrate that both breed and DOF affect feedlot performance, feed efficiency, carcass yield and quality, whole body and carcass composition. Therefore, these factors should be considered when making management and marketing decisions such sorting strategies, length of the feeding program, optimal slaughter points, lean meat yield, and grid prices of both feeder and slaughter cattle. Furthermore, the results of the present thesis can be used to develop new and improve existing prediction models of animal growth, feed intake, efficiency, economic outcomes, and beef yield.

Key words: whole body, carcass composition, efficiency, performance, breed, days on feed

Chapter 1 - Feed efficiency, carcass quality and yield, and  
body and carcass composition of feedlot cattle as effected  
by breed and days on feed: a review

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## 1.1. Abstract

The objective of the present review was to analyse existing literature comparing feedlot performance, carcass quality and whole body and carcass composition of British, European and *Bos indicus* feedlot steers over increasing DOF. Predicting the optimal carcass endpoint through factors affecting the whole body and carcass composition has been a point of research for decades but currently, there are no models that can precisely determine this endpoint at an individual animal level. Additionally, not all prediction considers the effect of breed on animal performance and carcass composition. Furthermore, the present review identified that there is no recent data comparing the effect of breed and days on feed (DOF) on the whole body and carcass composition using the gold standard method of physical dissection of bone, lean and fat. Existing body composition data is up to 80 years old using mostly British breeds and therefore it is unknown if the results still apply to modern breed and herd genetics due to intensive selective breeding in recent decades. Thus, there is a need to collect updated data on the effects of breed and DOF on feed intake and efficiency, carcass quality, and whole body and carcass composition by physical dissection, using the most popular beef biotypes (i.e. British, European and *Bos indicus*) with modern genetics. This data presents the opportunity to renew the baseline and reference data for prediction models to assess their accuracy and adjust equations to correctly reflect modern genetics of beef breeds.

## 1.2. Introduction

As the population rapidly increases globally, there is greater pressure on the beef industry to increase production to meet rising protein requirements whilst maintaining environmental sustainability. In 2024, the US has the greatest feedlot production with approximately 11.4 million cattle on feed, followed by Brazil with a record 8.8 million head, then Australia at 1.5 million and Canada at 1.1 million (ABIEC, 2025; MLA, 2025; StatCan, 2025; USDA, 2025). Feedlot cattle represent approximately 40% of beef production (MLA, 2025) and play a significant role in food supply in extreme climate conditions such as drought, without increasing land usage such as in grazing systems (Greenwood, 2021).

For producers, it is critical to achieve the optimal carcass endpoint, defined as the carcass weight and other market specifications that maximises the profit of the slaughtered animal (MLA, 2024), whilst minimising wastage in the form of feed and excess carcass fat.

However, the optimal endpoint is affected by numerous variables including breed, diet and days on feed, among others. Thus, the goal is to accurately predict the optimal carcass endpoint from the early stages at the feedlot (e.g. induction). Nutritional simulation models can be used to help predict carcass endpoints under different nutritional, genetic, management, and environmental factors (Tedeschi et al., 2005). Some nutritional simulation models available to producers include the Beef Cattle Nutrient Requirement Model (BCNRM) (National Academies of Sciences & Medicine, 2016), Cattle Value Discovery System (CVDS) (Tedeschi, 2003) and Ruminant Nutrition System (RNS) (Tedeschi, 2016). However, these aforementioned models were developed using whole body and carcass composition data collected 25 – 80 years ago from British breeds (Guiroy et al., 2001; Hankins & Howe, 1946). The methodology to measure body composition comprises physical dissection into bone, lean and fat tissues, followed by subsequent chemical analysis (Lunt et al., 1985; Navajas et al., 2010). This data is then used to develop prediction equations of

energy and protein retained (gained) or lost, which drives nutrition simulation models and can be used to predict the cost of gain and changes in carcass yield and quality (Freer et al., 2007). However, body composition analysis is rarely performed due to its immense cost, labour and infrastructure requirements and overall impracticality (Navajas et al., 2010). Therefore, most models do not fully include the effect of beef biotypes or specific breeds on whole body and carcass composition but instead may include broader factors such as frame size or mature body weight (Tedeschi, 2015). Additionally, the composition of carcass and non-carcass components determines whole body composition and the effect of breed and feeding duration (Marcondes et al., 2010). As a result, the accuracy of the equations used in these simulation models (and of the entire models) is uncertain on modern breeds, genetics and management (Smith et al., 2018).

The present literature review described and critically discussed the factors influencing feedlot performance, body composition, and carcass characteristics, with particular emphasis on days on feed since feedlot entry and breed biotypes (British, European, and *Bos indicus*). This review examined the temporal patterns of bone, muscle and fat accretion, the methods used to quantify these tissues and how these data inform nutritional and growth models with implications for animal physiology, production efficiency, and economic outcomes.

Therefore, this review also linked empirical data to the development of precise, biotype-specific models to determine the optimal carcass endpoint in feedlot cattle synthesising evidence of the trade-off between cost of gain and carcass quality across different market specifications.

### 1.3. Feeding programs and markets for feedlot cattle

Feedlots use different feeding programs depending on the production capacity and targeted markets. Feeding programs are defined by the number of days on feed (DOF) from feedlot

induction, which is directly associated with cost of production and carcass endpoint achieved. Broadly, feeding programs consist of short, mid and long fed, which usually cater to the domestic supermarkets, higher-end domestic restaurants and then export markets, respectively (Greenwood, 2021). Generally, DOF range from 50-100 days, 150-200 days and 200-600 days for the short, mid and long fed markets, respectively (Greenwood, 2021). However, the exact number of days for each program and their designated markets will vary depending on the production system, target markets and location, diet, induction body weight (BW) and breed amongst others, varying in each country (Greenwood, 2021).

Producers aim to assign cattle to feeding programs that will result in the greatest economic return by carcasses satisfying the target market specifications including carcass yield and quality. Angus and Wagyu are often placed into their separate breed programs whilst the remaining animals (purebred or crossbred) are assigned to markets based on their induction BW and potential for growth measured through mature body size or frame (Harrison & Oltjen, 2020). Sorting of animals to feeding programs is most often based on factors such as induction BW and breed (i.e. Angus and Wagyu) or breed biotypes (e.g. European) to produce consistent carcass quality reduce the marketing of animals outside market specifications, typically being over or underfed (Pyatt et al., 2005). Mixing animal biotypes with different maturity types (early vs late maturing) and growth trajectories exacerbates this heterogeneity in optimal endpoints, reducing profits (Pyatt et al., 2005).

These factors highlight the opportunity to reevaluate sorting strategies to pen cattle based on the number of DOF required to achieve similar optimal carcass endpoints rather than a set DOF program for all animals. This could result in more uniform carcasses in terms of weight, lean meat and fatness content for the intended market specifications, reducing economic penalties excess time in the feedlot, and feed wastage. Additionally, this may optimise productivity and efficiency, reducing their overall carbon footprint (Greenwood, 2021).

#### 1.4. Feed intake

Feed intake and efficiency are critical to the feedlot industry, because of the influence on average daily gain (ADG), composition of tissue growth, and cost of gain, thereby affecting DOF required to achieve a target carcass endpoint and market specifications. Feed costs represent one of the greatest variables costs of feedlot production and hence, quantifying and understanding differences in feed intake and efficiency is of great importance to production systems (Crowley et al., 2010; Na & Guan, 2022). There are numerous variables that control the dry matter intake (DMI) of feedlot beef cattle including but not limited to diet chemical and ingredient composition, BW and composition, age, maturity and hormonal implant status, among others (Freer et al., 2007). However, it should be noted that these complex mechanisms continue to be studied as their effects are not always fully understood (Freer et al., 2007).

Studies focusing on feedlot performance, feed intake and feed efficiency, have noted differences in these traits between *Bos taurus* cattle such as British and European (also referred to as Continental), and *Bos indicus* biotypes (Freer et al., 2007). In particular, differences in feed intake have been identified, with several contributing factors and proposed explanations. Feed intake is regulated by the central nervous system and hormones (e.g. leptin) which transmits signals in feedback loops regarding animals' energy balance (Gouvêa et al., 2022). Leptin is a hormone secreted by white adipose tissue with many physiological functions including controlling feed intake through suppressing appetite (Gouvêa et al., 2022; Thomas et al., 2002). Research has indicated that leptin in *Bos indicus* cattle differs from *Bos taurus* on a genetic level, which may indicate differences seen in appetite, however further research is required to confirm this (Choudhary et al., 2005; Foote et al., 2015). Importantly, *Bos indicus* cattle are estimated to have up to an 8-10% lower net energy maintenance (NEm)

compared to *Bos taurus* thus indicating that less feed is required to maintain each unit of BW (Chizzotti et al., 2019; Freer et al., 2007). This lower NEm is due to *Bos indicus* greater thermoregulation ability, reduced tissue turnover rates and overall lower total energy expenditure mediated through behavioural differences (Freer et al., 2007). Studies have shown that *Bos indicus* have been found to have a lower appetite and therefore a lower voluntary feed intake in comparison to their British and European counterparts, particularly when placed under feedlot conditions (Elzo et al., 2009a; Schutt et al., 2009b). To the authors best knowledge, there are no studies that measure and compare the DMI of Angus, Brahman and Charolais under the same diet and environmental conditions. However, some studies compared subsets of these breeds, such as Angus and Charolais (Crowley et al., 2010; Kayser et al., 2015) or Angus and Brahman (Schutt et al., 2009; Elzo et al., 2009a). Research has reported that Angus bulls and steers exhibit higher daily DMI than Charolais under the same diet conditions (Crowley et al., 2010; Kayser et al., 2015; Tilepova et al., 2024). Conversely, Brahman steers and heifers have consistently shown lower DMI than British and European breeds, reflecting their lower NEm than their *Bos taurus* counterparts (Schutt et al., 2009; Elzo et al., 2009a). Overall, these findings provide insight into breed effect on feed intake, but it remains that there is still an absence of literature directly comparing feed intake across Angus, Brahman and Charolais under identical environmental and diet conditions, indicating a clear need for further research to address these knowledge gaps.

### 1.5. Feed efficiency

Feed efficiency, defined as the amount of output (ADG) per unit of input (DMI), is of concern from an economic and environmental sustainability point of view (Greenwood, 2021; Rauw et al., 2025). There are numerous ways to estimate feed efficiency including residual feed intake (RFI), residual gain (RG), feed conversion ratio (FCR) and gain-to-feed ratio

(GF). The FCR is defined as the ratio between DMI and ADG, whereas GF is the inverse (Nunes et al., 2024). Generally, FCR and GF are more often used in studies as the collection of data and calculations are easier and can be calculated for both individual animals and a group of animals. However, FCR and GF are affected by frame size, body weight, and ADG. Therefore, selecting animals for lower FCR or lower GF can result in breeding for larger animals, which can result in great feed requirements for maintenance (Ojo et al., 2024).

#### 1.5.1. Residual feed intake

The RFI is defined as the observed minus predicted DMI for the observed BW and ADG, and it is calculated as the residuals from a multiple linear regression model between observed DMI against metabolic BW and ADG, whereas RG is a similar concept, but regressing ADG against DMI and BW (Berry & Crowley, 2012). Therefore, RFI and RG are considered a better reflection of an individual's efficiency because it is phenotypically independent of BW and ADG, as opposed to FCR and GF (Berry & Crowley, 2012; Cantalapiedra-Hijar et al., 2018). Thus, higher RFI (kg DMI/d) and lower RG (kg ADG/kg) indicate a less efficient animal. However, both FCR and GR are utilised more widely due to their ease of calculation. To accurately determine feed efficiency, it is recommended to measure both DMI and BW for a minimum of 30 days and a standard test period of 70 days with fortnightly recordings to accurately estimate RFI (Archer et al., 1997; Schutt et al., 2009b).

There are few published studies that directly compare the effect of breed on RFI, particularly comparing *Bos taurus* and *Bos indicus* cattle (Olson et al., 2019). However, existing studies have produced inconsistent findings regarding the RFI differences among breeds, which could be attributed to different diets, feeding duration, and experimental designs. *Bos indicus* and European breeds have lower RFI compared to British breeds (Elzo et al., 2009b; Schenkel et al., 2004; Schutt et al., 2009b). However, some studies have also reported no differences in RFI between British and European cattle (Jiu et al., 2019; Kayser et al., 2015).

Additionally, European breeds have lower RFI than *Bos indicus*, Crowley et al. (2010) and Schutt et al. (2009b) reported Charolais were more efficient (-3.26 MJ/d; -0.457kg/d) compared to Brahman bulls (0.015kg/d; 0.015kg/d). Therefore, the existing literature suggests that European cattle are the most feed efficient followed by *Bos indicus* as intermediate and British steers the least.

Additionally, it should be noted that RFI is a moderately heritable trait, which is included in Estimated Breeding Values (EBVs) to allow producers to select animals with lower RFI (Herd, 2008). Importantly, Retallick et al. (2013) found that a 10% improvement in feed efficiency traits such as FCR, RG, RFI and GF was associated with substantial increases in profit per animal in a feedlot (e.g. approximately \$34.65 USD/steer for FCR, and \$31.21 USD/animal for RG), highlighting the substantial economic importance of feed efficiency.

### 1.5.2. Residual gain

Residual gain is used as a feed efficiency trait, and it is calculated as the actual ADG less the predicted ADG (Berry & Crowley, 2013). Residual gain (RG) is estimated regressing ADG against DMI and metabolic BW similarly to RFI, which makes it independent of both DMI and BW (Berry & Crowley, 2013). Conversely to RFI, a positive RG value indicates that the animal is gaining more weight (kg/d) than predicted for its DMI and BW, and therefore more desirable. Importantly, few studies directly compared RG of different purebred cattle under feedlot conditions. However, Crowley et al. (2010) reported Charolais bulls showed greater RG compared to Angus, and Olson et al. (2019) reported Angus bulls showed greater RG than Brangus. There are no studies focused on the effect of breed over increasing DOF on RG, however, it is important to note that other variables such as GF decreases and FCR increases as DOF increases because fat in gain (and body fat) increases as animals reach maturity (Barber et al., 1981; Mandell et al., 1997; Pyatt et al., 2005; Volpi-Lagreca et al.,

2021). Further research is required to determine the effect of breed on RG throughout the feeding period.

As outlined above, literature has shown that breed and feeding length (maturity) has an effect on feed intake and efficiency traits, however no studies have directly compared different purebred biotypes with increasing days on feed.

## 1.6. Measurement of body composition and carcass quality

The accurate measurement of body composition and carcass quality is fundamental to the beef industry, as it underpins production efficiency, economic return and the ability to meet market specifications. Body composition determines nutrient requirements, growth efficiency, and the partitioning of energy between muscle and fat deposition (Owens et al., 1995; National Academies of Sciences, Engineering, and Medicine, 2016). Whereas carcass quality traits such as marbling, fat depth and eye muscle area are directly influencing carcass value and consumer eating quality experience. Therefore, reliable methods for quantifying muscle, fat and bone deposition throughout growth of the animal are essential for informing management decisions, breeding plans and nutrition, as well as for validating prediction models of carcass yield and quality.

### 1.6.1. *Ultrasound scanning*

Ultrasonic scanning is a commonly used non-invasive method for estimating body composition in both live animals and carcasses by measuring fat and muscle tissue (Beriain et al., 2021). Ultrasound technology uses high-frequency soundwaves that penetrates tissues and reflect off structures in the sample to create an image (NRC, 1988). In live animals, four main areas are measured to predict carcass composition, including backfat or rib fat, intramuscular fat, rump fat (P8 site), and the *M. longissimus thoracis et lumborum* muscle area, commonly referred to as the eye muscle area (EMA) (Williams, 2002). Ultrasound measurements are an

integral practice in many seedstock operations and as such the aforementioned traits are included in EBVs for most breeds, enabling producers to make more informed decisions on carcass quality and yield traits for their selective breeding (Ruchay et al., 2025). Therefore, a significant proportion of the literature focused on the genetic heritability aspects of ultrasound scanning (Mao et al., 2013). Ultrasound data can be used for a variety of purposes such as refining farm management, progeny testing and predicting carcass endpoints (Williams, 2002). Furthermore, some studies have concluded that ultrasound scanning conducted by a trained operator on the 12<sup>th</sup> rib area and *M. longissimus thoracis et lumborum* muscle of live cattle can give an acceptable accurate estimate of carcass traits (Greiner et al., 2003; Realini et al., 2001). To the author's best knowledge, there is no recent data that compares purebred biotypes over increasing days on feed, under the same environmental and feed conditions.

However, ultrasound scanning demonstrated the effect of beef cattle biotypes and time spent on feed on fat and muscle tissue accretion rates (Liu et al., 2024; Wegner et al., 2000). In general, British breeds showed greater subcutaneous and intramuscular (Mao et al., 2013) than their European and *Bos indicus* counterparts at similar age or BW (Chambaz et al., 2003; Mao et al., 2013; Schutt et al., 2009a). However, *Bos indicus* showed greater subcutaneous and intramuscular fat than European breeds (Peacock et al., 1982; Schutt et al., 2009a). Furthermore, European breeds have been reported to have greater eye muscle areas than British or *Bos indicus* cattle, in line with their larger frames, greater muscling capacity and late maturity (Mao et al., 2013). Ultrasound measurements of fat and muscle are useful for assessing carcass yield and quality, helping producers determine if animals are market ready. The EBV traits measured with ultrasound provide only indirect estimates of carcass composition. However, ultrasound scanning is rarely performed in feedlots due to the logistical challenges and costs of scanning large groups of animals.

### *1.6.2. Slaughtering procedures*

The exact slaughtering procedures, particularly when it comes to trimming the carcasses, can differ between processors and countries. Thus, carcass processing can affect carcass weight and carcass tissue composition. In the case of non-religious slaughter, cattle are stunned, typically by the use of a captive bolt gun, to render animals' unconscious before being hung from their back legs and then exsanguinated by cutting the jugular vein (Davis et al., 2022). Bodies can then be electro-stimulated to improve quality and tenderness, going on to have all non-carcass components (NCC) removed (Savell et al., 2005). These NCC include blood during exsanguination, and later removal of the hide, feet and hooves, head, reproductive tract, gastrointestinal tract, and all internal organs such as heart, lungs, liver, and kidneys. Carcasses are then trimmed of excess fat if required for the intended market, hanging tissues to clean the carcass, and cutting out any bruising that is identified (Kline et al., 2020). Excess fat of the carcass includes both internal fat from the kidney, heart and pelvic (KPH) area and excess external subcutaneous fat commonly trimmed using circular saws. Excess external subcutaneous fat removal allows carcasses to cool faster when placed into the chiller, because it reduces the insulating effect on internal carcass temperature. Additionally, trimming of excess fat is required for carcasses to be within the intended market specifications. Following this, carcasses are typically placed into the chillers for approximately 24 to 48 hours to achieve an internal temperature of 7°C or less, most commonly hanging by the Achilles tendon (Hanes et al., 2022). Cold carcasses are then broken down into wholesale primal and retail cuts, depending on the processor and intended market.

### *1.6.3. Carcass assessment and grading*

Carcass evaluation is determined by qualified graders by visual (subjective) or other objective measurements to determine quality traits such as marbling, meat and fat colour; however, measurements for carcass grading depend across different countries and processing systems

(Delgado-Pando et al., 2021). Carcass quality has become exceedingly important to determine eating quality and prices, and thus it also aids processors with market allocation (Delgado-Pando et al., 2021). Therefore, carcass evaluation has a direct effect on carcass value, with the potential for high-quality carcasses to receive financial premiums (Polkinghorne & Thompson, 2010). The standardised grading and description of these characteristics allow beef producers, processors, and retailers to communicate the quality of the product using a common terminology and grading system (Greenwood et al., 2018; Polkinghorne & Thompson, 2010). However, this translation of carcass quality traits is not always clear and precise across the supply chain when buying and trading internationally across different grading systems. Dependent on the country and their primary markets, evaluation systems tend to place emphasis towards either meat yield, quality or a mixture of both (Polkinghorne & Thompson, 2010). Polkinghorne and Thompson (2010) give a comprehensive overview of the different assessment systems used globally.

Carcass quality is assessed by measuring and recording the sex, dentition (as a proxy for age), hot carcass weight, marbling, and meat and fat colour after chilling for 24-48 hours (Polkinghorne & Thompson, 2010). However, the method of measuring these attributes and the scale against which they are graded vary across grading systems, particularly for marbling, and meat and fat colour. For example, in Australia, the Meat Standards Australia (MSA) and AUS-MEAT grading systems are heavily geared towards catering to consumer eating quality, utilising their own developed MSA (scores from 100 to 1200 with increments of 100) and AUS-MEAT (scores from 0 to 9+) marbling scales. The MSA system is a quality assurance program used to predict the palatability and eating quality of each cut of meat by assigning a grade and estimating the MSA index. In addition, MSA assesses ossification as a proxy for age and other factors such as *Bos indicus* percentage using hump height as a proxy, and use of hormone growth promotants amongst others (Polkinghorne & Thompson, 2010).

In contrast, the US (USDA) quality grade system is determined by the degree of marbling to carcass maturity (Polkinghorne & Thompson, 2010). The MSA and AUS-MEAT systems are continuously evolving for global use, however, the United States, Europe, Korea and Japan utilise their unique grading systems for beef (Greenwood et al., 2018; Polkinghorne & Thompson, 2010).

Carcass assessment traits including marbling, rib fat thickness, and EMA are heritable traits with EBV widely used for genetic selection (Dikeman, 2017). Under the same conditions and time on feed, British breeds have greater marbling in comparison to the European (continental) biotype; however, European breeds have greater lean meat yield, EMA, and carcass weight (Peacock et al., 1982; Reinhardt et al., 2009). *Bos indicus* cattle often do not perform well in eating quality at carcass assessment, tending to have lower marbling compared to European breeds. Therefore, carcasses are penalised according to their *Bos indicus* content due to its association with poorer tenderness and eating quality for consumers (Dikeman, 2017). Furthermore, increasing DOF results in a linear increase of EMA until plateauing, indicating that mature BW has been reached (Owens & Gardner, 2000). In contrast, marbling increases with increasing DOF and is affected by other variables such as age and initial induction weight (Owens & Gardner, 2000).

Traditionally, carcass assessment has been conducted subjectively by qualified and trained carcass graders, although there has been a shift towards developing objective technologies to remove any subjective bias or human error (Gardner et al., 2025). These technologies include dual energy x-ray absorptiometry (DEXA), computer tomography (CT), and ribeye cameras, which have become increasingly popular, such as the QFOM (Frontmatec, Denmark), E+V (Germany), Masterbeef (Masterbeef, Sarina, Australia), MEQ (MEQ, Australia), and VIASCAN (Marel, Murarrie, Australia) (Allen, 2021; Gardner et al., 2025). These technologies are quickly becoming beneficial for processors and continue to be validated and

adopted in the beef supply chain. Subsequently, these data can be utilised to determine factors affecting carcass quality and yield such as breed and feeding duration, and in prediction model development for carcass composition from time of induction at the feedlot.

Carcass assessment is a key aspect of the beef industry in determining value for both yield and quality traits, allowing producers to secure financial premiums for high quality carcasses. Further research comparing breeds over increasing DOF under the same diet and environmental conditions would provide additional knowledge to guide management decisions. For example, producers may be able to assign cattle to different feeding programs with more specificity if the point at which a particular biotype has reached its maximum yield and quality potential can be identified whilst remaining within market specifications and therefore limiting excess fat. Additionally, such knowledge of the biology of tissue deposition could aid in the development of accurate prediction models of yield and quality traits and improve the estimation of carcass value.

#### 1.7. The biology of tissue growth of beef cattle

The biology and growth of tissues, including bone, muscle and fat, determines whole body and carcass composition, which differs between cattle biotypes, age, nutrition, and genetics amongst others. Therefore, the biology of tissue deposition can aid in the development of prediction models of whole body and carcass composition from induction (McPhee, 2024).

Bone is the earliest tissue to develop in cattle, with the most growth occurring early in life and tapering off at approximately 12-15 months of age, with exceptions such as the humerus which continues to grow beyond this age (Gibson et al., 2021). Skeletal muscles secrete growth factors (i.e. IGF-1) to stimulate bone growth, and the time taken to complete bone growth is affected by frame size, with larger framed biotypes such as European breeds, will take longer to finish growing (Gibson et al., 2021).

Muscle growth is rapid from birth to puberty, with muscling capacity of the animal genetically pre-determined, and its growth slows at the end of puberty until the animal has met its approximate mature weight (Owens et al., 1993). Muscle fibres are formed during foetal life and myogenesis occurs as cells (myoblasts) mature and become more specified muscle fibres, and therefore, muscling potential is greatly determined by the number of muscle fibres formed prenatally (Therkildsen & Oksbjerg, 2022). Myogenesis is a crucial stage as it is associated with performance factors such as ADG and lean meat yield (Therkildsen & Oksbjerg, 2022). Protein synthesis is greatest in fast growing animals before plateauing as they reach mature BW (Owens et al., 1993). Muscle growth is affected by factors including but not limited to genetics (breed), hormonal status, and nutrition (Hocquette, 2010).

As animals approach physiological maturity, nutrient partitioning progressively shifts from lean tissue accretion toward adipose deposition once maximal muscle growth potential has been largely attained. Importantly, adipose tissue is not deposited uniformly; the primary fat depots being internal (i.e. visceral and mesenteric), subcutaneous, intermuscular and intramuscular – all differ in both the timing and rate of deposition, with each depot reaching maximal accretion at distinct developmental stages (McPhee, 2024). The role of these fat depots or adipose tissues is to store energy to be mobilised when metabolisable energy is deficient, to protect internal organs, to provide insulation to prevent heat loss, and to store vitamin, amongst others (McPhee, 2024). Body fatness and the distribution of fat is genetically pre-determined, with each different type of fat having different adipocyte cell sizes and quantities. Internal fat adipocytes are larger (120-138  $\mu\text{m}$ ) compared to subcutaneous fat (107-133  $\mu\text{m}$ ) of which intermuscular being a similar size, and intramuscular the smallest with 40-110  $\mu\text{m}$  (Allen, 1976), but it is important to note that these cell sizes are also affected by nutrition (McPhee, 2024). Internal fat is deposited before other

fat depots to protect and insulate the organs and continues being deposited at a slower rate post-puberty (Cianzio et al., 1982; Johnson et al., 1972). Subcutaneous fat begins to accumulate after weaning, and sufficient development of these adipose cells increases leptin secretion, which in turn helps trigger the onset of puberty (Fantuz et al., 2024). Intramuscular fat is deposited latest as the animal matures, increasing more rapidly after 250 days old (Nguyen et al., 2021). Additionally, as intramuscular fat deposition increases, other fat cells grow much slower or conclude growth (Park et al., 2018).

Initially, nutrients are used for bone tissue growth as the calf grows, protein is then used for muscle growth and retained as protein and energy (Berg & Butterfield, 1976). Therefore, the quantification of body composition of cattle is integral to understand the efficiency of energy and nutrient retention. The whole-body composition encompasses both the composition of carcass and non-carcass components of the animal after slaughter (De Paula et al., 2013).

Data on the quantity of energy and nutrients retained in the body and their distribution are the key drivers of nutritional models. Furthermore, whole body fat determines the cost of production for producers, as feeding an animal past the optimal carcass endpoint could be both a financial waste of resources such as feed and a waste of yield due to excess fat being trimmed from the carcass at processing (De Paula et al., 2013). Thus, understanding the patterns of tissue growth and fat deposition provides a fundamental basis for predicting carcass composition, optimising feeding strategies and improving efficiency in beef production across different breeds and developmental stages.

#### *1.7.1. Carcass composition*

Carcass composition optimisation to satisfy the specifications of the targeted market is the main goal. This is achieved by maximising lean meat yield and quality while minimising excess fats, thereby maximising carcass value and minimising cost of production, therefore profitability. Carcass composition is determined by quantifying the proportions and weight of

bone, lean, and subcutaneous fat of the carcass and chemical composition analysis. The gold standard method of determining physically separable composition is physical dissection, where each tissue is meticulously separated from one another to the greatest extent possible and individually weighed, as outlined by Hankins and Howe (1946). However, because absolute precision in separating tissues cannot be guaranteed, subsequent chemical analysis of homogenised tissue samples is necessary to determine compositional attributes. Despite this being the gold standard, this method is not frequently used because it is extremely expensive, labour intensive and not practical for most studies (Lunt et al., 1985; Navajas et al., 2010). Therefore, there is no recent literature utilising this method of the entire carcass (or side) comparing different beef biotypes (i.e. British, European and *Bos indicus*) over increasing time on feed in the feedlot. This information is crucial to identify the optimal carcass endpoint considering the biology of tissue deposition of different biotypes.

Furthermore, such vital data would be valuable to develop new and evaluate existing prediction models of carcass composition. For example, the effect of breed on fat deposition with maturity is not directly considered by some prediction models such as BCNRM, CVDS, RNS (National Academies of Sciences & Medicine, 2016; Tedeschi, 2003; Tedeschi, 2006), although it is partly considered in the form of frame size.

Nevertheless, there has been substantial amount of research to determine carcass composition from the dissection of sections of the body. For example, the 9<sup>th</sup>-11<sup>th</sup> rib section or the *M. longissimus thoracis et lumborum* can be dissected to predict whole-body and carcass composition (Block et al., 2001; Conroy et al., 2010). Santos et al. (2013) thoroughly investigated selecting different ribs (i.e. 10<sup>th</sup>, 12<sup>th</sup>, 13<sup>th</sup>, 9-11<sup>th</sup>) to determine empty body composition but note that these predictions were affected by sex and breed (Alhassan et al., 1975). Additionally, Conroy et al. (2010) showed that dissected hindquarter bone, muscle, and fat predicted whole-carcass composition with  $R^2 = 0.77, 0.94, \text{ and } 0.91$ , respectively, indicating

high precision for muscle and fat and moderate for bone. In Simmental bulls, Žgur et al. (2006) found that the leg cut predicted carcass bone, muscle, and fat with  $R^2$  values of 0.59, 0.78, and 0.80, respectively, demonstrating moderate precision from a single primal cut. Although studies have shown reasonable accuracy using a variety of body sections to predict whole body or carcass composition, there has not been one that can replace physical dissection and thus remains the gold standard and reference method for these studies. However, emerging imaging technologies, such as CT and DEXA, amongst others, continue to advance and are increasingly demonstrating potential as viable alternatives to physical dissection as the gold standard method (Gardener et al., 2025).

The proportion of carcass tissues can differ between cattle biotypes. Berg and Butterfield (1976) reported that the proportion of carcass bone did not differ between European and *Bos indicus* (Charolais and Brahman) steers. In contrast, Gregory et al. (1994) reported that British (Angus) had less carcass bone compared to Charolais steers (14.1, 16.2% carcass weight). Furthermore, LeVan et al. (1979) found that Charolais had greater total bone percentage from the chuck, rib, loin and round cuts compared to Angus, and further reported that bone weight increased until reaching a maximum at approximately 242 DOF and 378 DOF, for Angus and Charolais respectively. However, it should be noted that the proportion of carcass bone is also affected by other factors such as DOF and body condition (Berg & Butterfield, 1976). These results suggest that breed and age or degree of maturity at slaughter affect the proportion and distribution of carcass bone.

Cutability refers to the proportion of saleable retail cuts that can be obtained from a carcass and therefore directly linked to saleable meat yield (Stewart et al., 2024). Similarly, retail beef yield (RBY) is the percentage of saleable product from a fabricated carcass into boneless retail cuts, with a specified external fat trim (Reverter et al., 2003; Wolcott et al., 2001). In contrast, lean meat yield (LMY) is the proportion of the carcass composed of lean tissue, expressed as a

percentage of the carcass weight (Alempijevic et al., 2021). As carcass cutability is determined by the proportion of bone, muscle and fat, emphasising the importance of determining and quantifying the effects of factors such as breed and DOF on carcass composition (Lunt et al., 1985). Both breed and DOF have been reported to affect the proportion of carcass lean. For example, Gregory et al. (1994) reported that Charolais steers had greater carcass lean (kg, % carcass weight) compared to Angus steers slaughter between 204 to 267 DOF. Furthermore, LeVan et al. (1979) also reported that Charolais had heavier wholesale and retail lean meat weights across all primal cuts compared to Angus steers at different points of similar physiological maturity. Few recent studies directly compared the LMY of purebred *Bos indicus* cattle to European and British breeds across a range of increasing DOF. DeRouen et al. (1992) explored the effects of crossing *Bos indicus* with European and British breeds to ascertain differences in carcass composition. *Bos indicus* breeds crossed with British biotypes had greater carcass quality whereas those crossed with European breeds showed greater LMY (DeRouen et al., 1992). Schutt et al. (2009a) reported that European crosses (Charolais, Limousin) achieved the highest RBY of 67.2 - 68.5% of hot carcass weight (HCW), compared to purebred Brahman (66.3%) and British breeds (65.7 - 66.1%), with Brahman × Limousin crosses showing the greatest RBY. Peacock et al. (1982) concluded that Brahman had a negative impact on carcass weight, USDA quality grade and EMA/100 kg carcass weight. Additionally, Cole et al. (1964) reported that Brahman (60.1% carcass weight) had greater proportion of separable lean meat compared to Angus (52.7%) and Hereford steers (54.5%) in a study determining the breed effect on physically separated LMY. Finally, Lunt et al. (1985) concluded that Brahman steers had a greater proportion of physically separable lean in the muscles within the round compared to Angus over increasing DOF.

Carcass fat is also a vital component of carcass composition that determines value and represents a major proportion of the cost in feed due to its high energy density and low water

content (Freer et al., 2007). Coleman et al. (1993) reported that Angus steers had greater carcass fat (kg) from both the empty body weight (EBW) and cold carcass weight (CCW) compared to Charolais steers. In agreement with this, Gregory et al. (1994) also reported Angus had greater carcass fat (%CCW) over increasing DOF compared to Charolais steers.

Furthermore, LeVan et al. (1979) also reported that Angus had 0.57-1.62% more fat from four key primal cuts compared to Charolais steers over increased DOF. Furthermore, *Bos indicus* breeds showed greater carcass fat compared to European breeds, but less than British cattle (LeVan et al., 1979; Schutt et al., 2009a). Schutt et al. (2009a) reported that purebred Brahman steers were intermediate for hot P8 fat depth (6.3 mm) compared to Angus (9.9 mm) and Charolais (5.8 mm).

Furthermore, carcass composition appears to also be reflective of maturity patterns and body size of each biotype. For example, European cattle are larger framed and later maturing, requiring longer time on feed and heavier carcasses to achieve adequate fat coverage with a greater LMY (Dikeman, 2017; Mao et al., 2013). British cattle are smaller framed and earlier maturing and thus tend to produce fattier carcasses with greater quality traits compared to European breeds (Dikeman, 2017; Mao et al., 2013). *Bos indicus* cattle can range in frame size but tend to be medium framed similar to British but tend to be later maturing, depositing less fat than British breeds but more than European (Dikeman, 2017). The proportion of bone, lean and fat change throughout the feeding period. As the animal reaches their mature BW, the proportion of bone decreases, lean also decreases or remains steady and fat increases (Schutt et al., 2009a). In conclusion, breed and DOF both affect carcass composition, yet no comparative dissection data have been published in over two and a half decades, leaving current breed-specific differences unclear. Therefore, a contemporary dissection study of purebred British, European, and *Bos indicus* cattle is required to update baseline parameters for predictive modelling if required.

### *1.7.2. Non-carcass components*

Non-carcass components include the head, feet, hide, tail, blood, internal organs, gastrointestinal tract, and trimmable external fat, which are all removed at processing (De Paula et al., 2013). The NCC are not typically measured due to the immense labour requirements to harvest, clean, and physically dissect, instead the NCC are often predicted or determined from EBW minus the carcass weight (Marcondes et al., 2010). However, the NCC make up approximately 35-40% of the animal EBW, which is the BW of the animal minus the gastrointestinal tract contents (Marcondes et al., 2010; Rotta et al., 2016). Such large proportion of the EBW highlights its importance to determine whole body composition and factors that affect the proportion of NCC should be considered, such as breed and days on feed. As previously mentioned, internal fat is one of the first adipose tissues to be deposited and continues to accumulate throughout the animal's life. Critically, this fat is considered as 'waste fat', as it is not paid for by the processors because it is removed from the carcass (Ribeiro & Tedeschi, 2012). Furthermore, this is a great cost to producers because it takes a great amount of energy (in the form of feed), thus representing economic waste (Ribeiro & Tedeschi, 2012). Therefore, fat in NCC is ideally kept at a minimum to minimise wastage and cost. Only a handful of studies have measured the entire NCC and its composition (i.e. bone, lean and fat), other than loosely in the form of dressing percentage or as kidney, heart and pelvic (KPH) fat. The KPH fat is often used as a reflection of total NCC fat and has been shown to linearly increase with DOF (Pyatt et al., 2005). Furthermore, the effect of breed on fat in NCC was greater in British compared to European feedlot steers when adjusted for hot carcass weight (Bergen et al., 2006).

Measuring carcass tissues weight may give a more accurate determination of the bone, muscle, and fat content of the whole body. Silva et al. (2016) developed numerous equations to predict percentages of bone, muscle, fat and chemical composition in the carcass and non-

carcass components of *Bos indicus* breeds. These latter authors emphasised that the inclusion of visceral fat (mesenteric, kidney, heart, pelvic) in all prediction equations is vital as fat is the most variable component of the animal. The inclusion of NCC such as visceral fat, viscera lean, and organs greatly improved carcass and empty body chemical composition estimations in Zebu cattle (Silva et al., 2016). Consequently, prediction models often estimate body composition based on carcass fat measurements (Ribeiro & Tedeschi, 2012). Incorporating data on components such as visceral fat into nutritional models can further enhance understanding of how animals convert feed into body mass (Marcondes et al., 2010; Silva et al., 2016). Furthermore, approximately 25-33% of body protein, water, and fat reside in the NCC of the animal, further emphasising the importance of considering NCC in whole-body composition predictions (Berg & Butterfield, 1976). Berg and Butterfield (1976) outlines that there is 26% of crude protein (CP), 23% of water, and 25% of fat in the NCC of a steer weighing approximately 580 kg. Neglecting to measure NCC when developing nutritional models would lead to inaccurate results and recommendations, ultimately miscalculating profit. Thus, further research is required to establish the effect of different biotypes and increasing DOF on the NCC and its composition to accurately establish whole body composition.

#### 1.8. Economic implications

Numerous factors affect carcass value including the location, market specifications and requirements, and consumer demand (Hocquette, 2010). However, as outlined throughout this review both breed and DOF affect carcass composition, lean meat yield, and quality traits. High carcass quality gives the opportunity to secure financial premiums and grid prices (\$/kg carcass weight) are affected by quality traits, making both carcass weight and quality key variables in determining carcass value. Furthermore, different primal cuts are assigned different values after the carcass is broken down. Broadly, high-value primal cuts include loin

and rump, wholesale ribset (6<sup>th</sup> – 12<sup>th</sup> rib) and part of the butt (i.e. round) (Connolly et al., 2018). These high-value wholesale primal cuts tend to be from postural sections of the body, containing less collagen and greater subcutaneous and intramuscular fat, and thus tending to have greater quality traits. Low value cuts tend to be from the neck and chuck, blade and front leg, brisket, spareribs and flank. These cuts have either greater locomotive function, with greater collagen content in the muscle and therefore lower in quality traits or tend to be much fattier (i.e. brisket) (Anderson et al., 2015; Roy & Bruce, 2024). McGilchrist et al. (2022) concluded that the LMY determined 97% of the carcass value when a flat price is applied to all cuts. Thus, it is suggested that European biotypes may produce the carcasses of a greater value due to greater LMY and feed efficiency without the inclusion of quality traits. However, British breeds tend to have greater quality traits and may secure financial premiums, although these may be fattier with lower LMY. However, majority of pricing grids do not include payments based on LMY other than in the form of carcass weight or through calculation of measured traits (EMA, rib fat depth, carcass weight) at grading.

Feedlots often aim to have fast turnover of cattle shortening DOF required to reach market specifications for weight and fatness. It is important to highlight that overfat cattle will have lower LMY and require fat trimming at processing, leading to financial deductions on the grid price in \$/kg carcass weight (Slack-Smith et al., 2009). As previously mentioned, fat requires a great amount of energy to be deposited, so excess fat represents waste both on feed and financially. Additionally, trimmed fat is paid for but at an extremely low price (e.g. \$0.30 AUD/kg), which could lead to a net loss in profit after accounting for the cost of feed required to deposit that fat (McGilchrist et al., 2022). On the other hand, underfed cattle are financially penalised due to inadequate fat cover, lower LMY and ultimately not satisfying market specifications for carcass weight (Slack-Smith et al., 2009). Therefore, the assignment of cattle biotypes to a feeding program based on factors such as breed, potential for growth,

mature BW, LMY and fatness potential is vital to ensure that cattle are not spending an insufficient or excessive amount of time in the feedlot and produce carcasses within specifications to maximise value. Furthermore, accurate allocation of individual animals to the correct feeding program is expected to produce uniform carcasses reducing the financial penalties and maximising carcass value. Overall, LMY, quality traits, and carcass composition are affected by breed and DOF, which become extremely important to manage from an economic perspective to accurately determine and forecast carcass value.

### 1.9. Conclusion and Implications

This review concluded that both breed and DOF influence feedlot performance, efficiency, body and carcass composition, and carcass quality. Not one biotype or breed excels in all areas of value such as yield and quality, and price of the feeder animal. Therefore, it is important to understand differences in whole body and carcass composition at different points in time to strategically assign individuals to feeding programs and markets that maximise potential profits. Although breed and DOF affect performance and composition, their magnitude in modern British, European, and *Bos indicus* genotypes remains unquantified. Controlled studies comparing purebred animals of these biotypes under identical diets and environmental conditions with increasing DOF are therefore essential. Furthermore, this prospective research needs to take a holistic approach of recording feedlot performance and carcass composition, which must utilise the gold standard method of physical dissection and chemical analysis. Such data can then be utilised to update baseline reference data for use in predictive models. An opportunity would arise to review existing models to determine which equations are still accurate for modern breeds and possibly create new models. This would be beneficial for producers, with the ultimate goal of being able to predict whole body and carcass composition from induction, and therefore more accurately forecast carcass value.

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## Chapter 2– Knowledge gaps, hypothesis and objectives

The feedlot sector represents a substantial proportion of beef production and is essential in addressing the protein requirements of a growing global population (Greenwood, 2021).

Therefore, optimising productivity and environmental sustainability has become a significantly important aspect for producers (Greenwood, 2021) with fast turnover of cattle that reach market specifications. To achieve this, producers aim to reach the optimal carcass endpoint (carcass weight and market specification) that maximises profit for each animal (MLA, 2024). Feedlot performance, feed efficiency, body and carcass composition, and carcass quality and yield are affected by numerous factors including diet, breed and feeding length amongst others (Greenwood, 2021; Mandell et al., 1997). However, there are currently no prediction models that can precisely determine the optimal carcass endpoint for individual animals. The gold standard method of physical dissection to determine both body and carcass composition has not been used in recent decades with the three most common cattle biotypes due to its immense labour requirements and cost (Lunt et al., 1985; Navajas et al., 2010). Therefore, the accuracy to predict body and carcass composition of the modern national herd is unknown. There is no recent literature that directly compares feedlot performance, body and carcass composition, carcass yield and quality traits of different purebred beef breeds under the same feed and environmental conditions over increasing DOF. The primary beef biotypes consist of British, European (Continental) and *Bos indicus* represented through Angus, Charolais and Brahman, respectively (Dikeman, 2017). Additionally, interactions between breed and time on high-grain diets to achieve various carcass endpoints have received even less attention.

As feed is one of the greatest expenses incurred by feedlots (Crowley et al., 2010; Na & Guan, 2022), determining the effect of different biotypes and DOF on feedlot performance and efficiency is a critical point of knowledge to optimise production. There are multiple factors

that effect and control feed intake of cattle including age, maturity and body composition (Freer et al., 2007). Existing literature indicates that differences exist both between breeds and over DOF for performance traits such as feed intake, feed efficiency (residual feed intake and residual gain) and growth (Berry & Crowley, 2013; Freer et al., 2007). However, there are no studies that directly compare purebred beef breeds under the same diet and environmental conditions over increasing DOF. Quantifying these differences using diverse beef biotypes would substantially aid in influencing managerial decisions such as sorting animals that are similar in efficiency and performance into feeding programs, designing feed rations and forecasting an animal's growth and point of finishing. Ultimately, optimising production with faster turnover of animals and meeting market specifications could maximise profits and minimise feed and excess fat wastage.

Ultrasound scanning and carcass assessment are methods of measuring live and carcass composition and quality (Beriain et al., 2021). Breed has an effect on the muscle and fat accretion rates over time, which can be measured through ultrasound scanning (Liu et al., 2024; Wegner et al., 2000). Despite the common usage of ultrasound scanning for yield and fatness traits in seedstock, this practice is not done in feedlots due to the significant cost and overall impracticality with time and needless movement of animals from pens to stockyards. Thus, there is no literature that quantify ultrasound measurements of different purebred feedlot steers over increasing DOF, additionally there are no recent studies that validate ultrasound measurements against direct methods of physical carcass dissection. Furthermore, carcass assessment and grading provide important measurements of carcass yield and quality to manage financial premiums or penalties giving more accurate estimation of carcass value (Polkinghorne & Thompson, 2010). Therefore, grading is an economically vital process to provide feedback to producers and enable changes to managerial decisions that maximise profits. Breed is known to affect carcass quality and yield such as muscle and fat accretion,

and body size and maturity is heavily influenced by biological type (Dikeman, 2017). *Bos indicus* cattle are known to have poorer beef eating quality compared to *Bos taurus* breeds and therefore receive financial penalties that increase as *Bos indicus* content increases (Dikeman, 2017). As carcass grading is an essential aspect of determining carcass value, further research of the effects of breed over increasing DOF on carcass traits will further aid prediction model development.

Determining the differences in body and carcass composition and value of each beef biotype over DOF requires quantifying bone, lean and fat tissue growth (McPhee, 2024). Therefore, physical dissection along with chemical composition analysis is necessary to understand yield, quality, and the efficiency of energy and nutrient retention of the animal. As previously mentioned, there are no recent studies that utilise the physical dissection method of the whole-body including carcass and non-carcass components, particularly comparing difference purebred biotypes over increasing DOF.

Finally, quantifying the yield of tissues in various primal cuts throughout the carcass can help determining the cutability (i.e. saleable meat yield) and therefore value of the carcass (Lunt et al., 1985). There is no literature that quantifies the composition and yield of primal cuts of popular beef biotypes with increasing DOF. Particularly, changes to the composition of the animal over time indicates the allometric grow patterns useful for prediction models but processors to make more informed value-based marketing decisions (Sakamoto et al., 2014). The knowledge gaps outlined above demonstrate a need to determine the effect of breed over increasing DOF on feedlot cattle performance and carcass attributes. Subsequently, accurate prediction of the optimal carcass endpoint at an individual level could be developed and promote management decisions to optimise carcass value, production, sustainability, and profitability. Therefore, the present thesis has constructed the following experimental chapters to address the outlined research gaps.

### 2.1. General thesis objective

The general objective of the present thesis was to determine the effect of breed and DOF on the feedlot performance, efficiency, whole body and carcass composition, carcass yield and quality through a serial slaughter experimental design.

### 2.2. General thesis hypothesis

The general hypothesis of the present thesis was that breed and DOF affect all aspects of feedlot production from animal performance and efficiency to whole body and carcass composition, yield and quality.

### 2.3. Objectives of each experimental chapter

Furthering the general aims and hypothesis of the thesis, each of the experimental objectives were as follows:

1. To assess the performance and feed efficiency of Angus, Brahman and Charolais steers from 50 to 200 DOF (Chapter 3).
2. To determine differences in fat and muscle tissue of Angus, Brahman and Charolais feedlot steers on both the live animals via ultrasound scanning and their carcasses throughout 200 DOF (Chapter 4).
3. To determine the whole body and carcass bone, lean and fat tissues of Angus, Brahman and Charolais feedlot steers over 200 DOF (Chapter 5).
4. To evaluate the effect of breed and days on feed on tissue yield of each wholesale primal cut of Angus, Brahman and Charolais steers over 200 DOF (Chapter 6).

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Chapter 3- Performance, feed intake, and feed efficiency of  
Angus, Brahman, and Charolais feedlot steers fed from 50  
to 200 days

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### 3.1. Abstract

Animal performance and feed efficiency are important aspects of the beef feedlot industry as feed is the greatest variable cost. This study aimed to determine the differences in feedlot performance, DMI, and feed efficiency of three popular beef breeds representing British, European and *Bos indicus* cattle biotypes. Angus (n= 24), Brahman (n = 24) and Charolais steers (n = 23) were inducted at average BW of 354, 344, and 320 ± 3.8 kg, respectively. Animals were fed for up to 200 days on feed (DOF), intake being measured by electronic feeders. Six animals per breed (n = 18) were randomly selected for slaughter every 50 days. Data was analysed using a linear model with breed, DOF, and their interaction as fixed effects. Breed × DOF interactions were significant for final shrunk BW (FSBW) and residual gain (RG), and a tendency for gain to feed ratio (GF). Breed affected all variables ( $P < 0.05$ ), and DOF affected all but initial SBW, initial body condition score, water intake, feed conversion ratio, RG and residual feed intake (RFI). Angus steers had the heaviest FSBW from 100-200 DOF, Charolais intermediate at 150-200 DOF, Brahman were lightest from 100-200 DOF ( $P < 0.05$ ). Angus had the greatest, Charolais intermediate, and Brahman the lowest DMI (kg/d) ( $P < 0.05$ ). GF and WI (% BW) were similar for Angus and Charolais ( $P > 0.05$ ) and greater than Brahman ( $P < 0.05$ ). Charolais were most efficient with the lowest RFI, and the greatest RG compared to other breeds ( $P < 0.05$ ). Breed and DOF both affect performance, DMI, and feed efficiency traits and these need to be considered to optimise productivity and profitability of feedlot cattle.

Key words: feed efficiency, performance, breed, days on feed

### 3.2. Introduction

Feed efficiency and performance of beef feedlot cattle is critical to optimise productivity and economic returns of the operation (Kenny et al., 2018). Feed costs represent one of the greatest variable expenses across the industry (Crowley et al., 2010; Na & Guan, 2022).

Feedlot cattle are penned, provided the same ration and marketed together as a uniform group despite there being considerable variation in performance and carcass composition (Pyatt et al., 2005). Cattle are assigned to feeding programs ranging from 60 to 600 days on feed depending on the breed, diet, the targeted market and its specifications (Greenwood, 2021). Thus, understanding the effect of breed and days on feed on feedlot cattle performance, feed intake, and efficiency is crucial to tailor breeding, feeding, and marketing programs to best convert feed into saleable product, whilst minimising costs and feed wastage (Greenwood, 2021).

Differences between beef and dairy breeds in feedlot performance has been well documented, with research primarily focused on selective breeding for feed efficient animals, and the differences between and within breeds (Archer et al., 1999; Berry & Crowley, 2013).

However, to date, there is no recent literature comparing feedlot performance and feed efficiency of British, European and *Bos indicus* beef breeds over increasing days on feed in the same environmental conditions.

British cattle are selected for their smaller frames, earlier maturity, and higher meat quality traits compared to other biotypes, whereas European cattle are selected for their large frames and higher yielding carcasses (Freer et al., 2007). In contrast, *Bos indicus* are utilised for their environmental tolerance and adaptability to harsher, tropical climates, and are typically used to crossbreed with British or European breeds (Schutt et al., 2009). Thus, these breed biotypes are integral to the feedlot industry as they contribute unique growth, feed efficiency, meat yield and quality traits to the production system, and therefore the appropriate breed is

selected based on market specifications. However, it should be noted that differences in feed efficiency between breeds must be interpreted with the context of the slaughter endpoint for those animals (Moloney & McGee, 2023). For example, animals fed to fatter endpoints will tend to observe lower ADG and feed efficiency (Pyatt et al., 2005). Studies have shown that Angus have higher residual feed intake (are less efficient) than their European Charolais counterparts, even with adjustments made for subcutaneous fat depth, which has a weak negative relationship to RFI (Arthur & Herd, 2008; Schenkel et al., 2004). Furthermore, animals that have a greater muscling capacity, such as European breeds, have greater maintenance requirements but need lesser energy for growth compared to early maturing and fattening breeds such as British (Mao et al., 2013). Thus, the aforementioned research have established multiple differences between beef cattle breeds in performance and feed efficiency.

The objective of the present study was to determine performance and feed efficiency differences between Angus, Brahman and Charolais steers feedlot performance between 50 and 200 days on feed. It was hypothesised that Charolais steers were more efficient and growth faster than the other breeds due to later maturity and higher muscle yield. Angus were expected to be the least efficient due to greater fat accretion rate compared to the other breeds. Brahman will remain intermediate throughout due to their tendency to have poorer performance under good environmental and feeding conditions.

### 3.3. Materials and Methods

The present study was approved by the Institutional Animal Ethics Committee of The University of Sydney (approval number 2020/1822).

### *3.3.1. Experimental Design*

The study was undertaken at the University of Sydney's research feedlot located in New South Wales, Australia. The trial consisted of 71 purebred steers including Angus (n = 24), Brahman (n = 24) and Charolais (n = 23). Angus and Brahman steers were approximately 16-18 months of age and the Charolais steers were approximately 10-12 months old at induction. Each breed group was sourced from the same property, therefore having the same backgrounding history but had differing sires within the breed group. Sires had registered bloodlines within each breed society to ensure purebred status of the steers. The steers were inducted into the feedlot at  $339 \text{ kg} \pm 2.7 \text{ kg BW}$  for Angus, Brahman and Charolais. Steers were weighed, tagged, vaccinated and inspected by a veterinarian at induction. All animals were placed together in a pen for up to 200 days, and six of each breed (n = 18) were randomly selected for slaughter every 50 days.

Steers were transitioned from a starter to a finisher ration mixing both at an increasing proportion of the finisher ration over a 21-day period (Table 3.1). The finisher ration consisted of dry rolled barley (78%), cottonseed (11%), wheat straw (5%) and mineral supplement (6%), with a total of 12.15 MJ of ME/DM kg and 13.76% CP of the formulated diet (Table 3.2). Feed intake was measured in real time using 10 individual electronic feeders with load cells (Intergado Ltd., Contagem, Minas Gerais, Brazil) identifying the radiofrequency ear tag (National Livestock Identification Systems, Integrity Systems Company Ltd, North Sydney, Australia) of each animal. Both feed and water were offered to allow for ad libitum consumption throughout the trial period. Two water troughs were provided in the pen, with two walk-on weighing (WOW) platforms (Intergado Ltd., Contagem, Minas Gerais, Brazil) at each trough providing access points for steers and measured real time liveweight simultaneously. In addition, the change in weight while the animal stands drinking water is used to estimate water consumption during each visit.

**Table 3.1.** Two-ration mix fed to feedlot steers during the 21-day transition from starter to finisher feedlot ration.

Day	Ration Type	Starter, %	Finisher, %
1-5	Starter	100	0
6-7	Transition 1	85	15
8-9	Transition 2	75	25
10-11	Transition 3	65	35
12-13	Transition 4	55	45
14-15	Transition 5	45	55
16-17	Transition 6	35	65
18-19	Transition 7	25	75
20-21	Transition 8	15	85
22	Finisher	0	100

**Table 3.2.** Ingredient and chemical composition of the starter and finisher rations on an as-fed basis feed to Angus, Brahman, and Charolais steers in a serial slaughter trial.

Variable	Unit	Starter Ration	Finisher Ration
Diet composition			
Barley (dry rolled)	%	44.0	78
Millrun	%	23.0	0
Oat hay	%	15.0	0
Cottonseed (high lint)	%	8.5	11
Wheat straw	%	5.0	5
Mineral supplement	%	4.5	6
Chemical composition of ration			
DM	%	87.60	90.10
NDF	%DM	50.10	27.10
ADF	%DM	24.60	11.90
CP	%DM	15.60	12.20
Crude fat	%DM	1.80	2.90
Water soluble carbohydrates	%DM	5.20	3.30
Dry matter digestibility	%DM	59.60	75.40
Dry organic matter digestibility	%DM	59.40	74.60
Inorganic ash	%DM	9.50	6.30
Organic matter	%DM	90.50	93.70
Metabolisable energy *	MJ/kg DM	11.30	12.15
Net energy for maintenance *	Mcal/kg DM	1.77	1.96
Net energy for gain *	Mcal/kg DM	1.15	1.32
Monensin *	ppm	16.40	22.00

\*Formulated using the Beef Cattle Nutrient Requirement Model (BCNRM) (NASEM, 2016).

### 3.3.2. Performance data collection

At the start and at 50-days intervals prior to slaughter, BW was measured before feed delivery (initial shrunk bodyweight; ISBW; kg) using a traditional weighing box system sitting on load cells to record a static weight. Body weight was recorded using the Tru-Test weigh scale indicator (Model XR3000; Datamars, Lamone, Switzerland), with all calibrations completed. Body condition scores and hip height were recorded at the crush side by the same two assessors at each 50-day interval. Hip height was recorded using the iPhone 12 Pro (Apple Inc., Cupertino, CA, 2020) on the 3D Scanner application (AI Photo Editor Lab SRL, Version 2.4, 2022). Frame scores were subsequently calculated from hip height measurements, sex, and age (months) using the Australian NSW Department of Primary Industries method (NSW DPI, n.d.). As the present study used steers, frame scores were averaged between bulls and heifers (NSW DPI, n.d.). Average daily gain (ADG; kg/d) was calculated using the final shrunk bodyweight (FSBW; kg) and ISBW, divided by the number of days the animal spent on feed. The Intergado system reported the daily water intake (WI; kg/d) and feed intake (FI; kg/d) on an as fed basis per animal (Oliveira et al., 2017). Water and feed intake were also calculated as a percentage of the mid trial BW, the average of the initial and final shrunk BW (WI, % BW). Dry matter of the feed was determined from composited weekly samples of offered feed, which were then separated into three subsamples of approximately 100 g each as replicates. All samples were oven dried for approximately 48 hours at 65 °C, and then the dry weight recorded and used to determine the dry matter percentage. Dry matter intake (DMI) was calculated using the feed intake multiplied by the measured DM of samples collected from the offered feed. DMI was calculated as a percentage of the mid trial BW (DMI, % BW) and of the metabolic BW also using the mid trial BW (DMI, g/kg<sup>0.75</sup>).

Feed conversion ratio (FCR; kg/kg) was calculated as the total sum of daily DMI for each individual animal divided by the total weight gain from induction to slaughter using ISBW and FSBW. The gain to feed ratio (GF; kg/kg) was calculated using shrunk weight gain difference from the ISBW and FSBW divided by total DMI of the individual animal. The residual gain (RG; kg/d) was calculated as ADG regressed on the DMI (kg/d) and BW (Berry & Crowley, 2013). Residual feed intake (RFI; kg/d) was calculated using the observed minus expected DMI for the observed BW and ADG throughout the trial (Arthur & Herd, 2008). Additionally, RFI was adjusted by body fatness measured through ultrasound before slaughter as intramuscular fat, P8, rib, and kidney fat depth (Duff et al., 2021)

### 3.3.3. *Statistical analysis*

All variables were analysed using R (R Core Team, 2021) in RStudio (RStudio Inc., Boston, MA, USA) with a linear model containing breed, DOF, and their interaction as fixed effects. The breed  $\times$  DOF interaction was dropped from the model if not significant and results are presented for the main effect of breed and DOF. Initial BW and BCS differed between breeds and thus, data was also analysed using the statistical model above with the addition of initial BW and BCS as covariates. Further, RFI was also analysed in a similar linear model with and without initial ultrasound body fat (intramuscular, P8, rib and kidney) recorded at 0 DOF as covariates. Variables were tested for normality and outliers considered with student residual  $> 3$  and deleted; one outlier for RG and another for initial BCS were removed. The estimated marginal means for each variable and differences between means were obtained using the 'emmeans' package (Lenth, 2024) with adjustments for multiple comparisons using the Tukey. Statistical significance was declared at  $P \leq 0.05$ , and tendencies discussed at  $0.05 < P \leq 0.10$ .

### 3.4. Results

Summary statistics of all variables are shown in Table 3.3. Residual feed intake (RFI), residual gain (RG), and water intake (WI) had the greatest variability, whereas initial shrunk bodyweight (ISBW), initial body condition score (BCS) and dry matter intake (DMI) (%BW and g/kg MBW) had the lowest variability overall. Interestingly, RG showed a smaller range than RFI (Table 3.3).

**Table 3.3.** Summary statistics for feedlot performance, intake, and feed efficiency of steers between 50 and 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Initial shrunk BW, kg	289	382	339.2	23.09	6.81
Final shrunk BW, kg	348	712	516.2	100.93	19.55
Initial body condition score	2.75	3.5	3.04	0.192	6.315
Final body condition score	2.75	5.00	3.75	0.526	14.029
Average daily gain, kg/d	0.098	2.347	1.386	0.505	36.44
Frame score	1.00	7.74	5.02	1.29	25.65
Feed conversion ratio, kg/kg	2.70	21.96	6.45	2.60	40.31
DMI, kg/d	4.26	12.33	8.20	1.67	20.37
DMI, % BW	1.17	2.47	1.91	0.25	13.23
DMI, g/kg <sup>0.75</sup>	51.19	116.63	86.72	12.45	14.35
Water intake, kg/d	1.1	93.4	39.7	21.41	53.93
Water intake, % BW	0.30	21.28	9.14	4.74	51.89
Water intake, g/kg <sup>0.75</sup>	13.18	922.11	416.47	216.67	52.03
Gain: Feed, kg/kg	0.02	0.31	0.16	0.05	28.24
Residual gain, kg/d	-0.84	0.58	-0.02	0.28	-1252.31
Residual feed intake, kg/d	-2.63	2.17	0.00	0.75	2.94 x 10 <sup>16</sup>

Table 3.4 shows the effect of breed and DOF for each variable and the P-values for breed ×

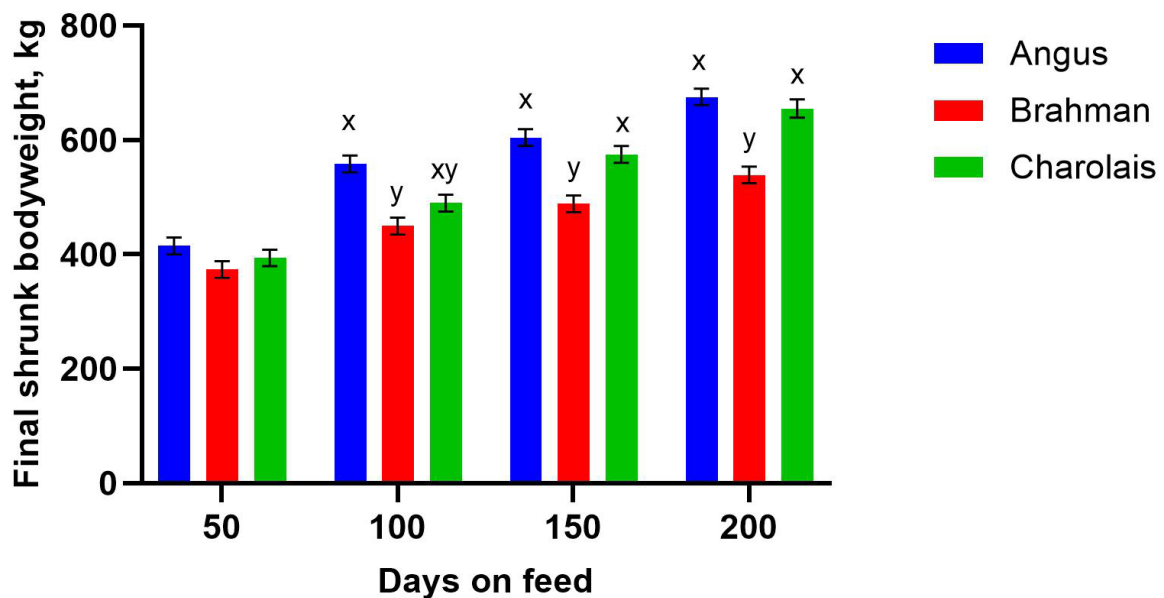
DOF interaction. The breed × DOF interaction was significant for FSWB, RG, RFI intramuscular fat, P8 fat, rib fat and kidney fat ( $P < 0.05$ ), with GF being a tendency ( $P < 0.10$ ). The main effect of breed affected all variables ( $P < 0.05$ ). DOF did not affect ISBW, initial BCS, frame score, WI, WI (%BW), WI (g/kg MBW), FCR and RFI ( $P > 0.05$ ), tended to affect RG ( $P < 0.10$ ), and affected the remaining variables ( $P < 0.05$ ).

**Table 3.4.** Effect of breed and days on feed on feedlot performance, feed intake, water consumption, and feed efficiency of steers fed for 50 to 200 days on feed (DOF).

Variable	Breed				Days on feed					P-value		
	Angus	Brahman	Charolais	SE	50	100	150	200	SE	Breed	DOF	B × DOF
Initial shrunk BW, kg	353.5 <sup>x</sup>	343.9 <sup>x</sup>	319.5 <sup>y</sup>	3.82	337.9	342.1	332.9	342.8	4.44	< 0.001	0.349	0.300
Final shrunk BW, kg	563.3	462.7	527.5	8.16	394.3	499.3	555.9	621.9	9.489	< 0.001	< 0.001	0.009
Final shrunk BW covariate, kg	550.8	458.5	544.8	8.91	395.4	496.8	561.3	618.7	8.77	<0.001	<0.001	0.002
Initial body condition score	3.14 <sup>x</sup>	3.04 <sup>xy</sup>	2.92 <sup>y</sup>	0.036	3.01	3.05	2.97	3.10	0.041	< 0.001	0.176	0.786
Final body condition score	4.02 <sup>x</sup>	3.43 <sup>z</sup>	3.83 <sup>y</sup>	0.043	3.14 <sup>d</sup>	3.65 <sup>c</sup>	3.97 <sup>b</sup>	4.27 <sup>a</sup>	0.049	< 0.001	< 0.001	0.242
Average daily gain, kg/d	1.67 <sup>x</sup>	0.90 <sup>z</sup>	1.60 <sup>x</sup>	0.069	1.12 <sup>c</sup>	1.58 <sup>a</sup>	1.50 <sup>a</sup>	1.37 <sup>ac</sup>	0.080	< 0.001	0.001	0.900
Frame score	3.76 <sup>y</sup>	5.60 <sup>x</sup>	5.69 <sup>x</sup>	0.171	5.35	4.82	5.03	4.92	0.221	< 0.001	0.506	0.527
Dry matter intake (DMI), kg/d	9.29 <sup>x</sup>	6.97 <sup>z</sup>	8.38 <sup>y</sup>	2.195	6.68 <sup>c</sup>	8.52 <sup>a</sup>	8.64 <sup>a</sup>	9.02 <sup>a</sup>	0.255	< 0.001	< 0.001	0.233
DMI, % BW	2.02 <sup>x</sup>	1.72 <sup>y</sup>	1.99 <sup>x</sup>	0.043	1.82 <sup>b</sup>	2.01 <sup>a</sup>	1.93 <sup>ab</sup>	1.87 <sup>ab</sup>	0.050	< 0.001	< 0.035	0.220
DMI, g/kg MBW	93.29 <sup>x</sup>	77.12 <sup>y</sup>	89.93 <sup>x</sup>	2.006	79.60 <sup>b</sup>	91.24 <sup>a</sup>	88.80 <sup>a</sup>	87.48 <sup>ab</sup>	2.333	< 0.001	0.003	0.274
Water intake, kg/d	55.74 <sup>x</sup>	16.70 <sup>z</sup>	47.14 <sup>y</sup>	2.743	35.16	39.40	40.33	44.56	3.190	< 0.001	0.238	0.731
Water intake, % BW	10.16 <sup>x</sup>	3.56 <sup>y</sup>	9.05 <sup>x</sup>	0.556	9.50	9.16	8.91	9.07	0.755	<0.001	0.952	0.557
Water intake, g/kg MBW	565.86 <sup>x</sup>	183.56 <sup>y</sup>	504.00 <sup>x</sup>	29.195	416.61	416.72	410.94	426.97	33.955	<0.001	0.990	0.655
Gain: Feed, kg ADG/kg DMI	0.179 <sup>x</sup>	0.124 <sup>y</sup>	0.191 <sup>x</sup>	0.0072	0.155 <sup>ac</sup>	0.181 <sup>a</sup>	0.172 <sup>ac</sup>	0.149 <sup>c</sup>	0.0083	< 0.001	0.023	0.091
Feed conversion ratio, kg/kg	5.64 <sup>y</sup>	8.52 <sup>x</sup>	5.14 <sup>y</sup>	0.445	6.97	5.87	6.01	6.88	0.518	< 0.001	0.264	0.172
Residual gain, kg/d	- 0.007	- 0.241	0.190	0.0433	0.030	0.036	- 0.024	- 0.121	0.0503	< 0.001	0.108	0.037
Residual feed intake (RFI), kg/d	- 0.02 <sup>xy</sup>	0.29 <sup>x</sup>	- 0.29 <sup>y</sup>	0.149	- 0.10	0.07	0.22	- 0.21	0.174	0.023	0.303	0.233
RFI intramuscular fat, kg DMI/d	- 0.053	0.062	- 0.003	0.1557	- 0.092	0.132	0.020	0.020	0.1810	0.871	0.824	0.019
RFI P8 fat, kg DMI/d	0.065	0.077	- 0.104	0.1697	- 0.160	0.276	0.110	- 0.177	0.1848	0.636	0.193	0.039
RFI rib fat, kg DMI/d	0.047	0.046	- 0.091	0.1545	- 0.173	0.276	0.075	- 0.176	0.1797	0.769	0.225	0.036
RFI kidney fat, kg DMI/d	0.094	0.007	- 0.105	0.1541	- 0.016	0.126	0.017	- 0.133	0.1792	0.654	0.786	0.040

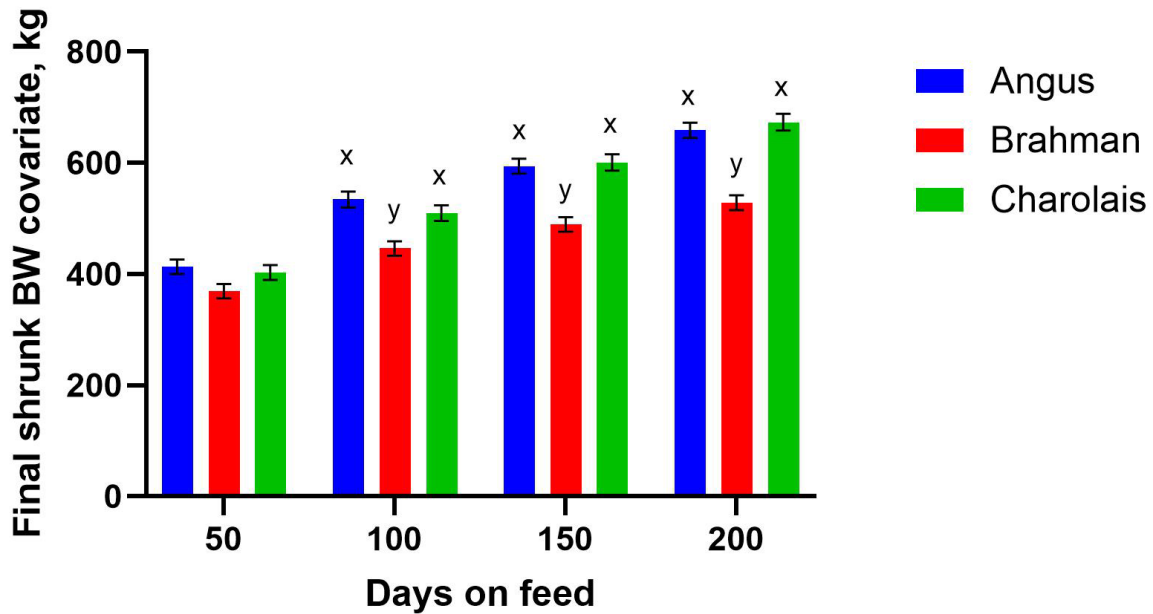
<sup>x-z</sup> Means without a common superscript differ between breed (P < 0.05). <sup>a-c</sup> Means without a common superscript differ between days on feed (P < 0.05).

At the beginning of the trial, both Angus and Brahman had similar ISBW and were heavier than Charolais steers ( $P < 0.05$ ). However, Angus had the heaviest FSBW, followed by Charolais, and Brahman were the lightest ( $P < 0.05$ ; Figure 3.1). Additionally, FSBW increased from 50 to 200 DOF ( $P < 0.05$ ; Table 3.4). Similarly to ISBW, Angus and Charolais were faster growing which a greater ADG than Brahman steers ( $P < 0.05$ ). At 100 and 150 DOF, ADG was greater than 50 DOF ( $P < 0.05$ ), but ADG at 200 DOF did not differ from any other DOF because it was intermediate ( $P > 0.05$ ; Table 3.4).



**Figure 3.1.** Final shrunk bodyweight of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

The FSBW with initial values as covariate also showed a significant breed  $\times$  DOF interaction ( $P < 0.05$ ; Figure 3.2). However, the use of initial values as covariate (Figure 3.2) did not change the results or differences between means for FSBW compared to results without the covariate (Figure 3.1).



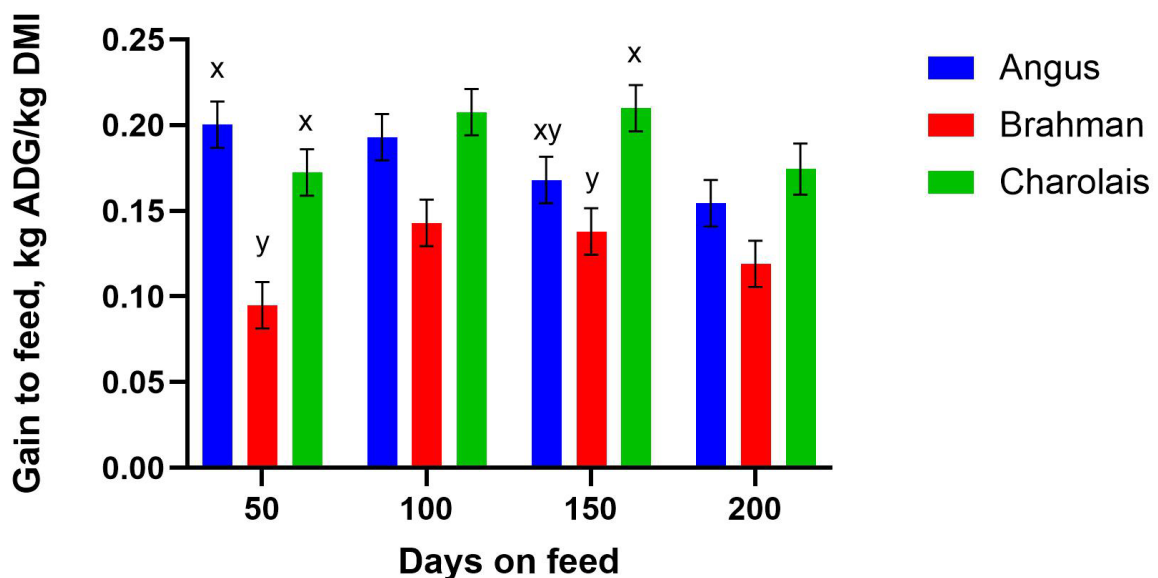
**Figure 3.2.** Final shrunk bodyweight using initial shrunk body weight as a *covariate* of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

Initial BCS was greatest for Angus compared to Charolais steers ( $P < 0.05$ ) where Brahman were similar to other breeds ( $P > 0.05$ ; Table 3.4). Interestingly, the final BCS differed for all breeds, Angus remaining the greatest, Brahman intermediate and Charolais the lowest ( $P < 0.05$ ), Final BCS increased as DOF increased, being at the lowest at 0 DOF and the greatest at 200 DOF ( $P < 0.05$ ). The use of initial BCS as a covariate did not affect final BCS ( $P > 0.05$ ) and therefore results have not been included in Table 3.4. Frame score was similar for Brahman and Charolais ( $P > 0.05$ ), and greater than Angus ( $P < 0.05$ ).

Angus steers had the greatest average daily DMI (kg/d), Charolais intermediate, and Brahman the lowest DMI ( $P < 0.05$ ). Additionally, the effect of DOF increased from 50 to 100 DOF and remained similar for longer DOF ( $P < 0.05$ ; Table 3.4). However, Angus and Charolais had greater DMI (%BW) compared to Brahman steers ( $P > 0.05$ ). Days on feed also had an effect showcasing the greatest DMI (%BW) at 100 DOF compared to the first 50 DOF ( $P < 0.05$ ), however at 150 and 200 DOF was similar to both 50 and 100 DOF ( $P > 0.05$ ). DMI corrected for MBW showed similar pattern to DMI (%BW), with Charolais similar to Angus

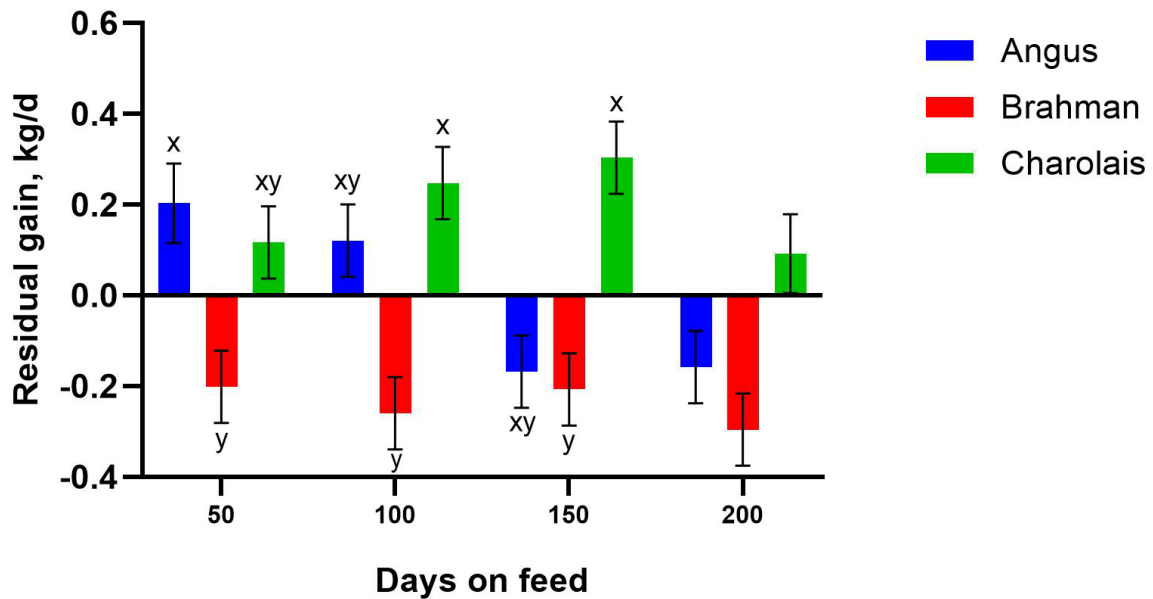
( $P > 0.05$ ) and both greater than Brahman ( $P < 0.05$ ). The DMI (g/kg MBW) at 100 and 150 DOF was greatest compared to 50 DOF, but 200 DOF was similar to all other DOF ( $P < 0.05$ ; Table 3.4). Daily average WI was lowest for Brahman steers ( $P < 0.05$ ) and lower in Charolais compared to Angus which had the greatest WI ( $P < 0.05$ ). However, WI (%BW) and WI (g/kg MBW) was similar between Angus and Charolais ( $P > 0.05$ ) and lower in Brahman steers ( $P < 0.05$ ).

The GF was greater in Angus and Charolais compared to Brahman steers ( $P < 0.05$ ), and greater at 100 compared to 200 DOF ( $P < 0.05$ ; Figure 3.3; Table 3.4). The FCR was greater for Brahman compared to Angus and Charolais ( $P < 0.05$ ), but DOF did not affect FCR ( $P > 0.05$ ).



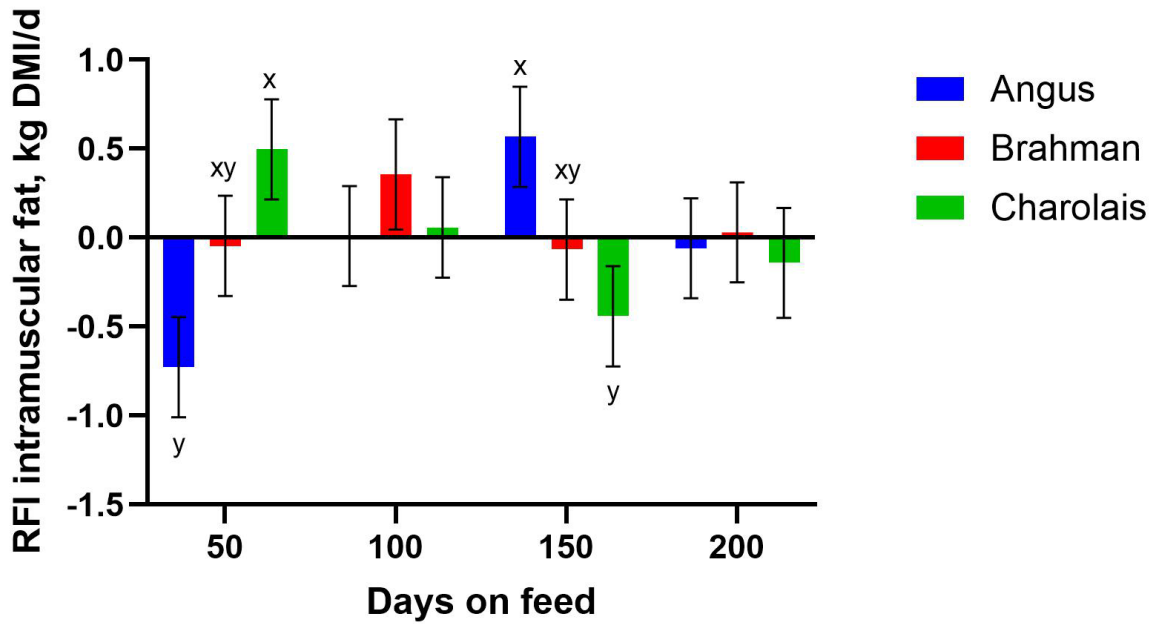
**Figure 3.3.** Gain to feed ratio of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

The RG of Angus were greater than Brahman at 50 DOF ( $P < 0.05$ ), whereas Charolais were similar to other breeds ( $P > 0.05$ ). However, at both 100 and 150 DOF, Charolais steers had the greatest RG compared to Brahman ( $P < 0.05$ ), with Angus remaining intermediate ( $P > 0.05$ ; Figure 3.4).



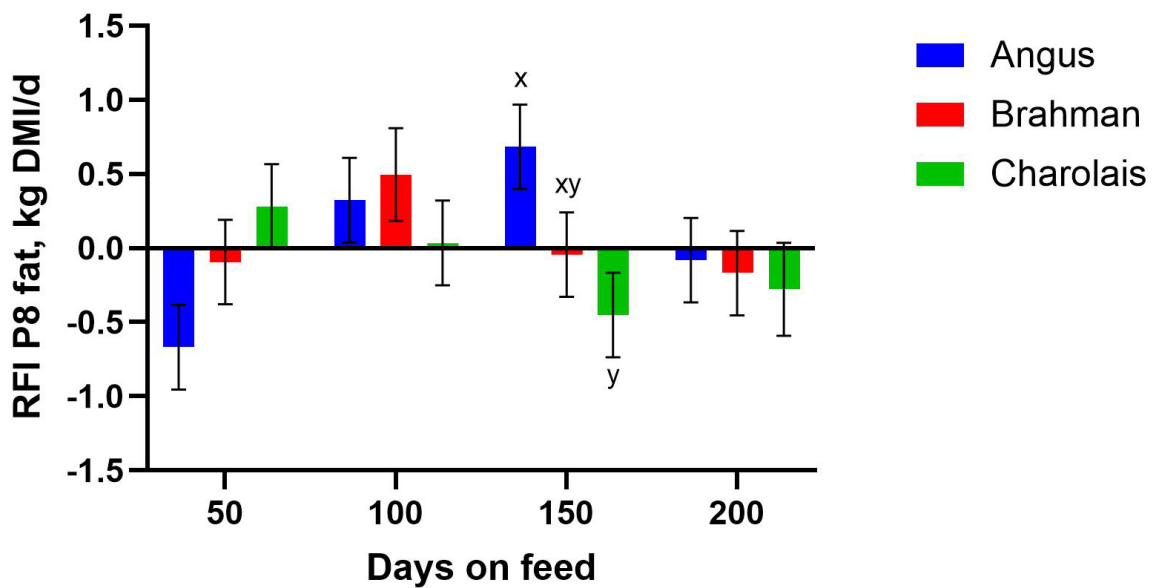
**Figure 3.4.** Residual gain of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

The RFI was greater in Brahman compared to Charolais ( $P < 0.05$ ), and Angus showed RFI similar to both breeds ( $P > 0.05$ ; Table 3.4). The RFI corrected for initial body fat measurements at 0 DOF as covariates were not significant ( $P > 0.05$ ) and therefore not shown in Table 3.4. However, RFI corrected by final intramuscular fat showed that Charolais had the greatest RFI compared to Angus ( $P < 0.05$ ) at 50 DOF, whereas at 150 DOF results were opposing, as Angus had the greatest RFI compared to Charolais ( $P < 0.05$ ; Figure 3.5).

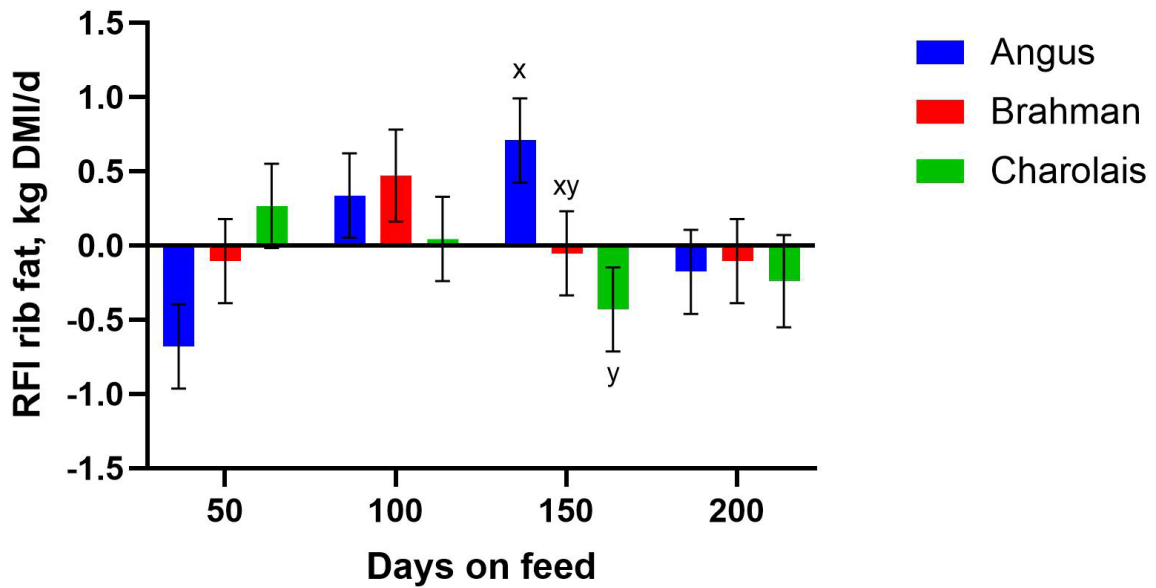


**Figure 3.5.** Residual feed intake (RFI) corrected by final intramuscular fat of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

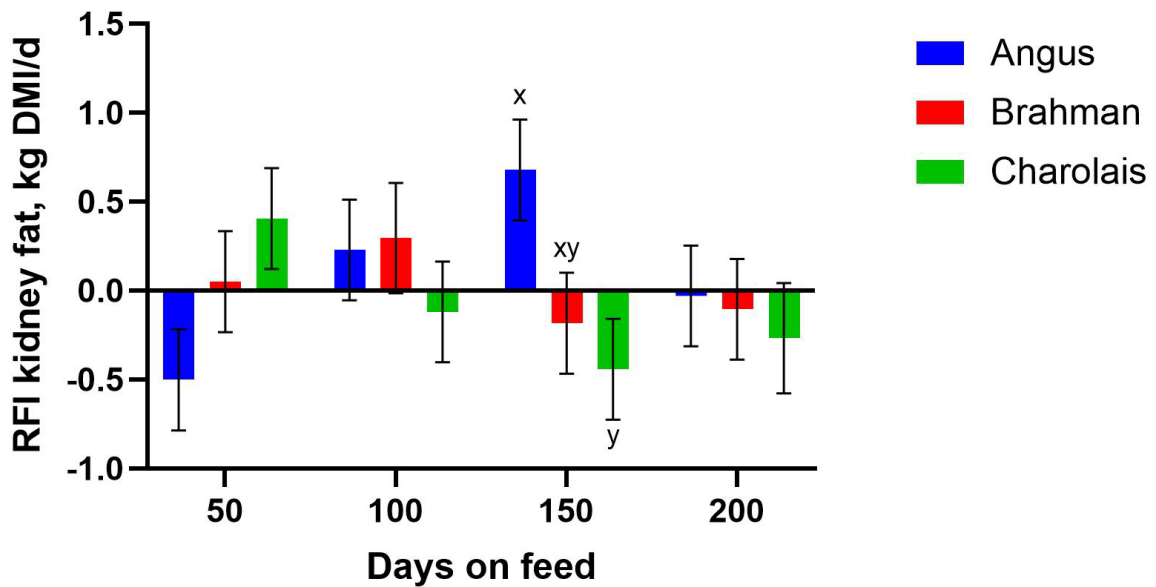
Whereas RFI corrected separately by rib, P8 and kidney fat each showed similar results (Figure 3.6, 3.7, 3.8), with Angus having the greatest RFI at 150 DOF compared to Charolais ( $P < 0.05$ ), and Brahman being similar to other breeds ( $P > 0.05$ ).



**Figure 3.6.** Residual feed intake (RFI) corrected by final P8 fat of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.



**Figure 3.7.** Residual feed intake (RFI) corrected by final rib fat of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.



**Figure 3.8.** Residual feed intake (RFI) corrected by final kidney fat of Angus, Brahman and Charolais steers fed for 50 to 200 days in a feedlot.

### 3.5. Discussion

It was hypothesised that Charolais steers would be more feed efficient and grow faster than the other breeds because of their leaner body, greater muscling, and larger frames which makes them suitable as a terminal breed (Mao et al., 2013; Taussat et al., 2019). In contrast, Angus were expected to have intermediate growth and efficiency because of fatter bodies and small frames (Mao et al., 2013), whereas Brahman steers show the poorest growth and efficiency in feedlot conditions (Burrow, 2012; Schutt et al., 2009). The present study confirmed and quantified these hypotheses using modern genetics for most of the variables. Furthermore, the present study has demonstrated that breed and DOF has a clear effect on animal performance and feed efficiency with some interactions between them. Studies directly comparing feedlot performance and feed efficiency of British, European and *Bos indicus* purebred beef cattle under the same environmental conditions and diets are limited. In the present study, frame scores should be interpreted cautiously, as further research is required to determine the accuracy of the camera and application used to measure hip height. However, in line with existing literature, Angus were found to be smaller framed and therefore have earlier maturity, than Brahman and Charolais (Mao et al., 2013; Schutt et al., 2009; Taussat et al., 2019). As characteristically seen for European beef breeds, Charolais are typically heavier conferring them greater potential for growth and greater muscling capacity compared to Angus (Jones et al., 1984; Mao et al., 2013). However, there have been inconsistent results when comparing ADG of these breeds. Similar to the present study, Jiu et al. (2019) found that Angus and Charolais steers had similar ADG (1.75 and 1.65 kg/d, respectively) on a finisher feedlot diet. In addition, Chambaz et al. (2003) reported Angus and Charolais steers had similar ADG (1.30 and 1.22 kg/d, respectively) when fattened to a similar intramuscular fat content, with Charolais being fattened for 281 days, 140 days longer than Angus. However, both Chewning et al. (1990) and Crowley et al. (2010) found that

Charolais bulls had greater BW and ADG compared to Angus bulls, in agreement with results of the present study for FSBW, but not for ADG. In contrast, Albertí et al. (2008) found that Angus bulls had higher ADG (1.97 kg/d) compared to Charolais (1.53kg/d). The discrepancies in ADG seen in previous research could be attributed to several factors such as diet, feeding length, environmental conditions, sex, and genetic variation within breeds. It must be noted that Charolais steers of the present study were inducted into the feedlot at approximately 20-30 kg lighter and 6-8 months younger than other breeds, which may confound the interpretation of results and thus, the comparison with Angus and Brahman steers should be done with caution.

Research has consistently reported Brahman steers have lower ADG compared to British and European breeds in a feedlot environment, consistent with results from the present study (Adams et al., 1982; Schutt et al., 2009). Schutt et al. (2009) found that Brahman steers had the lowest ADG (1.064 kg/d) compared to nine other breeds including Angus (1.465 kg/d) and Charolais (1.345 kg/d). However, this study utilised Brahman dams for crosses, so comparisons should be interpreted with caution when compared to purebred animals of the present study. Furthermore, older studies such as Adams et al. (1982) reported that Angus steers grew faster (1.12 kg/d) compared to Brahman (0.80kg/d). Schutt et al. (2009) suggested that the lower ADG observed in Brahman may be attributed to lower appetite compared to other breeds, which could be supported by lower DMI. Dry matter and water intake directly affect growth and feedlot performance (Silvestre et al., 2023; Wagner & Engle, 2021). Dry matter intake can vary due to factors such as breed, environmental conditions, diet and feed management (Guiroy et al., 2001). Determining differences in intake allows for optimising management procedures and feeding allocation to maximise productivity and minimise waste. Importantly, DMI of the present study did not seem to have been limited by the number of feeders available or access to feed because the 10 feeders were

only occupied 44% of the time during the first 50 DOF (data not shown). Numerous studies have reported that Angus show greater daily DMI compared to other breeds. For example, Crowley et al. (2010) and Tilepova et al. (2024) reported Charolais bulls had 3.5 - 4.5 % lower DMI compared to Angus whereas Kayser et al. (2015) reported a greater difference in DMI of 19.6% when comparing Red Angus steers compared to Charolais bulls. In contrast to these previous studies, the present study showed similar DMI in Angus and Charolais steers when corrected for BW. There are limited research reports that directly compared DMI of purebred Brahman to Angus and Charolais, however, *Bos indicus* cattle were seen to consistently have lower DMI, agreeing with the present study. Schutt et al. (2009) reported that Brahman had the lowest DMI compared to Angus and Charolais ( $P < 0.001$ ). The present study and aforementioned research demonstrate Brahman as a tropically adapted breed having a low fasting metabolism and intake, leading to an overall poorer growth and performance compared to British and European cattle (Schutt et al., 2009).

The relationship between WI and DMI is affected by variables such as weather conditions, temperature and sodium content of available water. As a generalisation, WI increased and DMI decreased in hotter months so the WI to DMI ratio increased, whereas the opposite is observed in cooler months (Sexson et al., 2012). Conversely, other studies have reported that WI increased with DMI (Hicks et al., 1988; Loneragan et al., 2001). The present study agrees with the latter as WI (kg/d) increased over DOF as the DMI (kg/d) increased. However, the present trial started in autumn and finished in late spring, so DMI, BW, and weather are confounded. Nevertheless, it has been established that tropically adapted *Bos indicus* breeds consume less water than British and European breeds, even when adjusted for BW (Brew et al., 2011), and in agreement with the present study. In the present study, WI (kg/d) was greatest for British steers, followed by European being the intermediate and Tropical the lowest. Similarly, European breeds consume less water compared to British breeds (Ahlberg

et al., 2019), which could be attributed to a great DMI in British cattle compared to European. However, Tropical breeds have adapted to harsh environmental conditions including high ambient temperature by having slick coats, a higher density of sweat glands closer to the surface of the skin and excess loose skin to dissipate heat (Aggarwal et al., 2013). Thus, due to *Bos indicus* cattle having a greater ability to thermoregulate compared to *Bos taurus* breeds, their requirement for water consumption is lower. Therefore, *Bos indicus* cattle are the most water efficient, making them a highly advantageous breed for not long regions with harsh tropical climates but particularly when drought occurs, which is becoming increasingly important due the effects of climate change.

Feed efficiency continues to be an important facet of the beef industry with an increasing world population and thus requirements for reliable protein sources. The industry is challenged to optimise productivity and minimise wastage, whilst experiencing rising costs in feed (Nkrumah et al., 2006). There are numerous variables that can be measured to determine the feed efficiency of animals including but not limited to FCR, GF, RG and RFI (Kenny et al., 2018). These feed efficiency variables have a direct impact on the economics of the feedlot, Retallick et al. (2013b) predicted that which each singular unit each of these variables improved by there would be a 10% profit increase. This added profit is a substantial increase for any operation and further highlights the importance of understanding the breed and DOF effect on feed efficiency. Additionally, feed intake and BW data must be collected for a minimum of 30 days on feed to accurately determine feed efficiency, however, it is a test period of 70 days with fortnightly BW measurements is recommended. (Archer et al., 1997; Schutt et al., 2009). Thus, it should be noted that the present studies experimental design is not typical for a feed efficiency study but does meet the minimum duration needed at 50 DOF to accurately assess collated data, and the subsequent 100, 150 and 200 DOF surpassing requirements.

There have been conflicting reports on FCR of different beef breeds, which could be attributed to various factors including diets and DOF. Chewning et al. (1990) and Crowley et al. (2010) reported that Angus had greater FCR compared to Charolais, however, Kayar and İnal (2019) reported Angus and Charolais having no difference in their FCR, in agreement with the present study. Furthermore, Schutt et al. (2009) found no differences in FCR between Angus, Charolais × Brahman, and purebred Brahman steers. Whereas Elzo et al. (2009) found similar differences between breeds to the present study, with greater FCR in Brahman (9.53 kg/kg) compared to Angus (7.36 kg/kg) of a large population of bulls, heifers and steers. Although FCR is a frequently used measure of efficiency due to the ease of collection of data and calculations, it is influenced by other factors such as not taking into account frame size, Charolais steers may be lower than Angus due to being larger and heavier.

The gain to feed ratio not only was a tendency for the breed × DOF interaction but is the only feed efficiency variable where DOF had a significant effect and is one of the most commonly used feed efficiency traits, however, the effect of breed was similar to FCR and other studies. Literature has shown that GF decreased as DOF increased and animals reach maturity and increase body fat, aligning with the present study (Pyatt et al., 2005). Previous research showed that Angus and Simmental steers (Retallick et al., 2013a), and Angus and Charolais steers (Jiu et al., 2019) had similar GF, in agreement with the results of the present trial. Rouquette Jr et al. (2023) reported the GF for Brahman of 0.123 kg/kg over a 70-day period, whereas Olson et al. (2019) reported that Angus had greater GF compared to Brahman × British crosses, both studies supporting the results from this trial. Angus, Brahman and Charolais show a different pattern of GF, with Angus steers peaking earlier at 50 DOF, Brahman at 100 DOF and Charolais at 150 DOF all before then decreasing as DOF increases. A similar pattern was seen as reported Owens and Gardner (2000) when consider the effect of

DOF on GF. The results of the present study highlight the differences in maturity patterns and fattening rates over time, revealing the peak periods of efficiency (GF) for these animals as well as the optimal timing for slaughter. Angus will reach their optimal slaughter points earlier, followed by Brahman, whilst Charolais benefit from longer time before slaughter. Residual gain has become one of the key measures for feed efficient, as it calculated as the actual ADG less the predicted ADG, where the predicted ADG is regressed on DMI and metabolic BW, which allows for a fair comparison of growth as it is independent of BW and feed intake (Berry & Crowley, 2012). In the present study, residual gain differed between breeds with greater positive values being desirable and indicating the animal had greater weight gain than predicted (Berry & Crowley, 2012). Similar to the trends of the present study, previous research showed that Charolais had greater RG compared to Angus bulls (Crowley et al., 2010). There are few studies comparing the RG of Brahman to Angus or Charolais, however, Angus have showed a greater RG than Brangus (Olson et al., 2019). In the present study, Charolais steers increase in performance before peaking at 150 DOF before RG starts to decrease, indicating that there is a benefit to longer feeding programs, as they remain efficient for longer compared to other breeds before plateauing. In contrast, Angus steers mature earlier and deposit fat sooner than other breeds, making longer DOF programs not ideal as they will likely exceed carcass fat specifications for their destined market. However, Brahman steers have the lowest RG efficiency but maintain a consistent level throughout the feeding period. Their low appetite and reduced feedlot performance make them less suitable to intensive feeding programs for a long period of time, yet their adaptability is a key and valuable trait in the industry, allowing for production under harsh tropical environmental conditions (Schutt et al., 2009).

Residual feed intake has become an important and increasingly popular measurement of feed efficiency because it is independent and not influenced by BW and ADG (Berry & Crowley,

2013). A negative RFI value is desirable as it indicates the animal eat less than expected for growth and maintenance, and therefore more efficient (Berry & Crowley, 2013). Similar to the results of the present study, Jiu et al (2019) reported no differences in RFI between Angus and Charolais steers, similar to Kayser et al. (2015) between Charolais heifers and Red Angus steers. In agreement with results of the present study, Olson et al. (2019) reported Angus and Brahman had a similar RFI differences to the present study. Conversely, Schutt et al. (2009) found Angus had the greatest RFI (0.542 kg/d), Brahman intermediate (0.015 kg/d) and Charolais the least (-0.457 kg/d) and thus the most efficient. Crowley et al. (2010) demonstrated that Charolais bulls were the most feed efficient with an RFI of -3.26 MJ/d compared to Angus which were the least (14.66 MJ/d) in a group of multiple different British and European sires. Schenkel et al. (2004) also reported Angus being less efficient than Charolais bulls with an RFI of 0.48 and 0.047 kg/d, respectively. Further, body fat affects feed efficiency and feedlot performance even within breed as used in breeding and genetic selection including Estimated Breeding Values (Graser et a., 2005). Thus, it is important to correct RFI by body fatness as seen in the present study, which demonstrated breed differences in fat deposition as the animals mature. Although there is a variety of results reported throughout literature, the present study does reflect Charolais being the most efficient in comparison to other breeds. Charolais had one less steer (n = 23) compared to the other breeds (n = 24), noting that the SEM for RFI means an additional steer would likely change the results of the present study to show Charolais having a greater RFI compared to Angus. Similarly to the previous feed efficiency variables of the present study, Brahman were the least efficient breed and therefore are not as suited for feedlot production, however, provides a strategy for programs situated in harsh environmental conditions, and are not an ideal option from an economic standpoint for long fed programs. Similarly to the

aforementioned feed efficiency traits, the RFI has again demonstrated that both Angus and Charolais are suited to a shorter and longer feeding programs respectively.

### 3.6. Conclusions and implications

The present study's results demonstrates that Charolais steers are the most efficient breed for a longer period of DOF and are best suited to markets requiring heavier lean carcasses and thus, will need longer days on feed. Angus cattle perform well under feedlot conditions in terms of both efficiency and performance but have shown a decrease in feed efficiency as DOF increases and therefore are best suited to short fed programs due to their early maturity and thus propensity to fatten quicker, ready to send to slaughter quicker than other breeds. Brahman steers were the least efficient breed of the present study, however they could be advantageous when utilised in feedlots situated in harsher tropical climates and thus are highly valuable as a crossbreed with *Bos taurus* cattle. However, results of the present study suggest Brahman cattle are not suitable for long fed programs because their ADG, and muscle and fat deposition were slowed after 100 DOF and lower compared to Angus and Charolais steers.

The effect of both breed and days on feed on performance and feed efficiency traits was clear in the present study. However, it is important to note that the present study had an  $n = 6$  for each breed  $\times$  DOF group, which may have limited the statistical significance of some variables such as RG and RFI. Therefore, further research with a greater number of animals per breed and DOF group would be beneficial to reinforce the results shown in the present study. This demonstrates the need for industry to consider these differences when making management decisions such as the assignment of individuals to pens, feeding and marketing programs. This information can help refining the production system to increase productivity, profitability and minimising feed wastage.

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# Chapter 4 - Ultrasound and carcass traits of Angus, Brahman and Charolais feedlot steers throughout a 200-day feeding period

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#### 4.1. Abstract

Cattle breeds exhibit varying fat and muscle deposition rates, influencing the time required to meet market specifications and maximise profitability. This study aimed to evaluate differences in fat and muscle depots using ultrasound and carcass grading. Angus (n = 30; initial BW of  $361 \pm 5.3$  kg), Brahman (n = 30;  $355 \pm 5.3$  kg), and Charolais (n = 29;  $317 \pm 5.3$  kg) steers were inducted into the feedlot for up to 200 days on feed (DOF) with 6 animals per breed (n = 18) slaughtered every 50 DOF. Ultrasound measurements included rib fat (URF), P8 fat depth (UP8), kidney fat (UKF), eye muscle area (UEMA), and intramuscular fat percentage (UIMF). Carcass grading included intramuscular chemical fat (IMF), kidney, pelvic and heart fat (KPH), rib fat depth (CRF), eye muscle area (CEMA), MSA marbling (MSAmarb), carcass weight (HCW) and dressing percentage. All variables showed a breed  $\times$  DOF interaction ( $P < 0.05$ ) except for dressing percentage and inorganic ash ( $P > 0.05$ ), with MSAmarb and KPH being tendencies ( $P < 0.10$ ). At 200 DOF, Angus had the greatest URF and UP8 ( $P < 0.05$ ), Brahman intermediate ( $P < 0.05$ ), and Charolais the least ( $P < 0.05$ ). Angus had the greatest UKF and UIMF ( $P < 0.05$ ), and the largest UEMA ( $P < 0.05$ ), similar to Charolais at 150 DOF ( $P > 0.05$ ). Angus had the greatest MSAmarb score throughout ( $P < 0.05$ ) except at 50 DOF ( $P < 0.05$ ). Chemical analysis showed Angus had higher IMF, but lower crude protein compared to other breeds ( $P < 0.05$ ). Breed and DOF both influence fat and muscle deposition rates, which should be considered to optimise management strategies for maximum feedlot profit.

Key words: breed, days on feed, ultrasound, carcass grading

## 4.2. Introduction

The rate of muscle and fat deposition and distribution in different depots of feedlot cattle is essential information to achieve market specifications and optimise carcass value (Slack-Smith et al., 2009). Amongst other traits, both subcutaneous and intramuscular fat determine carcass quality and value, thus greatly impacting profitability of the production system (Alempijevic et al., 2021; Tan & Jiang, 2024). Similarly, eye muscle area (EMA) measured at the *M. longissimus thoracis et lumborum* affects carcass value (Polkinghorne et al., 2008). In addition to eating quality, these traits also determine lean meat yield of carcasses (Heggli et al., 2023; Walmsley et al., 2010).

Breed or biotype have a large impact on fat and muscle tissue accretion rates (Liu et al., 2024; Wegner et al., 2000). For instance, British cattle such as Angus are an early maturing breed with faster fat accretion compared to *Bos indicus* and European cattle biotypes such as Brahman and Charolais, respectively (Freer et al., 2007). In contrast, Charolais cattle have high muscling potential and lean body composition whereas Brahman cattle are known for their adaptability to harsh tropical environments (Freer et al., 2007). However, no studies have directly compared the rate and distribution of accretion of rib, P8 and kidney fat depth, eye muscle area (EMA), and intramuscular fat (IMF) percentage of Angus, Brahman, and Charolais steers under the same conditions, over increasing days on feed. In addition to the effect of breed, age or stage of maturity also have a large influence on body composition and therefore in carcass traits, with greater proportion of body fat as animals reach maturity (Berg, 1976). Angus, Brahman and Charolais represent some of the most popular British, *Bos indicus* and European beef cattle breeds due to the aforementioned abilities to excel in meat quality, meat yield and adaptability, respectively. As there is not one single breed that excels in all traits, it is crucial to understand the effect breed has on muscle growth and fat accretion to effectively and strategically incorporate these cattle into different feeding programs in

commercial feedlots destined to different markets (Wheeler et al., 2005). This knowledge will allow the tailoring of breed and feeding program selection for targeted end markets, potentially maximising economic returns.

Induction weight and age are factors that reflect the stage of maturity and body composition in feedlot animals which then increase with days on feed (length of the feeding period) with diets formulated to optimise growth and carcass composition (Owens & Gardner, 2000). The allocation of cattle to a days on feed (DOF) program is generally determined by the intended market or carcass endpoint (e.g. light supermarket or heavy export). The effect of DOF on muscle growth and fat deposition of different breeds needs to be understood to determine individual optimal carcass endpoints and feeding strategies, minimise excess fat and feed wastage, and maximise returns.

These traits can be measured on the live animal through real time ultrasound and on the carcass upon grading (Beriain et al., 2021). Ultrasonic measurements have been recognised and established as a reliable, accurate, real-time, non-invasive method for assessing fat depth, intramuscular fat percentage, and muscle area in live cattle (Beriain et al., 2021; S. P. Greiner et al., 2003; Houghton & Turlington, 1992).

The Meat Standards Australia (MSA) carcass grading criteria is used to assess quality and yield, providing a pathway for producers to secure premiums on cattle with higher eating quality and lean meat yield (Polkinghorne et al., 2008). The MSA system has been recognised globally as one of the most comprehensive beef eating quality grading systems (Greenwood et al., 2018). In recent years, technologies have been developed to provide an objective method to assess carcass quality and yield (Velazco et al., 2024). Many of these technologies such as those based on image analysis, assess key attributes of the *M. longissimus thoracis* that determine carcass value (Velazco et al., 2024).

The objective of the present study was to determine differences between Angus, Brahman, and Charolais in fat and muscle tissues deposition on both live animals using ultrasound and carcasses using image analysis of throughout a feeding period of up to 200 days.

#### 4.3. Materials and Methods

The present study was approved by the Institutional Animal Ethics Committee of The University of Sydney (approval number 2020/1822).

##### *4.3.1. Animals, diet and experimental design*

The study was undertaken at the University of Sydney's research feedlot located in New South Wales, Australia. The trial consisted of a total of 89 purebred steers consisting of Angus (n = 30), Brahman (n = 30), and Charolais (n = 29). Angus and Brahman steers were approximately 16-18 months of age and Charolais were approximately 10 months old. Each of the breeds were sourced from the same property and thus had the same backgrounding history but differing sires within the breed. All steers were sired by bulls whose bloodlines are registered in each breed society to ensure purebred status. Steers were inducted into the feedlot with 361, 355, and 317 ± 5.3 kg bodyweight (BW), respectively. At induction, steers were weighed, tagged, vaccinated, and inspected by a veterinarian. All animals were then placed together into a pen for up to 200 days and six steers of each breed (n = 18) were randomly selected for slaughter every 50 days.

Animals were transitioned over a 21-day period from a starter to a finisher ration comprised of dry rolled barley (78%), cottonseed (11%), wheat straw (5%) and mineral supplement (6%), with a total of 12.15 ME MJ/DM kg and 13.76% CP (Table 4.1; Table 4.2). Feed intake was measured in real-time using 10 individual electronic feeders with load cells (Intergado Ltd., Contagem, Minas Gerais, Brazil) identifying the radiofrequency ear tag of each animal.

**Table 4.1.** Two-ration mix fed to feedlot steers during the 21-day transition from starter to finisher feedlot ration.

Day	Ration Type	Starter, %	Finisher, %
1-5	Starter	100	0
6-7	Transition 1	85	15
8-9	Transition 2	75	25
10-11	Transition 3	65	35
12-13	Transition 4	55	45
14-15	Transition 5	45	55
16-17	Transition 6	35	65
18-19	Transition 7	25	75
20-21	Transition 8	15	85
22	Finisher	0	100

**Table 4.2.** Ingredient and chemical composition of the starter and finisher rations on an as-fed basis feed to Angus, Brahman, and Charolais steers in a serial slaughter trial.

Variable	Unit	Starter Ration	Finisher Ration
Diet composition			
Barley (dry rolled)	%	44.0	78
Millrun	%	23.0	0
Oat hay	%	15.0	0
Cottonseed (high lint)	%	8.5	11
Wheat straw	%	5.0	5
Mineral supplement	%	4.5	6
Chemical composition of ration			
DM	%	87.6	90.1
NDF	%DM	50.1	27.1
ADF	%DM	24.6	11.9
CP	%DM	15.6	12.2
Crude fat	%DM	1.8	2.9
Water soluble carbohydrates	%DM	5.2	3.3
Dry matter digestibility	%DM	59.6	75.4
Dry organic matter digestibility	%DM	59.4	74.6
Inorganic ash	%DM	9.5	6.3
Organic matter	%DM	90.5	93.7
Metabolisable energy *	MJ/kg DM	11.30	12.15
Net energy for maintenance *	Mcal/kg DM	1.77	1.96
Net energy for gain *	Mcal/kg DM	1.15	1.32
Monensin *	ppm	16.40	22.00

\*Formulated using the Beef Cattle Nutrient Requirement Model (BCNRM) (NASEM).

Feed and water from two troughs were provided to allow for ad libitum consumption throughout the trial period. Steers were fasted off feed for approximately 16 hours with ad libitum access to water before being slaughtered over a consecutive three-day period (Tuesday, Wednesday, Thursday), two of each breed being randomly selected for each day. Steers were transported from the feedlot to a commercial abattoir early morning for approximately an hour (50 km) and slaughtered shortly after arrival. Steers were stunned via captive bolt, then hanged from the back legs with chains, exsanguinated via the jugular vein, and electro-stimulated. Non-carcass components including blood, hide, limbs, gastrointestinal tract, organs, head and tail were then removed. The hot carcass weight was then recorded without any trimmings being done, within two hours of steers being slaughter. Carcasses were split longitudinally into two equal halves and then placed in a chiller.

#### 4.3.2. *Ultrasound scanning*

Ultrasound measurements were conducted using a real-time ultrasound scanner (Model 411281 Esaote Pie Medical Aquila; Esaote SPA, Genova, Italy) by a highly experienced Australian genetic evaluation system BREEDPLAN accredited ultrasound scanning operator (Allen, 2002). Vegetable oil was used to eliminate any air between the probe and the scanning site on the hide. Measurements collected included rib fat (URF) and rump (UP8) fat depth, eye muscle area (UEMA), intramuscular fat percentage (UIMF) and kidney fat depth (UKF) on the left side of the animal.

URF depth (mm), UIMF, and UEMA (cm<sup>2</sup>) were measured on the *M. longissimus thoracis et lumborum* between the 12-13<sup>th</sup> rib, UP8 measurements were taken at the site defined as the “point of intersection of a vertical line from the dorsal tuberosity of the tripartite tuber ischii parallel with the chine, and a horizontal line from the crest on the spinous process of the third sacral vertebra” (Hopkins 1993; Marimuthu et al., 2025). The UKF (mm) was measured as described by Ribeiro et al. (2007), approximately 15 cm from the midline of the animal.

Ultrasound measurements and BW were recorded 1-3 days prior to slaughter. All ultrasound measurements were recorded every 50 days until each animal was slaughtered depending on DOF.

#### *4.3.3. Abattoir and carcass grading*

Untrimmed hot carcasses were placed in the chillers at 3-5 °C for 16-24 hours prior to grading. The MasterBeef camera was used to measure MSA marbling (MSAmarb), rib fat depth (CRF) and EMA (CEMA) on the left half of the carcass (Hamblin, 2023; Masterbeef, 2020). All photos recorded and process by the MasterBeef application were assessed to ensure the correct identification of perimeter of the ribeye and that rib fat depth was at the correct location. Kidney and heart fat were physically dissected from lean tissue from the hot non-carcass components after collection at the abattoir. Pelvic fat dissected from the chilled carcass from the pelvic channel. Each of these fats were weighed separated and the sum make up the total kidney, pelvic and heart (KPH) fat. Dressing percentage was calculated using the shrunk BW of steers recorded prior to being loaded for transport to the abattoir and the hot untrimmed carcass weight recorded by the abattoir.

#### *4.3.4. Chemical intramuscular fat composition*

Samples were taken from 5 steers on the final day of the 0 DOF slaughter and all animals from 50-200 DOF (n = 76). Count of samples from Angus, Brahman and Charolais were n = 26, 24 and 26, respectively. Two thin slices of approximately 50 g were dissected from the exposed ribeye muscle (*M. longissimus thoracis et lumborum*) at the 12-13<sup>th</sup> rib, where the carcass was assessed for grading (Stewart et al., 2024). Each sample was equally split into three subsamples to represent repeats, weighed and placed into a freeze drier for approximately 24 hours when constant weight was achieved (Harvest Right, Salt Lake City, Utah). After drying, each subsample was weighed and the dry matter content calculated. One subsample was ground into a fine powder using a coffee bean grinder (the Coffee & Spice™,

Model BCG200, Breville Group Ltd., Sydney, Australia) and analysed for dry matter (DM), inorganic ash (Ash), crude fat (EE) and crude protein (CP) using the Dumas Combustion Method. Inorganic Ash is obtained by heating the up at a rate of 100°C/hour until reaching 200°C and then maintaining for 30 minutes. The sample is then heated to 550°C at the same rate and maintained for 6 hours. Crude fat is obtained using the AOCS Am 5-04 standard procedure (Am, 2005).

#### *4.3.5. Statistical analysis*

All variables were analysed using R Core Team (RStudio Inc., Boston, MA, USA; R Core Team, 2021) with a linear mixed-effects regression model containing breed, DOF, and their interaction as fixed effects. The animal was used as a random effect for BW and ultrasound measurements. The estimated marginal means for each variable and differences between means were obtained using the ‘emmeans’ package (Lenth 2024). Statistical significance was declared at  $P \leq 0.05$  and tendencies discussed at  $0.05 < P \leq 0.10$ . Adjustments were made for multiple comparisons using the Bonferroni correction. All estimated marginal means were calculated and presented using the original units even if the data was transformed to obtain the P-values. The URF, UP8, CRF, MSAmarb, EE, DM, and CP variables required log transformation, and their P-values are presented from analysis of the log-transformed values.

#### 4.4. Results

Summary statistics of all variables is shown in Table 4.3. Fat thickness at the P8 site was the ultrasound variable with the largest variability whereas UEMA showed the lowest variability. The CRF showed the largest variability of the carcass measurements, ranging from 1 to 33 mm, whereas EE was the chemical component that showed the largest variability.

**Table 4.3.** Summary statistics for ultrasound, carcass grading, and chemical composition of the 12-13<sup>th</sup> rib muscle of feedlot steers from induction up to 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Bodyweight, kg	284.0	720.0	442.1	103.08	23.32
Ultrasound					
Rib fat, mm	1	27	5	3.29	60.63
P8 fat, mm	1	38	8	4.70	61.04
Eye muscle area, cm <sup>2</sup>	40	127	83	21.18	25.47
Intramuscular fat, %	1.5	8.3	4.3	1.85	43.38
Kidney fat, mm	6	43	17	7.84	45.80
Carcass grading					
Hot carcass weight, kg	145.6	460.0	288.0	82.00	28.47
Dressing, %	53.5	65.6	60.3	2.85	4.73
Kidney, pelvic, heart fat, kg	1.2	17.5	7.8	4.39	56.38
Rib fat, mm	1	33	6.7	6.65	99.20
Eye muscle area, cm <sup>2</sup>	41.5	102.9	66.5	12.86	19.33
MSA marbling	100	930	320	127.48	49.99
Chemical composition 12-13 <sup>th</sup> rib					
Dry matter, %	23.1	37.3	28.2	2.5	8.95
Ether extract, %	1	42	11.1	8.3	74.39
Crude protein, %	53.8	88.9	80.7	6.8	8.42
Inorganic ash, %	2.7	7.4	5.1	0.9	17.96

Table 4.4 shows the significance of breed and DOF main effects and their interaction.

Bodyweight, all ultrasound and carcass variables showed a breed  $\times$  DOF interaction ( $P < 0.05$ ) except for MSA marbling ( $P = 0.06$ ) and KPH ( $P = 0.09$ ) which showed a tendency, and dressing percentage which was not significant ( $P = 0.132$ ). Similarly, EE, CP and DM were also affected by the breed  $\times$  DOF interaction ( $P < 0.05$ ) but this was not the case for ash which were affected by breed and DOF ( $P \leq 0.05$ ; Table 4.4).

**Table 4.4.** Effect of breed, days on feed (DOF) and the breed  $\times$  DOF interaction for ultrasound, carcass grading and chemical composition of the 12-13<sup>th</sup> rib of Angus, Brahman and Charolais steers fed for up to 200 days in the feedlot.

Variable	P-Value		
	Breed	DOF	Breed $\times$ DOF
Bodyweight	<0.001	<0.001	<0.001
Ultrasound			
Rib fat	<0.001	<0.001	<0.001
P8 fat	<0.001	<0.001	<0.001
Kidney fat	<0.001	<0.001	<0.001
Intramuscular fat	<0.001	<0.001	<0.001
Eye muscle area	<0.001	<0.001	<0.001
Carcass grading			
Hot carcass weight	<0.001	<0.001	<0.001
Dressing percentage	<0.001	<0.001	0.132
Kidney, pelvic, heart fat	<0.001	<0.001	0.092
Rib fat	<0.001	<0.001	0.026
MSA marbling	<0.001	<0.001	0.062
Eye muscle area	<0.001	<0.001	<0.001
Chemical composition 12-13 <sup>th</sup> rib			
Dry matter	<0.001	<0.001	0.008
Ether extract	<0.001	<0.001	<0.001
Crude protein	<0.001	<0.01	<0.010
Inorganic ash	0.053	<0.001	0.139

#### *4.4.1. Live ultrasound measurements*

The bodyweights and ultrasound measurements are shown in Table 4.5. Charolais steers were lighter than Angus and Brahman at the commencement of the trial ( $P < 0.05$ ), but their LWT was similar to Brahman steers at 50 DOF ( $P > 0.05$ ) and similar to Angus at 200 DOF ( $P > 0.05$ ; Table 4.5). However, Angus were heaviest, Charolais intermediate, and Brahman steers lightest at 100 and 150 DOF ( $P < 0.05$ ) whereas Brahman steers were lightest from 100 DOF onwards ( $P < 0.05$ ).

There was no difference between breeds in URF at 0 DOF ( $P > 0.05$ ) but Charolais showed lowest values from 50 DOF onwards, Brahman intermediate from 100 DOF, and Angus greatest URF until 200 DOF ( $P < 0.05$ ; Table 4.5). At 0 DOF Brahman had the greatest UP8 ( $P < 0.05$ ), whereas Angus and Charolais had similar UP8 ( $P > 0.05$ , Table 4.5). At 50 DOF, Angus had similar UP8 to Brahman ( $P > 0.05$ ), and Charolais remained the lowest ( $P < 0.05$ ). From 100 DOF, Angus had the greatest UP8, followed by Brahman and thinnest UP8 in Charolais ( $P < 0.05$ ).

Angus steers consistently had greater UIMF ( $P < 0.05$ ) compared to both Brahman and Charolais throughout the entire trial (Table 4.5). At 0 DOF, Brahman showed intermediate and Charolais the lowest UIMF ( $P < 0.05$ ), but no differences between them existed until the end of the trial ( $P > 0.05$ ).

**Table 4.5.** Bodyweight and ultrasound measurements of rib fat depth, P8 fat depth, kidney fat, intramuscular fat and EMA of Angus, Brahman and Charolais steers in a serial slaughter trial.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Body weight, kg	360.8	354.5	317.3	445.8	395.8	397.1	551.7	461.8	496.9	620.6	502.1	581.4	680.4	539.4	663.7	9.31
Ultrasound																
Rib fat, mm	3.0	3.2	3.1	5.0	4.7	3.5	8.4	6.8	4.3	11.0	8.6	5.9	17.1	10.4	7.2	0.60
P8 fat, mm	4.0	4.6	3.9	7.1	6.6	5.1	11.9	9.7	6.4	16.0	12.6	8.3	23.0	16.7	9.9	0.84
Kidney fat, mm	12.6	11.4	11.2	13.8	11.4	9.9	26.7	23.0	21.1	29.7	25.3	21.6	34.9	26.7	26.2	1.50
Intramuscular fat, %	4.3	3.0	1.7	5.3	2.9	2.6	7.6	4.8	4.6	7.3	5.2	5.1	7.8	5.1	5.2	0.29
Eye muscle area, cm <sup>2</sup>	64.9	59.0	55.8	89.4	75.8	80.1	106.1	87.6	97.7	113.8	105.5	112.1	121.1	98.2	110.5	2.88

<sup>x, y, z</sup> means without a common superscript differ ( $P < 0.05$ ).

For UKF, no differences between breeds were found at 0 DOF ( $P > 0.05$ ) but Angus showed greater UKF compared to Brahman and Charolais for the rest of the trial ( $P < 0.05$ ). Charolais and Brahman steers had similar UKF throughout the trial ( $P > 0.05$ ; Table 4.5) except at 150 DOF when Brahman had greater UKF compared to Charolais steers ( $P < 0.05$ ).

Angus had the greatest UEMA at 0, 50, 100 and 200 DOF ( $P < 0.05$ ), except for similar UEMA to Charolais steers at 150 DOF (Table 4.5). Brahman and Charolais had similar UEMA at 0 and 50 DOF, but Charolais had larger UEMA at 100 and 200 DOF ( $P < 0.05$ ) and also tended to be larger at 150 DOF ( $P < 0.10$ ) compared to Brahman steers for the remaining DOF ( $P < 0.05$ ), which had the smallest UEMA.

#### *4.4.2. Carcass grading measurements*

In Table 4.6, the hot carcass weight, dressing percentage and grading measurements are shown. The HCW followed a similar trend to LWT with Charolais steers had the lightest HCW compared to Angus and Brahman at 0 DOF ( $P < 0.05$ ; Table 4.6) and no differences between breeds at 50 DOF ( $P > 0.05$ ). However, Angus steers had the heaviest HCW at 100 DOF compared to Brahman and Charolais ( $P < 0.05$ ), but Angus and Charolais were similar and heavier than Brahman at 150 and 200 DOF ( $P < 0.05$ ). The dressing percentage of the Brahman steers were greater than Charolais ( $P < 0.05$ ) but similar to Angus ( $P > 0.05$ ) at 0 and 50 DOF. However, Angus increased to have a greater dressing percentage at 150 DOF than Brahman ( $P < 0.05$ ) but similar to Charolais steers ( $P > 0.05$ ). There were no differences observed between breeds at both 100 and 200 DOF.

Angus had the greatest CRF at 0, 100, 150 and 200 DOF compared to Brahman and Charolais ( $P < 0.05$ ; Table 4.6). At 50 DOF Angus tended to have a greater CRF than Brahman and Charolais ( $P < 0.10$ ). At 50 DOF Brahman tended to have a greater CRF compared to Charolais ( $P < 0.10$ ), but the breeds remained similar throughout the rest of the trial.

Angus had the greatest MSArmb throughout the trial ( $P < 0.05$ ; Table 4.6), except at 50 DOF when differences between breeds existed ( $P > 0.05$ ). Brahman and Charolais steers showed similar MSArmb throughout the trial ( $P > 0.05$ ).

Charolais steers had the smallest CEMA compared to the other breeds at 0 DOF ( $P < 0.05$ ), but larger than Brahman at 150 and 200 DOF ( $P < 0.05$ ) ( $P < 0.10$ ; Table 4.6). Angus steers had similar CEMA compared to Brahman steers at 0 DOF ( $P > 0.05$ ), but larger CEMA at 150 DOF ( $P < 0.05$ ), thus Brahman showed the smallest CEMA ( $P < 0.05$ ).

**Table 4.6.** Hot carcass weight, dressing percentage, kidney, pelvic and heart fat, rib fat, Meat Standards Australia (MSA) marbling score and eye muscle area for as Angus, Brahman and Charolais steers in a serial slaughter trial measured at the abattoir.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Hot carcass weight, kg	198.4	204.9	161.3	232.9	218.3	221.3	331.5	273.3	294.2	370.1	296.6	350.0	426.0	341.3	422.2	9.52
Dressing %	0.54	0.54	0.53	0.56	0.58	0.56	0.59	0.61	0.60	0.61	0.61	0.61	0.63	0.63	0.64	0.01
Carcass measurements																
Kidney, pelvic, heart fat, kg	2.95	2.1	0.53	3.73	2.99	2.09	9.88 <sup>x</sup>	5.42 <sup>y</sup>	5.12 <sup>y</sup>	9.1	7.97	8.21	15.0	11.6	13.16	0.77
Rib fat, mm	3.7	1.7	1.2	3.7	3.3	2.2	12.2	5.0	3.2	12.0	5.7	4.2	25.7	10.5	6.6	1.20
MSA marbling score	280 <sup>x</sup>	180 <sup>y</sup>	150 <sup>y</sup>	370	350	330	360 <sup>x</sup>	250 <sup>y</sup>	250 <sup>y</sup>	380 <sup>x</sup>	260 <sup>y</sup>	280 <sup>y</sup>	630 <sup>x</sup>	350 <sup>y</sup>	390 <sup>y</sup>	32.8
Eye muscle area, cm <sup>2</sup>	62.3	63.5	50.3	60.6	61.7	67.0	63.3	58.2	66.9	68.4	54.5	81.5	83.0	69.6	91.3	3.68

<sup>x, y, z</sup> means without a common superscript differ (P < 0.05).

#### *4.4.3. Chemical composition of 12-13<sup>th</sup> rib*

The chemical composition of samples taken from the 12-13<sup>th</sup> rib are shown in Table 4.7. Angus steers tended to be greater than Charolais at 0 DOF ( $P < 0.10$ ), but had greater EE compared to the other breeds throughout the trial ( $P < 0.05$ ; Table 4.7). Brahman and Charolais steers had similar EE throughout the trial ( $P > 0.05$ ) except at 50 DOF when Brahman steers had greater EE compared to Charolais ( $P < 0.05$ ). No differences between breeds existed for CP at 0 DOF ( $P > 0.05$ ) and at 50 DOF, Angus tended to have lower CP compared to Charolais steer ( $P < 0.10$ ). However, Brahman and Charolais steers had greater CP than Angus at 100, 150 and 200 DOF ( $P < 0.05$ ). Angus tended to have lower concentration of ash than Brahman.

**Table 4.7.** Chemical composition of intramuscular fat of *M. longissimus thoracis et lumborum* including dry matter percentage, crude fat ether extract, crude protein, inorganic ash for Angus, Brahman and Charolais steers in a serial slaughter trial measured.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Dry matter, %	27.35	24.30	25.17	27.01	27.01	25.34	29.41	27.38	27.70	31.58 <sup>x</sup>	28.61	28.19	33.04	27.48	27.64	1.557
Crude fat, %	9.40	3.10	5.45	8.78	4.37	1.38	15.32	6.45	5.87	20.12	10.88	11.05	30.65	10.02	12.90	1.756
Crude protein, %	80.25	85.1	84.9	79.5	82.72	85.92	76.98	85.57	84.37	73.45	82.83	82.65	65.72	84.47	82.94	1.886
Ash, %	6.60	5.40	6.25	5.33	5.47	5.35	5.65	5.73	5.53	4.68	5.37	5.08	3.35 <sup>x</sup>	4.65 <sup>y</sup>	4.48 <sup>y</sup>	0.298

#### 4.5. Discussion

The hypothesis posited that there would be significant differences in fat and muscle deposition among Angus, Brahman, and Charolais steers was confirmed in the present study. Importantly, the present study has demonstrated that both breed and DOF have an effect on fat and muscle accretion patterns measured by ultrasound and carcass grading in agreement with previous reports (Albertí et al., 2008; Hocquette et al., 2010; Long et al., 1979; Williams & Bennett, 1995).

British breeds, such as Angus, have smaller frame and earlier maturity, and a propensity to lay down subcutaneous, internal and intramuscular fat earlier, faster, and at a greater extent in comparison to *Bos indicus* and European breeds (Mao et al., 2013). European breeds have large frames, leaner bodies, and a later maturity pattern compared to Angus (Mao et al., 2013). This was reflected in the present study with Charolais steers BW and subcutaneous fats continuing to grow and increase by the end of the feeding period. In contrast, *Bos indicus* were found to be later maturing than Europeans, with a range of frame sizes (Mao et al., 2013; Randel, 2021). Nevertheless, results of the present study suggest that Brahman have a similar frame size to Charolais steers however will reach maturity at an early age as supported by lower live and carcass weights at long days on feed compared to the other breeds, and lower genetic potential for fat accumulation. Interestingly, Brahman steers showed intermediate subcutaneous fat accretion compared to Angus and Charolais suggesting an early maturity pattern without the fat deposition potential of British cattle (Lunt et al., 1985).

Mao et al. (2013) found that Angus steers had greater URF and CRF, but lower UEMA and CEMA compared to Charolais. These findings on rib fat are consistent with results of the present study. However, results on EMA of the present study were not as consistent as in Mao et al. (2013), which is likely because Charolais started the trial with lower live weight

and smaller EMA compared to Angus, although EMA was similar between breeds at 150 and 200 DOF. In addition, measurement errors with UEMA have previously been reported. For example, S. Greiner et al. (2003) found greater error in URF and UEMA measurements as CRF increased. It is also important to highlight that results of the present study from ultrasound measurements cannot be directly compared with carcass measurements because ultrasound and BW was analysed with repeated measurements on the same animals every 50 days until slaughter whereas carcass data only occurred once for each animal, thus the number of observations per breed and DOF differs between live and carcass measurements. Previous research reported that P8 fat depth measured on the hot carcass was greatest for Angus followed by Brahman and then Charolais ( $12.5 \pm 0.4$ ,  $10.5 \pm 0.3$ ,  $9.1 \pm 0.4$  mm, respectively) (Schutt et al., 2009). Such results align with findings on UP8 of the present study although the differences between breeds at 150 and 200 DOF were much larger (2.3-fold) in the present study compared to (Schutt et al., 2009). Therefore, it seems likely that differences between breeds become larger with longer days on feed of a high-energy concentrate diet as that fed in the present trial. The ability of Angus cattle to accumulate fat quicker than European and *Bos indicus* counterparts may allow them to reach a carcass endpoint suitable for some markets in a shorter feeding period, younger age, and smaller frames (Freer et al., 2007). This quicker fat accretion rate reduces the overall time spent on feed to achieve a desired carcass endpoint and allows for earlier marketing, which could translate into reduced feed costs. These results of the present study also highlighted that European cattle require extended feeding durations to achieve the same subcutaneous fat thickness compared to British steers. However, no scientific publications were found in the literature demonstrating the economic outcomes of feeding different breeds for different lengths of time and further research is recommended.

Schutt et al. (2009) analysed the effect of British, European and *Bos indicus* sires over Brahman females, and concluded that British breeds have a high marbling potential, European breeds have average marbling, and *Bos indicus* below average marbling. However, the present study found that European and *Bos indicus* had similar marbling by the end of the feeding period (both UIMF and MSAmarb). Chambaz et al. (2003) showed that Charolais steers had to spend approximately double the days on feed (281 days) compared to Angus steers (141 days) to achieve a similar UIMF (3.25% and 3.23%, respectively), which is similar to the present study although our results also suggest that Brahman steers may never achieve the marbling scores of Angus because they plateaued at 100 DOF. At a similar UIMF, Angus steers also had greater CRF in comparison to Charolais (Chambaz et al., 2003), similar to the present study which demonstrates the Angus' early maturity and propensity to accrete fat faster than the European steers.

Previous studies showed that *Bos indicus* had lower UIMF compared to British steers (Park et al., 2018) however the present study showed no differences between Brahman and Charolais since 50 DOF. Brahman tend to exhibit slower growth rate and lower marbling compared to British breeds (Schutt et al., 2009). Findings of the present study support these observations with lower live weight and HCW in Brahman compared to both Angus and Charolais. In contrast to (Schutt et al., 2009) but in agreement with Peacock et al. (1982), Brahman steers demonstrated greater subcutaneous fat deposition and similar marbling compared to Charolais steers up to 200 DOF, and both breeds were lower than Angus steers. These results could be due to greater genetic potential for subcutaneous fat deposition in Brahman compared to Charolais steers, or to Brahman steers reaching maturity during the trial but Charolais not, or both. No conclusions can be drawn from the present study without feeding both animals for longer than 200 DOF.

Stewart et al. (2021) and Elzo et al. (2011) showed the marbling scores were greater in Angus compared to Brahman steers at similar HCW as in the present study. Peacock et al. (1982) concluded that breed affects carcass characteristics and should be taken into consideration to maximise profits when assigning steers to market destinations or categories. Results of the present study demonstrate that DOF has a strong interaction with breed and both must be considered together. Nevertheless, Angus steers far outperformed the other breeds for IMF, reflecting their suitability for premium markets where marbling is a critical factor for high-quality beef production.

The muscularity of an animal is an important attribute as it is a key contributor to carcass value (Alempijevic et al., 2021). Angus steers had greater UEMA than Brahman and Charolais throughout the present trial, which is inconsistent with previous studies that have thoroughly demonstrated European cattle show superior muscling potential compared to British breeds (Freer et al., 2007; Mao et al., 2013). These results may be due to Charolais steers being inducted at 40 kg lighter BW and approximately 6-8 months younger compared to Angus in the present.

Kidney fat is categorised as internal fat (non-carcass component) and therefore waste at processing, but it requires feed energy to be deposited at a great cost (Ribeiro & Tedeschi, 2012; Rouse & Wilson, 2002). UKFAT was similar between breeds at 0 DOF but it was greater in Angus steers than the other breeds from 50 DOF onwards. These results suggest that the higher carcass quality traits of Angus steers may also be counterbalanced by greater waste of fat. This was similarly seen in the measured KPH dissected from the carcass of Angus compared to other breeds. There is limited literature regarding ultrasound scanning of UKFAT, as it is typically discussed in the form of dissected kidney, pelvic and heart fat (KPH) or channel fat post slaughter (Ribeiro et al., 2008). However, Ribeiro and Tedeschi (2012) noted there were differences in ultrasound imaging between *Bos indicus* and *Bos*

*taurus*, the former displaying a darker image, possibly making images more difficult to interpret. It is important to note that ‘waste’ fat at slaughter comes from different depots, with the most important being internal fat discarded with the gastrointestinal tract and internal organs, KPH fat trimmed at carcass cleaning, and excess subcutaneous fat also trimmed from the carcass with circular saws (Rashid et al., 2015). Hot carcass weight of the present study was measured on the untrimmed carcasses and therefore, the differences between breeds of the present study should be interpreted within that context. For instance, it is expected that more fat would have to be removed from Angus compared to Brahman and Charolais carcasses in preparation for boning and marketing.

Angus had approximately 2-fold greater EE at 150 DOF and 3-fold greater EE at 200 DOF compared to the other breeds in agreement with higher marbling. Teixeira et al. (2017) found that Angus steers had higher EE content compared to Nellore steers on two feedlot diets, adding that this may be due to smaller frame size and greater HCW of Angus compared to *Bos indicus*. Consistently with the present trial, Angus had higher EE and lower CP than Charolais bulls (Bures et al., 2006).

#### 4.6. Conclusions and Implications

The development of breed-specific prediction equations of fat accretion rate could be particularly valuable for decision support tools aimed at improving the efficiency and profitability of feedlot operations with a higher proportion of animals reaching market specifications, reduction of feed costs, and minimise excess fat wastage. These tools could optimise the timing of slaughter, ensuring that cattle are marketed at the optimal time to maximise returns for producers. For markets that pay for carcass fat, Angus are best suited, whereas Charolais are an ideal selection for markets that pay for lean meat. However, there seems to be little financial benefit for Brahman steers to be fed past 100 DOF. It should also be noted that animals of the present study were not implanted with hormonal growth

promotants because the objective was to obtain baseline information where the effects of different implant strategies can then be added if desired. However, it is important to note that hormonal implants reduce fat accretion and improve lean muscle growth (Hunter, 2010), so a meta-analysis from multiple studies may be required.

The effect of breed and days on feed can be seen in both the live animals and carcass through ultrasound and grading. This highlights the clear need to consider breed and feeding length when assigning cattle to feeding programs and slaughter dates. This will allow feedlots to tailor pens to have a more uniform group of cattle, reaching their intended market specifications as a group, to ensure maximum productivity and therefore profitability, as well as minimising fat and feed wastage. Additional research should be conducted with a greater number of animals in a commercial setting to reinforce the results of the present study.

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Chapter 5 - Whole-body and carcass physically separable  
tissues of Angus, Brahman and Charolais feedlot steers  
throughout 200 days on feed

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## 5.1. Abstract

Changes in body composition of different breeds with maturity degree in feedlot cattle is key in tailoring management strategies for optimal productivity and carcass value. The objective of the present study was to determine differences in bone, lean and fat of the carcass and non-carcass components of British, European and *Bos indicus* biotypes throughout 200 days on feed (DOF). Angus (n = 30; initial BW of  $361 \pm 5.3$  kg), Brahman (n = 30;  $355 \pm 5.3$  kg), and Charolais (n = 29;  $317 \pm 5.3$  kg) steers were inducted into the feedlot and 6 animals per breed were slaughtered every 50 DOF (n = 18). Non-carcass (NCC) and carcass components (CC) were collected, physically separated into bone, lean and fat, and weighed. The CC were calculated as a proportion of empty BW (EBW) and cold carcass weight (CCW). Data was analysed using a linear model with breed, DOF and their interaction as fixed effects. The interaction was significant for all variables ( $P < 0.05$ ). Fat (%EBW) in NCC was greater in Angus compared to Charolais from 0 to 200 DOF ( $P < 0.05$ ), and fat (%EBW) in CC was greater for Angus than other breeds at 50 to 200 DOF ( $P < 0.05$ ). The CC lean (% EBW) was greater for Charolais compared to Angus and Brahman from 50 to 200 DOF ( $P < 0.05$ ), but CC lean (% CCW) was greater for Charolais from 50 to 150 DOF ( $P < 0.05$ ), but similar to Brahman at 200 DOF ( $P > 0.05$ ). Tissue composition as a proportion of both EBW and CCW should be considered to identify the optimal economic endpoint for slaughter feedlot cattle of different breeds. This allows optimising productivity, minimising feed and excess fat wastage, and ensuring carcasses are within specification, therefore maximising profitability.

Key words: days on feed, body composition, carcass composition, breed.

## 5.2. Introduction

Body composition of feedlot cattle is affected by breed and days spent on feed (Berg & Butterfield, 1976; Freer et al., 2007; Marshall, 1994; Volpi-Lagreca et al., 2021). This information is critical to accurately predict the optimal time of slaughter, where economic returns are maximised. Currently, feedlot cattle are assigned to feeding programs of varying length based on factors such as induction liveweight, market destination and breed (Greenwood, 2021). However, there exists carcass variation between penned cattle groups that have been fed for the same amount of time, under the same conditions (Harrison & Oltjen, 2023). The optimal carcass endpoint is the point at which the animal has grown out to meet the ideal market specifications for yield and fat, without being over or underfed, thus minimising feed wastage and excess fat trimmings at processing. Reaching this point allows for more retail product to be sold from the carcass, rather than waste fat trimmings, and to utilise a higher proportion of the carcass, optimising productivity and profitability while increasing sustainability (Pyatt et al., 2005). Economic returns and carcass performance change throughout the feeding period, with average daily gain and feed efficiency decreasing as cattle are fed for longer due to increasing fat in gain (Block et al., 2001; Pyatt et al., 2005). On the other hand, underfed cattle could lead to inadequate fat cover, low yield and financial deductions at processing (Slack-Smith et al., 2009). Different breeds have been shown to differ in frame size, fat accretion, fat distribution, carcass yield and quality (Pyatt et al., 2005; Williams et al., 2010). Thus, differences between breeds in whole body and carcass composition throughout the feeding period is integral to reach optimal carcass endpoints. As a result, allocating different breeds of beef cattle into the same feeding program may not produce uniform carcasses, optimise performance and maximise profitability.

Physical dissection of bone, lean and fat is the gold standard to determine body composition of the animal but is rarely done due to the great expense, labour requirements and need for

infrastructure (Lunt et al., 1985; Navajas et al., 2010). Additionally, animals allocate energy for maintenance and tissue accretion for both carcass and non-carcass components (NCC) throughout the feeding period (Berg & Butterfield, 1976). The NCC are notably important to understand whole body composition and nutrient retention (Marcondes et al., 2010) albeit this is rarely measured.

Critically, there is no literature in the recent decades reporting whole-body and carcass composition comparing the three main biotypes of beef cattle, i.e. British, European and *Bos indicus* steers, under the same environmental and feeding conditions.

The objective of the present study was to determine whole-body and carcass composition of bone, lean, and fat tissues of Angus, Brahman and Charolais steers over 200 days on feed. It was hypothesised that Charolais would have the greatest proportion of lean throughout the trial due to being a European breed with a greater muscling capacity compared to other breeds (Dikeman, 2017). Angus steers would have the greatest proportion of fat particularly at the end of the feeding period, due to being earlier maturing and have a greater propensity to lay down fat (Dikeman, 2017). Brahman were hypothesised to have intermediate lean and fat throughout the trial because they have been bred and evolved for environmental hardiness rather than carcass quality or yield (Dikeman, 2017).

### 5.3. Methods and Materials

The present study was approved by the Institutional Animal Ethics Committee of The University of Sydney (approval number 2020/1822).

#### 5.3.1. *Experimental design*

The study was undertaken at the University of Sydney's research feedlot located in New South Wales, Australia. The trial consisted of 89 purebred steers including Angus (n = 30), Brahman (n = 30) and Charolais (n = 29). Angus and Brahman steers were approximately 16-

18 months of age and the Charolais steers were approximately 10-12 months old at induction. Each breed group was sourced from the same property, therefore having the same backgrounding history but with differing sires within the breed group. Sires had registered bloodlines within each breed society to ensure purebred status of the steers. The steers were inducted into the feedlot at 361, 355 and 371  $\pm$  5.3 kg BW for Angus, Brahman and Charolais, respectively. Steers were weighed, tagged, vaccinated and inspected by a veterinarian at induction. All animals were placed together in a pen for up to 200 days, and six of each breed (n = 18) were randomly selected for slaughter every 50 days. Steers were transitioned from a starter to a finisher ration mixing both at an increasing proportion of the finisher ration over 21 days (Table 5.1). The finisher ration consisted of dry rolled barley (78%), cottonseed (11%), wheat straw (5%) and mineral supplement (6%), with a total of 12.15 MJ of ME/ kg DM and 13.76% CP (Table 5.2). Both feed and water were offered to allow for ad libitum consumption throughout the trial period. At the start and 50-days intervals prior to slaughter, BW was measured before feed delivery (shrunk bodyweight; SBW, kg) using a traditional weighing box system sitting on load cells (Tru-Test Model XR3000; Datamars, Lamone, Switzerland), with all calibrations completed accordingly.

### *5.3.2. Slaughter procedure*

Steers were slaughtered over a consecutive three-day period (Tuesday, Wednesday, Thursday), two of each breed being randomly selected for each day (n = 6 per day). Steers were transported from the feedlot to a commercial abattoir early morning for approximately an hour (50 km) and slaughtered approximately 1 h after arrival.

**Table 5.1.** Two-ration mix fed to feedlot steers during the 21-day transition from starter to finisher feedlot ration.

Day	Ration Type	Starter, %	Finisher, %
1-5	Starter	100	0
6-7	Transition 1	85	15
8-9	Transition 2	75	25
10-11	Transition 3	65	35
12-13	Transition 4	55	45
14-15	Transition 5	45	55
16-17	Transition 6	35	65
18-19	Transition 7	25	75
20-21	Transition 8	15	85
22	Finisher	0	100

**Table 5.2.** Ingredient and chemical composition of the starter and finisher rations on an as-fed basis feed to Angus, Brahman, and Charolais steers in a serial slaughter trial.

Variable	Unit	Starter Ration	Finisher Ration
Diet composition			
Barley (dry rolled)	%	44.0	78
Millrun	%	23.0	0
Oat hay	%	15.0	0
Cottonseed (high lint)	%	8.5	11
Wheat straw	%	5.0	5
Mineral supplement	%	4.5	6
Chemical composition of ration			
DM	%	87.6	90.1
NDF	%DM	50.1	27.1
ADF	%DM	24.6	11.9
CP	%DM	15.6	12.2
Crude fat	%DM	1.8	2.9
Water soluble carbohydrates	%DM	5.2	3.3
Dry matter digestibility	%DM	59.6	75.4
Dry organic matter digestibility	%DM	59.4	74.6
Inorganic ash	%DM	9.5	6.3
Organic matter	%DM	90.5	93.7
Metabolisable energy *	MJ/kg DM	11.30	12.15
Net energy for maintenance *	Mcal/kg DM	1.77	1.96
Net energy for gain *	Mcal/kg DM	1.15	1.32
Monensin *	ppm	16.40	22.00

\*Formulated using the Beef Cattle Nutrient Requirement Model (NASEM, 2016).

Steers were stunned via a captive bolt, then hanged from the back legs with chains, exsanguinated via the jugular vein, and electro-stimulated. Non-carcass components including blood, hide, limbs, head, tail, gastrointestinal tract and internal organs were then removed and placed in labelled containers. Hot carcass weight (HCW) was then recorded without any trimmings being done, within two hours after slaughter. Carcasses were split longitudinally into two equal halves and then placed in a chiller. Untrimmed hot carcasses were placed in the chillers at 3-5 °C for 24-48 hours until being weighed again to obtain the chilled carcass weight (CCW). The left side of the carcass was processed as described by Hankins and Howe (1946); the right side of the carcass was sold.

### *5.3.3. Manual physical dissection procedure*

Non-carcass components included the blood, skin, head, hooves, gastrointestinal tract and internal organs (e.g. kidneys, heart, lungs, liver, trachea, reproductive tract, spleen, trachea and tail). The gastrointestinal tract (GIT) remained whole and intact when removed from the abattoir and placed in a single container with the oesophagus and rectum tied to avoid loss of contents. All internal organs, hide, blood and remaining head, feet and hooves were placed in separate labelled containers before being transported from the abattoir to the laboratory in a refrigerated vehicle at 3-4 °C. All non-carcass components were collected and brought back to the laboratory on the day of slaughter and weighed prior to dissection. The gastrointestinal tract was weighed, then emptied of ruminal contents, washed of any remaining waste, and weighed again. All fat was physically dissected by hand with a knife from all non-carcass components, weighed separately, and then weighed as a whole to make the total non-carcass component fat (NCF) weight for each animal. All lean tissue was separated from bone where applicable, weighed separately, and then weighed together to make the total non-carcass component lean (NCL). All bones collected were also weighed after separating lean and fat,

then weighed together again to make the non-carcass component bone (NCB). The total NCC was calculated as the sum of the NCF, NCL and NCB weights.

After carcasses had remained in the chiller for 24 – 48 hours, the left half of the carcass was collected and transported to the laboratory in a refrigerated truck at 3-4 °C, and bodies were placed back into the lab chiller at 3-5 °C. For each carcass, the fat, lean and bone were physically dissected and separated from one another by hand with a knife. The carcass bone (CB), lean (CL) and fat (CF) were weighed and recorded for each individual carcass.

#### *5.3.4. Statistical analysis*

Empty body weight was calculated as the sum of the NCC and CC after eliminating the contents of the gastrointestinal tract. All variables were analysed using R (R Core Team, 2021) in RStudio (RStudio Inc., Boston, MA, USA) with a linear model containing breed, DOF, and their interaction as fixed effects. Variables were tested for normality and outliers; no outliers were removed. The estimated marginal means for each variable and differences between means were obtained using the ‘emmeans’ package (Lenth, 2024). The total empty body bone (B\_EBW), lean (L\_EBW) and fat (F\_EBW), the sum of the carcass and non-carcass components bone, lean and fat weights were calculated as a percentage of the EBW. Additionally, the NCC and CC bone, lean and fat each separately calculated as a percentage of the EBW. Additionally, the carcass component bone (B\_CCW), lean (L\_CCW) and fat (F\_CCW) were calculated as a percentage of the CCW and presented in the results section. Statistical significance was declared at  $P \leq 0.05$ , and tendencies discussed at  $0.05 < P \leq 0.10$ . Adjustments were made for multiple comparisons using the Bonferroni correction.

#### *5.4. Results*

Summary statistics for all variables are shown in Table 5.3. The NCF (kg, %EBW) and CF (kg) had the greatest variability, whereas total lean (% EBW), CL (%EBW) and NCB (kg)

had the lowest variability overall. Empty BW had the greatest range from 221.8 to 649.8kg, of the composition tissues the CF had the greatest range from 12.3 to 204.9kg.

**Table 5.3.** Summary statistics for bone, lean and fat of carcass and non-carcass components, and as a proportion of empty BW (EBW) and cold carcass weight (CCW) of feedlot steers over 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Shrunk bodyweight, kg	278.8	697.0	466.1	111.0	23.81
GIT content, kg	18.6	80.8	47.7	14.3	29.89
GIT content, %SBW	4.1	23.7	11.0	4.9	44.38
Non-carcass components, kg	73.6	206.2	137.4	33.9	24.65
Non-carcass bone, kg	15.6	28.0	21.2	2.6	12.47
Non-carcass lean, kg	23.4	53.6	37.0	7.3	19.60
Non-carcass fat, kg	2.3	71.3	24.9	17.1	68.45
Carcass components, kg	145.9	454.2	281.0	80.6	28.70
Carcass bone, kg	34.6	61.2	44.8	6.3	13.96
Carcass lean, kg	91.5	249.0	158.5	37.3	23.52
Carcass fat, kg	12.3	204.9	77.8	43.9	56.48
Empty BW, kg	221.8	649.8	418.4	113.8	27.20
Total bone, % EBW	11.0	25.7	16.6	3.5	20.97
Total lean, % EBW	37.8	56.0	47.6	4.4	9.26
Total fat, % EBW	6.0	41.0	22.5	8.5	37.74
NCC bone, % EBW	3.6	8.0	5.3	1.0	18.50
NCC lean, % EBW	6.7	13.5	9.2	1.6	17.43
NCC fat, % EBW	0.8	11.8	5.4	2.6	48.96
CC bone, % EBW	7.1	18.2	11.3	2.5	22.39
CC lean, % EBW	31.0	46.2	38.4	3.5	9.11
CC fat, % EBW	5.1	31.5	17.2	6.1	35.39
Hot carcass weight, kg	145.6	460.0	288.0	82.0	28.47
Cold carcass weight, kg	143.9	457.5	281.5	81.5	28.94
Bone, % CCW	10.4	27.7	16.9	4.0	23.64
Lean, % CCW	44.0	68.8	57.4	5.4	9.35
Fat, % CCW	8.0	44.8	25.6	8.9	34.61

Table 5.4 shows the significance of breed and DOF main effects and their interaction. All variables showed a breed  $\times$  DOF interaction ( $P < 0.05$ ), except for NCF %EBW ( $P = 0.537$ ) and GIT contents (% shrunk BW;  $P = 0.111$ ). Days on feed and breed affected all variables ( $P < 0.001$ ).

**Table 5.4.** Effect of breed, days on feed (DOF), and breed  $\times$  DOF interaction body composition of Angus, Brahman and Charolais steers over 200 DOF.

Variable	P-Value		
	Breed	DOF	Breed $\times$ DOF
Shrunk BW, kg	<0.001	<0.001	<0.001
GIT contents, kg	<0.001	<0.001	0.024
GIT contents, %SBW	<0.001	<0.001	0.111
Non-carcass components, kg	<0.001	<0.001	<0.001
Non-carcass bone, kg	<0.001	<0.001	<0.001
Non-carcass lean, kg	<0.001	<0.001	0.013
Non-carcass fat, kg	<0.001	<0.001	<0.001
Carcass components, kg	<0.001	<0.001	<0.001
Carcass bone, kg	<0.001	<0.001	<0.001
Carcass lean, kg	<0.001	<0.001	<0.001
Carcass fat, kg	<0.001	<0.001	<0.001
Empty BW, kg	<0.001	<0.001	<0.001
Total bone, % EBW	<0.001	<0.001	<0.001
Total lean, % EBW	<0.001	<0.001	0.001
Total fat, % EBW	<0.001	<0.001	0.013
NCC bone, % EBW	<0.001	<0.001	<0.001
NCC lean, % EBW	<0.001	<0.001	<0.001
NCC fat, % EBW	<0.001	<0.001	0.537
CC bone, % EBW	<0.001	<0.001	<0.001
CC lean, % EBW	<0.001	<0.001	0.014
CC fat, % EBW	<0.001	<0.001	0.003
Hot carcass weight, kg	<0.001	<0.001	<0.001
Cold carcass weight, kg	<0.001	<0.001	<0.001
Bone, % CCW	<0.001	<0.001	<0.001
Lean, % CCW	<0.001	<0.001	0.013
Fat, % CCW	<0.001	<0.001	0.045

#### 5.4.1. *Non-carcass and carcass components*

Shrunk bodyweight, the total non-carcass component and carcass component weight, and the weight of bone, lean and fat for each were presented in Table 5.5. Angus and Brahman steers were initially heavier than Charolais at the beginning of the trial at 0 DOF and finished the trial with Angus and Charolais being greater than Brahman at 150 and 200 DOF ( $P < 0.05$ ). Charolais had the lightest total NCC compared to other breeds at 0 DOF ( $P < 0.05$ ), however, Charolais were similar to Brahman at 100 DOF ( $P > 0.05$ ) and less than Angus ( $P < 0.05$ ). By the conclusion of the trial, Angus and Charolais had a greater quantity of NCC compared to Brahman at 200 DOF ( $P < 0.05$ ).

The non-carcass bone weight was similar at 100 and 150 DOF, with Angus and Charolais having a similar quantity of bone which was similar compared to Brahman ( $P < 0.05$ ). At 200 DOF, Charolais had a greater NCB weight compared to other breeds ( $P < 0.05$ ). At the beginning of the trial, Angus had a greater amount of non-carcass lean (NCL) compared to other breeds ( $P < 0.05$ ). However, at 50, 150 and 200 DOF, Angus and Charolais had a similar amount of NCL compared to Brahman ( $P < 0.05$ ). The NCF followed a similar trend, with NCF beginning greater for Angus and Brahman compared to Charolais steers at 0 DOF ( $P < 0.05$ ). The NCF trend became more consistent from 100-200 DOF, with Angus having a greater amount of NCF compared to Brahman and Charolais ( $P < 0.05$ ).

At the beginning of the trial Charolais had the lowest weight of total CC compared to Angus and Brahman ( $P < 0.05$ ; Table 5.5), however, from 150 to 200 DOF, Angus and Charolais had heavier CC compared to Brahman steers ( $P < 0.05$ ). Carcass component bone (CB) was not different between breeds at 0 and 50 DOF but began to differ at 100 DOF, with Charolais having the greatest bone weight compared to Brahman ( $P < 0.05$ ), whereas Angus were similar to other breeds ( $P > 0.05$ ). At 150 DOF, all breeds differentiated from one another,

with Charolais having the greatest CB, followed by Angus, and then Brahman with the lightest CB ( $P < 0.05$ ). However, Brahman increased at 200 DOF to be similar to Angus steers ( $P > 0.05$ ), whereas Charolais had heavier CB compared to the other breeds ( $P < 0.05$ ). Carcass component lean (CL) was greatest for Brahman steers compared to Charolais at 0 DOF ( $P < 0.05$ ), whereas Angus was similar to other breeds at 0 DOF ( $P > 0.05$ ). At 100 to 150 DOF, both Angus and Charolais had a similar and greater CL weight compared to Brahman steers ( $P < 0.05$ ). However, at 200 DOF, CL weight of Charolais was heavier than other breeds ( $P < 0.05$ ), and Brahman had similar CL to Angus steers ( $P > 0.05$ ; Table 5.5).

At the commencement of the trial, Angus and Brahman had a greater weight of CF compared to Charolais ( $P < 0.05$ ), however, at 50 DOF, Brahman had a similar weight of CF as other breeds ( $P > 0.05$ ). Angus had greater CF compared to other breeds from 100 to 200 DOF ( $P < 0.05$ ). Brahman steers had greater CF compared to Charolais at 100 DOF ( $P < 0.05$ ), but from 150 to 200 DOF, both breeds had a similar CF content ( $P > 0.05$ ) and were less than Angus steers.

**Table 5.5.** Shrunken bodyweight (BW), gastrointestinal tract (GIT) contents, non-carcass and carcass components, and bone, lean and fat tissues of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed (DOF). Breed × DOF P-value < 0.05 for all variables.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Shrunken BW, kg	355.7	368.1	300.0	393.9	355.1	376.0	539.8	433.9	469.5	578.7	478.4	547.8	658.1	525.5	640.3	15.03
GIT contents, kg	64.3	65.7	64.5	47.1	32.3	47.8	53.7	29.4	48.8	47.2	41.2	53.4	46.3	27.3	46.5	4.02
GIT contents, % shrunken BW	18.1 <sup>y</sup>	17.8 <sup>y</sup>	21.6 <sup>x</sup>	11.8 <sup>x</sup>	9.1 <sup>y</sup>	12.7 <sup>x</sup>	9.8 <sup>x</sup>	6.8 <sup>y</sup>	10.4 <sup>x</sup>	8.2	8.6	9.7	7.1	5.2	7.3	0.79
Non-carcass component																
Total, kg	101.4	103.0	80.0	119.9	109.4	112.3	159.6	134.3	134.2	170.4	144.8	156.4	194.3	164.4	183.7	5.02
Bone, kg	18.4	19.3	17.8	19.3	18.2	19.7	22.8	20.3	22.2	23.5	20.9	24.0	23.8	22.2	26.1	0.54
Lean, kg	34.4	27.0	26.3	39.1	29.8	36.3	42.7	32.4	40.1	46.9	33.6	43.4	46.4	34.2	44.3	1.51
Fat, kg	9.6	7.2	2.6	17.1	13.0	9.2	38.4	21.7	17.7	40.8	27.3	27.5	60.5	40.8	43.7	2.70
Carcass component																
Total, kg	190.0	199.4	155.4	226.8	213.3	215.9	326.4	270.2	286.4	361.2	292.4	338.0	417.5	333.9	410.1	9.51
Bone, kg	38.9	41.6	41.5	38.9	38.7	43.4	45.9	41.9	50.8	46.6	41.1	53.5	48.5	44.7	57.6	1.58
Lean, kg	114.7	126.4	100.1	132.3	126.4	139.3	166.8	146.7	175.9	187.5	159.1	198.6	196.6	184.2	235.8	5.53
Fat, kg	36.4	31.3	13.9	55.7	48.2	33.2	113.7	81.6	59.8	127.2	92.2	85.9	172.4	105.0	116.6	5.26

<sup>x, y, z</sup> means without a common superscript differ (P < 0.05).

#### 5.4.2. Bone, lean, and fat of empty bodyweight (EBW)

The empty body weight (EBW) of Angus and Brahman were greater than Charolais at 0 DOF ( $P < 0.05$ ). From 50 to 100 DOF, Brahman and Charolais steers were of a similar weight ( $P > 0.05$ ) compared to Angus, which were heavier ( $P < 0.05$ ; Table 5.6). At 150 to 200 DOF, the EBW of Charolais increased to be similar to Angus steers ( $P > 0.05$ ), and both breeds had greater EBW compared to Brahman which were the lightest ( $P < 0.05$ ).

The total bone (B\_EBW) varied slightly throughout the trial. Charolais had a greater proportion of bone from 0 to 50 DOF compared to other breeds ( $P < 0.05$ ). At 100 DOF, B\_EBW of Brahman steers were greater than Angus ( $P < 0.05$ ), however, Charolais had greater B\_EBW than both ( $P < 0.05$ ). Angus and Brahman both had lower B\_EBW compared to Charolais ( $P < 0.05$ ) at 150 DOF, but at 200 DOF, Charolais and Angus were similar compared to Brahman steers ( $P < 0.05$ ). In summary, bone (% EBW) was greater in Charolais compared to Angus and Brahman at 0 DOF and the difference between breeds became smaller with DOF with Charolais and Brahman showing greater B\_EBW compared to Angus at 200 DOF.

The total lean as a proportion of EBW (L\_EBW) began greatest for Charolais compared to Brahman ( $P < 0.05$ ), with Angus similar to other breeds ( $P > 0.05$ ) at 0 DOF. At 50 to 150 DOF breed differences in L\_EBW remained consistent, Charolais having the greatest amount compared to other breeds ( $P < 0.05$ ). This differed at 200 DOF, with Angus having the lowest L\_EBW, followed by Brahman sitting intermediately, and Charolais remaining the highest ( $P < 0.05$ ). Therefore, the reduction in L\_EBW throughout DOF was greater in Angus, intermediate in Brahman, and least pronounced in Charolais, which maintained always greater L\_EBW.

Similarly, F\_EBW of Angus and Brahman was greater compared to Charolais on 0 and 50 DOF ( $P < 0.05$ ). However, Angus had greater F\_EBW than Brahman ( $P < 0.05$ ), and

Brahman greater than Charolais steers ( $P < 0.05$ ) at both 100 and 150 DOF. At 200 DOF, Angus had a greater F\_EBW compared to other breeds ( $P < 0.05$ ). Thus, Angus showed the largest increase in F\_EBW over DOF, Charolais intermediate, and Brahman the lowest increase of F\_EBW over time.

#### *5.4.3. Non-carcass bone, lean, and fat as a proportion of EBW*

The NCB %EBW was greatest in Charolais steers compared to Angus throughout the trial ( $P < 0.05$ ), with Brahman steers being similar to other breeds at 50 to 150 DOF, and similar to Charolais at 200 DOF ( $P > 0.05$ ). The NCL %EBW was greatest for Angus and Charolais compared to Brahman at 0, 50 and 150 DOF ( $P < 0.05$ ), with no differences between breeds at 200 DOF. Angus steers had the greatest NCF %EBW compared to Charolais at 0, 50 and 150 DOF ( $P < 0.05$ ), with Brahman being similar to other breeds. However, at 100 and 200 DOF Angus were greater than the other breeds ( $P < 0.05$ ).

#### *5.4.4. Carcass bone, lean and fat as a proportion of EBW*

The CB %EBW was greatest in Charolais steers compared to other breeds throughout the trial ( $P < 0.05$ ), Angus and Brahman remained similar at 0, 50, 150 and 200 DOF ( $P > 0.05$ ). However, Brahman were intermediate and Angus with the least CB %EBW at 100 DOF ( $P < 0.05$ ). Charolais steers had the greatest CL %EBW compared to other breeds at 50 to 200 DOF ( $P < 0.05$ ), with Angus and Brahman being similar from 0 to 150 DOF ( $P > 0.05$ ), however, at 200 DOF Brahman sat intermediately and Angus the lowest proportion ( $P < 0.05$ ). The CF %EBW was initially greatest for Angus and Brahman steers compared to Charolais at 0 DOF ( $P < 0.05$ ). Interestingly, all breeds differed from 50 to 150 DOF, Angus remaining the greatest, Brahman intermediately and Charolais the least ( $P < 0.05$ ). At 200 DOF, Angus was greater than other breeds ( $P < 0.05$ ).

**Table 5.6.** Empty bodyweight (EBW), the total, carcass and non-carcass component bone, lean and fat (% EBW) of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed (DOF). Breed × DOF P-value < 0.05 for all variables.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Empty BW, kg	291.4	302.4	235.5	346.8	322.7	328.2	486.1	404.5	420.6	531.6	437.2	494.4	611.8	498.3	593.8	13.51
Total bone, %EBW	19.70	20.14	25.19	16.87	17.66	19.23	14.14	15.45	17.38	13.18	14.27	15.69	11.83	13.42	14.13	0.388
Total lean, %EBW	51.15	50.69	53.66	49.49	48.42	53.44	43.12	44.39	51.37	44.19	44.07	48.97	39.77	43.80	47.19	0.818
Total fat, %EBW	15.74	12.82	7.05	20.77	18.84	12.96	31.24	25.31	18.35	31.48	27.22	22.91	38.01	29.32	26.95	1.053
Non-carcass components, %EBW																
Bone	6.32	6.39	7.60	5.58	5.66	6.00	4.69	5.05	5.29	4.43	4.81	4.86	3.90	4.45	4.40	0.122
Lean	11.81	8.94	11.12	11.29	9.23	11.10	8.77	8.02	9.54	8.81	7.70	8.79	7.59	6.87	7.45	0.254
Fat	3.28 <sup>x</sup>	2.40 <sup>xy</sup>	1.12 <sup>y</sup>	4.85 <sup>x</sup>	3.97 <sup>xy</sup>	2.82 <sup>y</sup>	7.88 <sup>x</sup>	5.26 <sup>y</sup>	4.18 <sup>y</sup>	7.62 <sup>x</sup>	6.18 <sup>xy</sup>	5.56 <sup>y</sup>	9.91 <sup>x</sup>	8.24 <sup>y</sup>	7.34 <sup>y</sup>	0.494
Carcass components, %EBW																
Bone	13.38	13.75	17.59	11.29	12.00	13.23	9.45	10.40	12.09	8.76	9.46	10.83	7.93	8.97	9.72	0.299
Lean	39.34	41.75	42.54	38.20	39.18	42.34	34.36	36.36	41.83	35.38	36.38	40.18	32.18	36.94	39.74	0.840
Fat	12.46	10.42	5.93	15.92	14.87	10.14	23.36	20.06	14.18	23.86	21.04	17.35	28.10	21.08	19.60	0.786

<sup>x, y, z</sup> means without a common superscript differ (P < 0.05).

#### 5.4.5. Carcass bone, lean, and fat as a proportion of CCW

The differences in breed and DOF for both HCW and CCW are shown in Table 5.7. Angus and Brahman began the trial with the heaviest HCW and CCW compared to Charolais at 0 DOF ( $P < 0.05$ ). However, no differences between breeds existed at 50 DOF ( $P > 0.05$ ) but at 100 DOF, Angus had heavier HCW and CCW compared to Brahman and Charolais ( $P < 0.05$ ). At 150 and 200 DOF, Charolais HCW and CCW increased to become similar to Angus ( $P > 0.05$ ) and were both greater than the Brahman steers ( $P < 0.05$ ). Carcass bone (% CCW) was lower in Angus and Brahman compared to Charolais steers at 0 and 50 DOF ( $P < 0.05$ ). However, all breeds differed at 100 DOF, with Charolais showing the greatest, Brahman intermediate, and Angus the lowest B\_CCW ( $P < 0.05$ ). Charolais steers had greater L\_CCW compared to Angus steers ( $P < 0.05$ ) at 0 DOF but Brahman were similar to other breeds ( $P > 0.05$ ). In addition, Angus and Brahman had a similar L\_CCW at 50 and 150 DOF ( $P > 0.05$ ) and lower than Charolais steers ( $P < 0.05$ ). At 100 DOF, Angus had the least, Brahman intermediate, and Charolais the greatest proportion of carcass lean ( $P < 0.05$ ). The trial concluded at 200 DOF with Charolais and Brahman steers showing the greatest L\_CCW compared Angus ( $P < 0.05$ ). Carcass fat (% CCW) was greater in Angus and Brahman compared to Charolais steers at 0, 50 and 150 DOF ( $P < 0.05$ ). However, at 100 DOF all breeds differed with Angus having the greatest F\_CCW, Brahman intermediate, and Charolais the least ( $P < 0.05$ ). At the end of the study (200 DOF), Angus had the greatest F\_CCW compared to both Brahman and Charolais ( $P < 0.05$ ).

**Table 5.7.** Hot carcass weight, cold carcass weight (CCW), and bone, lean and fat of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 DOF.

	Days on feed (DOF)															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Hot CW, kg	198.4	204.9	161.3	232.9	218.3	221.3	331.5	273.3	294.2	370.1	296.6	350.0	426.0	341.3	422.2	9.52
Cold CW, kg	190.2	199.8	154.4	227.4	213.5	217.6	324.2	267.1	286.5	361.2	290.9	341.6	420.3	334.8	415.4	9.35
Bone, % CCW	20.52	20.82	26.80	17.21	18.15	19.99	14.16	15.75	17.76	12.87	14.23	15.68	11.55	13.36	13.90	0.458
Lean, % CCW	60.32	63.20	64.82	58.22	59.26	63.87	51.49	55.03	61.39	51.98	54.98	58.17	46.87	54.96	56.80	1.054
Fat, % CCW	19.09	15.77	9.04	24.31	22.48	15.34	35.03	30.34	20.84	35.10	31.65	25.09	40.91	31.41	28.01	1.188

<sup>x, y, z</sup> means without a common superscript differ ( $P < 0.05$ ). Hot carcass weight (hot CW); Cold carcass weight (cold CW).

## 5.5. Discussion

The present study hypothesised that Charolais steers would have the greatest proportion of lean meat over the whole trial compared to other breeds due to larger frame, later maturity and greater muscling capacity (Mao et al., 2013). In contrast, Angus steers were expected to have fatter bodies than the other breeds, particularly towards the end of the feeding period, due to smaller frames and early maturity (Mao et al., 2013). Finally, Brahman were predicted to have intermediate lean and fat throughout the trial due not having a high muscling capacity or early maturing as the other breeds, primarily being utilised for their environmental hardiness than their carcass yield or quality traits (Flowers et al., 2018; Schutt et al., 2009). The present study confirmed the proposed hypotheses using modern genetics for the aforementioned beef breeds. However, the present study demonstrated that breeds change body composition differently with increasing DOF similar to results reported with ultrasound and carcass grading (Chapter 4) and performance as well (Chapter 3). There are no studies that directly compared bone, lean and fat content of both carcass and non-carcass components of Angus, Brahman and Charolais purebred feedlots steers under the same environmental conditions and diet with serial slaughters.

The aforementioned hypothesis was confirmed by the findings that the difference in carcass weight between 0 and 200 DOF was 230, 135, and 261 kg for Angus, Brahman, and Charolais confirming the higher potential for growth of Charolais and surprisingly low for Brahman steers. Furthermore, the difference in bone content from 0 to 200 DOF was -9.0, -7.5, and -12.9 % EBW for Angus, Brahman, and Charolais, respectively, whereas such difference for lean content from 0 to 200 DOF was -13.5, -8.2, -8.0 % of EBW, respectively. In the present study, Brahman and Charolais had similar B\_EBW and B\_CCW, and greater in comparison to Angus. For dissected body fat, the change from 0 to 200 DOF was 22.3, 16.5, 19.9 % EBW for Angus, Brahman, and Charolais, respectively. Therefore, these changes in

the relative proportion of the different tissues were primarily driven by a faster increase of body fat of Angus (136 kg) and of body lean in Charolais (136 kg) whereas the weight of body bones experienced smaller change over DOF. However, it is important to note that Charolais had lower body condition score and muscle score at 0 DOF (data not shown).

#### *5.5.1. Non-carcass components*

Quantification of the non-carcass components is crucial in understanding whole body composition because these make up approximately 35-40% of the EBW of the animal (Rotta et al., 2016). The present study reported a total NCC of a slightly lower range of 30.9 to 34.8% (excluding GIT content) of the EBW. Non-carcass internal fat is the first to be laid down as the animal matures, and it makes up the majority of non-carcass fat particularly around the internal organs before any other fats (Andrews, 1958; Schumacher et al., 2022). However, non-carcass fat is wasted (not paid for by abattoirs) and a considerable expense as it requires a great amount of feed (i.e. energy) to be deposited (Ribeiro & Tedeschi, 2012). There is limited literature that measured physically dissected internal non-carcass fat, but studies rather use kidney, pelvic and heart (KPH) fat as an indication of internal fat, which was presented in the companion study (Chapter 5). As with all internal fat, it is most desirable to keep the KPH at a minimum (Kempster et al., 1976). Pyatt et al. (2005) showed that KPH increased linearly with time on feed, similar to NCF %EBW of the present study, particularly for Charolais and Brahman steers. Bergen et al. (2006) found that British feedlot steers had higher NCF adjusted for HCW compared to European breeds, which was similarly observed in the present study for NCF weight and %EBW.

There was a clear difference in the NCC between breeds and over DOF, however, this is currently not considered in some available prediction models to determine whole body composition (Ribeiro & Tedeschi, 2012). Rather, carcass fat is used to predict empty body fat content (Ribeiro & Tedeschi, 2012). The present study suggests the need to take breed and

DOF into consideration for more accurate and precise determination of whole-body composition of different breeds of feedlot steers over DOF.

### 5.5.2. Carcass components

The ideal carcass composition entails maximising lean meat yield, maintaining adequate subcutaneous fat coverage while avoiding excessive fat that must be trimmed off, achieving high meat quality traits including marbling, and overall meeting the specifications for the destined market (Amer et al., 1994; Berg & Butterfield, 1976; McPhee et al., 2020). This is key to achieving maximum profitability for the production system, thus determining and understanding the differences in carcass composition of different biotypes of beef cattle is crucial (Segura et al., 2023). Each beef cattle biotype is best suited to different markets due to lean meat yield or quality traits with preferences ranging from very lean to very fatty beef (Greenwood, 2021). Therefore, selective breeding can be focused traits that can satisfy specific markets. However, the authors of the present study could not find studies with physical dissection of purebred steers of different biotypes under the same environmental and diet conditions in the 21<sup>st</sup> century.

Berg and Butterfield (1976) reported Brahman and Charolais steers had similar B\_CCW however the present study demonstrated that this may not always be the case as it is dependent on factors such as DOF and body condition, amongst others. Furthermore, Koch et al. (1982) found that Charolais × British cross steers had greater CB %CCW compared to British crosses, and Gregory et al. (1994) reported that Angus had less CB compared to Charolais steers at 14.1 and 16.2% CCW, respectively, at approximately 235 DOF. The aforementioned studies both support the notion that British biotype has a smaller frame compared to the European breeds, and therefore differences between breeds in the proportion of bone is seen. This can be crucial to buyers such as processors paying over the hooks and

wholesalers when considering the composition of the cuts, particularly when paying on the basis of \$/kg of carcass weight.

Lean meat yield and adequate fat coverage of the carcass to meet target market specifications are key components of determining carcass value (Alempijevic et al., 2021). Similar to the present study, Coleman et al. (1993) found that Angus steers had a greater CF from EBW (kg) and CF from CCW (kg) accretion rate compared to Charolais steers under the same feeding conditions. Furthermore, Gregory et al. (1994) discovered that over four slaughter groups from 204 – 267 DOF, at an average age of 438 days, Angus steers had less CL and greater CF (kg, %CCW) compared to Charolais, also agreeing with the differences in CL and CF (kg, %EBW and %CCW) at 200 DOF of Angus and Charolais from the present study. Furthermore, DeRouen et al. (1992a) demonstrated that Brahman showed an increase and yield when crossed with British and European breeds, respectively. LeVan et al. (1979) assigned Angus and Charolais steers to four slaughter groups of initial, light, middle and heavy, steers carcass weight resulting in 149.7, 237.8, 287.9 and 338.6kg, at 0, 96, 169 and 242 DOF for Angus, and 152.9, 324.7, 384.5 and 449.6kg, at 0, 180, 303 and 378 DOF for Charolais. LeVan et al. (1979) results showed that bone weight increased as DOF increased but were greatest at the middle and heavy slaughter groups for Angus and Charolais, respectively, with Charolais steers having greater total CB (%CCW) at all slaughter points. These results were similarly seen in the present study, with CB %CCW of Charolais steers being greater than Angus from 0 to 200 DOF. Charolais had greater total retail lean weight from four primal cuts including chuck, ribset, loin and round (3.5 - 28.5kg) compared to Angus at each slaughter point, both breeds increasing with increasing DOF (LeVan et al., 1979). However, in the present study the Charolais only had a greater CL weight (kg) than Angus at 200 DOF, but CL %CCW was greater for Charolais than Angus from 0 – 200 DOF. Furthermore, LeVan et al. (1979) showed Angus having greater total fat percentage from the

aforementioned primal cuts (0.57 - 1.62%) than Charolais through each slaughter group, both increasing over DOF. Similarly, Angus also had greater CF (kg, %CCW) than Charolais in the present study, however, at much greater proportions due to being the entire carcass. Furthermore, Angus had greater carcass fat, these findings again reinforcing the results seen in the present study (LeVan et al., 1979). DeRouen et al. (1992b) study showed that Brahman steers had a smaller eye muscle area (EMA) similar to Angus steers, but smaller than Charolais, although only an indication of muscularity and not directly comparable to CL, these findings agree with the same trends seen in the present study. The proportion of bone, lean and fat of the EBW (rather than the CCW) is more suitable and applicable for prediction models, producers or the live animal trade to determine the composition and growth and therefore can be used to aid in management decisions such as grouping similar animals together, assigning DOF programs and slaughter dates (Fordyce et al., 2022). In contrast, the composition of CCW is applicable to processors, retailers, and meat buyers to make more informed sourcing decisions (Segura et al., 2023).

### *5.5.3. Economic importance of carcass composition*

Globally, there are a variety of value-based marketing systems that are utilised to assign carcass value depending on a range of factors including location, consumer demand and market specification and access (Hocquette et al., 2022). However, carcass weight, yield and quality are the most important factors priced and incentivised at different rates (Hocquette et al., 2022). Lean meat yield is a driving factor of value, as it is closely associated with both cutability and saleable retail meat yield, and therefore directly associated with value (Stewart et al., 2024). McGilchrist et al. (2022) found that if a flat price is assigned to all carcass cuts, then lean meat yield would determine 97% of the carcass value, demonstrating its importance. Carcass subcutaneous and intramuscular fat also plays a vital role in determining value, with the latter being a key trait of carcass quality (Liu et al., 2022). Subcutaneous fat

plays a role in both eating quality and sufficiently covering the carcass to reduce the effects of cold shortening, but excess subcutaneous fat is an economic waste for the producer as trimmed fat is assigned a very small price (e.g. \$0.30 AUD/kg) (McGilchrist et al., 2022; Pacheco et al., 2023). Thus, predicting carcass composition considering breed and days on feed could enable producers to optimise carcass value to best meet the optimal market specifications for those individual animals.

#### 5.6. Conclusions and implications

The present study showed clear differences in whole body and carcass composition through the breed and DOF interaction. Consistent with the British biotypes, Angus steers accreted fat faster and earlier in the feeding period due to their characteristically smaller frame and earlier maturity type, have typically less lean compared to the European breeds, and thus are best suited to reach carcass endpoint with high fat content in shorter fed programs in the feedlot compared to European biotypes (Freer et al., 2007). Charolais whole body and carcass composition is dominated by great proportion of lean muscle compared to Angus and Brahman. Due to their larger frames and late maturation, Charolais are best suited to long fed programs with markets that desire heavier carcass weight. In contrast, Brahman steers showed intermediate body and carcass lean and fat, making the breed more suited for short fed programs and crossbreeding to infuse tolerance to harsh tropical environmental conditions. Crossing either British or European breeds with *Bos indicus* allows for increases in either meat quality or yield, respectively, and this can be used to tailor genetics to market specifications (Wyatt et al., 2005).

It is important to note that the present study had  $n = 6$  for each breed  $\times$  DOF group and thus would be beneficial for further research with a greater number of animals per slaughter group to confirm the results seen in the present study. In addition, it is important to note that there are genetic lines with low or high estimated breeding values for frame, maturity weight,

carcass weight, and fat content within each breed (Boerner et al., 2014) albeit the present study used animals from only one genetic source. There is a need to consider the response of these breed to increasing length of the feeding programs in the feedlot when selecting or purchasing cattle for different markets and assigning them to feeding programs. This knowledge could aid with management decisions that optimise the productivity and environmental sustainability through minimising both feed and fat wastage and maximise profitability.

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# Chapter 6 - Tissue composition of different primal cuts of three biotypes of feedlot cattle slaughtered between 0 and 200 days on feed

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## 6.1. Abstract

The proportion and composition of wholesale primal cuts of different breeds changes with days on feed (DOF) and this information is critical to optimise carcass value. The objective of the present study was to determine changes in the proportion and tissue composition of six wholesale primal cuts of British, European and *Bos indicus* biotypes up to 200 DOF. Angus (n = 30; initial BW of  $361 \pm 5.3$  kg), Brahman (n = 30;  $355 \pm 5.3$  kg) and Charolais (n = 29;  $317 \pm 5.3$  kg) purebred steers were inducted into the feedlot and 6 animals per breed were slaughtered every 50 DOF (n = 18). After slaughter, half the cold carcass was broken down into six wholesale primal cuts including neck and chuck (NC), blade and front leg (BL), brisket and spareribs (BSR), wholesale ribs (WSR), loin and rump (LR), and the butt. Each primal cut was physically dissected into bone, lean and fat by knife, and weighed separately. Primal cuts and tissue weights were calculated as proportion of empty BW (%EBW) and cold carcass weight (%CCW). Breed, DOF, and their interaction were fixed effects. Breed, DOF, and the interaction effected all variables in kg except WSR bone ( $P < 0.05$ ). For all primal cuts (%EBW and %CCW), Charolais had the greatest lean, Angus had the greatest fat and Brahman intermediate, with the differences between breeds becoming greater as DOF increased. Both breed and DOF effected the proportion of primal cuts of the CCW and their tissue composition. Therefore, both factors should be considered when sorting cattle into feeding programs and determining the optimal DOF according to the target market. Such information can help to maximise yield of each primal cuts and optimise carcass endpoint and profitability of feedlot cattle.

Key words: wholesale primal cuts, carcass composition, breed, days on feed

## 6.2. Introduction

The global beef industry utilises a variety of value-based marketing systems to determine carcass value from quality and yield traits (Cross & Savell, 1994; Kempster, 1986). Yield and composition of primal cuts is a key determinant of carcass value and understanding the factors that influence them is of financial interest to all stakeholders throughout the supply chain (Hankins & Howe, 1946). The yield of primal cuts may be affected by morphological differences between breed and the composition of bone, lean and fat tissue which ultimately determines carcasses cutability, saleable meat yield and value (Lunt et al., 1985).

Different biotypes of beef cattle have traits such as maturity rate and frame size that effects their propensity to accrue lean muscle and fat at different rates and capacities (Freer et al., 2007). European breeds have greater muscling capacity and larger frames compared to British cattle with smaller frames and greater propensity to lay down fat (Mao et al., 2013; Taussat et al., 2019). Additionally, the length of the feeding program is managed to reach the optimal carcass endpoint to satisfy market specifications such as fatness (Slack-Smith et al., 2009). Thus, breed and DOF are crucial factors in determining wholesale primal cut yield and composition of feedlot beef cattle.

Furthermore, some primal cuts have higher values than others such as the wholesale ribset (6<sup>th</sup> – 12<sup>th</sup>), loin, rump and butt are higher value compared to the neck, chuck, blade and brisket (Connolly et al., 2018; Kempster et al., 1976). However, there are no published studies quantifying the yield and composition of primal cuts of the main breed biotypes and with different length of the feeding program despite the importance to achieving the highest price for selected markets (Sood et al., 2023). Importantly, the international trade is primarily comprised of chilled primal cuts, emphasising the importance of composition at a primal cut level compared to the carcass level (Polkinghorne & Thompson, 2010). Such information on yield and composition of primal cuts allows the supply chain to make more informed value-

based marketing decisions, which may feedback to producers to make more informed management and breeding decisions (Sakamoto et al., 2014). This may reveal an opportunity for producers to be paid further incentives for producing animals consistently achieving greater yielding high value wholesale primal cuts, similar to the premiums established for quality traits such as marbling.

The objective of the present study was to evaluate how breed-specific conformations and days on feed affect yield and tissue allocation to different wholesale primal cuts of the carcass. It was hypothesised that conformational differences among breeds would drive divergent patterns of wholesale primal cut tissue allocation as the feeding duration increased with Angus having higher yield of high value cuts compared to Charolais and Brahman.

### 6.3. Materials and Methods

The present study was approved by the Institutional Animal Ethics Committee of The University of Sydney (approval number 2020/1822).

#### *6.3.1. Experimental design*

The present study was carried out at the University of Sydney's feedlot research facility located in New South Wales, Australia. The trial used Angus (n = 30), Brahman (n = 30) and Charolais (n = 29) purebred steers with an initial BW of 361, 355 and 371 ± 5.3 kg, respectively. Angus and Brahman steers were approximately 16-18 months of age and the Charolais steers were approximately 10-12 months old at induction. Each breed was sourced as a group from the same property, thus having experienced the same backgrounding conditions and diet. Additionally, the steers' sires had registered bloodlines within each breed society to ensure the purebred status of the steers. At induction, steers were weighed, tagged, vaccinated, inspected by a veterinarian, and placed together in a single pen for up to 200

days. Six steers of each breed (n = 18) were randomly selected for slaughter every 50 days on feed.

Steers were transitioned from a starter to a finisher ration mixing both at an increasing proportion of the finisher ration over a 21-day period. The finisher ration consisted of dry rolled barley (78%), cottonseed (11%), wheat straw (5%) and mineral supplement (6%), with a total of 12.15 MJ of ME/DM kg and 13.76% CP. Steers were allowed ad libitum access to both feed and water throughout the trial period. Empty BW (EBW, kg) was calculated as the sum of the carcass and non-carcass components after eliminating the contents of the gastrointestinal tract.

### *6.3.2. Slaughter procedure*

Steers were slaughtered over a consecutive three-day period (Tuesday, Wednesday, Thursday), with two steers of each breed randomly selected for each day (n = 6 per day). Steers were transported from the feedlot to a commercial abattoir early morning for approximately an hour (50 km) and slaughtered shortly after arrival. Steers were stunned via captive bolt, then hanged from the back legs with chains, exsanguinated via the jugular vein, and electro-stimulated. Hot carcass weight (HCW) was then recorded within two hours of steers being slaughtered and no trimmings done to the carcass. Carcasses were split longitudinally into two equal halves and then placed in a chiller at 3-5 °C for 24-48 hours. The left side of the carcass was processed as described by Hankins and Howe (1946) and the right side of the carcass was sold.

### *6.3.3. Carcass breakdown and dissection procedure*

Untrimmed carcass sides were broken down into six primal cuts following the Handbook of Australian Meat 7<sup>th</sup> Edition and further detailed descriptions of carcass sectioning in Supplementary Table 1 (AUS-MEAT Limited, 2005). Carcass sections, with their AUS\_MEAT identification numbers, were labelled as the neck and chuck (NC) (Figure 6.1

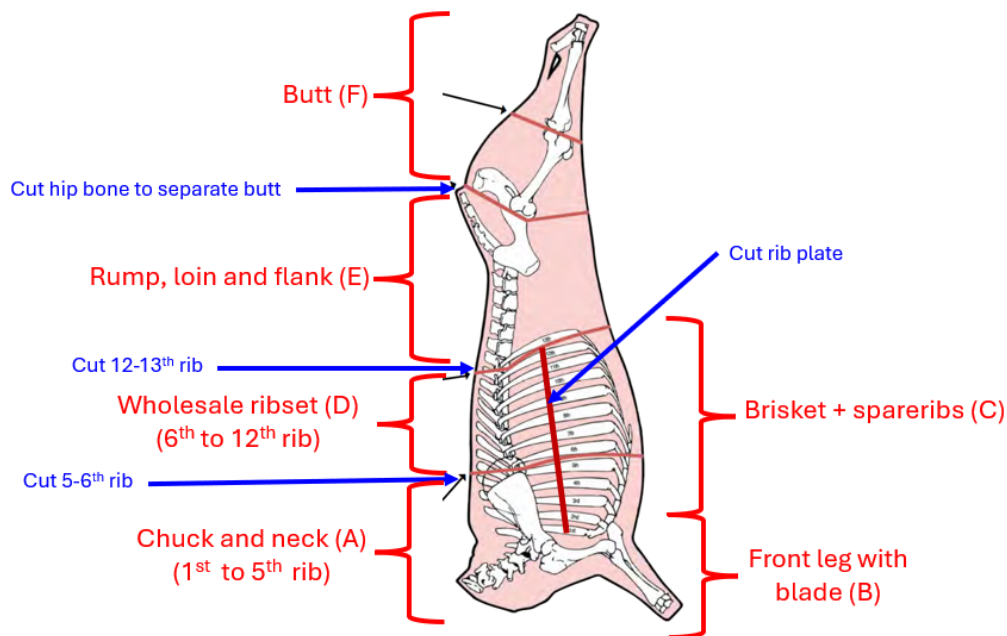
(A); 1630, 2260) which was composed of the neck and chuck removed from the forequarter by cutting between the 5<sup>th</sup> and 6<sup>th</sup> rib and removing the front leg and blade. The blade (BL) consisted of the blade and front leg together, separated from the forequarter and chuck (Figure 6.1 (B); 1682, 1685, 2300). The brisket and spareribs (BSR) were split from the forequarter, with a line cut at the junction of the 1<sup>st</sup> rib and 1<sup>st</sup> sternal segment to the reflection of the diaphragm at the 11<sup>th</sup> rib, continuing to the 13<sup>th</sup> rib, with the diaphragm removed (Figure 6.1 (C); 1643). The wholesale ribs (WSR) were separated from the forequarter, including from the 6<sup>th</sup> – 12<sup>th</sup> ribs (Figure 6.1 (D); 2223). The loin and rump (LR) from the hindquarter from the 13<sup>th</sup> rib to just below the hip joint (Figure 6.1 (E); 1543). The butt was separated from the hindquarter with a cut from the hip joint (Figure 6.1 (F); 1500). Each section was weighed to determine total weight before physically separating bone, lean and fat by hand using a knife. Each of the separated bone, lean and fat were weighed and recorded.

#### *6.3.4. Statistical analysis*

Total primal cut weight and the dissected bone, lean and fat tissue weights were multiplied by two to reflect the weight of the entire carcass. Cold carcass weight (CCW) was calculated as the sum of the wholesale primal cuts. The primal cuts and tissue weight were calculated and presented as kg and as the proportion of EBW and CCW. All variables were analysed using R (R Core Team, 2021) in RStudio (RStudio Inc., Boston, MA, USA) with a linear model containing breed, DOF, and their interaction as fixed effects. Variables were tested for normality and outliers with a studentised residual larger than  $\pm 3$  were deleted. There were 6 outliers out of 2136 datapoints removed from the %EBW, 7 out of 2136 from the %CCW, and 5 out of 2403 from the kilogram datasets. The estimated marginal means for each variable and differences between means were obtained using the ‘emmeans’ package.

Statistical significance was declared at  $P \leq 0.05$ , and tendencies discussed at  $0.05 < P \leq 0.10$ .

Adjustments were made for multiple comparisons using the Bonferroni correction.



**Figure 6.1.** Diagram of carcass side sectioning and cut lines into 6 primal cuts: neck and chuck (NC; A), blade and front leg (BL; B), brisket and spareribs (BSR; C), wholesale ribset (WSR; D), loin and rump (LR; E), and butt (6; F).

#### 6.4. Results

Summary statistics of weights for all primal cuts and their components, and as a proportion of EBW and CCW are shown in Tables 6.1, 6.2, and 6.3, respectively. The WSR and LR fat showed the largest variation between animals whereas BL, BSR, and butt bone were the least variability. The butt was the heaviest and the BSR the lightest body parts. For the tissue weights in each primal cut, fat showed the largest variability between animals and bone the least, whereas lean tissue was the heaviest and bone the lightest (Table 6.1). The total weights of the primal cuts added up to 67% EBW (Table 6.2) and the remainder 33% is comprised of non-carcass weight (data not shown). The BSR and WSR as %EBW showed the largest variation between animals, but the butt was the heaviest and NC the lightest as %EBW (Table 6.2). The average values and CV expressed as %CCW for the primal cuts followed a similar

trend to those as %EBW, with the largest variation between animals observed in the BSR and the butt weight representing the largest %CCW (Table 6.3). It is important to note that the sum all primal cuts as %CCW adds up to 100.

Table 6.4 shows the significance of breed and DOF main effects, and their interaction for the primal cut weights (kg). All variables showed a breed  $\times$  DOF interaction ( $P < 0.05$ ) except for WSR bone ( $P = 0.13$ ). The breed  $\times$  DOF interaction was also significant for EBW (kg) but as %EBW only LR and butt were affected by the interaction (Table 6.6). The breed  $\times$  DOF interaction affected CCW (kg), only the butt primal, bone and fat of both BL and BSR, LR lean, and butt bone and lean as %CCW (Table 6.7). The interaction tended to be significant for WSR bone and total LR ( $P < 0.10$ ). DOF and breed affected all measures as %EBW and %CCW ( $P < 0.05$ ) except NC as %EBW ( $P = 0.32$ ).

Results are presented below for those variables, factors, and interactions that were significant with a focus on data presented as %EBW and %CCW because these are more appropriate for comparisons and commercial applications compared to the total weight in kg.

**Table 6.1.** Summary statistics for the weight of the entire primal cut and each tissue of feedlot steers slaughtered between 0 and 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Cold carcass weight, kg	143.9	457.5	281.5	81.47	29.84
Neck and chuck, kg	17.92	63.12	39.00	11.14	28.56
Bone, kg	4.36	9.10	6.21	1.04	16.80
Lean, kg	11.56	37.9	23.49	6.04	25.73
Fat, kg	1.28	24.5	9.11	4.87	53.46
Blade and front leg, kg	25.24	66.40	43.95	11.33	25.78
Bone, kg	5.72	13.10	9.48	1.38	14.51
Lean, kg	14.84	40.10	25.83	6.38	24.72
Fat, kg	1.70	19.3	8.36	4.32	51.62
Brisket and spareribs, kg	10.08	30.50	41.77	4.98	27.06
Bone, kg	4.20	8.20	5.74	0.91	15.87
Lean, kg	10.08	30.50	18.40	4.98	27.06
Fat, kg	1.12	45.40	17.50	10.79	61.62
Wholesale ribset, kg	10.76	53.20	26.11	9.57	36.65
Bone, kg	2.92	7.30	4.65	0.91	19.59
Lean, kg	6.76	23.60	12.92	3.67	28.37
Fat, kg	0.32	29.60	8.37	5.90	70.54
Loin and rump, kg	24.52	110.00	56.10	19.72	35.15
Bone, kg	4.68	9.20	6.40	.09	17.11
Lean, kg	16.56	47.10	29.96	7.46	24.90
Fat, kg	2.52	55.00	17.86	10.79	60.42
Butt, kg	43.60	115.54	74.57	17.01	22.81
Bone, kg	8.92	17.20	12.17	1.89	15.51
Lean, kg	29.52	74.60	47.90	10.25	21.40
Fat, kg	2.86	32.10	14.40	6.74	46.80

**Table 6.2.** Summary statistics for the empty bodyweight (EBW) and the weight of each and the bone, lean and fat as a proportion on empty bodyweight of feedlot steers over 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Empty bodyweight, kg	221.8	649.8	418.4	113.8	27.20
Neck and chuck, %EBW	7.83	11.06	9.30	0.72	7.69
Bone, %EBW	0.99	2.31	1.55	0.33	21.57
Lean, %EBW	4.19	6.93	5.66	0.59	10.40
Fat, %EBW	0.57	3.77	2.04	0.68	33.58
Blade and front leg, %EBW	8.63	12.32	10.58	0.78	7.39
Bone, %EBW	1.44	3.96	2.39	0.55	23.25
Lean, %EBW	4.78	7.99	6.25	0.65	10.39
Fat, %EBW	0.76	3.96	1.92	0.62	32.52
Brisket and spareribs, %EBW	7.78	12.50	9.80	1.06	10.84
Bone, %EBW	0.88	2.61	1.44	0.35	24.07
Lean, %EBW	2.86	6.58	4.46	0.65	14.50
Fat, %EBW	0.50	7.38	3.83	1.58	41.37
Wholesale ribset, %EBW	4.81	8.19	6.06	0.66	10.97
Bone, %EBW	0.73	1.66	1.16	0.23	20.02
Lean, %EBW	2.17	4.11	3.11	0.38	12.15
Fat, %EBW	0.14	4.56	1.80	0.91	50.63
Loin and rump, %EBW	0.95	16.93	13.15	1.22	9.29
Bone, %EBW	1.03	2.90	1.60	0.36	22.70
Lean, %EBW	5.76	8.95	7.24	0.67	9.06
Fat, %EBW	1.11	8.46	3.94	1.54	39.11
Butt, %EBW	13.13	21.62	18.09	1.51	8.37
Bone, %EBW	1.79	5.51	3.10	0.85	27.54
Lean, %EBW	7.89	15.39	11.72	1.44	12.31
Fat, %EBW	1.28	5.26	3.27	0.88	26.94

**Table 6.3.** Summary statistics for the weight of the cold carcass weight (CCW), each primal cut and the bone, lean and fat as a proportion of cold carcass weight of feedlot steers over 200 days on feed.

Variable	Minimum	Maximum	Mean	STD	CV
Cold carcass weight, kg	143.9	457.5	281.5	81.47	28.94
Neck and chuck, %CCW	12.07	16.53	13.88	0.99	7.12
Bone, %CCW	1.42	3.58	2.32	0.53	22.64
Lean, %CCW	5.95	10.32	8.46	0.87	10.34
Fat, %CCW	0.89	5.36	3.03	0.99	32.68
Blade and front leg, %CCW	12.74	19.05	15.80	1.18	7.44
Bone, %CCW	2.02	6.07	3.57	0.88	24.56
Lean, %CCW	6.82	12.42	9.33	0.98	10.48
Fat, %CCW	1.18	5.84	2.85	0.90	31.52
Brisket and spareribs, %CCW	11.62	18.50	14.62	1.50	10.24
Bone, %CCW	1.25	4.06	2.17	0.56	25.99
Lean, %CCW	4.28	9.56	6.66	0.98	14.72
Fat, %CCW	0.75	10.89	5.70	2.32	40.73
Wholesale ribset, %CCW	7.48	11.78	9.03	0.88	9.69
Bone, %CCW	1.07	2.55	1.74	0.37	21.16
Lean, %CCW	3.30	5.81	4.64	0.54	11.72
Fat, %CCW	0.21	6.47	2.69	1.33	49.47
Loin and rump, %CCW	16.92	24.04	19.61	1.53	7.82
Bone, %CCW	1.50	4.31	2.40	0.57	23.79
Lean, %CCW	8.53	13.00	10.81	0.99	9.15
Fat, %CCW	1.67	12.02	5.86	2.24	38.24
Butt, %CCW	19.38	32.07	27.04	2.40	8.88
Bone, %CCW	2.34	8.44	4.65	1.33	28.69
Lean, %CCW	11.45	23.93	17.51	2.25	12.83
Fat, %CCW	1.99	7.84	4.87	1.28	26.29

**Table 6.4.** Effect of breed, days on feed (DOF), and breed × DOF interaction of wholesale primal cuts and their composition of Angus, Brahman and Charolais steers over 200 DOF.

Variable	P-Value		
	Breed	DOF	Breed × DOF
Empty bodyweight, kg	< 0.001	< 0.001	< 0.001
Cold carcass weight, kg	< 0.001	< 0.001	< 0.001
Neck and chuck, kg	< 0.001	< 0.001	< 0.001
Bone, kg	< 0.001	< 0.001	0.017
Lean, kg	0.127	< 0.001	< 0.001
Fat, kg	< 0.001	< 0.001	< 0.001
Blade and front leg, kg	< 0.001	< 0.001	< 0.001
Bone, kg	< 0.001	< 0.001	0.009
Lean, kg	< 0.001	< 0.001	< 0.001
Fat, kg	< 0.001	< 0.001	< 0.001
Brisket and spareribs, kg	< 0.001	< 0.001	< 0.001
Bone, kg	< 0.001	< 0.001	0.002
Lean, kg	< 0.001	< 0.001	0.013
Fat, kg	< 0.001	< 0.001	< 0.001
Wholesale ribset, kg	< 0.001	< 0.001	< 0.001
Bone, kg	0.044	< 0.001	0.126
Lean, kg	< 0.001	< 0.001	< 0.001
Fat, kg	< 0.001	< 0.001	< 0.001
Loin and rump, kg	< 0.001	< 0.001	< 0.001
Bone, kg	< 0.001	< 0.001	0.045
Lean, kg	< 0.001	< 0.001	< 0.001
Fat, kg	< 0.001	< 0.001	< 0.001
Butt, kg	< 0.001	< 0.001	< 0.001
Bone, kg	< 0.001	< 0.001	0.002
Lean, kg	< 0.001	< 0.001	< 0.001
Fat, kg	< 0.001	< 0.001	0.027

At the start of the trial, Angus and Brahman steers had a greater CCW compared to Charolais steers ( $P < 0.05$ ), however, at 150 and 200 DOF Angus and Charolais had a similar and heavier CCW compared to Brahman steers ( $P < 0.05$ ; Table 6.5). Despite similar CCW between Angus and Charolais at the end of the trial, Angus had heavier BSR, WSR, and LR but lighter butt compared to Charolais ( $P < 0.05$ ) whereas no differences between them existed for NC and BL weight ( $P > 0.05$ ). At the end of the trial (200 DOF), Brahman showed the lightest weight of all primal cuts compared to Angus and Charolais ( $P < 0.05$ ) except for similar butt weight to Angus steers ( $P > 0.05$ ). Despite similar NC and BL weight of Angus and Charolais at 200 DOF, Charolais had heavier lean and lighter fat in these body parts, similar to the rest of the primal cuts ( $P < 0.05$ ).

The breed  $\times$  DOF interaction ( $P < 0.05$ ) affected both EBW and CCW (Table 6.5). However, the breed  $\times$  DOF interaction only affected LR and butt weight as %EBW ( $P < 0.05$ ; Table 6.6) and %CCW ( $P \leq 0.06$ ; Table 6.7) but not the other primal cuts ( $P > 0.05$ ). The breed  $\times$  DOF interaction on butt %CCW was due to the difference between Charolais and the other two breeds increasing throughout time due to faster decrease over DOF in lean and bone proportion of Charolais steers (Supplementary Figure 2). Results were similar for butt %EBW (data not shown).

**Table 6.5.** Empty body weight, cold carcass weight, primal cuts neck and chuck, blade and front leg, brisket and spareribs, wholesale ribs, loin and rump, and butt, and the bone, lean and fat of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Empty body weight, kg	291.4	302.4	235.5	346.8	322.7	328.2	486.1	404.5	420.6	531.6	437.2	494.4	611.8	498.3	593.8	13.51
Cold carcass weight, kg	190.2	199.8	154.4	227.4	213.5	217.6	324.2	267.1	286.5	361.2	290.9	341.6	420.3	334.8	415.4	9.35
Neck and chuck, kg	25.33	28.09	19.97	33.00	32.15	31.76	45.35	37.03	40.31	48.35	40.88	46.36	55.55	46.01	58.07	1.802
Bone, kg	5.25	5.61	5.11	5.32	5.55	6.07	6.59	5.91	7.03	5.56	5.86	7.61	6.88	6.12	7.82	0.323
Lean, kg	15.53	18.56	13.17	19.47	20.37	20.34	25.18	21.93	25.53	27.25	25.17	28.19	29.72	28.89	34.94	1.139
Fat, kg	4.53	3.39	1.59	7.95	6.31	5.08	13.61	9.17	7.71	13.37	9.72	10.47	18.73	10.91	15.08	0.842
Blade and front leg, kg	31.35	32.85	27.59	35.75	33.00	34.62	50.91	41.28	47.62	58.24	45.90	56.11	58.33	47.41	61.20	1.644
Bone, kg	8.22	8.71	8.90	8.53	7.84	9.32	9.70	8.89	10.71	9.91	8.81	11.49	10.35	9.36	12.43	0.408
Lean, kg	18.68	19.73	16.85	20.85	19.76	21.07	27.94	24.30	29.72	33.04	26.86	32.99	31.50	28.70	37.30	1.053
Fat, kg	4.39	4.39	2.15	6.14	5.39	4.14	13.09	7.99	6.91	14.16	10.13	10.35	16.23	9.19	12.46	0.727
Brisket and spareribs, kg	26.23	26.25	20.47	34.41	29.69	29.99	51.13	37.46	36.89	57.94	42.88	47.72	74.22	51.06	63.92	2.014
Bone, kg	5.17	5.43	5.51	5.31	4.57	5.47	6.39	5.14	5.97	6.45	4.95	6.74	6.45	5.41	7.34	0.266
Lean, kg	13.50	14.37	12.71	16.42	13.99	17.46	18.77	14.83	18.64	21.65	17.57	21.81	25.78	21.53	28.76	1.119
Fat, kg	7.77	6.53	2.28	12.53	11.15	6.32	25.97	17.35	12.22	29.65	20.19	19.07	41.60	24.06	27.54	1.302

<sup>x-z</sup> Means without a common superscript differ between breed ( $P < 0.05$ ). <sup>a-d</sup> Means without a common superscript differ between days on feed ( $P < 0.05$ ).

**Table 6.5 (continued).** Empty bodyweight, cold carcass weight, primal cuts neck and chuck, blade and front leg, brisket and spareribs, wholesale ribs, loin and rump, and butt, and the bone, lean and fat of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed.

	Days on feed															SEM
	0			50			100			150			200			
	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	Angus	Brahman	Charolais	
Wholesale ribset, kg	16.17	16.72	12.39	20.35	18.95	18.72	31.15	26.18	26.05	32.42	25.60	29.46	46.20	33.38	40.30	1.440
Bone, kg	3.85	4.04	3.75	4.28	4.24	4.19	4.61	4.89	5.21	4.62	4.24	5.09	5.58 <sup>xy</sup>	5.09 <sup>y</sup>	6.46 <sup>x</sup>	0.292
Lean, kg	8.99	9.71	7.93	10.28	9.93	11.46	13.17	12.49	14.0	14.37	11.71	15.99	17.98	15.63	20.98	0.642
Fat, kg	3.23	2.85	0.67	5.67	4.68	2.86	13.38	8.76	6.29	13.30	9.53	8.23	22.53	11.51	12.80	1.000
Loin and rump, kg	37.67	37.75	26.96	41.39	39.13	39.29	65.48	52.17	53.21	75.60	59.15	67.75	94.75	70.76	85.38	2.314
Bone, kg	5.73	5.88	5.76	5.10	5.37	5.72	6.70	6.09	7.22	7.14	6.23	7.62	7.28	6.22	8.22	0.331
Lean, kg	22.57	24.39	17.92	24.49	22.86	25.75	31.99	27.11	32.29	35.88	29.65	38.90	38.77	34.91	44.96	1.109
Fat, kg	9.27	7.11	3.07	11.7	10.74	7.69	26.67	18.68	13.37	29.71	19.99	18.23	41.72	25.38	25.92	1.732
Butt, kg	53.41	58.17	47.07	62.49	60.62	63.17	80.15	72.98	82.41	88.69	76.52	94.25	91.22	86.22	106.57	2.374
Bone, kg	10.71	11.41	12.43	10.34	10.31	12.59	11.91	11.01	14.62	11.88	11.04	14.98	11.97	11.53	16.20	0.442
Lean, kg	35.41	39.68	31.52	40.79	39.47	43.25	49.77	46.03	55.17	55.26	48.13	61.32	52.85	54.52	68.90	1.692
Fat, kg	7.25	7.05	4.12	11.34	9.81	7.00	18.50	15.84	12.51	21.33	16.82	18.30	26.27	19.90	21.06	1.068

<sup>x-z</sup> Means without a common superscript differ between breed ( $P < 0.05$ ). <sup>a-d</sup> Means without a common superscript differ between days on feed ( $P < 0.05$ ).

For those primal cuts with no significant breed  $\times$  DOF interaction, breed affected BL, BSR, and WSR as % of EBW and CCW ( $P < 0.05$ ) except for NC ( $P > 0.05$ ). Charolais had greater % of EBW and CCW in BL and lower BSR and WSR compared to Angus ( $P < 0.05$ ) accompanied by lower % in LR and butt despite the significant breed  $\times$  DOF interaction of the latter ( $P < 0.05$ ). Brahman steers had similarly low proportion of BL as Angus and similarly low proportion of BSR and WSR as Charolais ( $P > 0.05$ ). However, Brahman LR and butt was intermediate to the other breeds ( $P < 0.05$ ; Table 6.6 and 6.7). The amount of fat in all primal cuts as %CCW was greatest in Angus, intermediate in Brahman, and lowest in Charolais ( $P < 0.05$ ) except for fat in the butt being similar between Angus and Brahman ( $P < 0.05$ ; Table 6.7). These trends were similar for fat as %EBW (Table 6.6). Lean tissue in each primal cut as % of CCW was greater in Charolais compared to both Angus and Brahman steers for all primal cuts ( $P < 0.05$ ) except for NC where both Charolais and Brahman had greater lean compared to Angus ( $P < 0.05$ ).

In addition, DOF affected the proportion of all primal cuts ( $P < 0.01$ ) with a reduction of butt and increase of WSR, BSR, and LR with increasing DOF for both %EBW (Table 6.6) and %CCW (Table 6.7). Such changes were reflected in a reduction in the proportion of bone and lean, and an increase in fat proportion over time ( $P < 0.05$ ). However, the increase in fat proportion from 0 to 200 DOF was smaller in the butt and BL, and greatest in the BSR and LR (Table 6.7).

**Table 6.6.** Primal cuts including neck and chuck, blade and front leg, brisket and spareribs, wholesale ribs, loin and rump, and butt, and the bone, lean and fat as a proportion of empty BW (EBW) of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed (DOF).

	Breed				Days on feed						P-value		
	Angus	Brahman	Charolais	SE	0	50	100	150	200	SE	Breed	DOF	B × DOF
Neck and chuck, % EBW	9.15	9.39	9.36	0.124	8.80 <sup>b</sup>	9.71 <sup>a</sup>	9.37 <sup>ab</sup>	9.28 <sup>ab</sup>	9.34 <sup>ab</sup>	0.161	0.317	0.003	0.365
Bone	1.42 <sup>z</sup>	1.53 <sup>y</sup>	1.71 <sup>x</sup>	0.034	1.95 <sup>a</sup>	1.71 <sup>b</sup>	1.50 <sup>c</sup>	1.37 <sup>cd</sup>	1.23 <sup>d</sup>	0.045	< 0.001	< 0.001	0.976
Lean	5.23 <sup>y</sup>	5.88 <sup>x</sup>	5.88 <sup>x</sup>	0.089	5.67 <sup>ab</sup>	6.03 <sup>a</sup>	5.57 <sup>b</sup>	5.54 <sup>b</sup>	5.51 <sup>b</sup>	0.116	< 0.001	0.009	0.130
Fat	2.44 <sup>x</sup>	1.94 <sup>y</sup>	1.73 <sup>y</sup>	0.066	1.11 <sup>c</sup>	1.92 <sup>b</sup>	2.30 <sup>a</sup>	2.28 <sup>a</sup>	2.57 <sup>a</sup>	0.087	< 0.001	< 0.001	0.084
Blade and front leg, % EBW	10.42 <sup>y</sup>	10.27 <sup>y</sup>	11.04 <sup>x</sup>	0.142	11.10 <sup>a</sup>	10.37 <sup>b</sup>	10.68 <sup>ab</sup>	10.95 <sup>a</sup>	9.78 <sup>c</sup>	0.132	< 0.001	< 0.001	0.598
Bone	2.17	2.28	2.70	0.040	3.16	2.58	2.25	2.07	1.85	0.052	< 0.001	< 0.001	< 0.001
Lean	5.92 <sup>y</sup>	6.12 <sup>y</sup>	6.71 <sup>x</sup>	0.088	6.68 <sup>a</sup>	6.19 <sup>b</sup>	6.29 <sup>b</sup>	6.36 <sup>ab</sup>	5.73 <sup>c</sup>	0.116	< 0.001	< 0.001	0.206
Fat	2.31	1.85	1.59	0.066	1.29	1.57	2.10	2.44	2.18	0.086	< 0.001	< 0.001	0.021
Brisket and spareribs, % EBW	10.61 <sup>x</sup>	9.43 <sup>y</sup>	9.40 <sup>y</sup>	0.104	9.00 <sup>c</sup>	9.41 <sup>c</sup>	9.51 <sup>c</sup>	10.11 <sup>b</sup>	11.03 <sup>a</sup>	0.136	< 0.001	< 0.001	0.144
Bone	1.37	1.35	1.61	0.028	1.95	1.55	1.34	1.24	1.13	0.037	< 0.001	< 0.001	< 0.001
Lean	4.30 <sup>y</sup>	4.21 <sup>y</sup>	4.88 <sup>x</sup>	0.086	4.91 <sup>a</sup>	4.78 <sup>a</sup>	3.99 <sup>b</sup>	4.16 <sup>bc</sup>	4.46 <sup>c</sup>	0.113	< 0.001	< 0.001	0.863
Fat	4.79	3.86	2.85	0.109	1.94	2.99	4.16	4.68	5.40	0.142	< 0.001	< 0.001	0.005
Wholesale ribset, % EBW	6.29 <sup>x</sup>	5.95 <sup>y</sup>	5.98 <sup>y</sup>	0.080	5.45 <sup>c</sup>	5.81 <sup>bc</sup>	6.21 <sup>b</sup>	5.97 <sup>b</sup>	6.93 <sup>a</sup>	0.126	0.004	< 0.001	0.198
Bone	1.06 <sup>y</sup>	1.17 <sup>x</sup>	1.25 <sup>x</sup>	0.026	1.41 <sup>a</sup>	1.28 <sup>ab</sup>	1.13 <sup>bc</sup>	0.96 <sup>c</sup>	1.01 <sup>c</sup>	0.035	< 0.001	< 0.001	0.125
Lean	2.89 <sup>y</sup>	3.04 <sup>y</sup>	3.41 <sup>x</sup>	0.054	3.22 <sup>a</sup>	3.18 <sup>a</sup>	3.09 <sup>ab</sup>	2.88 <sup>b</sup>	3.20 <sup>a</sup>	0.070	< 0.001	0.004	0.547
Fat	2.33	1.80	1.29	0.081	0.78	1.31	2.12	2.11	2.72	0.106	< 0.001	< 0.001	0.032
Loin and rump, % EBW	13.61	13.04	12.83	0.122	12.30	12.00	13.00	13.82	14.69	0.159	< 0.001	< 0.001	0.043
Bone	1.47 <sup>y</sup>	1.56 <sup>y</sup>	1.77 <sup>x</sup>	0.036	2.12 <sup>a</sup>	1.63 <sup>b</sup>	1.54 <sup>bc</sup>	1.44 <sup>c</sup>	1.28 <sup>d</sup>	0.047	< 0.001	< 0.001	0.245
Lean	6.90	7.13	7.69	0.090	7.81	7.33	6.99	7.10	6.97	0.117	< 0.001	< 0.001	0.001
Fat	4.87 <sup>x</sup>	3.98 <sup>y</sup>	2.98 <sup>z</sup>	0.127	2.28 <sup>d</sup>	3.00 <sup>c</sup>	4.41 <sup>b</sup>	4.60 <sup>b</sup>	5.42 <sup>a</sup>	0.165	< 0.001	< 0.001	0.115
Butt, % EBW	16.90	18.19	19.18	0.156	19.22	18.68	18.07	17.77	16.72	0.203	< 0.001	< 0.001	0.036
Bone	3.56	3.44	2.82	0.088	4.25	3.42	2.89	2.60	2.35	0.070	< 0.001	< 0.001	< 0.001
Lean	10.65	11.74	12.75	0.142	12.92	12.39	11.60	11.28	10.39	0.185	< 0.001	< 0.001	0.006
Fat	3.56 <sup>x</sup>	3.44 <sup>x</sup>	2.82 <sup>y</sup>	0.089	2.20 <sup>c</sup>	2.80 <sup>b</sup>	3.57 <sup>a</sup>	3.85 <sup>a</sup>	3.94 <sup>a</sup>	0.115	< 0.001	< 0.001	0.474

<sup>x-z</sup> Means without a common superscript differ between breed (P < 0.05). <sup>a-d</sup> Means without a common superscript differ between days on feed (P < 0.05).

**Table 6.7.** Cold carcass weight (CCW), primal cuts including neck and chuck, blade and front leg, brisket and spareribs, wholesale ribs, loin and rump, and butt, and the bone, lean and fat as a proportion of CCW of Angus, Brahman and Charolais steers in a serial slaughter trial from 0 to 200 days on feed (DOF).

	Breed				Days on feed						P-value		
	Angus	Brahman	Charolais	SE	0	50	100	150	200	SE	Breed	DOF	B × DOF
Cold carcass weight, kg	304.64	261.25	281.21	5.210	181.48	219.49	292.59	331.27	388.67	6.804	< 0.001	< 0.001	< 0.001
Neck and chuck, % CCW	13.69	14.14	13.80	0.164	13.41 <sup>b</sup>	14.72 <sup>a</sup>	13.99 <sup>ab</sup>	13.66 <sup>b</sup>	13.61 <sup>b</sup>	0.214	0.130	< 0.001	0.641
Bone	2.13 <sup>z</sup>	2.31 <sup>y</sup>	2.54 <sup>x</sup>	0.051	2.98 <sup>a</sup>	2.60 <sup>b</sup>	2.24 <sup>c</sup>	2.02 <sup>cd</sup>	1.79 <sup>d</sup>	0.067	< 0.001	< 0.001	0.933
Lean	7.84 <sup>y</sup>	8.85 <sup>x</sup>	8.67 <sup>x</sup>	0.122	8.64 <sup>ab</sup>	9.14 <sup>a</sup>	8.30 <sup>b</sup>	8.15 <sup>b</sup>	8.03 <sup>b</sup>	0.160	< 0.001	< 0.001	0.180
Fat	3.63 <sup>x</sup>	2.92 <sup>y</sup>	2.54 <sup>z</sup>	0.095	1.70 <sup>c</sup>	2.91 <sup>b</sup>	3.44 <sup>a</sup>	3.36 <sup>ab</sup>	3.74 <sup>a</sup>	0.124	< 0.001	< 0.001	0.118
Blade and front leg, % CCW	15.59 <sup>y</sup>	15.47 <sup>y</sup>	16.30 <sup>x</sup>	0.136	16.91 <sup>a</sup>	15.72 <sup>b</sup>	15.94 <sup>b</sup>	16.11 <sup>b</sup>	14.26 <sup>c</sup>	0.178	< 0.001	< 0.001	0.545
Bone	3.26	3.44	4.01	0.064	4.82	3.91	3.36	3.05	2.71	0.083	< 0.001	< 0.001	< 0.001
Lean	8.87 <sup>y</sup>	9.21 <sup>y</sup>	9.91 <sup>x</sup>	0.125	10.18 <sup>a</sup>	9.38 <sup>b</sup>	9.38 <sup>b</sup>	9.35 <sup>b</sup>	8.35 <sup>c</sup>	0.164	< 0.001	< 0.001	0.168
Fat	3.44	2.79	2.33	0.095	1.97	2.38	3.14	3.60	3.17	0.124	< 0.001	< 0.001	0.037
Brisket and spareribs, % CCW	15.85 <sup>x</sup>	14.20 <sup>y</sup>	13.85 <sup>y</sup>	0.169	13.69 <sup>c</sup>	14.27 <sup>bc</sup>	14.21 <sup>bc</sup>	14.90 <sup>b</sup>	16.09 <sup>a</sup>	0.220	< 0.001	< 0.001	0.331
Bone	2.07	2.03	2.39	0.046	3.00	2.34	2.00	1.82	1.65	0.060	< 0.001	< 0.001	< 0.001
Lean	6.44 <sup>y</sup>	6.34 <sup>y</sup>	7.21 <sup>x</sup>	0.127	7.48 <sup>a</sup>	7.24 <sup>a</sup>	5.95 <sup>b</sup>	6.13 <sup>b</sup>	6.50 <sup>b</sup>	0.166	< 0.001	< 0.001	0.650
Fat	7.14	5.81	4.17	0.165	2.95	4.55	6.24	6.90	7.88	0.216	< 0.001	< 0.001	0.035
Wholesale ribset, % CCW	9.40 <sup>x</sup>	8.96 <sup>y</sup>	8.81 <sup>y</sup>	0.110	8.30 <sup>c</sup>	8.80 <sup>bc</sup>	9.28 <sup>b</sup>	8.79 <sup>bc</sup>	10.11 <sup>a</sup>	0.148	< 0.001	< 0.001	0.734
Bone	1.59 <sup>y</sup>	1.77 <sup>x</sup>	1.84 <sup>x</sup>	0.040	2.16 <sup>a</sup>	1.94 <sup>b</sup>	1.69 <sup>c</sup>	1.41 <sup>d</sup>	1.47 <sup>d</sup>	0.053	< 0.001	< 0.001	0.069
Lean	4.32 <sup>y</sup>	4.58 <sup>y</sup>	5.03 <sup>x</sup>	0.076	4.90 <sup>a</sup>	4.81 <sup>a</sup>	4.61 <sup>ab</sup>	4.23 <sup>b</sup>	4.67 <sup>a</sup>	0.099	< 0.001	< 0.001	0.571
Fat	3.46 <sup>x</sup>	2.81 <sup>y</sup>	1.89 <sup>z</sup>	0.105	1.20 <sup>d</sup>	1.98 <sup>c</sup>	3.17 <sup>b</sup>	3.10 <sup>b</sup>	4.14 <sup>a</sup>	0.141	< 0.001	< 0.001	0.141
Loin and rump, % CCW	20.33 <sup>x</sup>	19.63 <sup>y</sup>	18.90 <sup>z</sup>	0.155	18.73 <sup>c</sup>	18.18 <sup>c</sup>	19.42 <sup>c</sup>	20.36 <sup>b</sup>	21.42 <sup>a</sup>	0.202	< 0.001	< 0.001	0.064
Bone	2.21 <sup>y</sup>	2.36 <sup>y</sup>	2.62 <sup>x</sup>	0.054	3.23 <sup>a</sup>	2.48 <sup>b</sup>	2.30 <sup>bc</sup>	2.12 <sup>c</sup>	1.86 <sup>d</sup>	0.071	< 0.001	< 0.001	0.112
Lean	10.34	10.75	11.34	0.122	11.90	11.10	10.43	10.46	10.16	0.160	< 0.001	< 0.001	0.001
Fat	7.25 <sup>x</sup>	5.98 <sup>y</sup>	4.36 <sup>z</sup>	0.185	3.47 <sup>d</sup>	4.55 <sup>c</sup>	6.60 <sup>b</sup>	6.79 <sup>b</sup>	7.90 <sup>a</sup>	0.242	< 0.001	< 0.001	0.163
Butt, % CCW	25.32	27.41	28.34	0.211	29.28	28.30	26.97	26.17	24.39	0.276	< 0.001	< 0.001	0.007
Bone	4.00	4.46	5.47	0.085	6.47	5.18	4.31	3.83	3.42	0.111	< 0.001	< 0.001	< 0.001
Lean	15.97	17.69	18.84	0.196	19.68	18.77	17.30	16.61	15.15	0.257	< 0.001	< 0.001	0.003
Fat	5.32 <sup>x</sup>	5.17 <sup>x</sup>	4.13 <sup>y</sup>	0.131	3.35 <sup>c</sup>	4.25 <sup>b</sup>	5.33 <sup>a</sup>	5.68 <sup>a</sup>	5.76 <sup>a</sup>	0.171	< 0.001	< 0.001	0.554

<sup>x-z</sup> Means without a common superscript differ between breed (P < 0.05). <sup>a-d</sup> Means without a common superscript differ between days on feed (P < 0.05).

## 6.5. Discussion

Allometric development in cattle refers to the differential growth of body parts, organs and tissues relative to each other or to the overall body size (Gayon, 2000). In the present study, there was a focus on comparing primal cuts and the tissues of each in relation to EBW and CCW for up to 200 DOF. Therefore, the proportion of these primal cuts and tissues can reflect allometric growth patterns of economic interest to processors. Animals are most often purchased on a \$/kg carcass weight, so a greater proportion of weight of higher value cuts or lean meat may allow maximising product return relative to the purchase cost. This information also provides insights of the growth of primal cuts and tissues over time for different breeds due to genetic selection, environmental adaptation, and functional specialisation.

The present study hypothesised that differences in body anatomy and conformation between divergent cattle biotypes and degree of maturity would reflect in divergent patterns of wholesale primal cut tissues allocation. This hypothesis was confirmed by the present study with significant effects of breed, DOF and their interaction. There is limited literature directly comparing the composition of these primal cuts of Angus, Brahman and Charolais purebred feedlot steers under the same diet and environmental conditions using a serial slaughter experimental design.

To the authors best knowledge, there is no recent existing literature that discusses the breed effect of purebred steers and increasing DOF on not only the proportion of the entire wholesale primal cuts but also their tissue composition. However, there are some available studies on the smaller sub-primal or retail cuts (Jaborek et al., 2019; Judge et al., 2019; Sood et al., 2023; Wheeler et al., 1997), though not under the aforementioned conditions or methods. Each primal and sub-primal cut has different value in the retail market (McGilchrist et al., 2022). Thus, beef processors may record the weight of each primal cut to calculate

figures on potential yield, which are then used to determine prices to pay for the live animal, entire carcasses or primal cuts. The present study provides key insights and information on the effect of both breed biotype and degree of maturity (carcass endpoint) on primal cut yield. This information can also be used to inform breeding, procurement, management (including feeding), business and marketing decisions to allocate different primal cuts to various markets dependent on their requirements.

#### *6.5.1. Breed effect*

The different biotypes had an evident effect on the distribution and proportion of each wholesale primal cut throughout the carcass both as a proportion of EBW and CCW. Breed trends could be seen when analysing the proportion of the total wholesale primal cuts, such as Charolais carcasses had the greatest BL and butt however Angus had the greatest BSR, WSR and LR, but breed did not affect the NC. Brahman were similar to Charolais except for having intermediate LR and butt.

There is a considerable amount of research attempting to predict the entire carcass composition from physical dissection of one or a few ribs (Santos et al., 2013). This has primarily been done to avoid the expensive and laborious physical dissection of the entire carcass as has been done in the present study. However, results of the present study suggests caution should be taken when extrapolating these prediction equations between breeds because the rib section may represent a different proportion of the entire carcass. For example, Santos et al. (2013) found that purebred Charolais bulls fed for 100 DOF had 16.03, 65.49 and 17.92% of bone, lean and fat in the 10-12th rib, respectively, at average hot carcass weights of 316 kg. In contrast, the present study found Charolais steers at 100 DOF had more bone and fat (20, 53.74, 24.15% bone, lean and fat in the WSR, respectively). Such discrepancies may be due to differences in rib sections dissected but also that bulls have greater lean muscle compared to non-implanted steers as in the present study. Both hormone

growth promotants and endogenous hormones in entire males of the same age could produce leaner bodies (Schoonmaker et al., 2002).

Wheeler et al. (1997) studied the effect of sire breed when mated to Angus or Hereford dams on the wholesale round, loin, rib, chuck and minor cuts (brisket, plate and flank), which is comparable to the present study's wholesale butt, LR, WSR, NC and BSR, respectively. Charolais sired steers had the greatest proportion of round (24.17% CCW) compared to Nellore (23.91% CCW), and Angus × Hereford crosses with the lowest proportion (23.45% CCW) (Wheeler et al., 1997). These results somewhat agree with those of the present study, although the differences between breeds were larger herein. In contrast to results of the present study, Wheeler et al. (1997) found no differences between sire breed on the wholesale loin, which averaged (14% CCW). Such differences between studies could be due to many factors including adjustment to the same age, different dissection points, genetics, and nutrition. Furthermore, Wheeler et al. (1997) reported the proportion of WSR was greatest in Angus × Hereford and Nellore steers (8.86 and 8.82% CCW) compared to Charolais (8.61% CCW), however in the present study Brahman had similar WSR to Charolais, both lesser than Angus. Thus, this may reflect breed differences amongst several other factors as mentioned above. Finally, Wheeler et al. (1997) found that minor cuts were greatest for Angus × Hereford (25.28% CCW) compared to Nellore and Charolais steers (24.23 and 23.80% CCW, respectively), in agreement with the present study's BSR being greatest for Angus compared to other breeds.

Bartoň et al. (2006) discussed the proportion of 'Grade I' and 'Grade II' meat, the former being lean from high value primal cuts including the rump, shoulder, sirloin and fillet, whereas Grade II is lean from low value body parts including the remaining primal cuts and lean trimmings, of Angus and Charolais bulls of 14 and 17 months of age. Charolais bulls had greater proportion of Grade I meat overall compared to Angus (41.04 and 39.19% side CCW,

respectively) including greater rump lean (22.93 and 24.78% side CCW, respectively), although both breeds had similar Grade I cuts (Bartoň et al., 2006). This is similar to the findings of the present study, where Angus had greater LR but lower LR lean compared to Charolais. Kempster et al. (1976) discovered that crossbred cattle containing European breeds had greater lean meat of higher priced cuts compared to crosses of British breeds only. These findings agree with the present study, where higher priced primal cuts such as WSR, LR and butt had the greatest lean proportion in Charolais steers, demonstrating the greater muscling potential of European compared to British steers is particularly reflected in greater lean content of high value cuts.

Furthermore, to the authors best knowledge, there is little literature comparing primal cuts of purebred *Bos indicus*, British, and European cattle. However, Yar et al. (2022) compared the effect of breed on the weight of primal cuts of *Bos indicus* and *Bos indicus* × *Bos taurus* bulls. The latter authors showed that *Bos indicus* × *Bos taurus* bulls had greater yield of two of the six subprimal cuts of the forequarter (cube roll and foreleg shin) and most of the subprimal cuts from the hindquarter (flank, tenderloin, rump, round, topside, silverside and shin) compared to *Bos indicus* (Yar et al., 2022). However, the CCW were approximately 137 and 148kg HCW for *Bos indicus* and *Bos indicus* × *Bos taurus*, respectively, were lighter than that of the present study at 0 DOF. The present study showed that Brahman had the lowest weight for all primal cuts at 200 DOF (including NC, BL and BSR from the forequarter) compared to other breeds except for the butt, where they were similar to Angus. The present study showed that breed affects the proportion of the primal cuts and their tissue composition. Therefore, it is important that breed be considered to plan and target primal cuts to specific markets and thus potentially achieve the highest premiums and profitability. Furthermore, financial incentives for breeds such as Charolais that produce greater proportion

of lean for the high value primal cuts could promote stronger consideration of breeding and management decisions.

#### *6.5.2. Days on feed effect*

Days on feed and therefore steer maturity and carcass endpoint affected the proportion of the wholesale primal cuts of the carcass and their composition, making it clear that DOF needs to be considered when selecting the time of slaughter. Sorting individual animals to assign them to DOF programs is integral to determine the ideal slaughter point to optimise yield and cuttability, reduce feed and fat wastage, and most importantly to satisfy the target market specifications to maximise profitability. The present study demonstrated that carcass BL and butt were greatest at the beginning of the feeding period and decreased with time, with an overall difference of 2.65 and 4.89 % CCW, respectively. In contrast, carcass BSR, WSR and LR increased over time by 2.40, 1.81 and 2.69% CCW, respectively. Interestingly, the NC is one of the lowest value sections of the carcass and only had a 1.31% CCW increase throughout the trial.

The NC and BSR showed little change in the proportion of lean throughout the 200 DOF whereas the LR and BSR showed the largest increase, and the butt showed the largest decrease as %EBW and %CCW. Therefore, the butt seems to grow slower (negative allometry) whereas the LR and BSR grow faster (positive allometry) than the body and carcass during the feeding period. This is likely due to steers reaching maturity and thus faster growth occurs in those body parts with greater potential to deposit fat tissue such as the BSR and LR.

The NC, BL and butt had the smallest increases in fat from 0 to 200 DOF at 2.04, 1.20 and 2.41%, most likely due to containing mainly locomotive muscles, collagen and connective tissue (Roy and Bruce, 2024). However, the BSR, WSR and LR showed the greatest increases in fat at 4.93, 2.94 and 4.43%, which is consistent with being postural sections of

the body, with muscles containing far less collagen than locomotive muscles, and greater subcutaneous, intermuscular, and intramuscular fat deposition (Anderson et al., 2015; Roy & Bruce, 2024). Furthermore, Owens and Gardner (2000) noted that as DOF increased, lean proportion decreased, and muscle size naturally reach maturity plateauing muscle growth and shifting into fat deposition.

In the present study, primal cuts seemed to grow slower (butt) or faster (WSR and LR) compared to the empty body or carcass. Therefore, the ideal time of slaughter to maximise the yield of each primal cut in the shortest DOF differ for each body part. Nevertheless, it is important to highlight that other factors in addition to yield of a primal cut should be considered to determine the optimal slaughter time such as adequate intramuscular fat for eating quality and fat cover for carcass insulation. The NC is considered a low value cut, but it is also not affected by DOF suggesting its growth is isometric to the empty body or carcass. Therefore, steers could be slaughtered earlier in the feeding period without impacting the yield of NC. Importantly, findings of the present study can be used to determine the ideal times for slaughter in order to maximise the yield of high value primal cuts such as the WSR, LR and butt. Although the WSR increased over DOF, it should be noted that the WSR size is the smallest section albeit one of the most expensive as it produces cuts such as the Tomahawk. The present study suggests that the yield of the WSR is maximized at 100 to 200 DOF. In contrast, the yield of the LR as %CCW is maximised at 200 DOF but most of this increase from 100 to 200 DOF is due to fat. If the butt is the primal cut of interest, earlier slaughter results in the greatest proportion of lean at 100 DOF may ensure adequate fat cover and minimal bone. Interestingly, 100-150 DOF seem to be the ideal slaughter time to optimise yield of most primal cuts. However, the optimal slaughter point to maximise primal cut yield should not be determined by DOF only but in conjunction with other factors such as

intramuscular fat and the premium it may bring for high value cuts if that outweighs reduced yield of other primal cuts or lean meat.

### *6.5.3. Breed × DOF interactions*

The difference between breeds in allometric growth patterns can be seen through the breed × DOF interactions (Supplementary Figures 1 and 2). The BL, BSR and butt bone were greatest for Charolais at the commencement of the trial and rapidly decreased in the first 50 DOF, with such differences between breeds becoming smaller thereafter (Supplementary Figure 1). This may be explained by Charolais steers having lower initial body condition score compared to other breeds (data shown in Chapter 3). The total butt proportion (Supplementary Figure 2) was the heaviest primal cut of the carcass, but it grew slowest compared to the empty body or the carcass decreasing from 29.28% to 24.39% CCW. Furthermore, the proportion of butt and LR lean decreased with time as tissue allocation shifts from lean muscle to fat deposition. Angus steers showed the greatest decrease in LR and butt lean and the greatest increase in fat for the lower value cuts BL and BSR, partly due to genetic propensity for fat deposition (Dikeman, 2017). Conversely, Brahman and Charolais steers showed slower decreases in lean muscle for the LR and butt, and lower increase in fat for the BL and BSR. These results suggest greater lean tissue deposition and slower fat accretion (Dikeman, 2017). These interactions demonstrate that breed and time on feed interact to affect the speed at which different body parts (primal cuts) and tissues grow in regard to the rest of the body or carcass demonstrating different allometric patterns of for each genetic biotype. Such information is useful to determine the optimal slaughter time of each breed, feeding programs, breeding strategies, and management for feedlot production systems and processors, enabling to focus on yield of the most valuable primal cuts.

#### 6.5.4. Carcass value

Carcass value varies between processors, markets and most importantly, consumer demand. High end markets, such as restaurants, have a greater focus on eating quality traits whereas other markets place more importance on maximum yield and cutability. Lean meat yield (LMY) is a trait considered globally when assigning carcass value as it translates to the amount of saleable meat to consumers (Stewart et al., 2024). Furthermore, LMY is the basis for carcass value before considering quality traits to offer additional financial premiums. McGilchrist et al. (2022) determined that 97% of carcass value was accounted for by the LMY when a flat price was assigned to all cuts, with no consideration for quality traits. However, quality is also taken into account, and different values are assigned to the primal cuts depending on their quality, saleability and appeal to consumers. For example, the trimmed tenderloin, cube roll, striploin, rump cap and knuckle undercut are valued at approximately \$21.05, \$16.88, \$12.16, \$8.38 and \$7.73 AUD/kg, respectively, being cuts from the wholesale ribs, loin, rump and butt (McGilchrist et al., 2022). Comparatively, lower value cuts such as the trimmed point and navel end brisket, chuck tender, bolar blade, and 4<sup>th</sup> rib chuck are valued at \$4.60, \$3.63, \$4.38, \$4.43 and \$4.81 AUD/kg, respectively, coming from the brisket, blade and chuck primal cuts (McGilchrist et al., 2022). Overall, highlighting the WSR, LR and butt tend to be of higher value in comparison to the NC, BL and BSR. Noting that some individual cuts are exceptions such as the intercostals from the chuck and oyster blade from the blade, valued at \$7.26 and \$6.13, respectively (McGilchrist et al., 2022). Thereby, it's evident that the quantity and weight of high and low value primal cuts, cuts and the LMY of the carcass are key factors in determining value. Importantly, LMY of the various primal cuts of the body is integral for both producers and processors to make key management and marketing decisions to optimise economic profits and tailor production to specific markets.

## 6.6. Conclusion and implications

The present study showed the effect of breed and DOF on the allometric growth of wholesale primal cuts and tissue composition. The hypothesis of the present study was confirmed, demonstrating that both breed and DOF had an effect on primal proportions and their tissue composition. Angus steers had greater proportion of the CCW represented in the BSR, WSR and LR compared to other breeds, whereas Charolais had greater proportion of BL and butt. Brahman steers had intermediate proportion of LR and butt, but lower BSR and WSR compared to Angus, and a lower BL than Charolais. Furthermore, the proportion of CCW in BSR, WSR and LR increased whereas BL and butt decreased with increasing DOF. Finally, bone and lean proportion of all primal cuts decreased whereas fat increased as DOF increased.

Thus, these cattle biotypes exhibit differing allometric growth patterns throughout the feeding period. Existing and future whole body and carcass composition prediction models and technologies can utilise this data as a comparison of the gold standard method. There is a need to consider breed and feeding length when predicting or forecasting wholesale primal weight and composition. Importantly, information on the yield of primal cuts for different breeds and carcass endpoints offer an opportunity to further add to the modern value-based marketing by offering financial premium for cattle biotypes that are consistently producing high value wholesale primal cuts with a greater LMY. Ultimately, this information can optimise on-farm and processor management decisions that optimise both productivity and maximise profitability.

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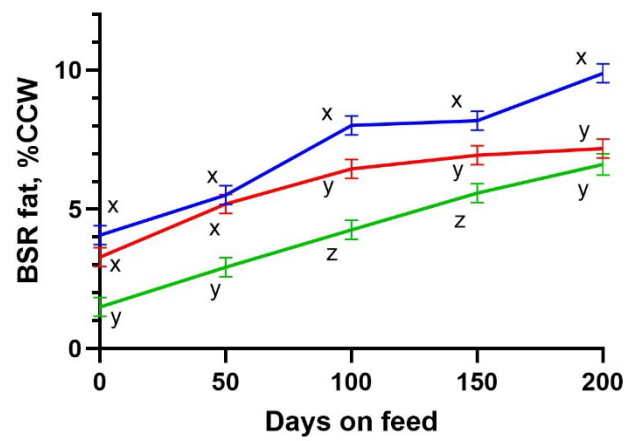
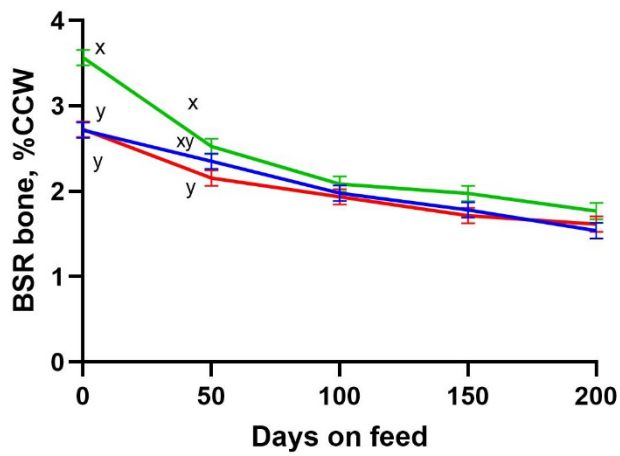
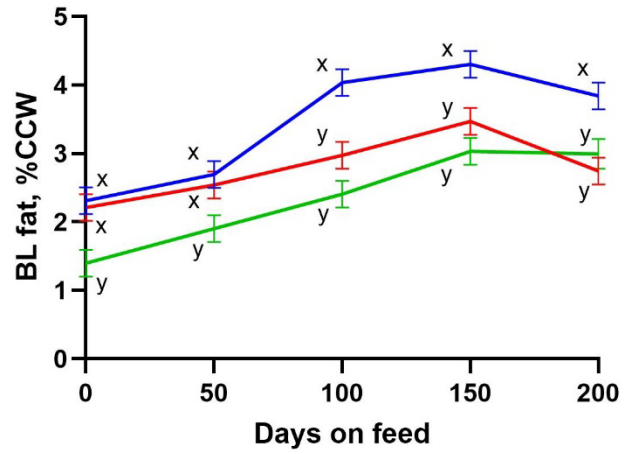
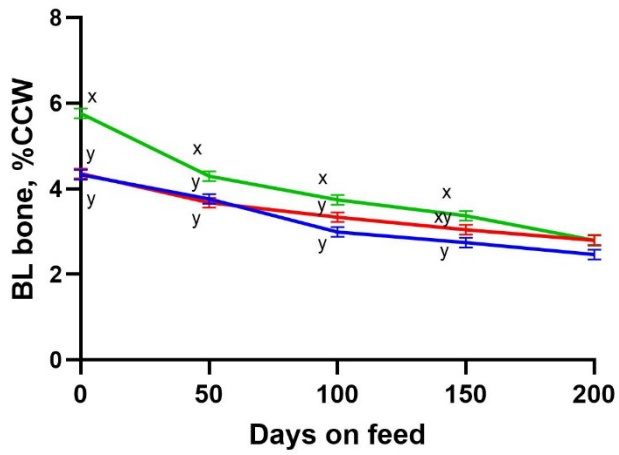
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## 6.8. Appendix 1: Supplementary material

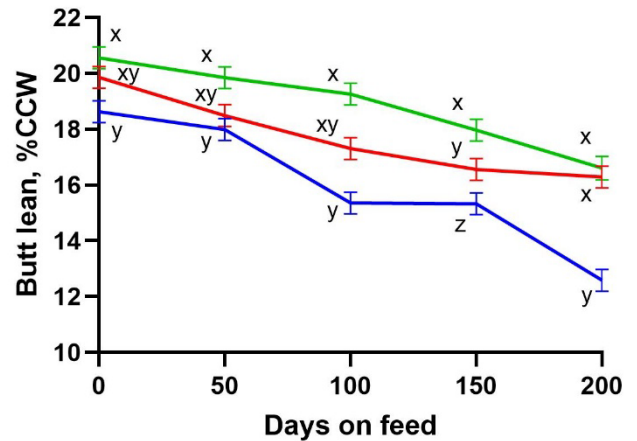
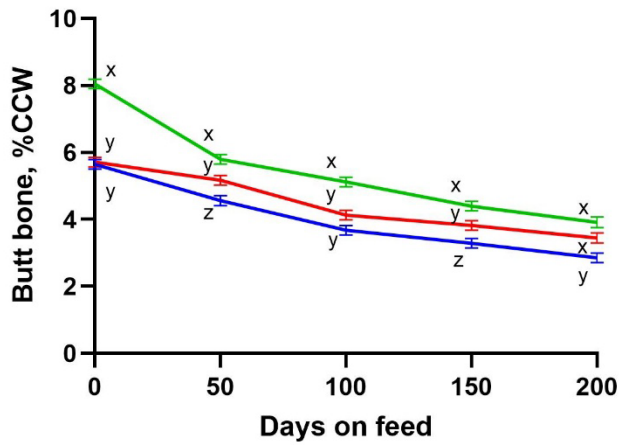
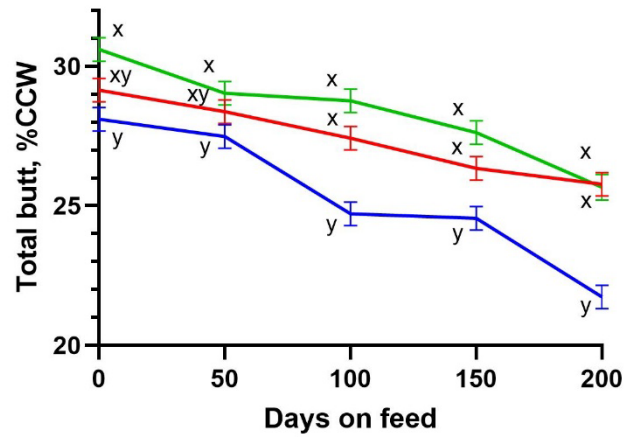
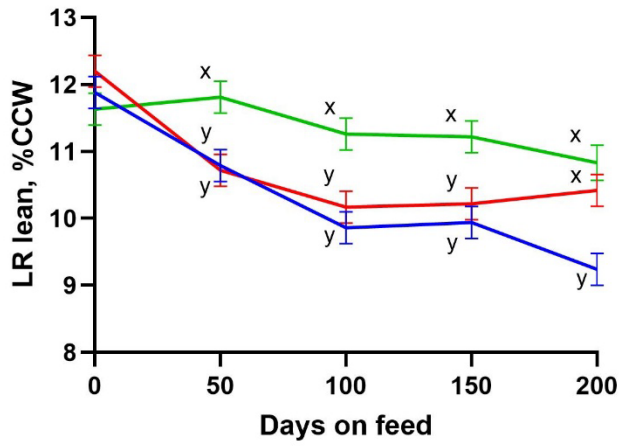
**Supplementary Table 1.** Descriptions of wholesale primal cuts from the cold carcass breakdown, adapted from the Handbook of Australian Meat 7<sup>th</sup> Edition – International Meat Manual (AUS-MEAT Limited, 2005).

Wholesale Primal	Code	Description
Neck and chuck (NC)	1630, 2260	Neck is removed from the Forequarter by a straight cut parallel and cranial to the 1st rib and through the junction of the 7 <sup>th</sup> cervical and 1st thoracic vertebra. Chuck is prepared from a Forequarter by the removal of the Rib Set at the 6 <sup>th</sup> – 12 <sup>th</sup> rib. The Brisket is removed along the cropping line. The Shin, Blade, Chuck Tender is removed along with all bones, cartilage, tendons, ligamentum nuchae and lymph nodes.
Blade and front leg (BL)	1682, 1685, 2300	Blade is prepared from a Forequarter by following the natural seam between the ribs and the scapular ( <i>M. latissimus dorsi</i> ) and overlying muscle ( <i>M. trapezius</i> ) and the underlying muscle ( <i>M. serratus ventralis</i> ). The Blade lies caudal to the humerus and below the spine of the scapula and comprises of a large portion of the triceps group of muscles. Shin-Shank is prepared from either Forequarter/Hindquarter legs (extensor/flexor group of muscles). The foreleg is removed by a cut following the Brisket removal line from the Forequarter through the <i>M. triceps</i> and <i>M. biceps brachii</i> and distal end to the humerus to include the radius/ulna and associated muscles. Arm-bone Shin is prepared from a Forequarter by the removal of the humerus bone with the <i>M. biceps brachii</i> attached. The ulna and radius are removed.
Brisket and spareribs (BSR)	1643	Brisket is prepared from a 13 rib Forequarter (item 1063) by a straight cut which commences at the junction of the 1st rib and 1st sternal segment to the reflection of the diaphragm at the 11th rib and continuing to the 13th rib. Diaphragm was removed.
Wholesale ribset (WSR)	2223	Rib Set is prepared from a Forequarter (item 1063) with the Brisket and Shin removed by a cut between the specified ribs following the contour of the rib to the Brisket removal line. 6 ribs in the set with intercostals retained.
Loin and rump (LR)	1540	Rump and Loin is prepared from a Hindquarter by a straight cut commencing at the subiliac lymph node passing just cranial of the hip joint to the ischiatic lymph node. The Thin Flank is removed at a point cranial to the tuber coxae and approximately 75mm from eye muscle ( <i>M. longissimus thoracis et lumborum</i> ) and running parallel to the body of the vertebrae to the specified rib. Diaphragm is removed.
Butt	1500	Butt is prepared from a Hindquarter by a cut commencing at the subiliac lymph node passing just cranial of the hip joint to the ischiatic lymph node.



- Angus
- Brahman
- Charolais

**Supplementary Figure 1.** Blade and front leg (BL) bone and fat, brisket and spareribs (BSR) bone and fat as a proportion of CCW of Angus, Brahman and Charolais steers over 200 days on feed (DOF).



- Angus
- Brahman
- Charolais

**Supplementary Figure 2.** Loin and rump (LR) lean, total butt, butt bone and lean as a proportion of cold carcass weight (CCW) of Angus, Brahman and Charolais steers over 200 days on feed (DOF).

## Chapter 7 - General Discussion

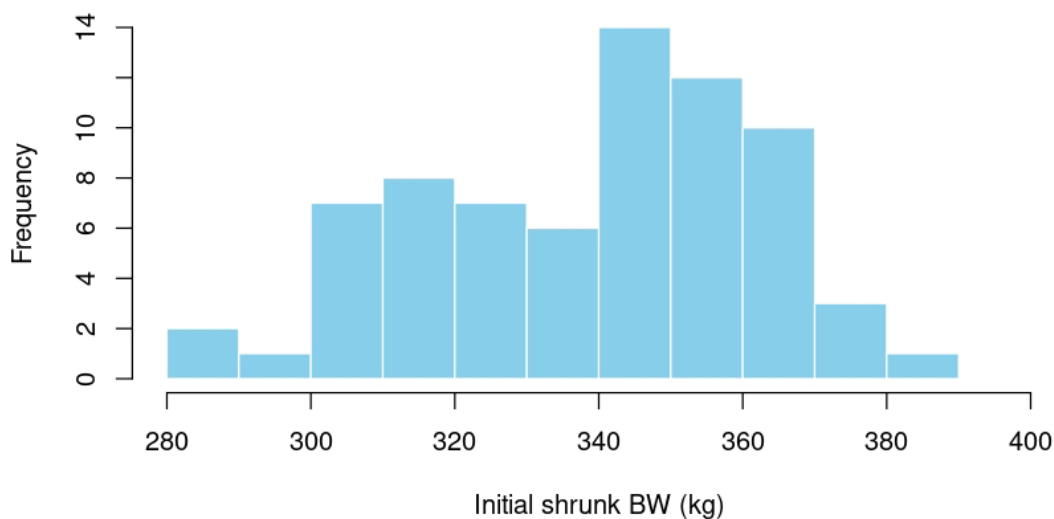
The research undertaken in the present thesis explored the effect of breed and DOF on the feedlot performance, carcass quality, whole body and carcass composition of three beef biotypes, British, European and *Bos indicus*. The present thesis utilised Angus, Brahman and Charolais breeds as representatives of the different biotypes due to their popularity and therefore prevalence in feedlot operations globally. These three breeds have different physiological, anatomical, and metabolic adaptation mechanisms acquired through evolution and domestication which have been reflected in the multiple measurements presented throughout the chapters of the present thesis. Chapter 3 aimed to determine the breed effect on feedlot performance, feed intake and efficiency over 200 DOF. Chapter 4 aimed to determine breed and DOF effect on muscle and fat deposition of live animals via ultrasound scanning, and carcass grading using image analysis technologies. Chapter 5 determined the breed and DOF effect on the whole body and carcass composition of bone, lean and fat tissues. Finally, the objective of Chapter 6 was to determine the effect of breed and DOF on tissue allocation to different wholesale primal cuts of the carcass. As a result, the present thesis has accepted the overarching hypothesis that breed and DOF effect feedlot performance, carcass quality, whole body and carcass composition of feedlot steers. Importantly, each of the experimental chapters replicate the processes and progression of feedlot steers moving through the supply chain, from induction, feeding and growth traits to carcass composition, yield and quality, and finally carcass breakdown. Furthermore, the aforementioned progression of the thesis is important to outlay the information necessary for the evaluation of the economic outcomes of production, which is paramount to achieve a profitable production system. Each of the experimental chapters outline processes that affect profit, such as the characteristics of the inducted animal (e.g. induction weight and breed) which determine the value the inducted animals, the feed required to achieve a target carcass

endpoint (market) and ultimately the carcass traits which determine carcass price. Thus, the findings of the experimental chapters of the present thesis can be applied to real-world industry situations to ascertain the overall economic effect on the production system.

### 7.1. Grid prices of feeder cattle

Purchasing the feeder animal and feed are the greatest variable costs in the beef feedlot industry. Therefore, the price paid for each animal, the growth and carcass performance, and the amount of feed consumed to achieve the desired carcass endpoint are critical aspects of feedlot production. Feeding cattle to their optimal carcass endpoints is vital to optimise productivity, profitability and environmental sustainability (Crowley et al., 2010; Na & Guan, 2022). In Chapter 3, feed intake was measured using individual electronic feeders and efficiency traits calculated. However, electronic feeders are not a viable method to measure feed intake in commercial feedlots due to the cost and impracticality. Therefore, feed intake is most often predicted using various available models such as the BCRC (Arthur et al., 2004) and this is then used to predict growth of the animal and the energy available to be deposited as muscle, bone, and fat (Freer et al., 2007). Chapter 4 and 5 reported data suitable to evaluate these and other prediction models. As mentioned in those chapters, under or overfeeding cattle for their market specifications is economically detrimental to producers both in the form of feed wastage, carcass falling below market specifications or requiring excess fat trimming at processing (McPhee et al., 2020; Pyatt et al., 2005). Breed, induction weight, and age (degree of maturity) affects growth and carcass performance and therefore, these factors are considered to determine the grid prices for feeder animals inducted into the feedlot. For example, underweight cattle at induction may incur a heavy penalty of \$2.00/kg if deemed out of specification and labelled as a cull < 350 kg BW whereas Brahman are paid less than British steers (Anonymous feedlot feeder grid, 2025). Applying this scenario to the present thesis would result in 48 steers of the 90 being under 350 kg BW at induction (Figure

7.1) and therefore would have been culled, incurring a total penalty of \$30,198. However, it is important to note that minimum induction weights vary across different feedlots. On the other hand, heavy cattle at induction are also penalised with \$0.10 to 1/kg from 480 to 550 kg and culled above 550 kg incurring \$2/kg penalty. In the present thesis, no steers were over 480 kg at induction. Overweight cattle are penalised as they are more likely to have reached or be closer to their mature BW, laying down fat throughout various depots and therefore resulting in lower feed efficiency (Pyatt et al., 2005).



**Figure 7.1.** Histogram of the initial shrunk BW of Angus, Brahman and Charolais steers at feedlot induction.

As seen in Chapter 3, heavier animals with lower mature weight such as Angus became less efficient converting feed into body growth with lower gain to feed ratio (GF) whereas Charolais steers with similar BW were the most feed efficient of the breeds. Both breeds had similar dry matter intake (DMI), but Angus were less efficient as they were reaching maturity and were accreting fat compared to Charolais who were accreting lean meat, reflected in the carcass composition of Chapter 5. However, it is important to note that both mature BW and

inherent body composition of each breed affect the composition of growth, and it is possible that Charolais would not deposit similar fat in gain as Angus even upon achieving maturity BW as suggested in the present thesis. Mature BW can be estimated from frame score, but age is required and therefore it becomes impractical under commercial feedlot conditions where animals are purchased from saleyards. However, many feedlots offer premiums for feeder cattle from supplier that provide consistent and known genetics with the desired ranges of frame score amongst other factors such as marbling capacity. These values can also be estimated or known from estimated breeding values (EBV) of the sires and dams, but this information is normally not passed through the supply chain from the breeding properties to the feedlot.

## 7.2. Optimal carcass endpoint and slaughter cattle grid prices

As outlined in the literature review, the optimal carcass endpoint can be defined as the carcass weight and specifications that maximises profit of the slaughtered animal. However, carcass specifications vary across markets and differences in quality traits limit the ability to secure additional premiums, so the optimal carcass endpoint varies across markets, groups, and individuals. The present thesis presented whole body and carcass composition by the gold standard method of physical dissection to obtain data of lean meat and primal cuts yield. In addition, this procedure then allows to determine the chemical composition of the body after grinding, sampling, and analysing all the tissues, which is also a gold standard method to measure energy and nutrient retention in the body which drives nutritional prediction models (Al-Jammas et al., 2016). For example, chemical composition of animals at 0 – 50 DOF resulted in an average ether extract (EE) of 5.2% DM but increased to 18.1% DM at 200 DOF (data not shown). Similar to carcass composition in Chapter 5, breed and DOF also affected the chemical composition ( $P < 0.05$ ; data not shown). Thus, this data and knowledge can be utilised to evaluate existing nutritional models and determine the energetic cost and

applicability of achieving different carcass endpoints of different beef biotypes. Additionally, the present data from experimental chapters provide updated values to improve existing prediction models for numerous variables that are both directly and indirectly accounted for including but not limited to feed intake, feed efficiency, growth rate, carcass traits, and body composition. However, further research is recommended to evaluate the adequacy of existing animal growth and nutrition models to predict the cost of achieving different carcass endpoints using modern genetics and feeding systems.

Ranges in acceptable fat depth varies across markets and particularly in over the hooks (OTH) sales, but generally often require a minimum of 3 mm rib fat in carcasses being graded and require even distribution of fat coverage across the carcass to reduce the issues with cold shortening and eating quality (Cottle & Kahn, 2014). The P8 fat depth is included in most grid prices, whereas rib fat is included as part of carcass grading schemes. The maximum P8 fat depth before processors begin to apply penalties is typically 22 mm and some processors apply penalties of 5, 30, 50 and 80 c/kg of carcass weight for every 10 mm over 22 mm (Anonymous abattoir grid prices, 2025). The partitioning of energy intake (Chapter 3) into lean meat and fat depots can be linked to the ultrasound scanning and carcass grading in Chapter 5. There were two Angus with 24 and 38 mm and a Brahman with 26 mm P8 fat depth at 200 DOF, with HCW of 445, 460 and 328 kg, respectively. Thus, the Angus steers would have received a penalty of 5 c/kg HCW and 50 c/kg HCW, incurring a total of \$22.25 and \$230 for each carcass, and \$16.4 for the Brahman at 5 c/kg HCW. Additionally, the Brahman would have received a further 25-45 c/kg HCW, totalling \$82 – 147.6 less than the Angus for *Bos indicus* content (Anonymous abattoir grid prices, 2025). This demonstrated a potential total loss of \$350.65 - 416.25 for only three bodies out of market specification highlighting the importance of optimising carcass endpoint. Furthermore, there are substantial premiums for steers hitting the grid of grading programs such as Meat

Standards Australia (MSA) and AUS-MEAT in Australia and the USDA carcass assessment seen in the United States (Polkinghorne & Thompson, 2010). Steers within the same ranges for dentition, meat and fat colour, HSCW, and P8 fat depth can receive a 35 c/kg HSCW premium compared to those that are not (Anonymous abattoir grid prices, 2025). For example, if the 89 steers from the present trial were processed as part of a grading program that would total \$280,786 compared to \$207,990 if they were not, based on HCW without considering any other possible premiums or penalties, resulting in a \$72,796 difference. These grading premiums reflect not only the consumers' willingness to pay for increase eating quality, but also the ability for businesses to utilise both grading stamps and premium branding to elevate their products in the market, (Polkinghorne & Thompson, 2010) and the uniformity of the products in retail outlets such as EMA because many retailers do not want too small or too large eye muscles. In addition, it is important that the present trial measured untrimmed HCW and this is widely different from HSCW where the Aus-Meat or customer trimmings reduce carcass weight. This can be particularly relevant for the Angus steers of the present trial which achieved excess fat that would be trimmed under commercial abattoir processing.

Interestingly, although premiums are paid for carcasses with greater quality, lean meat yield (LMY) is not considered directly in most pricing grids. Typically, carcasses lighter than 160 kg HSCW are not accepted except in the vealer market and thus are deemed out of specification (Cottle & Kahn, 2014). However, for an OTH grid, LMY is only accounted for through carcass weight, often with penalties for overweight carcasses particularly with excessive fat over specifications, thus it is crucial that animals must remain within the fat specifications and abide by the maximum dentition (i.e. age) of the abattoir or grid section (Anonymous abattoir grid prices, 2025). However, it is noteworthy that many grids do not offer greater premiums for carcasses exceeding their heaviest weight (i.e. 360+ kg HCW)

(Anonymous abattoir grid prices, 2025). For example, there were 20 out of 36 steers with HCW heavier than 360 kg across 150 to 200 DOF groups, the maximum weight of some domestic OTH grids. These steers would receive a base price of 895 c/kg HCW, if they comply with dentition, have acceptable meat colour, no bruising and no BIC, or 860 c/kg with BIC content of which two were Brahman. Three animals were over the P8 fat of 22 mm as previously mentioned, and their EMA ranged from 57.3 to 102.9 cm<sup>2</sup>. As part of carcass assessment in systems such as the USDA and MSA/AUS-MEAT in the United States and Australia, respectively, the 'Yield Grade' or 'Lean/Saleable Meat Yield' is determined based off carcass weight, 12<sup>th</sup> rib fat thickness and the EMA (Polkinghorne & Thompson, 2010). Although this is considered throughout carcass assessment models, it is not necessarily an accurate reflection of the quantity (kg) of physically separable lean from the carcass as outlined in Chapter 6. Furthermore, notably not all carcasses are quality assessed or graded and thus there is no method in place to determine LMY for these carcasses. With the results from Chapters 5 and 6, determining the breed and DOF did indeed affect the proportion of LMY and its distribution across various primal cuts. Thus, these results further highlight the importance in developing methods to predict and determine carcass LMY to assign a more accurate value for producers, as well as providing incentives for those that are consistently supplying animals with high LMY. Currently, as mentioned in the literature review, there are technologies such as dual energy x-ray absorptiometry (DEXA) and computer tomography (CT) aiming to objectively measure LMY without slowing production or chain speed but have not yet been established widely and commercially throughout processors (Gardner et al., 2025). Premiums for LMY have been seen in lamb processing on a grid of HSCW (kg) and LMY (%) measured with DEXA in Australia, offering the greatest incentives that fall within the processors targeted market specification (Anonymous abattoir grid prices, 2025). Thus, an opportunity for the beef industry to adopt a similar approach in addition to the current grid

system established would offer greater incentives for producers and feedlots to be accurately turning cattle off at the optimal carcass endpoints. Importantly, data from the present thesis can also be used to develop breed-specific LMY equations based on HCW, breed, carcass grading data in a practical and efficient fashion.

Finally, Chapter 6 results have shown the effect of breed on lean and fat distribution throughout the carcass across various primal cuts at different points in time or carcass endpoint which can also be linked to feed intake and performance shown throughout Chapter 3. This knowledge is extremely beneficial when determining when animals can reach or have reached the maximum yield for certain primal cuts, allowing producers the opportunity to utilise pricing feedback to inform management decisions, and processors to prioritise some primal cuts over others dependent on their destined markets. For example, yield of cuts from the neck and chuck changed very little over DOF with no differences between breeds (Chapter 6), suggesting that animals can be processed earlier without significantly affecting the yield of those cuts while reducing expense of feed. Furthermore, animals can spend less time on feed if IMF is not an important factor driving prices, because it is the last fat depot to be deposited (Nguyen et al., 2021). As discussed in Chapter 6, there is an opportunity to introduce financial incentives and premiums for animals that are producing greater LMY of higher valued cuts (i.e. loin and rump, wholesale ribset). Additionally, the knowledge of how breed and DOF effects the distribution of primal cuts throughout the carcass allows for producers and processors to better identify and assign animals or cuts to markets based on their requirements, therefore optimising profitability.

### 7.3. The effect of age, frame, and body condition score

Age, frame and body condition score (BCS) affects multiple aspects including feedlot performance, feed efficiency, carcass composition and quality traits. As outlined throughout

the present thesis experimental chapters, at the commencement of the trial Charolais steers were younger, lighter and of a lower body condition score compared to Angus and Brahman steers. Charolais steers may have experienced compensatory growth particularly throughout the first phase of the trial 50 DOF, as reflected by the initial BCS score (Coleman & Evans, 1986; Sainz et al., 1995). The effect of compensatory growth is seen across numerous traits including increased dry matter intake (DMI), average daily gain (ADG), feed conversion ratios (FCR) and prioritising internal fat deposition over subcutaneous (Coleman & Evans, 1986; Sainz et al., 1995; Wright & Russel, 1991). Therefore, any compensatory growth experienced by Charolais steers would have affected all measurements from feedlot performance and efficiency to body and carcass composition.

The age of cattle at feedlot entry and slaughter affects numerous factors including feedlot performance, efficiency and carcass composition and quality. Younger cattle are more efficient to convert feed into body growth due to accruing a greater proportion of lean muscle a lower of fat. For example, Pordomingo and Pordomingo (2021) found that 15–18-month-old steers were more efficient with a GF ratio of 145 g/kg compared to 24-month-old GF ratio of 135 g/kg who were also more efficient than 30-month-old steers (124 g/kg). The lower feed efficiency of older cattle is reflective of greater quantity of feed required to be consumed to deposit a unit of body growth that has greater proportion of fat (fat in gain), typically when mature BW is being or has been reached. Thereby, carcass composition is affected as older cattle lay down more fat in gain which could also result in greater trimming at processing. Additionally, age affects carcass quality traits such as ossification, with older cattle showing less tender meat compared to younger cattle with lesser ossification scores (Polkinghorne et al., 2008). On the other hand, older cattle tend to have greater marbling because intramuscular fat is the depot to be deposited latest in age but having the largest influence on eating quality. Under commercial feedlot conditions, age can only be estimated

from dentition and feedlots prefer to induct cattle with milk or two tooth depending on the length of the feeding program. In the present thesis, the Charolais steers were 6-8 months younger than Angus and Brahman steers, and this may have had a compounded effect on body composition being the breed with most lean and least fatty bodies and with lowest initial BCS as well. In the present thesis, it is critical to highlight that it is not practically possible for these breeds to be the same age, weight and body composition at the commencement of the trial due to the differences in birth and weaning weight, growth potential, and body composition outlined throughout the experimental chapters. For example, Charolais steers of the same age as the Brahman and Angus at the beginning of the trial would have been heavier and leaner. Therefore, it must be noted that age, BCS, and breed may have had confounding or compounded effects on some results although none of these factors were included as a covariate in the model.

Frame size is one factor that dictates an animal's mature BW, and it can affect both feedlot performance and carcass composition (Şentürklü et al., 2021). Cattle with large frames are later maturing and therefore heavier mature BW and greater muscling capacity which typically results in greater feed intake and efficiency (Dikeman, 2017). Cattle with smaller to moderate frames tend to mature and deposit fat earlier resulting in fewer DOF for the same body fat endpoint (Dikeman, 2017). Therefore, animals with larger frames require longer time on feed to reach the same carcass fat endpoints compared to smaller framed animals, and genetic differences suggest that European breeds may not achieve the same body fatness even at maturity. Notably, Charolais are a larger framed breed compared to Angus and Brahman steers. Frame size was analysed in Chapter 3, but should be interpreted with caution, as the camera and application used to collect hip height measurements requires further research to determine its accuracy. Although frame size is linked to breed, animals can be genetically selected for frame within a breed, which is then reflected EBV for 200, 400, 600, and mature

BW (Boerner et al., 2014). However, it is possible to also ‘bend the growth curve’ to have animals reaching heavy BW at young ages while maintaining smaller mature BW compared to other animals. Frame size

is expected to have impacted growth rate, lean and fat composition of both whole body and carcass.

Body condition score is directly related to both body fat and muscle content which thereby affects factors such as feedlot performance, carcass yield and quality. Animals with lower BCS have shown a period of compensatory growth characterised by growing faster and depositing fat compared to similar animals inducted with higher BCS (Cottle & Kahn, 2014). Conversely, animals with higher BCS would be accruing greater proportion of fat in gain (Cottle & Kahn, 2014). Crucially, BCS is used as part of live visual animal assessment for marketing and trading purposes reducing stress put, labour and overall cost associated with ultrasound measures, as outlined in Chapter 4. However, this is a visual subjective assessment and therefore does not provide consistency between scorers, precision or accuracy required (Xiong et al., 2023). For example, the Japanese market requires a 4-5 BCS but more specifically a 12-18 mm P8 fat depth, whereas the Korean market requires a 3-4 BCS and a 10-15 mm P8 fat depth (Cottle & Kahn, 2014). It is important to note that the initial and final BCS of the present trial (Chapter 4) may explain a proportion of the differences between breeds over DOF such as initial BW and carcass composition due to the Charolais steers aforementioned compensatory growth. Therefore, performance and carcass composition throughout each experimental chapter of the present thesis may have yielded different results if Charolais were of similar initial BW, BCS, age, and frame score as Angus and Brahman steers to compare the breed effect more robustly. Further analysis of performance and carcass traits with the inclusion of BCS included as a covariate in the statistical models could help correcting some of the differences between breeds but the effect of age and frame score

would still exist. These confounding factors are likely to persist in the industry because Charolais have leaner and larger frames resulting in heavier BW and frame size for the same age as Angus and Brahman.

#### 7.4. Payment grid pricing

Each feedlot and processor have different grid prices for payment of live cattle based on a variety of factors including location, market access and objectives. For both grid payments and market assignment, breed and biotype are considered for premiums and discounts for Wagyu, Angus, *Bos indicus* content and occasionally more general labels such as British or British crossbreeds. For example, typically included in grids are verified Angus, black Angus, British crossbred and *Bos indicus* content (BIC) ranging from 38 – 75% otherwise labelled as purely *Bos indicus*. MSA graded Angus cattle attract a premium price of approximately 40 c/kg HSCW compared to the non-graded Angus cattle, and 5 c/kg HSCW greater than other MSA graded carcasses (Anonymous abattoir grid prices, 2025). Conversely, the greater the BIC the more discounted the price becomes due to the BIC showing lower eating quality (Stewart et al., 2024). British and European pure or crossbreeds (Angus excluded) receive 25-45 c/kg HSCW more than animals with BIC when OTH, or 80 – 90 c/kg BW more than animals with BIC (Anonymous abattoir grid prices, 2025). *Bos taurus* breeds will also exhibit a hump on the carcass, an indication of BIC, in the case of bulls or steers that have been castrated late. Thus, the maximum BIC is approximately < 38% to not incur a price penalty for BIC, however this threshold may vary across businesses. With such a great difference in value of both the live animal and carcass, alongside the effect of breed over DOF seen in the present thesis, it is imperative to include breed in future animal performance and carcass composition predictive models to assign and forecast prices more accurately.

Furthermore, some companies weigh each product after slaughter and carcass breakdown into primal cuts, subprimal cuts, trimmings and byproducts. Therefore, the yield of primal, subprimal or retail cuts of a particular animal or lot of animals can be compared with historical data, with any significant variation between them being further investigated (Anonymous abattoir personal communication, 2025). Thus, it is reasonable to conclude that cattle that produce more uniform carcasses with similarly optimal carcass endpoints with high carcass lean meat, primal, subprimal, or retail yields should receive higher prices. Ultimately, this would increase profitability and encourage breeding and management decisions such as assigning cattle to optimal feeding programs or directing primal cuts to the right market. However, it is important to reiterate that although there are premiums paid for higher quality carcasses, there are no premiums offered for cattle producing greater LMY other than in the form of carcass weight, subcutaneous fat penalties, and butt shape. For example, the HCW seen in Chapter 5 for Angus and Charolais at 200 DOF were similar, although a greater proportion of the Angus steers were made up of carcass fat whereas the Charolais had a greater proportion of lean meat. It is sensible to consider price adjustments for cattle that are producing a higher degree of saleable meat yield compared to those that require excess trimmings, although receive financial penalties, are sold for a low cost and require more labour and attention at processing.

#### 7.5. Management decisions

Currently, there is no practical tools across businesses and feedlots to determine breed and age at induction for animals with unknown origin. Feedlots are guided by vendor declarations (i.e. National Vendor Declarations), staff determination at crush side by traits such as a rough assessment of anatomy, morphology, coat type and colour, presence of a hump and larger floppy ears. As previously mentioned, an example of breed classification is ‘Black Angus’,

‘Verified Angus’, Brahman cross (> 75% BIC), British cross (< 38% BIC), crossbred with no hump (< 50% BIC), and slight hump (< 75% BIC). These factors typically are determined by declarations from the vendors and sighting of the animal by feedlot personnel which although may be fitting for the requirements of the business currently, is not an accurate method of breed or age determination. Thus, there is an opportunity to evaluate the economic benefits and the viability of introducing accurate methods of determining breed such as genomic testing. Ideally, breed is determined prior to feedlot induction upon purchase, as this is the point in which animals are sorted into pens and assigned to feeding programs. Methods such as collecting tissue samples (TSUs) for DNA assessment is a common method by producers when registering seedstock cattle with their breed societies. Collecting tissue samples are an easy task carried out at crush side, taking a tissue sample typically from the ear, and can be done at any point in the animal’s life. Financial incentives could be introduced into pricing grids, offering premiums for cattle that are DNA tested and therefore making it worthwhile for producers and backgrounders. Furthermore, receiving this data prior to induction allows for feedlots to pen similar cattle and assign them to feeding programs based on optimal carcass endpoints for a variety of market specifications, without adding extra tasks and time at induction. The present thesis has demonstrated the importance of breed determination to forecast the optimal carcass endpoint.

## 7.6. Conclusions

The present thesis has determined that both breed and DOF influence feedlot performance, intake and efficiency, whole body and carcass composition, quality traits and primal yield. For the first time in decades, new baseline reference data has been presented using the gold standard of physical dissection for accurate quantification. The results of the present thesis can be used to evaluate and improve the accuracy and precision of existing animal growth

and nutrition prediction models with modern beef genetics. Future development of models to predict the optimal carcass endpoint can improve animal management through drafting, penning and assigning cattle to feeding programs that target specific markets based on their optimal endpoints that maximises net return of each animal. Future research should be conducted utilising a greater number of cattle in commercial feedlot environments to reaffirm the results and conclusions from the present thesis. Furthermore, the present thesis results unveil opportunities for feedlots and processors to revise grid pricing to include incentives for animals producing greater carcass and wholesale primal yield. This information and improved prediction models can be used to ultimately optimise productivity and environmental sustainability, and maximising carcass value and profitability for producers.

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