Prediction of the growth performance of feedlot cattle using phenotypic and anthropometric measures

by

Shanna Wells

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Supervisor: Prof. E.C. Webb

Co-Researcher: Miss A.M. du Preez

Declaration

I, Shanna Wells hereby declare that this dissertation, submitted for the MSc (Agric) Animal Science: Production Physiology and Product Quality degree at the University of Pretoria, is my work and has not previously been submitted by me for a degree at any other University.

Shanna

Shanna Wells
Pretoria
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Abstract

The price of purchasing and feeding feedlot cattle are expenses which contribute the most to the overall costs of a feedlot. Therefore, if the feedlot owner can purchase a specific breed type, or cattle with a specific weight or size, knowing that these cattle are likely to outperform the rest of the cattle, it may be possible to improve profits by maximising average daily gain (ADG) and reduce days in feed (DIF). Although, it is understood that other factors such as maturity type, frame size, nutrition, management and environment influence ADG and DIF. The purpose of this study was to assess the possibility of predicting the future growth performance of cattle entering the feedlot using phenotypic and anthropometric measurements. This study merely tried to determine if the ADG and DIF could be predicted based on initial measurements. Measurements such as initial body weight, initial hip height, initial shoulder height, initial body length and various ratios were used. The results of this study show that the use of these selected phenotypic and anthropometric measurements are useful predictors of the future feedlot performance of cattle. Cattle with higher initial weights (271.01 ± 40.288kg, P = 0.000), i.e. cattle which were heavier at placement, had higher ADG (1.45 ± 0.491kg, P = 0.000) compared to smaller cattle with lower initial weights. This is within limits because if the initial weight becomes too high the ADG decreases again. Larger and heavier cattle at placement also spent a shorter period (156.88 ± 32.287 days, P = 0.000) in the feedlot. This particular feedlot classifies cattle into either ideal (≥200kg) or sub-ideal (<200kg), while the initial weight in this study was taken on day one of cattle being in the feedlot, excluding the backgrounding period. Cattle classified as being of the ideal weight were fed for a shorter period compared to those categorised as sub-ideal, but the final weights and carcass weights did not differ. Although this feedlot suspected that the sheath length may influence the various variables, the lack of any significant effect indicates that there is no point in the feedlot taking this measurement. At best the tendency for cattle with a small sheath to have a numerically better initial weight, ADG, final weight and carcass weight may be explored in future research. The initial body length measurement had the strongest positive correlation with ADG (r = 0.329, R^2 = 11.7%, P = 0.000), while the initial weight had the strongest negative correlation with DIF (r = - 0.668, R^2 = 46.3%, P = 0.000). Therefore, the ADG and DIF can be predicted using certain of the anthropometric and phenotypic measurements.

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List of abbreviations

ADG	Average daily gain
BL_i	Initial body length
BL_f	Final body length
Carcass_c	Carcass compactness
Carcass_m	Carcass mass
Carcass_l	Carcass length
DIF	Days in feed
Dressing %	Dressing percentage
FCR	Feed conversion ratio
F:G	Feed to gain ratio
G:F	Gain to feed consumed ratio
HH_i	Initial hip height
HH_f	Final hip height
K	Small Sheath
kg/cm or kg cm^{-1}	Kilogram per centimeter
kg/day	Kilogram per day
L	Large Sheath
N	Number
Weight_m - weight_i	Median weight minus initial weight
Weight_m - weight_i/DIF	Median weight minus initial weight divided by DIF
M	Medium Sheath
SH_i	Initial shoulder height
SH_f	Final shoulder height
Std.	Standard deviation

Weight_i	Initial weight
Weight_f	Final weight
Weight_m	Median weight
Weight_i/BL_i	Initial weight divided by initial body length
Weight_i/HH_i	Initial weight divided by initial hip height
Weight_i/SH_i	Initial weight divided by initial shoulder height

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Chapter 1: Introduction

It is estimated that feedlots produce about 75% of the total beef production in South Africa (Frylinck, 2013; SAFA, 2016). However, the profitability of the beef industry remains under pressure due to various external factors even though the demand exceeds the supply of beef (Lombard *et al*., 2018). A large portion of the variation in profitability is due to the price of feeder cattle and the fed cattle price (Koknaroglu *et al*., 2005). It has been shown that many factors influence the performance and profitability of a feedlot such as average daily gain, feed conversion ratio, slaughtering/carcass price, weaner price, dressing percentage, total weight gain, feeding costs, and mortality (Sy *et al*., 1997; Maré *et al*., 2011; Tatum *et al*., 2012). Therefore, for beef producers to maintain profitability, they need to continue finding new methods and strategies to increase production efficiency and reduce the cost of production (Koknaroglu *et al*., 2005).

In the feedlot industry, value is added by converting feed into weight gain. Profit is largely dependent on the amount and value of weight added while expenses are associated with body weight at purchase, the purchase price of cattle, amount and cost of feed consumed, duration in the feedlot, morbidity and medical expenses, and mortality rate (Tatum *et al*., 2012). Live feedlot performance and carcass traits are influenced to a large degree by factors such as animal disposition, health, breed type, and frame score (Reinhardt *et al*., 2009). Feedlot performance does vary between breeds and for this reason, different breeds should be fed for different feeding periods to optimise both production and profitability (Chewning *et al*., 1990; Williams & Bennett, 1995; Bosman, 2002; Oosthuizen, 2016).

Feedlot profitability can be selected as seen by the heritability estimate of 0.36 (Van der Westhuizen *et al*., 2009). It has been shown that feed intake and measures of feed efficiency are heritable in beef cattle (Johnston, 2002). Cattle enter the feedlot at an average weight of 253kg, and at the end of the feedlot period (approximately 135 days), a weight of approximately 465kg is achieved, which results in a carcass weight of around 272kg (Ford, 2017).

Growth is expressed in quantitative terms (Batt, 1980). Measurable anthropometric features other than weight can be used to determine the growth of an animal such as height, length, girth, and volume (Batt, 1980). Linear measurements, as a measurement of skeletal size, have long been used to predict the future growth performance of an animal (Lamm, 1982). Direct measurements of hip height, body weight, ultrasound fat thickness and body condition scoring versus the visual assessment of body condition can result in the improvement in the sorting of cattle at the end of the backgrounding phase (Hendrickson *et al*., 2005). It is important to remember that linear measurements are more objective than a visual appraisal (Lamm, 1982). Linear measurements must never be used as a replacement for the weight of an animal at a given age, it should rather be used to supplement selection in terms of added growth information (Lamm, 1982). It is also important to remember that no single frame size will be optimum for all feed resources (Lamm, 1982).

Buyers of feedlot cattle prefer cattle that have a larger frame size and are more heavily muscled (Schroeder *et al*., 1988). In the feedlot industry, the goal is to produce the most kilograms of beef as possible to have a profit at a margin which is above feed costs (Johnson *et al*., 2010). A larger mature size is also indicative of feedlot performance - large animals grow faster, take longer to finish off, and are heavier at slaughter however they require more feed (Pritchard, 1995; Torell *et al*., 1999). The packing industry also prefers larger framed cattle because, hanging more kilograms of carcass, results in the greatest weight of meat possible in the assembly line, thus improving the efficiency of this type of industry (Johnson *et al*., 2010). Heavier carcasses favour slaughterhouse pricing (Pesonen *et al*., 2012) in many countries as well as South Africa (Agbeniga & Webb, 2018).

Predicting the performance of cattle which enter the feedlot will reduce the guessing game of purchasing cattle and hopefully not only maximize performance but profits as well. There was a need for this study as the purchase price of cattle and feed costs are factors that contribute a large proportion to the total costs which occur in the feedlot. If the future growth performance can be predicted it will save the feedlot money, as only cattle that can perform will be bought and fed.

This study aimed to determine if certain phenotypic and anthropometric measurements could be used to predict growth potential and performance of cattle entering a commercial feedlot. Measurements such as initial weight, initial body length, initial shoulder height, and numerous ratios were used to see if the ADG and DIF can be predicted.

In order to achieve the aim the following objectives were set:

1. To determine if the potential growth of cattle entering a commercial feedlot can be predicted from certain phenotypic and anthropometric measurements.
2. To determine if the performance (ADG and DIF) of cattle entering a commercial feedlot can be predicted from certain phenotypic and anthropometric measurements.

Chapter 2: Literature Review

2.1 An overview of the red meat industry

Once a highly regulated industry, the South African red meat industry is now completely deregulated (DAFF, 2018). The red meat industry has come under increased pressure due to the deregulation, but it is still one of the most important agricultural sub-sector in South Africa (Red Meat Marketing, 2000).

In South Africa, 80% of the total number of cattle is beef, while only 20% are dairy cows (DAFF, 2018). The gross value of beef production depends on the number of cattle which are slaughtered and the prices which are received by producers from buyers (DAFF, 2018). Beef is produced throughout South Africa, Figure 2.1 below indicates the beef production per province during the 2016/2017 production year (DAFF, 2018). However, the amount of beef which is produced is largely dependent on the infrastructure such as feedlots and abattoirs and not necessarily by the number of cattle available in a particular area (DAFF, 2018). Due to our highly developed transport system cattle and calves can be transported from one area to another, even from other neighbouring countries.

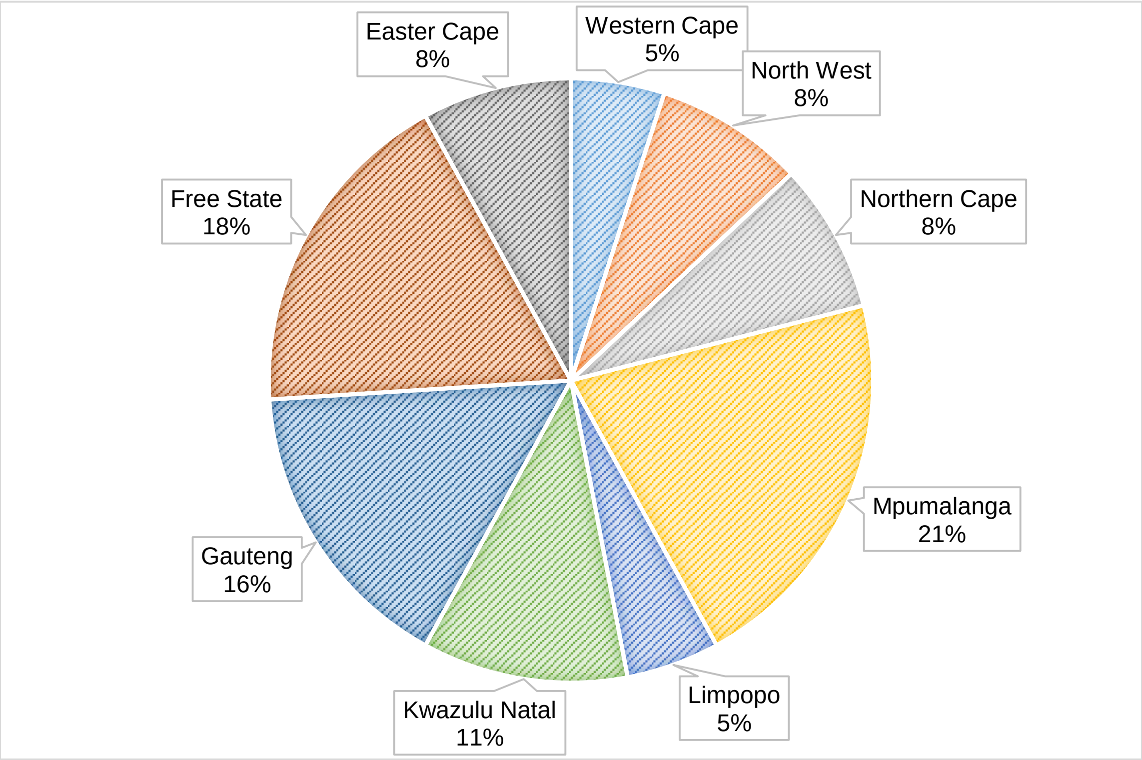


Figure 2.1 Number of beef slaughtered per province during 2016/2017 (adapted from DAFF, 2018)

The beef market value chain can be seen in Figure 2.2 below. There is estimated to be approximately 22 000 commercial farmers who are currently farming with livestock (DAFF, 2018). The figure includes producers that keep livestock as there their main enterprise and those which keep livestock as a secondary enterprise (DAFF, 2018). There are around 13.3 million cattle, with 240 000 small scale farmers and 3 million subsistence farmers that own approximately 5.69 million cattle (DAFF, 2018). The beef supply chain has (Figure 2.2), as well as the red meat value chain (Figure 2.3), become more and more vertically integrated, which is mainly fuelled by the feedlot industry as most feedlots have abattoirs or, at the very least, some business interest in a certain abattoir (AgriSeta, 2018; DAFF, 2018). Some feedlots even sell directly to consumers through their retail outlets (FPM report, 2004; AgriSeta, 2018; DAFF, 2018), while other abattoirs have started to move towards the wholesale level (DAFF, 2018).

Figure 2.3 gives is an indication of the red meat market value chain. The key components of the value chain include the primary producers, feedlots, abattoirs, wholesalers and retailers (AgriSeta, 2018). Some abattoirs have moved further down the value chain and sell directly to the consumers through their own retail outlet (FPM report, 2004; AgriSeta, 2018; DAFF, 2018). Previously, wholesalers used to purchase carcasses through an auction system, while these days they source live slaughter animals (not weaners) directly from farmers or feedlots on a bid or offer basis (DAFF, 2018).

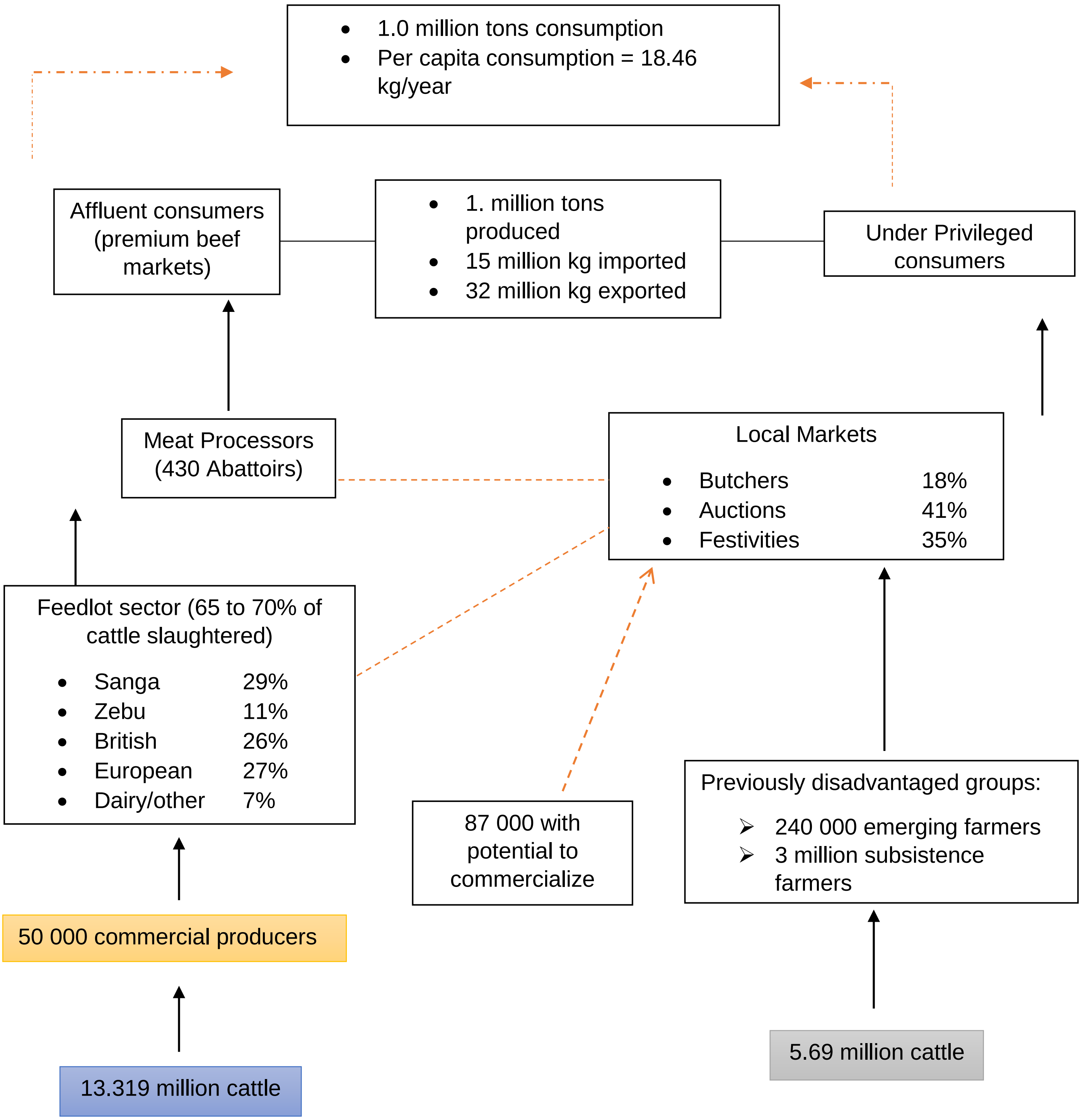


Figure 2.2 The beef market value chain in South Africa (adapted from DAFF, 2018)

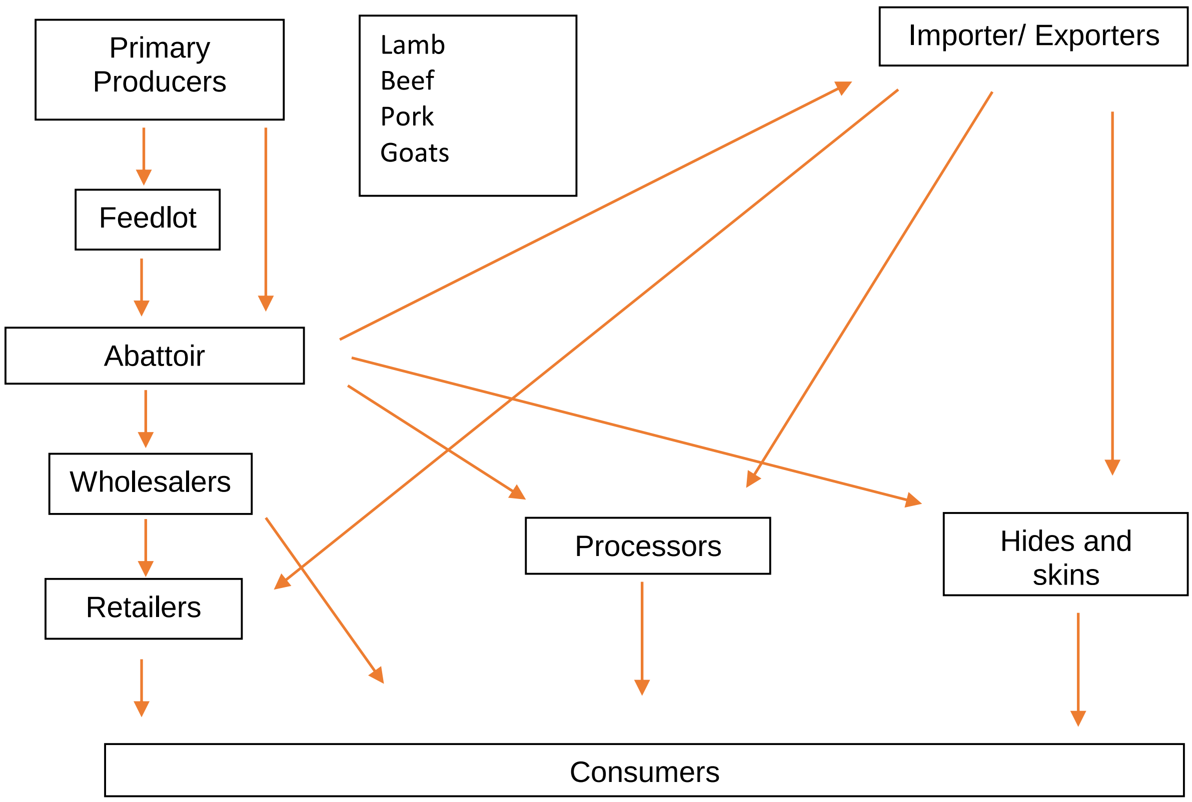


Figure 2.3 The red meat value chain (adapted from the Department of Agriculture, 2003; SAFA, 2003; FPM report, 2004; AgriSeta, 2018)

Before the deregulation of the red meat industry, the price formation in the formal markets was done by carcass auctions at the main metropolitan abattoirs (Red Meat Marketing, 2000). Nowadays the formation of the price is determined by the market forces on demand and supply (Red Meat Marketing, 2000; Department of Agriculture, 2003). If the supply is greater than the demand, then the producer price will reduce and if the demand is greater than the supply, then the producer price will increase - therefore there is a daily fluctuation in prices (Red Meat Marketing, 2000). Many other factors affect the price of livestock, namely: availability, price, climate (rain, drought or fodder flows), the economy of the country and imports of red or other meats (Red Meat Marketing, 2000). Due to the seasonal variation in the demand and supply, the prices of livestock are normally high during October to December and low during January to March (Red Meat Marketing, 2000).

South Africa has a well-established feedlot industry. In 2000 there were 60 commercial beef feedlots and 10 sheep/lamb feedlots which were registered with the South African Feedlot Association (Red Meat Marketing, 2000). Feedlots had a standing capacity of around 320 000 animals, marketed their animals throughout the year, and slaughtered around 70% of the commercial sector's annual 2 million cattle slaughtered at registered abattoirs (Red meat marketing, 2000). Approximately 340 000 tonnes of beef were produced by feedlots annually (SAFA, 2003). In 2017, this had grown to 100 beef commercial feedlots in South Africa which at any one time had approximately 650 000 head of cattle (Ford, 2017). The main supply of the feedlot industry is to the domestic market (Ford, 2017). By 2018, the beef industry produced around 1 million tonnes of meat of which 32 million kg of meat was exported and approximately 15 million kg of beef was imported (DAFF, 2018). In the agricultural sector the beef industry is the second-fastest-growing commodity, following the broiler sector (DAFF, 2018).

In recent times, there has been a slow yet steady increase in cattle carcass weights in most parts of the world (Pesonen *et al*., 2012; Savell, 2012). In 2003, cattle normally entered the feedlot at a weight of between 200 - 220kg and stayed in the feedlot for about 100 days (Department of Agriculture, 2003). During this time the animals gained about 100kg which resulted in a carcass weight of between 220 - 225kg (Department of Agriculture, 2003). In 2017, the approximate weight of cattle entering the feedlot was 253kg (Ford, 2017). At the end of the feedlot period a weight of approximately 465kg was achieved and this resulted in a carcass weight of around 272kg (Ford, 2017). Cattle spent about 135 days in the feedlot (Ford, 2017). Cattle can be placed in the feedlot at any age, but are normally placed after weaning (7 - 9 months), as yearlings (12 - 18 months of age), or at two and a half years of age (Department of Agriculture & Rural Development, 2005a). Animals gain about 150kg in a feedlot after which they are said to be ready for slaughter (Department of Agriculture & Rural Development, 2005a). Average daily gains of 1.7kg and feed conversion ratios of 5.5 are usually achieved (Ford, 2017). The increase in weight at which cattle enter the feedlot can be attributed to several factors such as better management, nutrition, the use of steroidal growth enhancers and beta-agonist, and management (Strydom *et al*., 2009; Delmore *et al*., 2010; Agbeniga & Webb, 2018).

According to the Department of Agriculture & Rural Development (2005a), a mortality rate of 1 to 2% is accepted as a norm, while Ford (2017) states that the mortality rate in a commercial feedlot is 0.8%. In South Africa, there are currently 430 abattoirs which slaughter cattle, pigs, and sheep. Approximately 40% of the slaughters are done by abattoirs that slaughter a limitless number of class A animals (DAFF, 2018). Approximately 60% of cattle are slaughtered by highly regulated abattoirs (Class A & B) and most abattoirs have ties to a feedlot (DAFF, 2018). A mean dressing percentage of 58.5% is achieved, with 95% of all carcasses being A grade with the remaining 5% being AB-grades (Ford, 2017). The dressing percentage varies, for lean animals it can be 49% which can increase to 60% at a high level of finish, while the mean dressing percentage varies from 54 to 56% when the fat score is 2 to 3 (Department of Agriculture & Rural Development, 2005a). According to Webb (2018, E.C. Webb, Pers. Comm, University of Pretoria, Department of Natural and Agricultural Sciences), most carcasses (>70%) in the A-age group are generally lean or contain a medium amount of subcutaneous fat compared to *ca*. 60% and 50% for carcasses in the B and C classes respectively. Carcass classification is not compulsory by law, and therefore to classify carcasses, an abattoir must register with the Department of Agriculture (Strydom, 2002b). Traders prefer to trade classified carcasses due to the ease of transaction when describing the product (Strydom, 2002b).

2.2 An overview of the feedlot industry

Confined livestock systems, such as feedlots for cattle, are increasing in number (*Kahl*, 2018). It has been shown that more than 70% of the beef consumed in South Africa is from a feedlot (Van der Westhuizen *et al*., 2009). These systems are forced to produce maximum production results with good and low feeding practices (*Kahl*, 2018). In South Africa, nearly all weaners are produced on natural pastures or veld (De Lange *et al*., 2014). Table 2.1 provides a summary of the different types of feedlots in South Africa.

Table 2.1 Summary of the various types of feedlots

Seasonal feeders:	Farmer feeder	Commercial feeder
Will take their own weaner calf	Has a local beef off take at the butcher or abattoir	The major farming enterprise
Either own grain or purchase grain	Has access to reasonable inexpensive feed ingredients	In the market twelve months of the year
Market generally year-end	Runs the feedlot in conjunction with other farming enterprises	Highly scientific and intensive
Ad hoc as market dictates	Buys calves locally or feeds own calves	Has permanent feedlots and staff
	Enter or exit the market as he sees fit	Permanent market for all beef producers
		Cannot enter and exit at will

Adapted from Ford (2002)

In beef cattle production systems, the growth performance of cattle is of economic importance (Sturaro *et al*., 2005). The growth rate of the animal during the perinatal to puberty growth phase is influenced by plane of nutrition, hormonal status, and the environment. Other factors which influence growth rate are variation in production systems and source of cattle (Widdowson, 1980; Gluckman, 1986; Owens *et al*., 1993). High growth rates are preferred because of the earlier marketing weight which is obtained when compared to slow growth (Mukuahima, 2007). Cattle which have the genetics for fast growth are normally heavier at any one time, have a delay in fat deposition, and have a final body weight which is heavier compared to cattle with the genetics for slower growth rates (Crouse *et al*., 1975; Laborde *et al*., 2001).

Variation due to source of cattle is a result of the previous environment and genetic potential and for this reason, it plays an important role in the feedlot decision making (Ralston *et al*., 1970). Cattle which come from a single source are at a decreased risk compared with cattle which come from multiple sources. Unlike single-source cattle, cattle from multiple sources have not been exposed to the same pathogens thus increasing their risk to disease, nor have these animals established a herd social hierarchy which leads to high levels of aggression in the first week of mingling (Noffsinger *et al*., 2015; Kahl, 2018). Priority access to the bunk is given to dominant animals, while the weaker animals will only get access after the more dominant feeders are satisfied (Šárová *et al*., 2010). The less dominant animals have to change their eating behaviour - these animals eat faster in order to maintain dry matter intake and spend less time at the feeding trough (Šárová *et al*., 2010).

While the visual estimation of body size and condition will remain the common method of sorting cattle entering the feedlot, the use of body weight provides a simple and useful tool to identify small differences in body size and improve detection and grouping of cattle in order to reach an optimum finish with a minimum number of days in feed (Hendrickson *et al*., 2005). Sorting cattle into uniform groups before entering the feedlot can be done by direct measurements of body size and condition (Hendrickson *et al*., 2005). This, therefore, results in groups of cattle that have similar feed efficiencies and endpoint carcass traits that have an economic advantage (Hendrickson *et al*., 2005). Visual appraisal is a subjective measurement and therefore accuracy is a problem in assessing body size and condition (Hendrickson *et al*., 2005). Improvements can be made by using objective measurements of body size and condition which can be closely related to carcass traits and values (Hendrickson *et al*., 2005).

The live feedlot performance and carcass traits are influenced to a large degree by factors such as, animal disposition, health, breed type, and frame score (Reinhardt *et al*., 2009). The primary breed makeup (Marshall *et al*., 1990; Laborde *et al*., 2001) and frame and muscle scores (Tatum *et al*., 1986a; Tatum *et al*., 1986b; Dolezal *et al*., 1993), have shown to affect not only the carcass composition but the days in feed as well (Reinhardt *et al*., 2009). While it was shown that an increase in frame size correlated with an increase in finished body weight, the differences in the muscle scores did not correspond to differences in the ultimate yield grade (Grona *et al*., 2002). However it's very important to remember that performance and carcass traits can also be influenced by factors such as heat stress, cold stress, disease and social stress (McGlone *et al*., 1993; Sutherland *et al*., 2006).

2.3 Main aims and goals of a feedlot

2.3.1 What is the purpose of a feedlot?

The feedlot industry in South Africa was started in the 1960s due to a shortage of quality grazing in the dry winter periods (Ford, 2002; Kahl, 2018). This forced farmers to feed cattle grains, potato by-products or bad quality hay (Ford, 2002; Kahl, 2018). However these methods used for feeding were not reliable, resulting in inefficient production performance (Kahl, 2018). In the 1990s, feedlots became vertically integrated as bigger feedlots started slaughtering their cattle, whilst others did the wholesaling and retailing of their cattle (Kahl, 2018).

A feedlot can be defined as "an intensive system that subjects an otherwise unmarketable calf to a process of intensive feeding and care, transforming it into a high-quality beef product" (Ford, 2017). Another definition of a feedlot is a production system where animals are kept in a confined area where they receive *ad libitum* water and feed; here they are fed either by hand or mechanically with the purpose to increase production (Clark, 2006). Cattle do not have access to pastures and are fed for production or weight gain (by adding muscle and fat) through the use of supplementary feeding techniques (Clark, 2006; Kahl, 2018; Beef Feedlot Manual, 2011). Feedlots make money by buying cattle that are in poor condition and, then increase the cattle weight by feeding cattle intensively after which they are sold as fattened cattle, at a higher price, to the abattoir (Chiriboga *et al*., 2008).

Feedlots have become popular for many reasons, namely: a greater number of cattle can be kept per unit area than on the natural veld (Kahl, 2018), cattle walk less in feedlots and therefore require less feed to produce 1 kilogram of meat (Hubbs, 2010), overgrazing, soil erosion and compaction are decreased and possibly eliminated (Kahl, 2018), and cattle receive nutritious feed of good quality throughout the year compared to animals on pasture, where there is a decrease in the nutritional value in the winter season and during droughts because of reduced rainfall during these periods (Frylinck, 2013).

2.3.2 Production parameters in a feedlot

One of the main objectives of a feedlot is to increase the efficiency of converting feed into meat (Kahl, 2018). This is described as the feed conversion ratio. The feed conversion ratio varies according to the quality and the ingredients of the feed as well as the condition, genetics and age of the animal (Kahl, 2018). The feed conversion ratio can also be defined as the efficiency with which animals grow and will have a major effect on the profitability (Coetzer, 2002). Efficiency in animal production is defined as a measure of the input costs to the total animal product produced (Johnson *et al*., 2010). The cost of feed in a feedlot is one of the largest costs, and for this reason the feed conversion ratio is one of the most important parameters to determine the profitability of the feedlot (De Lange *et al*., 2014). It has been shown that an ADG of 2kg and a FCR of as low as 4.5:1 is quite possible (Coetzer, 2002).

The total variation in average daily gain and carcass characteristics are largely affected by the source of cattle (Ralston & Taylor, 1963). The genetic correlation estimate (- 0.92) between feed conversion ratio and feedlot profitability is mostly due to the part-whole relationship between these two traits (Van der Westhuizen *et al*., 2009). This was anticipated because for each kg less feed an animal consumes to gain a kg in body weight the more profitable the animal will be (Van der Westhuizen *et al*., 2009). Therefore feedlot profitability can be selected for indirectly through the use of feed conversion ratio as a selection criteria (Van der Westhuizen *et al*., 2009).

Feed conversion ratio and feed efficiency are the two common measures of efficiency however, efficiency is linked to growth rate which may increase the mature size and therefore result in an increase of maintenance costs (Scholtz & Hendriks, 2014). It has been shown that feed conversion ratio is strongly negatively correlated with average daily gain, which suggests that a lower feed conversion ratio results in a higher growth rate and vice versa (Scholtz *et al*., 1998; Arthur *et al*., 2001; Nkrumah *et al*., 2004; Sainz *et al*., 2004). Post-weaning traits are more focused on growth and less on efficiency traits. Previously, feed efficiency traits such as feed conversion ratio (feed intake/growth) were used as measures of post-weaning efficiency (Scholtz *et al*., 2014). However alternative methods have now been developed such as residual feed intake and residual daily gain (Scholtz *et al*., 2014).

Residual feed intake has been suggested (first proposed by Koch *et al*., 1963) as an alternative method to measure feed efficiency as this method overcomes the difficulty associated with feed conversion ratio (Maiwashe, 2014). It does not depend on the size and growth of an animal, on the condition that it is calculated from genetic regression coefficients (Maiwashe, 2014). Residual feed intake is defined as the difference between actual feed consumed and expected feed intake based on size and growth rate (Maiwashe, 2014). The main advantage of using the residual feed intake is that it is phenotypically independent (mature size, average daily gain, etc) so that selection does not cause an increase in cow size or production, but rather it reduces feed intake (Adcock, 2011). Selection for a lower residual feed intake is different compared to other feed efficiency traits (such as feed conversion ratio and feed efficiency) as it is independent of growth and weight and therefore it does not increase the maintenance requirements of mature animals (Scholtz *et al*., 2014). Animals which have a lower residual feed intake have decreased intake compared to what would have been expected (Adcock, 2011). This indicates that these cattle have decreased maintenance requirements compared to cattle with a high residual feed intake (Adcock, 2011). The average animal has a value of 0, however the target would be to have a negative or low value, this means that the animal ate less than the predicted amount of feed (Adcock, 2011). Selection for lower residual feed intake in a feedlot is possible but it will result in a decrease in fat content (Robinson & Oddy, 2004).

A newer method which has been used to measure feed efficiency is residual average daily gain. It can be described as the difference between actual weight gain and the gain predicted based on dry matter intake, body weight and fat cover (Adcock, 2011). Most animals have a residual average daily gain of 0, however, animals which have a positive or a higher residual average daily gain are more desirable (Adcock, 2011). Selection for residual daily gain will improve growth however, it will not affect feed intake (Scholtz *et al*., 2014). The feedlot industry in South Africa prefers a certain minimum growth rate and carcass weight which cannot be achieved through the selection of residual feed intake alone (Scholtz & Hendriks, 2014).

In a cattle production system, the overall efficiency is a combination of biological efficiency or feed consumed to beef produced, and economic efficiency or dollars spent to dollars returned (Johnson *et al*., 2010). It can be shown that the body composition and variation inefficiency is largely influenced by age and maturity of the animal - younger animals, which are growing, utilize protein synthesis rather than the deposition of fat which is more efficient (Adcock, 2011). The turnover of protein is an energetically expensive process as its costs account for 15 - 20% of the basal metabolic rate and this variation by itself can have an impact on genetic selection for traits such as growth (Waterlow, 1988).

2.3.3 The performance of cattle in a feedlot

The profit of a feedlot is determined by the price margin, feed margin and other expenses (Department of Agriculture & Rural Development, 2005a; Niemand, 2013), and adding these together will indicate a profit or loss. Factors which affect profit margin in a feedlot include; price margin, feed margin, management, cost of feed, the buying price of feeder and selling price which is usually quoted as carcass price (Department of Agriculture & Rural Development, 2005a). The breakeven point in a feedlot can be defined as the point where the total input cost per kilogram beef produced equals the total income per kilogram beef sold (Ford, 2017). The input costs consist of; the purchase price, feed cost, yard age cost and marketing costs while the income costs consist of income from beef, income from offal, income from hide and other income (Ford, 2002; Ford, 2017). If animals are fed for too long, there is a decrease in average daily gain towards the end of the feeding period (Department of Agriculture & Rural Development, 2005a). This results in cattle which are over finished and a negative feed margin likely resulting in a reduced profit margin (Department of Agriculture & Rural Development, 2005a). Feeder and fed-cattle price, maize price, interest rates, feed conversion and average daily gain can explain 90% of the variation in steer profit while pricing factors alone account for nearly 80% (Albright *et al*., 1993a; Mintert *et al*., 1993; Mark *et al*., 2000; Pyatt *et al*., 2005). The ability to maintain or improve economies of scale is also influenced by the location of a feedlot (Department of Agriculture, 2003).

Another important concept is the price margin (calf purchase price vs meat price) and the feeding margin (feeding costs to produce 1kg of meat vs the price of 1kg of meat) (Niemand, 2013; Ford, 2017). Price margin can be defined as the profit or loss which the feedlotter makes as a result of an increase or decrease in the price from the time the animal is bought (cost price) to the time the animal is sold (sale price) (Department of Agriculture & Rural Development, 2005a). The price margin includes differences between the purchase price and selling price which is due to the fluctuations in beef price as well as the improvement in the carcass quality as a result of feeding (Department of Agriculture & Rural Development, 2005a). In other words, the calf price as a % of the beef price (calf price per kg live weight delivered to the feedlot divided by the beef price realised) should be below 55% (Ford, 2017). Supply and demand influence the purchase price of the weaners but it also relies on the world meat trends, as well as the present and expected prices of grain (Ford, 2011). It is important to remember that South Africa is the only country in the world where the price of the final carcass is not known when the weaner is purchased and indicates that the feedlot industry is a high-risk business (Department of Agriculture, 2003; SAFA, 2003).

Feed margin can be defined as the profit or loss a feedlotter makes as a result of live weight gain to the cost of feed consumed (Department of Agriculture & Rural Development, 2005a). A positive feed margin can be ensured by realising desired growth rates and by taking steps to achieve the best feed price (Department of Agriculture & Rural Development, 2005a). The animal and feed price are driven by supply and demand. Supply depends on various factors one of which is the weather and therefore the producers do not have control on the price they pay for production inputs or the price they receive for their outputs (Lombard *et al*., 2018).

In order for feedlots to achieve the highest positive feeding margin, they aim to operate at optimal capacity (Department of Agriculture, 2003). Optimum composition, body weight and economic end-point for cattle are influenced by sex, genetics, implants, health, initial body weight, diet, days in feed, growth rate, feedstuff and grid prices, endpoint criteria, pen conditions, weather and seasonality (Pritchard, 1999; Mark *et al*., 2000). Generally, the industry faces a negative buying margin and a positive feed margin (Department of Agriculture, 2003). The feed is the biggest single cost item of the variable costs in a feedlot enterprise (Norris, 2002). A positive feeding margin means that the value per kilogram carcass weight gained is higher than the cost of feeding the animal to gain a kilogram of carcass weight (Department of Agriculture, 2003). It can be shown that the viability of feeding cattle is largely based on the beef: grain price ratio because the price of grains is high in South Africa. Feedlots have started using by-products such as grain by-products and therefore the main feed in the industry is hominy chop (Department of Agriculture, 2003).

A feedlot is a biological production system which is supported by a high degree of capital outlay (Department of Agriculture, 2003). For example, cattle which are ready for market cannot be held from the market when prices are low, the market does not like overfat or heavy carcasses and therefore cattle are slaughtered despite the market price (Department of Agriculture, 2003). Cattle are kept in the feedlot for 90 to 100 days and during this time they are intensively fed (Department of Agriculture, 2003). This requires an initial capital (purchasing of weaners) and a continuous capital layout (purchasing of feed) before a feedlot can make a profit (Department of Agriculture, 2003).

When the price of cattle is high, or the price of feed is low it makes sense to add on as much weight as possible (Anderson *et al*., 2001). In dry years, the price of maize is normally high due to a low supply while the price of weaned calves will be low because the cow-calf producers will sell their calves to try and reduce the grazing pressure. While in wet conditions maize prices are low and calf prices are high as farmers hang onto their calves (Maré *et al*., 2011; BFAP, 2016; Lombard *et al*., 2018). It may be more beneficial to use *Bos indicus* cattle for fattening when the level of nutrition in the feedlot diet is limited as it has been shown when feed resources were limiting, crosses of large temperate breeds did not have an advantage over *Bos indicus* cattle (Norris *et al*., 2002). As both feed costs and dressed price increase, the cost of body weight gain increases parallel to the selling price and therefore the composition of body weight gain is more important than additional body weight itself for this pricing structure (Pyatt *et al*., 2005).

Cattle performance and carcass merit are influenced by both nutrition and management (Pyatt *et al*., 2005). The positive and negative correlations between the performance and carcass traits result in economic trade-offs that change with input costs, grid premiums and discounts (Pyatt *et al*., 2005). More cost-effective decisions can be made regarding management and marketing when the relative risk factors which contribute to profits are understood (Schroeder *et al*., 1993).

It has been shown that numerous factors affect the performance and profitability of a feedlot such as average daily gain, feed conversion ratio, slaughtering/carcass price, weaner price, dressing percentage, total weight gain, feeding costs and mortality (Sy *et al*., 1997; Maré *et al*., 2011; Tatum *et al*., 2012). Feedlot performance does differ between breeds and therefore different breeds should be fed for different feeding periods to optimise both production and profitability (Chewning *et al*., 1990; Williams & Bennett, 1995; Bosman, 2002; Oosthuizen, 2016).

Two terms which are used in a feedlot are average daily gain and feed efficiency. Average daily gain refers to the amount of weight an animal gains per day while on a high energy ration (Beef Feedlot Industry Manual, 2011). Feed efficiency is the amount of feed which is consumed per kg of gain (Beef Feedlot Industry Manual, 2011). Average daily gain can also be defined as the rate at which cattle grow (Coetzer, 2002). Cattle can achieve average daily gains of 1.7kg and a feed conversion ratio of 5.5 (Ford, 2017). In another article, it was stated that the average daily gains of 2kg and feed conversion efficiency as low as 4.5:1 is quite possible (Coetzer, 2002).

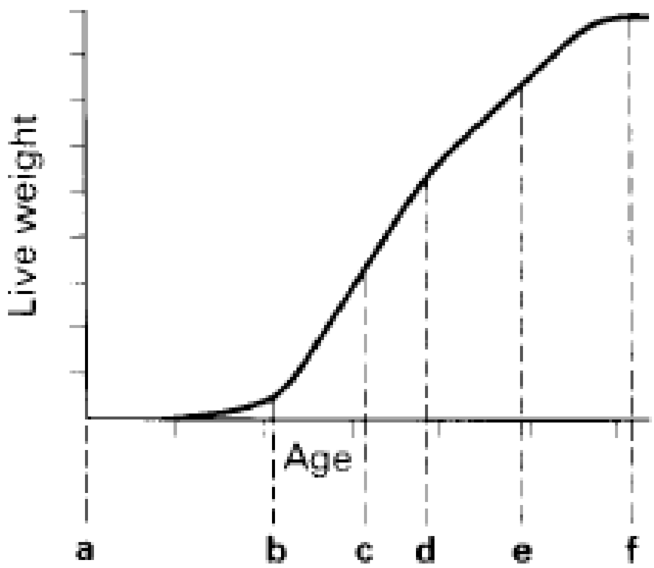
Beef to gain ratio is another important concept in the feedlot industry and can be defined as the “how many kilograms of gain that can be purchased per kilogram of beef sold” (Ford, 2017). In South Africa, this ratio is approximately 12:1 (Bosman, 2002) to 13:1 (Ford, 2017) compared to America and Australia where the ratio is 22:1 and 24:1 (Ford, 2002; Bosman, 2002). It is not economical to feed cattle below a ratio of 13:1 (Ford, 2017). The financial returns of the beef cattle enterprise is ultimately what a farmer looks for, however, the economic and financial viability of feedlotting is determined to a large degree by the beef-feed price ratio (Norris *et al*., 2002). The beef to grain ratio has traditionally been used to determine the viability of beef feedlotting or the maturity type that should receive reference (Bosman, 2002)

2.4 Animal's production requirements and allometric growth factors

Maintenance is the condition in which the animal is neither losing nor gaining body weight, body energy or any other nutrients (Leeuw, 2002). The nutrient requirements for this function get preference over any other production function, and for this reason, the nutrient supply must be more than maintenance before growth will take place (Leeuw, 2002; Manitoba Agriculture, 2016). Animals with a larger mature size, require more energy for maintenance and reach puberty at a later stage in life (Koch *et al*., 1989; Owens *et al*., 1993). The most important need for energy are the nerves while the least important is for fat and therefore, the animal will only begin to deposit fat once all other requirements (maintenance, growth, reproduction, production) have been met (Manitoba Agriculture, 2016).

Growth and fattening refer to an increase in body weight. The rate of growth is higher earlier in life with lean tissue growth becoming relatively slower and fat growth relatively faster later in life (Leeuw, 2002). These changes influence the nutrient requirements (Leeuw, 2002). Rate of growth is directly related to the animal's level of nutrition, there is a high positive correlation between average daily gain and the total digestible nutrient percentage (Strydom, 2002a).

A better understanding of the empirical nature of the growth processes can be achieved with mathematical descriptions of growth through the use of growth curves (Goonewardene *et al*., 1981) (Figure 2.4). Growth can be defined as a "phenomenon of change in size, weight, shape, composition, and structure" (Fuller, 1969), but is normally defined as an increase in size and weight (Dyer, 1985). When growth is plotted against age from conception to maturity, an S-shaped curve (Figure 2.4) forms which is known as the actual growth curve (Wallace, 1948; Pálsson & Vergés, 1952; Batt, 1980). The initial part of the curve, directly after birth is slow followed by a faster growth period during puberty (Strydom, 2002a). The self-accelerating phase is the steep initial limb of the curve; there is a considerable amount of growth occurring at this phase (Batt, 1980). Muscle growth takes place here, while there is less bone and organ growth (Strydom, 2002a). Towards the end of the accelerated phase, muscle growth slows down and fat deposition increases (Strydom, 2002a). Later growth is slowed down by several physical and chemical influences. The slowing occurs gradually, first beginning at the inflexion point at the phase called the "self retarding phase" and then becomes more pronounced with the development of the growth plateau (Batt, 1980). As the animal reaches maturity the whole process of growth slows down (Strydom, 2002a).



a - Conception
b - Birth
c - Self-accelerating phase
d - Inflexion point
e - Self-retarding phase
f - Growth plateau

Figure 2.4 A typical growth curve of slaughter stock, sigmoid curve (Wallace, 1948; Pálsson & Vergés, 1952; Batt, 1980)

Puberty is said to occur at approximately 60% of the animal's mature weight, at the point where the self-accelerating growth changes into self-inhibiting growth (Brody, 1964). While puberty occurs at a specific weight in some animals and a specific age in others, in cattle both the weight of the animal as well as the age plays an important role in determining puberty (Yelich *et al*., 1992).

The maximum body size is determined genetically however, it can be altered by nutritional and hormonal factors (Owens *et al*., 1993). The difference in size between different breeds is due to a difference in the skeletal size and in the number of muscle cells, not the size of muscle cells (Hammond, 1961). Almost all mammals are born with nearly their full amount of skeletal muscle fibres. While the hyperplasia of muscle occurs prenatally (Allen *et al*., 1979; Owens *et al*., 1993), the muscle fibres only increase slightly postnatally (Bergen & Merkel, 1991). Postnatal muscle growth occurs through muscle hypertrophy (Allen *et al*., 1979). Hyperplasia and satellite cell replication and incorporation are responsible for postnatal muscle growth (Goldspink, 1962; Goldspink, 1968; Goldspink, 1991).

The meaning of mature weight is not consistent even amongst simulation models (Arnold & Bennett, 1991). However, it can be defined as the point of maximum protein weight despite the increased fat deposition which can occur beyond this point (Owens *et al*., 1993). The heritability of mature weight is 0.82 in cows (Humes & Munyakazi, 1989) and the environment can play a vital role in determining the mature weight (Owens *et al*., 1993). Mature protein weight can be increased by retarding the deposition of fat (Owens *et al*., 1993) or through the administration of estrogenic compounds, which increased the steer mature size by 15% (Preston, 1978). Oestrogens work by increasing the secretion of growth hormones (Beitz, 1985). Fat production is expensive and excessive amounts cannot be marketed profitably through normal channels however, some fat must be present in the edible portion of the carcass in order to maintain the quality and flavour (Ralston *et al*., 1970). When the rate of protein growth plateaus, the rate of fat deposition accelerates rapidly (Byers, 1980a; Byers, 1980c). The rate of protein growth decreased as the body weight increased, which indicated the effect of age and relative maturity on protein deposition (Byers 1980a). While both mature size and genetic potential establish the upper limits for daily protein growth, there are other influences which also determine the degree to which these theoretical limits can be accomplished (Byers, 1980a).

Hyperplasia of adipose tissue continues throughout life (Owens *et al*., 1993). Fat accretion has an energetic efficiency which is approximately 1.7 times that of protein, but more water is stored when protein is deposited than when fat is deposited which makes lean tissue gain 4 times as efficient as accretion of fat tissue (Owens *et al*., 1995). The conversion of protein to fat is used very inefficiently which suggests that surplus protein is used inefficiently (Owens *et al*., 1995)

It has been assumed that the factors of the Brody equation are fixed genetically and cannot be changed (Owens *et al*., 1993), however, retardation of growth occurs due to malnutrition (Winick & Noble, 1966). The degree of the retardation depends on the stage of development as well as the degree of nutritional deficiency (McCance & Widdowson, 1962). If malnutrition occurs early in life it may hinder cell division and the animal may never recuperate, unless growth retardation occurs at a later stage, however, there will be a reduction in cell size (Winick & Noble, 1966).

The association between frame size and mature weight is normally direct. The frame size of skeletal size is measured as the length of specific bones or wither height, while weight is a weight measurement and not a linear measurement (Owens *et al*., 1993). Growth can sometimes be measured as the size or stature, while muscle or fat are judged subjectively (Owens *et al*., 1993). Long bones stop increasing in size after the closure of the epiphyseal plates and linear bone growth presumably stops when the closure occurs (Owens *et al*., 1993). However, the closure can be influenced by hormones and nutrient intake (Oberbauer *et al*., 1989). Oestrogens can limit mature size by stimulating earlier fusion of epiphyseal plates as well as an increase in ossification (Owens *et al*., 1993). This may explain why heifers are smaller in stature (Owens *et al*., 1993).

The rate of gain is normally determined as the change in weight during a specific period (Owens *et al*., 1993). Cattle which enter the feedlot at a higher weight normally have a higher intake of feed, particularly if they have a larger mature size or frame size, while the feed intake starts to decrease when the weight of fat increases which normally occurs during the finishing periods (Owens *et al*., 1993). An increase in mature body weight usually occurs when animals are selected for quick growth rate or a low fat content (Owens *et al*., 1993). This is because at a specific weight, animals which have a large skeletal weight or a large mature weight are earlier in their growth curve and contain fewer lipids (Owens *et al*., 1993). The efficiency of production of lean tissue and less fat at slaughter can be achieved by a large mature size animal (Greathouse, 1985. Owens *et al*., 1993).

2.5 Measurements which can be used to estimate growth before entry into a feedlot

Growth is expressed in quantitative terms. Measurable features other than weight can be used to determine the growth of an animal such as height, length, girth and volume (Batt, 1980). It is important to remember that linear measurements are more objective than visual appraisal (Lamm, 1982). There have been a few reports concerned specifically with the relationships between body measurements recorded early in life and subsequent growth, feedlot performance and carcass traits (Zerbino *et al*., 1983).

The main reason for using linear measurements is to predict the future performance of the animal, while the evaluation of animals considers any measurements or subjective evaluations that help describe a particular animal (Lamm, 1982). Linear measurements must never be used as a replacement for the weight of an animal at a given age, rather it should be used to supplement growth information as a supplement for selection purposes. It is important to remember that no single frame size will be optimum for all feed resources (Lamm, 1982).

2.5.1 Frame size

Frame size can be described as the hip height at a specific age and is correlated with the growth rate (Vargas *et al*., 1999). Frame size is linked to the growth rate and slaughter weight (USDA-Agricultural Marketing Service. 2000). And thus influences the marketing of cattle (Parish *et al*., 2012) as well as the price of feedlot calves (Troxel & Barham, 2007; Reuter *et al*., 2011; Troxel *et al*., 2011), bulls (Atkinson *et al*., 2010) and market cows (Troxel *et al*., 2002). Performance of cattle can be predicted by using frame scores, these scores can be used to show the mature size, the composition of the carcass or the fat to lean ratio, and estimate the potential performance as well as the feed requirements (Torell *et al*., 1999; Barham *et al*., 2011). These are however objective scores which range from 1 to 9 (categorical trait) (Torell *et al*., 1999, Vargas *et al*., 2000). With 1 indicating a small animal and 9 a large animal.

If the age adjustments are done properly the frame score should remain the same throughout the animal's life-time (Torell *et al*., 1999). This assumes that the animal will receive the correct nutrition and management (Torell *et al*., 1999). However, this does not happen and for this reason there will be a change in frame score, which is usually not more or less than one score in their lifetime (Torell *et al*., 1999). Getting an idea of the frame size is important when estimating the growing and finishing nutrient requirements for cattle and expected feed intake (Torell *et al*., 1999).

Animals which have a large frame are generally leaner at a given weight than small-framed animals (Barham *et al*., 2011). The amount of fat or the degree of finish will vary depending on the amount of feed fed to the cattle and as well as the season (Barham *et al*., 2011). The type of frame size is determined by the environment and the management objective and goals (Torell *et al*., 1999). While market weight, as well as reproduction efficiency, will determine the desired frame size range within a given set of feed resources, breeding system, production cost and management factors (Lamm, 1982). In feedlot cattle, the designation of large, medium and small frames are used (Torell *et al*., 1999). Cattle classed as large frame are cattle which have a large skeleton and are tall and long-bodied (Torell *et al*., 1999). Medium framed cattle are smaller than the large framed cattle but their frames are still slightly large (Torell *et al*., 1999). While small framed cattle are shorter (Torell *et al*., 1999).

Low frame scores indicate smaller and shorter cattle. These cattle normally mature earlier at lighter body weights and therefore are ready for slaughter earlier and at lighter weights in a feedlot (Torell *et al*., 1999). Small framed cattle have a higher muscle to bone ratio which indicate that large-framed animals have a large amount of non-muscle tissue (fat, bone, connective tissue) relative to the actual extra muscle that might exist along with the extra frame (Tatum *et al*., 1988). High numbered cattle are normally taller and mature later, they, therefore, weigh more at maturity and are finished off at higher weights in the feedlot (Torell *et al*., 1999). They also tend to gain weight faster and convert feed into gain better, however they may not carry as much marbling (Torell *et al*., 1999). The frame size is also linked to the slaughter weight at which cattle should achieve a given amount of fat thickness (Barham *et al*., 2011).

Large sized cattle respond more in fat deposition when there is an increase in energy compared to smaller sized cattle (Byers & Rompala, 1980; Byers, 1980a). If larger framed cattle are fed a low energy diet, they will be extremely large when the desired level of carcass fatness is reached (Byers, 1980a). This is due to the high level of daily protein growth. Therefore their ability to increase the rate of fat deposition on a high energy diet allows them to achieve the desired carcass fatness at a live weight which is much lighter and is more marketable (Byers, 1980a). Large framed cattle also have a greater rate of protein deposition compared to small mature sized cattle at any weight or rate of gain (Byers, 1980a; Byers, 1980b).

The frame size of cattle is considered to be moderately to highly heritable and for that reason selection can significantly change the frame score achieved mainly through sire selection (Torell *et al*., 1999). The heritability has been estimated at 0.4, about 40% of the bull's difference in frame score from the herd average will appear in the progeny (Torell *et al*., 1999). It has been suggested that larger framed cattle are more advantageous in times of land and feed supply shortage as these animals produced more edible beef from the same level of feed input (Fox & Black, 1975). A choice between different cattle sizes is largely dependent on the carcass and composition which is desired (Fox & Black, 1975).

Buyers who purchase feedlot cattle prefer cattle which have a larger frame size and are more heavily muscled (Schroeder *et al*., 1988). Heavier carcasses favour slaughter-house pricing (Pesonen *et al*., 2012). The packing industry prefers, larger framed cattle because hanging more kilograms of the carcass, which results in the greatest amount of meat possible in the assembly line which is more efficient for this type of industry (Johnson *et al*., 2010). A larger mature size is also indicative of feedlot performance, as these cattle grow faster and have heavier slaughter weights (Torell *et al*., 1999). The goal in the feedlot is to produce as many kilograms of beef as possible. This is done to have a profit at a margin which is above feed costs (Johnson *et al*., 2010). Larger animals will eat more feed than smaller cattle. Its additional feed requirements as a percentage are less than its additional weight as a percentage (Johnson *et al*., 2010).

According to Webb (2018, E.C. Webb, Pers. Comm, University of Pretoria, Department of Natural and Agricultural Sciences), animals with medium maturity are better because they can adapt fairly easily to new strategies when the market changes. It has been stated that the trend in South Africa is to feed animals which produce a medium-size carcass (180 - 220kg, medium maturing), however, there is a market for larger (220 - 260kg, late-maturing) and smaller (< 180kg, early maturing) sized carcasses but these carcasses come at a cost (Martins, 2002). Large and smaller carcasses are discounted in the market (Martins, 2002).

Larger cattle have a higher maintenance energy requirements compared to small cattle and will consume more feed than smaller cattle (Johnson *et al*., 2010). It has been stated that large-framed cattle may become a liability in the feedlot and they have no value in programs that use an extended growing phase (Pritchard, 1995). However larger framed cattle are more profitable, as there are more kilograms per unit of purchase cost (Pritchard, 1995). There is less shrink, processing costs and death loss per unit of feedlot gain and therefore the dilution of these and other feedlot inputs, by more total weight gain is cost-effective (Pritchard, 1995). It is important to take note that it's the total weight gain which is advantageous, not the frame size (Pritchard, 1995). Light cattle are not discounted for size however, they do reflect a high production cost as they failed to grow (Pritchard, 1995), while overweight carcasses are discounted (Pritchard, 1995).

2.5.2 Sheath length

In the study of Lombard *et al*. (2018) study, the profitability of feeding cattle was expressed as total margin and feed margin, while it was shown that the sheath length was significantly correlated with both the total margin and the feed margin (Lombard *et al*., 2018). Sheath length appeared to be negatively correlated with total margin and feed margin although it was expected to be positively correlated (Lombard *et al*., 2018). This suggests that cattle which have a lower sheath score, sheaths which are closer to their bodies, perform better in the feedlot and may, therefore, affect total margin and feed margin positively (Lombard *et al*., 2018). A lower score can be given for a sheath which is closer to the body while a higher score can be given to a bull/ steer with a sheath which is further away from the body (Lombard *et al*., 2018). A sheath which is deeper, and further away from the body, was previously believed to allow the animal to accumulate more weight (Lombard *et al*., 2018).

2.5.3 Shoulder height

Originally, wither (shoulder) height was used to describe the skeletal size as it was believed to be the best measurement of true genetic size and growth rate (Black *et al*., 1938; Brody, 1945). However, more recently, hip height has become the measurement of choice and is most easily obtained (Lamm, 1982). When compared with weight however it was shown that the ratio of weight to wither height will give the highest correlation with performance (Black *et al*., 1938).

2.5.4 Hip height measurement

The Beef Improvement Federation recommends hip height as the height measure of preference. Hip height has become the measurement of choice above shoulder height as it is more easily obtained (Lamm, 1982). The hip height can also be adjusted for the age and sex of the cattle being measured (Lamm, 1982). While body weight is the most common measure of body size, hip height is a better indicator of maturity than body weight (Hammack & Gill, 1997; Hendrickson *et al*., 2005). Hip height measurements can be used as another tool to refine performance records of beef cattle but it is important to keep these measurements in the proper context (Lamm, 1982).

The correlation between hip height and weaning, yearling and slaughter weight had an average of 0.56 (Zerbino *et al*., 1983). In crossbred cattle, it was found that the yearling hip height was more closely associated with feedlot average daily gain than that of weaning hip height, 0.29 vs 0.14 respectively (Zerbino *et al*., 1983). The most simple correlations between skeletal size and performance traits such as birth weight, weaning weight, post-weaning gain, yearly weight and mature size vary from 0.4 to 0.7 (Lamm, 1982). It was found that the heritability for body weight varied from 0.31 to 0.53 across the 170 day feeding period, while the heritability for hip height varied from 0.37 to 0.53 and body weight: hip height ratio varied between 0.23 to 0.6 (Riley *et al*., 2007). The heritability estimates for hip height increased from 0.37 to 0.53 by about 85 days in feed and then remained somewhat constant through the period of 170 days in feed (Riley *et al*., 2007).

The collection method, head restraint and condition score all effect the hip height measurement (Parish *et al*., 2012). The structure, posture and movement of the animal can also affect the accuracy of measurements (Parish *et al*., 2012). When these measurements are taken it is important that the animal is standing squarely and its head is held in a normal position for measuring (Torell *et al*., 1999). The recommended area for hip height measurement is directly over the hooks (Beef improvement federation, 2010). There are many different ways to measure the hip height of an animal, however, most cattle are measured in a chute either with a measuring stick or looking across the animal to a graduated board on the offside of a single animal scale, which in many cases is the most practical manner of measuring height (Lamm, 1982). The hip height of cows can be overvalued with the descending tape and undervalued with the visual approach relative to measurement using the altitude stick (Parish *et al*., 2012). If cattle are confined in a squeeze chute for hip height measurements their head should be unrestrained for this measurement otherwise there may be a risk for undervaluing hip heights (Parish *et al*., 2012). Operator error can also influence hip height measurements (Parish *et al*., 2012). Measurements are more accurate when taken by one operator as more errors occurred when there were different operators (Henderson *et al*., 1966).

As an animal grows towards maturity, the hip height gradually decreases relative to wither height, but hip height normally remains slightly greater at maturity (Brown & Shrode, 1971). The percentage of retail product decreased linearly with an increase in body weight per centimeter of hip height and ultra-sound fat thickness per 100kg of body weight which is in agreement with the inverse relationship between the percentage of retail product and yield grade (Hendrickson *et al*., 2005). For both bulls and heifers, there is a strong association between wither height, hip height and body length (Dyer, 1985). It has also been shown that the weight does not always increase proportionally with height (Dyer, 1985). Wither height is more closely associated with weight while, body length had a low and inconsistent relationship with other measurements and should therefore not be emphasized for selection decisions (Dyer, 1985).

Hip height at slaughter was not associated with the rate of gain in the feedlot, r = 0.02 (Zerbino *et al*., 1983). It was shown that hip height is mostly unrelated to carcass traits due to the low, inconsistent, non-significant correlations observed (Zerbino *et al*., 1983; Hendrickson *et al*., 2005). The hip height was found to be more highly correlated with carcass weight-per-day than for other carcass traits (averaged 0.31) (Zerbino *et al*., 1983). When prediction equations were used to predict carcass traits, it was found that weight was a more reliable predictor than hip height, and when hip height and weight yield were combined there was little practical improvement seen in predictability (Zerbino *et al*., 1983). Hip height and body weight are direct measures of body size and by combining these two measurements to calculate body weight per unit of hip height, it may provide a better predictor of carcass parameters (Hendrickson *et al*., 2005).

2.6 Cattle breeds and maturity types used in a feedlot and the effect on performance and profitability

Steers and heifers are the main type of cattle found in a feedlot; these cattle come from many different locations, however, there is only a small percentage of cull cows and bulls (Beef Feedlot Industry Manual, 2011). Females mature earlier than steers, while steers mature earlier than bulls (Department of Agriculture & Rural Development, 2005a). It has been estimated that 60% of cattle going to feedlots are crossbred or hybrid (Bosman, 2002). The majority of the commercial cow herd are crossbred which combines the adaptability traits of *Bos indicus* and Sanga breeds with the better performance of the *Bos taurus* breeds (Bosman, 2002).

Different cattle breed types are classified according to their maturity (Department of Agriculture & Rural Development, 2005a), which is linked to frame size (Niemand, 2013). As shown in Table 2.2, earlier maturing cattle deposit fat at an earlier age and can be marketed at a live weight of 380kg to 400kg, while later maturing cattle can be marketed at a live weight of 500kg or more (Department of Agriculture & Rural Development, 2005a). Cattle which mature later have higher growth rates and, are more efficient however, they need a longer feeding period in the feedlot (Department of Agriculture & Rural Development, 2005a; Niemand, 2013). A general rule of thumb is that dual-purpose breeds are late maturing, have a high growth rate and require a longer period in the feedlot (Department of Agriculture & Rural Development, 2005a). British breeds, excluding the Sussex which is a medium to late maturing breed, are normally early-maturing breeds and while their growth rates are relatively low, these breeds require a shorter period in the feedlot to reach a good carcass finish (Department of Agriculture & Rural Development, 2005a). *Bos Indicus* cattle perform well in feedlots however, temperament and problems with laminitis can occur (Department of Agriculture & Rural Development, 2005a).

Table 2.2 Live slaughter weight and carcass weight for different maturity groups

Maturity group	Slaughter weight (kg)	
	Live weight	Carcass weight
Early	<330	<180
Medium-early	330-360	180-200
Medium	360-400	200-220
Medium-late	400-440	220-250
Late	>440	>250

Adapted from Strydom (2002a)

Problems can sometimes occur, especially in Natal, where most of the cattle which enter the feedlot are crossbred and the maturity type does not always follow a mean of the breeds crossed (Department of Agriculture & Rural Development, 2005a). Table 2.2, 2.3 and 2.4 provide a summary of the maturity types for the different cattle breeds. Although the sources all provide the same information it is interesting to see how the different breeds are classified between the different sources. British breeds are primarily early maturing while the European continental breeds are medium to late maturing, however, some of the British breeds such as the Hereford have changed to medium maturity due to genetic selection (Strydom, 2002a). The majority of cattle slaughtered in the South African market are medium maturing, due to the cross-breeding (Strydom, 2002a). Earlier maturing breeds need to be slaughtered at lighter weights when compared to later-maturing breeds, to produce a carcass within fat codes 2 and 3 (Strydom, 2002a).

Table 2.3 Maturity types of the different cattle breeds

Frame score	Maturity type	Breed	Range in frame score
1	Early 1 to 2	Dexter	1 to 2
		Nguni	1 to 2
		Angus	1 to 3
		Porfontein Rooies	1 to 3
		Afrikaner	1 to 3
2		Herefords	2 to 4
		Rietvlei Reds	2 to 4
		Short Horn	2 to 4
		Sussex	3 to 5
3	Medium 3 to 5	Symons	3 to 5
		Smythe	3 to 5
		Bonsmara	3 to 5
		Bongihlati	3 to 5
		Brangus	3 to 5
		Brahman	3 to 5
4		Braford	3 to 5
		Tauricus	3 to 5
		Beefmaster	3 to 5
5		Limousin	4 to 6
		Drakensberger	4 to 6
		Santa Gertrudis	4 to 6
		Simbra	4 to 6
		South Devon	4 to 6
6	Late 6 to 7	Simmentaler	4 to 6
		Gelbvieh	4 to 6
		Pinzgauer	5 to 7
7		Charolais	5 to 7

Department of Agriculture & Rural Development, 2005a

Table 2.4 Different breeds classified into the different maturity types

Early maturing	Medium - early maturing	Medium maturing	Medium - Late maturing	Late maturing
Hereford	Afrikaner	Bonsmara	Simmentaler	Charolais
Angus	Brahman		Limousin	Chianina
Sussex			Santa Gertrudis	Blonde d' Aquitaine
Lincoln Red			Brown Switzer	Pinzgauer
Shorthorn			South Devon	Friesian

Adapted from Strydom (2002a)

Table 2.5 Classification of different breeds into maturity types and expected weights

Early maturing Live weight <360kg; carcass weight 180 - 200kg	Intermediate maturing Live weight 380 - 420kg; carcass weight 210 - 230kg	Late maturing Live weight 420 - 450kg; carcass weight 235 - 252kg
Afrikaner	Bonsmara	Brown Swiss
Brahman	Beefmaster	Charolais
Hereford	Brangus	Limousin
Nguni	Drankensbergers	Pinzgauer
SA Angus		Simmentaler
Sussex		South Devon
Tuli		

Adapted from Bosman (2002)

If animals are slaughtered at a constant weight, the highest percentage of fat and the lowest percentage of muscle to bone will be found in the early maturing cattle breeds (Strydom, 2002a). Late maturing breeds will have the highest percentage of muscle and bone while being lean (Strydom, 2002a). Hence, earlier maturing breeds need to be slaughtered at a lighter weight compared to later-maturing breeds to produce carcasses within fat codes 2 and 3 (Strydom, 2002a).

Cattle breeds can also be classified according to their type namely *Bos indicus* these are the Zebu type cattle, *Bos taurus*, which are European, British and dual-purpose breeds, and *Bos taurus africanus* breeds which are the Sanga and indigenous African cattle, and cross-bred cattle (Niemand, 2013). Explained differently in another article, in South Africa, there are four major types of breeds namely *Bos taurus* breeds which are hump-less cattle of the British Isles and Europe, *Bos indicus* these are humped Zebu cattle of Southern Asia, *Bos taurus indicus* breeds which are derived from *Bos taurus* and *Bos indicus* cattle, and finally *Bos taurus africanus* breeds known as Sanga breeds which are indigenous breeds (Bosman, 2002). Different types of cattle vary significantly in terms of feedlot performance and adaptability (Niemand, 2013). Cattle which are tropically adapted (Zebu and Sanga) perform poorer in the feedlot when compared to temperate cattle breeds (Bosman, 2002; Niemand, 2013). *Bos taurus* breeds are better adapted to temperate areas and do well in feedlot conditions, while *Bos indicus* breeds are more adapted to hot, humid areas and however don’t perform as well in feedlot conditions (Bosman, 2002). The *Bos taurus indicus* and composite *Bos taurus africanus* breeds do very well in feedlot conditions (Bosman, 2002). Breeds that have adaptability traits for tropical and sub-tropical climates do not perform well under feedlot conditions, these traits are however needed in the cow-herds which produce offspring for the feedlots (Bosman, 2002). The estimated number of cattle slaughtered from the different categories is as follows: Sanga types - 29%, Zebu types - 11%, British types - 26%, European types - 27%, Dairy and other - 7% (DAFF, 2018).

Cross-breeding of cattle has become popular, to take advantage of the potential heterosis (Norris *et al*., 2002). Some studies have shown that the growth rate of crossbred animals increased during the feedlot period, but the finical benefits achieved from an increase in live weight gains did not justify the higher cost of feed (Norris *et al*., 2002). Crossbred animals have daily live weight gains which are higher when compared to purebred Brahman animals and these higher growth rates were probably due to both heterotic and additive gene effect for growth and adaptation characteristics (Norris *et al*., 2002). Using cattle that have faster growth rates and a higher mature weight cannot be exploited unless sufficient feed resources in both quantity and quality are available to support such growth rates (Norris *et al*., 2002). It is also important to consider the following, an increase in growth traits (average daily gain, final body weight, hot carcass weight, loin muscle area) will generally result in a reduced fat deposition (marbling, yield grade, fat thickness) at a common time or final body weight (Tatum *et al*., 1988; Gruber *et al*., 2007).

Temperament can be described as the reactive behavioural response of an animal to close human handing (Burrow, 1997). It can also be described as the fear response to handling by man (Fordyce *et al*., 1985; Petherick *et al*., 2003). Due to its relatively high heritability (h^2=0.45), temperament can be genetically improved within a herd through the selection and culling (Bosman, 1999; Lanier *et al*., 2000). Studies have been done to determine the consequences of temperament on the average daily gains in feedlot cattle (Voisinet *et al*., 1997). A reduced performance, less favourable efficiency of gain and a leaner carcass, is said to occur in excitable cattle when compared to their calmer counterparts (Fordyce *et al*., 1988; Burrow & Dillon, 1997; Fox, 2004, Ferguson *et al*., 2006; Behrends *et al*., 2008). It was shown more excitable cattle have a decreased initial body weight, final body weight, average daily gain, hot carcass weight, yield grade, quality grade, fat thickness, loin muscle area, marbling score and mortality (Reinhardt *et al*., 2009). More excitable cattle have temperament scores which are higher and tend to have a lower live weight and/-or weight gains (Tulloh, 1961; Fordyce & Goddard, 1984), though, there is little data which has been presented on this topic. Another study found that calmer cattle did not have a greater initial body weight (Burrow & Dillon, 1997).

It was found that cattle which had Brahman breeding had a mean temperament rating that was higher or were more excitable when compared to animals which had no Brahman influence (Voisinet *et al*., 1997). Similar findings were reported in a study between Brahman and Brahman x Angus crosses. It has been suggested that the poor temperament in the Brahman is due to higher cortisol levels when compared to the Brahman x Angus cross (Hammond *et al*., 1998). In another study, it has been shown that Angus cattle have a calmer temperament than Brahman cattle (Cafe *et al*., 2011). The difference between temperature scores for Brahman influenced cattle and *Bos taurus* increased as the percentage of Brahman inheritance increased which suggests that Brahman genetics have an additive effect on temperament (Hearnshaw & Morris, 1984). Both the average daily gain and feed to gain ratio (F:G) decreases as the percentage of Brahman genetic influence increased (Elzo *et al*., 2009).

2.7 Association between weight and growth of feedlot cattle

It has been shown that the greatest loss of income in a well-run feedlot is caused by the failure of the operator to take advantage of the potential mature weight of the cattle (Ralston *et al*., 1970). Mature weight can be changed by both genetic and phenotypic selection (Jenkins *et al*., 1981; Ferrell & Jenkins 1984). Mature size can be described as the point at which protein weight reaches a plateau, beyond this point animals may deposit fat and gain weight but protein accretion is assumed to be zero (Owens *et al*., 1995). In another definition mature weight has been defined as the point where protein accretion ceases (Brody, 1964; Fox & Black, 1984). It has been shown that measuring growth and economic parameters based on body weight results in a biased estimate to the point where adding weight is no longer profitable for cattle which are sold on a carcass basis (MacDonald, 2007).

It was found that the lighter steers were generally more efficient for a given time on feed because of the greater feed intake per unit of body weight (Ralston *et al*., 1970). In a study done by Thornton *et al*. (1985) it was reported that the dry matter intake increased by 1.5kg for every 100kg increase in initial weight, or in other words, dry matter intake increased by approximately 0.7kg/45.5kg increase in the initial body weight. Average daily gain also increased with an increase in the initial weight, however, cattle became less efficient (Koknaroglu *et al*., 2005). These results are in agreement with the NRC (1996); the NRC's prediction equation DMI (kg/day) = 4.54 + 0.0125 x initial body weight indicates that dry matter intake increases linearly with an increase in initial body weight.

Early weaned steers had the greatest feed efficiency, while the total dry matter intake in the feedlot was similar, however, the daily dry matter intake was the lowest for early-weaned calves (Schoonmaker *et al*., 2002b). A lower dry matter intake and greater feed efficiency for younger calves were in agreement with other studies done by Myers *et al*., 1999; Story *et al*., 2000, Schoonmaker *et al*., 2002a. A possible reason for lighter cattle having a better feed efficiency is that these cattle have a lower maintenance requirement which allows a greater proportion of the energy intake to be directed towards growth or be available for weight gain (NRC, 1996). Another potential explanation for lighter cattle having a better feed efficiency is that younger cattle have a higher concentration of growth hormone which gradually decreases with age (Verde & Trenkle, 1987). The higher dry matter intake in heavy cattle is related to size (Koknaroglu *et al*., 2017).

It has been shown that an increased body weight at placement was associated with lower rates of morbidity and mortality (Sanderson *et al*., 2008; Reinhardt *et al*., 2009). In an analysis of results done by Loneragan (2004), based on arrival weight, it was found that most of the deaths were associated with bovine respiratory disease and the mortality rate increased by 20 - 35% for each 100kg weight decrease in the initial weight of cattle. Medical expenses and mortality were more common in cattle which weighed less than 295kg and 272kg for steers and heifers respectively, and less common in steers and heifers weighing more than 363kg and 340 kg respectively at placement (Tatum *et al*., 2012). The cost of the carcass gain increased with an increase in medical expenses and mortality rate, however, this occurred more often in lighter cattle than in heavier cattle (Tatum *et al*., 2012). With an increase in the initial body weight, the final body weight, hot carcass weight and respiratory morbidity decreased (Reinhardt *et al*., 2009).

The cost to purchase cattle increased as the initial weight increased, however, feed costs decreased as the initial weight increased due to a shorter time on feed and due to a lower total feed consumption (Koknaroglu *et al*., 2017). A large proportion of the variation in cost of gain can be explained by the feed cost (Albright *et al*., 1993b). By increasing the body weight, profitability increases until the cost of one additional unit exceeds the revenue generated by another unit of weight (Lawrence, 2007; MacDonald, 2007). At a given weight heavier steers are more efficient as they have been on the feed for a shorter period (Ralston *et al*., 1970).

Another reason for the large variation of profitability is due to the price of feeder cattle and the fed cattle price (Koknaroglu *et al*., 2005). As the initial body weight increased, the proportion of the feeder cattle price contributing to the variation in profitability also increased. This is to be expected because as the initial body weight of cattle increase, more money is needed to purchase the cattle (Koknaroglu *et al*., 2005). While the coefficients for fed price were positive and increased with an increase initial body weight (Koknaroglu *et al*., 2005). This indicates that cattle which are put onto feed at heavier weights are fed to heavier weights (Koknaroglu *et al*., 2005). With an increasing initial body weight, other factors such as feed cost, total cost and breakeven price also increased (Koknaroglu *et al*., 2005). Despite having a greater breakeven point than for cattle weighing 273kg to 364kg, cattle (>364kg) were slightly more profitable (Koknaroglu *et al*., 2005). This is because they were received at a greater fed price and were fed to heavier weights (Koknaroglu *et al*., 2005).

After 84 days, the longer the animals of an initial given weight are fed the smaller the daily gains become (Ralston *et al*., 1970). This can be reflected in more feed per unit of gain, which resulted in a greater cost per unit of gain (Ralston *et al*., 1970). As cattle become heavier, average daily gain and gain to feed consumed ratio (G:F) will eventually decrease while the cost of gain increases (Tatum *et al*., 2012). In an experiment done by Koknaroglu *et al*. (2017), it was found that the live weight gain throughout the feeding period was higher for the light-weight group, while cattle which had a heavy initial weight tended to have lower live weight gains during the feeding period, these cattle were however raised until heavier weights (Koknaroglu *et al*., 2017).

Small framed cattle types such as the Angus should not be fed to the same slaughter weight as large framed cattle types such as the Charolais (Ralston *et al*., 1970). Heavy mature weight cattle do not have the same degree of marbling at an acceptable market weight. This poses a problem as cattle receive a lower grading or may be overweight if fed for a longer period (Ralston *et el*., 1970). Selection for larger farmed cattle resulted in later maturing cattle which have a lower predisposition to fatness at a younger age and at lighter weights (Dyer, 1985). The condition of the animal should be used to indicate the slaughter weight rather than the weight of the animal (Ralston *et al*., 1970).

In the feedlot industry, value is added by converting feed into weight gain. Profit is largely dependent on the amount and value of weight added while expenses are associated with body weight and the purchase price of cattle, amount and cost of feed consumed, duration in the feedlot, medical expenses and mortality rate (Tatum *et al*., 2012). It has been found that the profit generated per unit of carcass gain reduced as the weight at placement increased (Tatum *et al*., 2012). In each sex group class, cattle which were put on feed at lighter weight had a lower beginning value and gained more carcass weight during the finishing period and therefore generated more added value per unit of carcass gain compared with the cattle which were fed at heavier weights (Tatum *et al*., 2012).

The production efficiency and marketing time need to be considered to increase the profitability of beef cattle production (Koknaroglu *et al*., 2005; Koknaroglu *et al*., 2017). The carcass weight and dressing percentage increased as the initial weight increased, and therefore heavier cattle have a heavier carcass and a higher dressing percentage when compared to light cattle (Koknaroglu *et al*., 2017). Cattle which had a greater initial body weight, had average daily gains, dry matter intake and a final weight which were higher but these cattle did, however, have a lower dressing percentage (Zinn *et al*., 2008). Therefore as the dry matter increased the gain to feed consumed ratio (G:F) and dressing percentage decreased and this expresses the anticipated difference between calves and yearlings (Zinn *et al*., 2008).

Chapter 3: Materials and Methods

3.1 Introduction

The purpose of this study was to determine if the growth and/or performance of cattle at the Beefmaster feedlot in Christiana, North West Province can be predicted before they enter the feedlot. This is intended to decrease the guessing game of purchasing cattle. The Beefmaster feedlot approached Prof Edward Webb at the University of Pretoria to determine if certain phenotypic, anthropometric measurements and some in-house feedlot measures (ideal vs sub-ideal types) can be used to predict the performance (ADG and DIF) of cattle entering the feedlot. The way the cattle were grouped and therefore, analysed was specific to this feedlot. In order to see if these results are applicable in other feedlots, more research is required.

Ethics approval for this research was given by the Ethics committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria – Ethics Reference NAS430/2019.

3.2 Contributing feedlot, processing, and measurements

The research was conducted at the Beefmaster Feedlot in Christiana, North West Province (27° 49'15.63''S 25°14'28.67''E). In summer the temperatures can vary from 20 to 40 degrees Celsius, while in winter the temperatures can be anything from -5 to 20 degrees Celsius. The average rainfall for this area is 350mm per annum.

Measurements of live cattle were taken three times (weight), while the body measurements were taken twice, once upon entry into the feedlot and then again at the end of the feeding period. The total number of cattle used to analyse the data was, 310, however, there was no specific breed of cattle used for these measurements. Cattle were placed into half open or open pens and thus the cattle were completely randomised. The carcass measurements were taken in November 2016 and/or February 2017 depending on when the cattle were slaughtered. Cattle were slaughtered based on body condition as judged by an experienced feedlot manager and not final weight in order to achieve a desirable carcass grade. Most of the cattle slaughtered in this study had a carcass grade of A2.

The feedlot manager at beefmaster categorised the weaned cattle into an ideal (≥200kg) and sub-ideal (<200kg) weight category upon entry into the feedlot. Since the cattle were classified according to body weight, the different breed types were mixed in camps. Cattle categorised as "ideal" enter the feedlot at a weight (≥200kg) which was regarded by this feedlot as an acceptable weight for processing and intensive feeding and hence did not go through the backgrounding process. Cattle which were classified and placed in the sub-ideal weight category (<200kg) were cattle which were classified as small upon arriving at the feedlot. The cattle were backgrounded for 54 days after which they were reprocessed and then officially entered the feedlot.

The initial weight in this study was the weight at which all the cattle entered the feedlot (excluding the backgrounding phase), and this weight was measured on day one. This included both the cattle in the ideal and sub-ideal weight category, their initial weight was the weight taken on day one of being in the feedlot, and this was also recorded as the 1st DIF on the feedlot ration. Cattle were all processed on this day, they received a blue ear tag compared to the standard pink ear tag to show they were part of the trail. All the bulls received a Revalor H implant, as well as other standard feedlot vaccinations. After 50 days the cattle all received their second Revalor H implant. The ration was a standard 4 phase feedlot ration consisting of a starter, production, finisher and Zilmax ration. Cattle were fed Zilmax for a 32 day period and a withdrawal period of 5 days prior to slaughter.

Upon entry into the feedlot the feedlot manager split the cattle into either the ideal weight category or sub-ideal weight category (Table 3.1). After the data collection, the cattle were split further into groups based on breed type and even further based on sheath length. All the anthropometric, carcass and sheath measurements were taken by the same person.

Table 3.1 Summary of raw data

Variables	Categories in variables	N
Size	Ideal weight (≥200kg)	102
	Sub-ideal weight (<200kg)	208
Breed type	Brahman	71
	Charolais	7
	Composite black	38
	Composite brown	179
	Composite white	10
	Hereford	5
Sheath size	Small (K; 0 - 10cm)	159
	Large (L; greater than 15cm)	68
	Medium (M; 10 - 15cm)	83

3.3 Data collection

All data used in this dissertation was received from the Beefmaster feedlot at Christiana in the North West Province. The data was then captured in an Excel spreadsheet (Microsoft Office Professional Plus® 2013). The original data was sorted and processed, with all outliers, incorrect or incomplete data being removed. Only bulls were used in this study; the two heifers which were measured were removed from the data set. Any cattle which had a lighter third mass or a final measurement which was lower than the original measurement was removed. Due to the fact that there was only one Nguni that was measured, it was also removed from the study. After which the analysis was performed.

All the data along with an explanation, are presented in Table 3.2. Calculations or ratios which were added after the data had been provided, are explained in Table 3.3.

Table 3.2 Information obtained from the feedlot, explained by definition

Data	Definition
Gender	Bulls
Number	The blue ear tag provided to a specific bull
Batch	How all the cattle were grouped 1,2,3,4,6 normal size and group 5 small
Month	Month in which the measurements were taken for the first time
Initial weight	Start weight, measured at the day one of the feedlot period
Median weight	Second weight during the feedlot period
Final weight	Weight at the end of the feedlot period
DIF	Days in feed, from the first day to the last day in the feedlot
Initial body length	Taken at entry into the feedlot, in cm
Final body length	A second measurement was taken at the end of the feedlot period, in cm
Initial shoulder height	Taken at entry into the feedlot, in cm
Final shoulder height	A second measurement was taken at the end of the feedlot period, in cm
Sheath Size	Either small (K; 0 - 10cm), medium (M; 10 - 15cm) or large (L; greater than 15cm)
Carcass weight	The weight after slaughter, after all the offal has been removed
Carcass length	Taken after slaughter
Breed type	Grouped broadly into Brahman, Composite either black, brown or white, Herefords and Charolais

Calculations or ratios which were added after the data had been provided, are explained in Table 3.3 by definition.

Table 3.3 Information calculated, using the obtained information, explained by definition

Data	Definition
ADG	Average daily gain, calculated by subtracting the final weight from the initial weight and dividing it by days in feed
Carcass compactness	Carcass weight divide carcass length
Median weight minus initial weight	Median weight minus initial weight
Median weight minus initial weight divided by DIF	Median weight minus initial weight divided by DIF
Ratio between initial weight and initial body length	Initial weight divided by initial body length
Ratio between initial weight and initial hip height	Initial weight divide by initial hip height
Ratio between initial weight and initial shoulder height	Initial weight divided by initial shoulder height

The structure, posture and movement of the animal can also affect the accuracy of measurements (Parish *et al*., 2012). Cattle were measured while restrained in a neck and body clamp, measurements were only taken when the cattle were standing properly in the clamp. Operator error can also influence measurements (Parish *et al*., 2012). Measurements are more accurate when taken by one operator as more errors occurred when there were different operators (Henderson *et al*., 1966). All the measurements were taken by the same operator in this study.

3.3.1 Body weight

Live/body weight can be measured using three different weight methods namely, full live weight, shrunk weight and empty body weight. Full live weight is determined without withholding feed or water, therefore there is a variation during the day due to a variation in feed and water intake (Zinn, 1990). Shrunk weight can also be taken which is measured after a duration of feed and water withdrawal (Owens *et al*., 1995). Finally, empty body weight, here digesta is removed totally after the animal has been slaughtered (Owens *et al*., 1995). This empty gut-weight can also be obtained by fasting the animal as well as water deprivation and a standardised time for livestock weighing (Mukuahima, 2007).When comparing live weight, the preferred method is using the empty gut body weight, because the variability between live animal weights is reduced (Mukuahima, 2007). The measurement of live weight is variable because of gut fill (Mukuahima, 2007). In ruminants, the contents of the rumen and reticulum proportionately account for at least 10% to 15% and frequently up 23% of the total live weight of the animal (Lawrence & Fowler 2002). Variation in weighing can be reduced slightly by weighing on consecutive days (Stock *et al*., 1983).

In this study, the cattle were weighed upon entry (one day in the feedlot) into the feedlot on a normal scale. The full live weight method was used. These cattle were weighed again during the feedlot period and then at the end, before slaughter. Cattle were weighed to see if there was 1) a difference in growth between cattle in the ideal vs sub-ideal weight category, 2) to see if different breed types weighed more and 3) lastly to see if the measurement of sheath length was useful in determining future weight of cattle.

3.3.2 Average daily gain

Average daily gain refers to the amount of weight an animal gains per day while on a high energy ration (Beef Feedlot Industry Manual, 2011). Cattle can achieve average daily gains of up to 1.7kg (Ford, 2017). In this study, the ADG was obtained by taking the final weight minus initial weight divided by the number of days in feed.

3.3.3 Days in feed

This is the period which the cattle are in the feedlot, measured from the first day of placement until the last day. The number of days in feed vary largely between cattle, the main reason for this is that cattle are slaughtered based on body condition and not final weight.

In 2017, it was estimated that a weight of 253kg is the weight at which cattle normally enter the feedlot. At the end of the feedlot period, a weight of approximately 465kg was achieved and resulted in a carcass weight of around 272kg (Ford, 2017) where cattle spent about 135 days in the feedlot (Ford, 2017).

3.3.4 Body length

It has been stated that obtaining accurate body length measurements is very difficult and therefore should not be emphasized for selection (Dyer, 1985).

In this study, measurements were taken using a measuring tape from the most cranial point of the scapula to the pin bones. Measurements were taken twice, once upon entry into the feedlot and then again at the end of the feedlot period. This measurement was taken to determine if a certain body length measurement would result in better performance in the feedlot. There is a lack of data for this section of the study and therefore, more research is required to support any findings in this study.

3.3.5 Shoulder height

Originally, wither (shoulder) height was used to describe the skeletal size as it was believed to be the best measurement of true genetic size and growth rate (Black *et al*., 1938; Brody, 1945). However, more recently, hip height has become the measurement of choice and is most easily obtained (Lamm, 1982). When compared with weight however it was shown that the ratio of weight to wither height will give the highest correlation with performance (Black *et al*., 1938).

In this study, measurements were taken from the ground to the most dorsal point of the scapula using a measuring tape. Measurements were taken twice, once upon entry into the feedlot and then again at the end of the feedlot period. This measurement was taken to determine if a certain shoulder height measurement would result in a better performance in the feedlot. Although, there is a lack of data for this section of the study and therefore, more research is required to support any findings in this study.

3.3.6 Hip heights

Beef Improvement Federation recommends hip height as the height measure of preference. The hip height can also be adjusted for the age and sex of the cattle being measured (Lamm, 1982). The collection method, head restraint and condition score all affect the hip height measurement (Parish *et al*., 2012). The recommended area for hip height measurement is directly over the hooks (Torell *et al*., 1999; Beef improvement federation, 2010). The structure, posture and movement of the animal can also affect the accuracy of measurements (Parish *et al*., 2012).

Operator error can also have an influence on hip height measurements despite the high reproducibility (Parish *et al*., 2012). Measurements are more accurate when taken by one operator and more errors occurred when there were different operators (Henderson *et al*., 1966). When measurements are taken it is important that the animal is standing squarely and its head is held in a normal position for measuring (Torell *et al*., 1999).

In this study, hip height was taken from the ground to the top of the ilium. The measurement was taken using a measuring tape. Measurements were taken twice, once upon entry into the feedlot and then again at the end of the feedlot period. This measurement was taken to determine if a certain hip height measurement would result in a better performance in the feedlot. Although, there is a lack of data for this section of the study and therefore, more research is required to support any findings in this study.

3.3.7 Sheath length

Sheath length appears to be negatively correlated with total margin and feed margin (Lombard *et al*., 2018). Therefore, this suggests that cattle with a lower sheath score, sheaths which are closer to their bodies, perform better in the feedlot and may affect total margin and feed margin positively (Lombard *et al*., 2018). A lower score can be given for a sheath closer to the body while a higher score can be given to a bull/ steer with a sheath further away from the body (Lombard *et al*., 2018). A sheath which is deeper, and further away from the body, was believed to allow the animal to accumulate more weight (Lombard *et al*., 2018).

In this study, the sheath length of bulls/steers were described as either small (K), medium (M) or large (L). Cattle with a small sheath had a sheath length of 0 - 10cm, while cattle with a medium sheath had a sheath length of 10 - 15cm. Cattle with a large sheath had a sheath length of greater than 15cm. The sheath length was determined by the eye. This measurement was taken to see if cattle with a specific sheath length measurement outperformed other cattle. Although, there is a lack of data for this section of the study and therefore, more research is required to support any findings in this study.

3.3.8 Carcass weight

The carcass weight is the cold weight (or cold dressed weight) of the carcass after refrigeration (Department of Agriculture & Rural Development, 2005b). Cold carcass weight is about 2 - 3% less than that of the carcass weight which is determined immediately after slaughter (Department of Agriculture & Rural Development, 2005b). While in another article it was stated that a chilled carcass may weigh 2 - 5% less than the hot carcass weight (Holland *et al*., 2014).

The hot carcass weight is determined immediately after slaughter (Schivera, 2011). While the hot carcass weight, or simply the carcass weight in some articles, is the hot or un-chilled weight of the carcass after slaughter with the removal of the head, hide, intestinal tract and finally the internal organs (Holland *et al*., 2014; Knight, 2017). The hot carcass weight is used to determine the yield grade as well as the dressing percentage (Knight, 2017). The hot carcass weight for most cattle breeds is approximately 60 to 64% of the live slaughter weight, however, the hot carcass weight can vary greatly from one animal to the next (Holland *et al*., 2014).

In this study, hot carcass weight was used. Cattle were weighed after the offal and hide had been removed. This measurement was obtained to see if a specific weight category, breed type or sheath length outperformed other cattle.

3.3.9 Carcass length

In this study, the carcass length was taken just after the warm carcass was weighed. It was taken from the middle of the first rib to the pelvis symphysis. This measurement was taken using a measuring tape. Although, there is a lack of data for this section of the study and therefore, more research is required to support any findings in this study.

3.3.10 Carcass compactness

The compactness index can be calculated in the following ways: from the length of the carcass (cm) and the hot carcass weight (kg) (De Toledo Piza Roth *et al*., 2009), hot carcass weight (kg) divided by internal length of the carcass (cm) (Gomes *et al*., 2013) or just by the carcass length (De Paula Rezende *et al*., 2019), or as the cold carcass weight divided by internal carcass length (Osório *et al*., 1998; Cezar & Sousa, 2007; Maciel *et al*., 2015; Venturini *et al*., 2017).

In this study, the carcass compactness was calculated as the carcass weight (kg) divided by carcass length (cm), in this case, the hot carcass weight was used.

3.3.11 Dressing percentage

Dressing percentage is defined as the percentage of live animal that ends up as carcass (Whiteheart, 2012). The dressing percentage is normally taken directly after skinning and evisceration and is normally known as the hot hanging weight (Whiteheart, 2012).

In this study, the dressing percentage was calculated as the hot carcass weight divided by final body weight multiplied by 100 to get a percentage.

3.4 Statistical analysis

Repeated measure analysis was used to analyse the data. All the data were checked for errors and then analysed by means of multivariate analysis of variance, as well as repeated measures analysis procedures employing the General Linear Model's procedures (GLM) of SPPS version 26. Growth was analysed through regression analyses and correlations between variables were tested. To calculate the correlations, a two-tailed analysis was used. The effects of the main factors were analysed at a level of confidence of 95%. The number of animals per group were unbalanced and therefore LS means and Bonferroni multiple range test were used to correct for this.

The following fixed variables were used to analyse the data: breed type, sheath length and weight category. The following dependent variables included in the general linear module procedure were: body weights, ADG, DIF, body length, shoulder height, hip height, carcass weight, carcass length, carcass compactness and dressing percentage. Median weight minus initial weight, median weight minus initial weight divided by DIF, initial weight divided by initial shoulder height, initial weight divided by initial hip height and initial weight divided by initial body length were also included in the study as dependent variables. The purpose of multi-variant analyses was to see the effects of the fixed factors on the dependent variables.

It is well understood that numerous factors influence both ADG and DIF, such as maturity type, frame size, nutrition, management and the environment. However, this study was merely designed to determine the possible use of certain initial measurements to predict ADG and DIF regardless of other factors. The way the cattle were grouped and analysed were also very specific to the feedlot where the data was received, therefore more research is required to support these results.

Chapter 4: Results and Discussion

4.1 Introduction

This section will discuss the effects of the various factors on the phenotypic and anthropometric measurements via a general linear model procedure. Correlations as well as regressions will be discussed in this section. Due to the large standard deviation and variation in the number of DIF, the ADG cannot simply be calculated by subtracting the final weight from the initial weight divided by DIF, this is the same for any other calculation done in this study. LS means and Bonferroni multiple range tests were used to correct for the unbalanced number of animals in the groups. There is variation in the number of DIF as the animals were removed from the feedlot and slaughtered based on body condition and not based on DIF or final weight to simulate the normal feedlot management practice at the Beefmaster feedlot.

4.2 General model procedure

4.2.1 Effect of the weight category on the initial, median and final weight

Table 4.1 provides a summary of the effects of the weight category (ideal or sub-ideal) of feedlot cattle on initial, median and final weight. The weight category at which cattle enter the feedlot, either the ideal or sub-ideal weight category had a significant effect on the initial weight (P = 0.000), although the weight category did not have a significant effect on the median (P = 0.074) and final weight (P = 0.501) groups. This shows that as cattle are fed during the feedlot period, the variation between the different cattle weights become less. Feeding and age may be responsible for the decrease in this variation.

Table 4.1 Effect of the ideal vs sub-ideal weight categories on initial, median and final weights of feedlot cattle

Weight category	N	Initial weight (kg)	Median weight (kg)	Final weight (kg)
			Mean ± Std. Deviation	
Ideal weight (≥200kg)	102	271.01^{a} ± 40.288	356.25 ± 64.154	489.21 ± 75.242
Sub-ideal weight (<200kg)	208	218.78^{b} ± 23.484	309.25 ± 35.732	494.74 ± 57.809

$^{a,\ b}$ Column means with different superscript letters differ (P < 0.05)

Recent South African feedlot data indicate that cattle normally enter the feedlot at a weight of about 253kg and are fed for about 135 days in local feedlots (Ford, 2017). Typically final and carcass weights of 465kg and 272kg respectively, are generally achieved in local feedlots (Ford, 2017).

The average initial weight of cattle in the ideal category (day one of being in the feedlot) in the present study of 271.01 ± 40.288kg was appreciably higher than the norm in South Africa. By contrast cattle in the sub-ideal category had a mean initial weight of 218.78 ± 23.484kg upon entry into the feedlot (after backgrounding), which is well below the norm of 253kg. Data presented in Table 4.1 confirms the difference between the initial weight of cattle in the ideal and sub-ideal weight category differed significantly ($P < 0.05$). Although as cattle were fed during the feedlot period the variation between the final weight for cattle in the ideal weight category (489.21 ± 75.242kg) and those in the sub-ideal weight category (494.74 ± 57.809kg) decreased to almost negligible ($P > 0.05$).

Cattle which are heavier at placement spent a shorter period on feed, therefore decreasing the feed costs, it is important to keep in mind that larger animals consume more feed than smaller cattle (Johnson *et al*., 2010). These larger cattle have a biology maintenance energy requirement which was higher, however, the additional feed requirements are as a percentage less than its additional weight as a percentage (Johnson *et al*., 2010).

4.2.2 Effect of the weight category on ADG and DIF

Table 4.2 provides a summary of the effect of the different weight categories on ADG and DIF. ADG is defined as the final weight - initial weight divided by the number of days in feed. The weight category had a significant effect on both the ADG ($P = 0.000$) and DIF ($P = 0.000$).

Table 4.2 Effect of the ideal vs the sub-ideal weight categories on ADG and DIF of feedlot cattle

Weight category	N	ADG (kg/day)	DIF (days)
		Mean ± Std. Deviation	
Ideal weight (≥200kg)	102	$1.45^{a} \pm 0.491$	$156.88^{a} \pm 32.287$
Sub-ideal weight (<200kg)	208	$1.22^{b} \pm 0.249$	$225.91^{b} \pm 15.704$

$^{a,\,b}$ Column means with different superscript letters differ ($P < 0.05$)

According to recent feedlot data, the ADG in South African feedlots is 1.7kg (Ford, 2017). The results in this study indicate that the ADG for cattle in the ideal weight category was 1.45 ± 0.491kg which is only slightly below the norm for South African cattle. While cattle in the sub-ideal weight category had an ADG of 1.22 ± 0.249kg, this is well below the norm for cattle in South Africa. Cattle which were heavier at placement had an ADG which is higher when compared to cattle which were lighter at placement. These findings are consistent with a study done by Koknaroglu *et al*. (2017) which found that the ADG increased with an increase in initial weight.

Cattle in the sub-ideal weight category are smaller in size, as a result, they may have less access to feed due to dominance when in the same pen. These smaller cattle may be over-powered by the larger cattle, causing a lower dry matter intake which will result in poor growth and a lower ADG. In a study done by Šárová *et al*. (2010), it was found that priority access to the bunk was given to the more dominant animals, while the weaker animals only got access after the more dominant feeders were satisfied. One can overcome this problem by feeding more frequently. A study has shown that feeding more frequently would stimulate feed intake, decrease competition amongst pen mates and would also decrease the incidence for acidosis (French & Kennelly, 1990; DeVries *et al*., 2005). The higher feed intake would be advantageous for the feedlot. In a study done by Gibson (1981) it was found that a higher dry matter intake resulted in an improved feed conversion ratio as well as ADG.

From the findings in this study, it can be seen that the DIF was influenced by the initial weight. Cattle in the sub-ideal weight category spent more time in the feedlot (225.91 ± 15.704 days). While cattle which were placed in the ideal weight category only spent 156.88 ± 32.287 days in the feedlot. Therefore, heavier cattle at placement spent fewer number of days in the feedlot. Cattle which had a heavier initial weight also had a higher ADG compared to cattle in the sub-ideal weight category.

The data in this study indicates that DIF is influenced by both ADG and the initial weight. Cattle need to gain a certain amount per day to reach a target final body condition. Cattle in the sub-ideal weight category need to spend a longer period (225.91 ± 15.704 days) in the feedlot to reach their target final condition. Cattle which had a heavier initial body weight had a higher ADG (Table 4.2). These cattle, therefore, grew faster and spent fewer number of days (156.88 ± 32.287) in the feedlot. Koknaroglu *et al*. (2017) found that the cost to purchase cattle increased as the initial weight increased. However, the feed costs decreased due to a shorter period on feed, which resulted in a lower total feed consumption. These findings were also supported by Ralston *et al*. (1970), who found that heavier animals required a shorter period in the feedlot.

4.2.3 Effect of the weight category on the initial and final body length measurements

Table 4.3 provides a summary of the effect of the weight category on the initial and final body length measurements. The weight category had a significant effect on the initial body length measurement ($P = 0.002$), but not on the final body length ($P = 0.244$).

Table 4.3 Effect of the ideal vs the sub-ideal weight categories on the initial body and final body length measurements of feedlot cattle

Weight category	N	Initial body length (cm)	Final body length (cm)
		Mean ± Standard deviation	
Ideal weight (≥200kg)	102	$123.65^{a} \pm 8.838$	131.65 ± 9.886
Sub-ideal weight (<200kg)	208	$114.04^{b} \pm 5.372$	128.15 ± 6.216

$^{a,\,b}$ Column means with different superscript letters differ ($P < 0.05$)

Cattle in the ideal weight category, those with a higher initial weight, had a longer initial body length (123.65 ± 8.838cm). In contrast, cattle in the sub-ideal weight category, those with a lower initial weight, had a shorter body length (114.04 ± 5.372cm). This may, indicate that cattle with a longer initial body length are heavier.
Weight category had a significant effect on the initial weight divided by initial body length ($P = 0.000$) (Table 4.4).

Table 4.4 Effect of the ideal vs sub-ideal weight categories on initial weight divided by initial body length of feedlot cattle

Weight category	N	Initial weight divided by initial body length (kg/cm)
		Mean ± Std. deviation
Ideal weight (≥200kg)	104	$2.18^{a} \pm 0.212$
Sub-ideal weight (<200kg)	208	$1.92^{b} \pm 0.164$

$^{a,\,b}$ Column means with different superscript letters differ ($P < 0.05$)

Cattle in the ideal weight category had a higher ratio between the initial weight and initial body length (2.18 ± 0.212kg/cm) compared to cattle in the sub-ideal weight category (1.92 ± 0.164kg/cm). This suggests that cattle in the ideal weight category have more weight per unit of body length when compared to cattle in the sub-ideal weight category.

4.2.4 Effect of the weight category on initial and final shoulder height measurements

Table 4.5 provides a summary of the effect of the ideal and sub-ideal weight category on the initial and final shoulder height measurements. There was a significant effect between the weight category and the initial shoulder height measurement ($P = 0.001$). However, there was no significant effect between the final shoulder height measurement and cattle in the ideal and those in the sub-ideal weight category ($P = 0.399$).

Table 4.5 Effect of the ideal vs sub-ideal weight categories on initial and final shoulder height measurements of feedlot cattle

Weight category	N	Initial shoulder height (cm)	Final shoulder height (cm)
		Mean ± Std. Deviation	
Ideal weight (≥200kg)	102	111.55^{a} ± 4.786	116.70 ± 4.778
Sub-ideal weight (<200kg)	208	106.54^{b} ± 4.027	114.90 ± 3.812

$^{a, b}$ Column means with different superscripts letters differ ($P < 0.05$)

The ideal weight group had an initial shoulder height which was higher (111.55 ± 4.786cm) when compared to cattle in the sub-ideal weight category (106.54 ± 4.027cm). This may indicate that cattle with a longer initial shoulder height are heavier.

Table 4.6 provides a summary of the effect of weight category on the initial weight divided by initial shoulder height measurement. There was a significant effect between the weight categories and initial weight divided by initial shoulder height ($P = 0.000$).

Table 4.6 Effect of the ideal vs sub-ideal weight categories on initial weight divided by initial shoulder height measurement of feedlot cattle

Weight category	N	Initial weight divided by initial shoulder height (kg/cm)
		Mean ± Std. Deviation
Ideal weight (≥200kg)	102	2.42^{a} ± 0.309
Sub-ideal weight (<200kg)	208	2.05^{b} ± 0.195

$^{a, b}$ Column with different superscript letters differ (*P* < 0.05)

Cattle in the ideal weight category, those with a higher initial weight, had a higher ratio (*P* < 0.05), these cattle had a measurement of 2.42 ± 0.309kg/cm. In contrast, to cattle in the sub-ideal weight category who had a ratio of 2.05 ± 0.195kg/cm. This indicates that cattle with a higher initial weight had more weight per unit shoulder height (*P* < 0.05).

4.2.5 Effect of the weight category on initial and final hip height measurements

Table 4.7 provides a summary of the effect of weight category on the initial and final hip height measurements. There was a significant effect between the weight category and initial hip height measurement (*P* = 0.004). In contrast, there was no significant effect between the weight categories and the final hip height measurement (*P* = 0.191).

Table 4.7 Effect of the weight category on the initial and final hip height measurements of feedlot cattle

Weight category	N	Initial hip height (cm)	Final hip height (cm)
		Mean ± Std. Deviation	
Ideal weight (≥200kg)	102	117.52^{a} ± 4.969	123.78 ± 5.085
Sub-ideal weight (<200kg)	208	112.65^{b} ± 4.419	121.37 ± 4.024

$^{a, b}$ Column means with different superscript letters differ (*P* < 0.05)

Cattle in the ideal weight category had a higher initial hip height measurement (117.52 ± 4.969cm) when compared to cattle in the sub-ideal weight category (112.65 ± 4.419cm). This therefore, suggests that cattle with a higher initial weight are taller. The findings in this study are supported by Dyer (1985). It was found that weight does not always increase proportionally with height. Cattle in the sub-ideal weight category are fed to heavier weights. In addition, they also had put on more weight throughout the feedlot period (Table 4.2). However, these cattle had lower hip height measurements when compared to cattle in the ideal weight category.

Table 4.8 provides a summary of the effect of weight category on the initial weight divided by the initial hip height measurement. There was a significant effect between cattle in the ideal and sub-ideal weight category on the ratio between initial weight and initial hip height measurement (P = 0.000).

Table 4.8 Effect of the ideal vs sub-ideal weight categories on the initial weight divided by initial hip height measurements of feedlot cattle

Weight Category	N	Initial weight divided by initial hip height (kg/cm)
		Mean ± Std. Deviation
Ideal weight (≥200kg)	104	2.30^{a} ± 0.288
Sub-ideal weight (<200kg)	208	1.94^{b} ± 0.191

$^{a,\,b}$ Column means with different superscript letters differ (P < 0.05)

Cattle in the ideal weight category, had a higher ratio between the initial weight and initial hip height measurement (2.30 ± 0.288kg/cm), while cattle in the sub-ideal weight category had a lower hip height measurement (1.94 ± 0.191kg/cm). This indicates that cattle which had a higher initial weight had more weight per unit hip height. This therefore, suggests that cattle with a higher initial weight are taller. The findings in this study are supported by Dyer (1985). It was found that weight does not always increase proportionally with height. Cattle in the sub-ideal weight category are fed to heavier weights. In addition, they also had put on more weight throughout the feedlot period (Table 4.2).

4.2.6 Effect of the weight category on carcass weight, dressing percentage, carcass length and carcass compactness

Table 4.9 provides a summary of the effect of the weight category on the various carcass traits. There were no significant effects between the weight category and carcass weight (P = 0.086) and carcass length (P = 0.580). There were, however, significant effects between the weight category and dressing percentage (P = 0.002) and carcass compactness (P = 0.044).

Table 4.9 Effect of the ideal vs sub-ideal weight categories on the carcass weight, dressing percentage, carcass length and carcass compactness for feedlot cattle

Weight category	N	Carcass weight (kg)	Dressing percentage (%)	Carcass length (cm)	Carcass compactness (kg/cm)
			Mean ± Std. deviation		
Ideal weight (≥200kg)	102	293.77 ± 48.401	60.08^{a} ± 4.300	122.61 ± 5.964	2.39^{a} ± 0.312
Sub-ideal weight (<200kg)	208	304.70 ± 35.534	61.61^{b} ± 1.644	121.64 ± 4.550	2.50^{b} ± 0.227

$^{a,\,b}$ Column means with different superscript letters differ ($P < 0.05$)

Cattle which had a heavier initial weight, (e.g. those in the ideal weight category) had a lower dressing percentage (60.08 ± 4.300%) compared to cattle in the sub ideal weight category (61.61 ± 1.644%; $P < 0.05$). The findings of Koknaroglu *et al*. (2017) are inconsistent to this study's findings. Koknaroglu *et al*. (2017), found that carcass weight and dressing percentage increased as initial weight increased. Therefore heavier cattle had a heavier carcass and dressing percentage when compared to light cattle. While a study done by Zinn *et al*. (2008) found that cattle with a greater initial body weight had higher average daily gain, dry matter intake and final weight but had a lower dressing percentage. These findings are in partial agreement with the findings in this study. Cattle in the ideal weight category (those with a heavier initial body weight) had a higher ADG (Table 4.2) and a lighter final weight (Table 4.1), carcass weight and dressing percentage (Table 4.9) when compared to cattle in the sub-ideal weight category.

Recent feedlot data has shown that a mean dressing percentage of 58.5% is normally achieved in a feedlot (Ford, 2017). However, the dressing percentage does vary, for lean animals, it can be 49% which can increase to 60% at a high level of finish, though when the fat score is 2 to 3, the mean dressing percentage varies from 54% to 56% (Department of Agriculture & Rural Development, 2005a). Cattle in the ideal weight category had a mean dressing percentage of 60.08 ± 4.300%, while cattle in the sub-ideal weight category had a mean dressing percentage of 61.61 ± 1.644%. These findings are both above the norm suggested by Ford (2017). The findings in this study are more closely supported by the Department of Agriculture & Rural Development (2005a) who stated that animals which are lean can have a dressing percentage of up to 60% at a high level of finish.

Carcass compactness was lower for cattle in the ideal weight category (2.39 ± 0.312kg/cm) when compared to cattle in the sub-ideal weight group (2.50 ± 0.227kg/cm). Tonetto *et al*.

(2004) found that there was a positive linear increase in carcass compactness index as the carcass weight increases.

4.2.7 Effect of sheath size on the initial, median and final weight

The effect of sheath length on the initial, median and final weights are summarised in Table 4.10. Sheath size did not have a significant effect on the initial (*P* = 0.515), median (*P* = 0.766) or final weight (*P* = 0.452).

Table 4.10 Effect of sheath length on the initial, median and final weight of feedlot cattle

Sheath	Weight category	N	Initial weight (kg)	Median weight (kg)	Final weight (kg)
				Mean ± Std. Deviation	
K	Ideal weight (≥200kg)	52	281.27 ± 40.319	372.96 ± 65.341	498.08 ± 69.390
	Sub-ideal weight (<200kg)	107	219.04 ± 24.337	313.77 ± 37.305	503.89 ± 60.650
	Average	159	239.39 ± 42.188	333.13^{a} ± 55.568	501.99^{a} ± 63.478
L	Ideal weight (≥200kg)	22	254.18 ± 37.864	332.18 ± 58.460	484.14 ± 85.237
	Sub-ideal weight (<200kg)	46	220.07 ± 23.769	307.33 ± 40.005	478.52 ± 53.107
	Average	68	231.10 ± 32.975	315.37^{b} ± 47.784	480.34^{b} ± 64.641
M	Ideal weight (≥200kg)	28	265.18 ± 37.648	344.11 ± 59.248	476.71 ± 78.087
	Sub-ideal weight (<200kg)	55	217.22 ± 21.832	302.05 ± 27.066	490.49 ± 53.212
	Average	83	233.40 ± 36.070	316.24^{b} ± 45.149	485.84^{ab} ± 62.572

$^{a,\,b}$ Column means for with different superscript letters differ (*P* < 0.05)
K (small; 0 - 10 cm); L (large; greater than 15cm); M (medium; 10 - 15cm)

4.2.8 Effect of sheath size on ADG and DIF

Table 4.11 provides a summary of the effect of sheath size on ADG and DIF. From Table 4.11 it can be seen that the sheath size does not have a significant effect on ADG (*P* = 0.124) nor on DIF (*P* = 0.197).

Table 4.11 Effect of sheath size on ADG and DIF of feedlot cattle

Sheath	Weight category	N	ADG (kg/day)	DIF (days)
			Mean ± Std. Deviation	
K	Ideal weight (≥200kg)	52	1.46 ± 0.447	153.58 ± 30.497
	Sub-ideal weight (<200kg)	107	1.26 ± 0.254	226.12 ± 16.938
	Average	159	1.33 ± 0.341	202.40 ± 40.722
L	Ideal weight (≥200kg)	22	1.43 ± 0.546	166.68 ± 35.767
	Sub-ideal weight (<200kg)	46	1.14 ± 0.237	228.11 ± 18.613
	Average	68	1.23 ± 0.387	208.24 ± 38.364
M	Ideal weight (≥200kg)	28	1.43 ± 0.539	155.32 ± 32.341
	Sub-ideal weight (<200kg)	55	1.22 ± 0.238	223.67 ± 9.175
	Average	83	1.29 ± 0.378	200.61 ± 38.170

K (small; 0 - 10cm); L (large; greater than 15cm); M (medium; 10 - 15cm)

4.2.9 Effect of sheath size on the initial and final body length measurement

Table 4.12 provides a summary of the effect of sheath size on the initial and final body length measurement. The sheath size did not have a significant effect on either the initial (*P* = 0.673) or final body (*P* = 0.915) length measurements.

Table 4.12 Effect of sheath size on the initial and final body length measurement for feedlot cattle

Sheath	Weight category	N	Initial body length (cm)	Final body length (cm)
			Mean ± Std. Deviation	
K	Ideal weight (≥200kg)	52	126.94 ± 8.047	134.21 ± 9.537
	Sub-ideal weight (<200kg)	107	113.96 ± 5.429	128.47 ± 6.283
	Average	159	118.21 ± 8.831	130.35^{a} ± 7.947
L	Ideal weight (≥200kg)	22	119.36 ± 9.011	127.73 ± 10.525
	Sub-ideal weight (<200kg)	46	114.39 ± 5.912	127.37 ± 6.790
	Average	68	116.00 ± 7.377	127.49^{b} ± 8.107
M	Ideal weight (≥200kg)	28	120.89 ± 7.937	129.96 ± 8.917
	Sub-ideal weight (<200kg)	55	113.91 ± 4.847	128.20 ± 5.612
	Average	83	116.27 ± 6.874	128.80^{ab} ± 6.901

$^{a, b}$ Column means with different superscript letter differ ($P < 0.05$)
K (small; 0 - 10cm); L (large; greater than 15cm); M (medium; 10 - 15cm)

Table 4.13 provides a summary of the effect of sheath size on the initial weight divided by initial body length measurement. The sheath size did not have a significant effect on the ratio ($P = 0.613$).

Table 4.13 Effect of sheath size on the initial weight divided by initial body length of feedlot cattle

Sheath	Weight category	N	Initial weight divided by initial body length (kg/cm)
			Mean ± Std. Deviation
K	Ideal weight (≥200kg)	52	2.21 ± 0.219
	Sub-ideal weight (<200kg)	107	1.92 ± 0.165
	Average	159	2.01 ± 0.229
L	Ideal weight (≥200kg)	22	2.12 ± 0.206
	Sub-ideal weight (<200kg)	46	1.92 ± 0.156
	Average	68	1.99 ± 0.197
M	Ideal weight (≥200kg)	28	2.19 ± 0.202
	Sub-ideal weight (<200kg)	55	1.91 ± 0.168
	Average	83	2.00 ± 0.223

K (small; 0 - 10cm); L (larger; greater than 15cm); M (medium; 10 - 15cm)

4.2.10 Effect of sheath size on the initial and final shoulder height measurement

Table 4.14 provides a summary of the effect of sheath size on the initial and final shoulder height measurements. Sheath size did not have a significant effect on either of the initial shoulder (P = 0.300) or the final shoulder (P = 0.645) height measurement.

Table 4.14 Effect of sheath size on the initial and final shoulder height measurement of feedlot cattle

Sheath	Weight category	N	Initial shoulder height (cm)	Final shoulder height (cm)
			Mean ± Std. Deviation	
K	Ideal weight (≥200kg)	52	112.17 ± 5.013	117.56 ± 4.771
	Sub-ideal weight (<200kg)	107	106.16 ± 3.912	114.46 ± 3.598
	Average	159	108.13 ± 5.137	115.47 ± 4.262
L	Ideal weight (≥200kg)	22	111.36 ± 4.875	116.00 ± 5.024
	Sub-ideal weight (<200kg)	46	107.72 ± 4.225	116.17 ± 3.732
	Average	68	108.90 ± 4.732	116.12 ± 4.156
M	Ideal weight (≥200kg)	28	110.54 ± 4.229	115.64 ± 4.449
	Sub-ideal weight (<200kg)	55	106.29 ± 3.966	114.71 ± 4.108
	Average	83	107.72 ± 4.508	115.02 ± 4.222

K (small; 0 - 10cm); L (larger; greater than 15cm); M (medium; 10 - 15cm)

Table 4.15 provides a summary of the effect of sheath size on the initial weight divided by initial shoulder height measurement. The sheath size did not have a significant effect on the ratio (*P* = 0.799).

Table 4.15 Effect of sheath size on the initial weight divided by initial shoulder height of feedlot cattle

Sheath	Weight category	N	Initial weight divided by initial shoulder height (kg/cm)
			Mean ± Std. Deviation
K	Ideal weight (≥200kg)	52	2.50 ± 0.297
	Sub-ideal weight (<200kg)	107	2.06 ± 0.206
	Average	159	2.21^{a} ± 0.316
L	Ideal weight (≥200kg)	22	2.28 ± 0.289
	Sub-ideal weight (<200kg)	46	2.04 ± 0.180
	Average	68	2.12^{b} ± 0.246
M	Ideal weight (≥200kg)	28	2.40 ± 0.310
	Sub-ideal weight (<200kg)	55	2.04 ± 0.188
	Average	83	2.16^{ab} ± 0.288

$^{a, b}$ Column means for with different superscripts differ (*P* < 0.05)
K (small; 0 - 10cm); L (large; greater than 15cm); M (medium: 10 - 15cm)

4.2.11 Effect of sheath size on the initial and final hip height measurements

Table 4.16 provides a summary of the effect of sheath size on the initial and final hip height measurements. Sheath size did not have a significant effect on the initial hip height (*P* = 0.509) or final hip height (*P* = 0.310) measurement.

Table 4.16 Effect of sheath size on the initial and final hip height measurement for feedlot cattle

Sheath	Weight category	N	Initial hip height (cm)	Final hip height (cm)
			Mean ± Std. Deviation	
K	Ideal weight (≥200kg)	52	118.17 ± 5.276	124.46 ± 4.913
	Sub-ideal weight (<200kg)	107	111.84 ± 4.475	121.00 ± 3.729
	Average	159	113.91 ± 5.594	122.13 ± 4.447
L	Ideal weight (≥200kg)	22	117.14 ± 5.045	123.45 ± 5.697
	Sub-ideal weight (<200kg)	46	113.96 ± 4.195	122.30 ± 4.076
	Average	68	114.99 ± 4.695	122.68 ± 4.650
M	Ideal weight (≥200kg)	28	116.61 ± 4.263	122.79 ± 4.887
	Sub-ideal weight (<200kg)	55	113.13 ± 4.230	121.31 ± 4.463
	Average	83	114.30 ± 4.528	121.81 ± 4.634

K (small; 0 - 10cm); L (larger; greater than 15cm); M (medium; 10 - 15cm)

Table 4.17 shows the effect of sheath size on the initial weight divided by initial hip height measurement. From the table it can be seen that the sheath size did not have a significant effect on the initial weight divided by initial hip height measurement (P = 0.717).

Table 4.17 Effect of sheath size on the initial weight divided by initial hip height measurement of feedlot cattle

Sheath	Weight category	N	Initial weight divided by initial hip height (kg/cm)
			Mean ± Std. Deviation
K	Ideal weight (≥200kg)	52	2.37 ± 0.279
	Sub-ideal weight (<200kg)	107	1.96 ± 0.199
	Average	159	2.09^{a} ± 0.300
L	Ideal weight (≥200kg)	22	2.17 ± 0.266
	Sub-ideal weight (<200kg)	46	1.93 ± 0.183
	Average	68	2.01^{b} ± 0.239
M	Ideal weight (≥200kg)	28	2.27 ± 0.286
	Sub-ideal weight (<200kg)	55	1.92 ± 0.181
	Average	83	2.04^{ab} ± 0.276

$^{a, b}$ Column means for with different superscript letters differ (P < 0.05)
K (small; 0 - 10cm); L (large; greater than 15cm); M (medium; 10 - 15cm)

4.2.12 Effect of sheath size on the carcass weight, dressing percentage, carcass length and carcass compactness

Table 4.18 shows a summary of the effect of sheath size on the carcass weight, dressing percentage, carcass length and carcass compactness. The sheath size did not have a significant on the carcass weight (P = 0.312), dressing percentage (P = 0.063), carcass length (P = 0.621) and carcass compactness (P = 0.303).

Table 4.18 Effect of sheath size on the carcass weight, dressing percentage, carcass length and carcass compactness

Sheath	Weight category	N	Carcass weight (kg)	Dressing percentage (%)	Carcass length (cm)	Carcass compactness (kg/cm)
			Mean ± Std. Deviation			
K	Ideal weight (≥200kg)	52	299.13 ± 45.718	60.00 ± 3.083	123.32 ± 5.437	2.42 ± 0.299
	Sub-ideal weight (<200kg)	107	309.73 ± 37.249	61.48 ± 1.012	122.20 ± 4.553	2.53 ± 0.242
	Average	159	306.27^{a} ± 40.379	61.00 ± 2.060	122.57 ± 4.871	2.49^{a} ± 0.266
L	Ideal weight (≥200kg)	22	288.23 ± 57.817	59.67 ± 7.454	122.14 ± 6.362	2.34 ± 0.368
	Sub-ideal weight (<200kg)	46	294.00 ± 33.060	61.43 ± 0.430	120.63 ± 4.297	2.43 ± 0.205
	Average	68	292.14^{b} ± 42.299	60.86 ± 4.270	121.12 ± 5.059	2.40^{b} ± 0.269
M	Ideal weight (≥200kg)	28	288.16 ± 45.851	60.56 ± 2.755	121.66 ± 6.607	2.36 ± 0.293
	Sub-ideal weight (<200kg)	55	303.84 ± 32.517	62.01 ± 2.824	121.40 ± 4.663	2.50 ± 0.205
	Average	83	298.55^{ab} ± 38.001	61.52 ± 2.867	121.49 ± 5.358	2.45^{ab} ± 0.245

$^{a, b}$ Column means for with different superscript letters differ ($P < 0.05$)
K (small; 0 - 10cm); L (large; greater than 15cm); M (medium; 10 - 15cm)

There is not much research on the effect of sheath size on the various variable, however, it was previously believed that sheaths which were deeper, and further away from the body allowed cattle to accumulate more weight (Lombard *et al*., 2018). Although, this feedlot suspected that the sheath length may influence the various variables, the lack of any significant effect indicates that there is no point in the feedlot taking this measurement. At best the tendency for cattle with a small sheath to have a numerically better initial weight, ADG, final weight and carcass weight may be explored in future research. The latter is supported by

Lombard *et al*., (2018) that sheath length is negatively correlated with total margin and feed margin.

4.2.13 Effect of breed type on initial, median and final weights

Cattle can be classified according to their maturity type; either late, intermediate or early maturing. Table 4.19 shows the overall mean effect of breed type on weight. Due to the fact that the number of cattle for the Charolais, composite white and Hereford were not sufficient to make any sort of conclusion in this study they will not be discussed in this section.

Table 4.19 provides a summary of the effect of breed type on the various initial, median and final weights. Although the number of cattle per breed type differed and affect the significance of comparisons, some observations will be discussed. Breed type did not have a significant effect on the initial weight (P = 0.233), however breed type influenced median (P = 0.009) and final weights (P = 0.004).

Table 4.19 Effect of breed types on the initial, median and final weight of feedlot cattle

Weight Category	Breed type	N	Initial weight (kg)	Median weight (kg)	Final Weight (kg)
			Mean ± Std. Deviation		
Average	Brahman	71	224.85^{a} ± 31.786	302.85^{a} ± 41.205	482.00^{a} ± 58.357
	Charolais	7	279.00^{b} ± 5.033	364.29^{b} ± 11.686	531.57^{ab} ± 28.676
	Composite black	38	249.03^{b} ± 41.716	344.37^{b} ± 57.384	506.18^{ab} ± 67.517
	Composite brown	179	236.47^{ab} ± 38.921	327.11^{b} ± 51.982	490.32^{ab} ± 65.280
	Composite white	10	231.50^{ab} ± 43.531	337.50^{ab} ± 59.783	542.80^{b} ± 64.069
	Hereford	5	225.20^{ab} ± 58.640	319.00^{ab} ± 59.367	486.00^{ab} ± 39.541
	Average	310	235.97 ± 38.783	324.71 ± 51.864	492.92 ± 64.000

$^{a, b}$ Column means with different superscript letter differ (P < 0.05)

Brahman have a low frame score of 3 to 5 (Department of Agriculture & Rural Development, 2005a). Torell *et al*. (1999) found that low frame score cattle are smaller and shorter. These cattle normally mature earlier and at lighter body weights and therefore are ready for slaughter earlier and at lighter weights in the feedlot. The research done by Torell *et al*. (1999), supports the findings of this study. Brahman breed type which have an early to medium maturity are slaughtered at lighter weights.

Brahman breed type had the lowest final weight (482.00 ± 58.357kg). Studies done by Voisinet *et al*. (1997) show that cattle which had Brahman breeding had a higher mean temperament rating or were more excitable when compared to animals which had no Brahman influence. Furthermore work done by Reinhardt *et al*. (2009) shows that more excitable cattle have a decreased initial body weight, final body weight, average daily gain, hot carcass weight, yield grade, quality grade, fat thickness, loin muscle area, marbling score and mortality. Tulloh (1961) and Fordyce & Goddard (1984) also found that more excitable cattle have temperament scores which are higher and tend to have a lower live weight and/-or weight gains. This can, therefore, be used to explain the lower final weight and ADG of Brahman cattle when compared to other breeds.

4.2.14 Effect of breed type on ADG and DIF

Table 4.20 shows the effect of breed type on ADG and DIF. Breed type had a significant effect on the ADG (*P* = 0.000) and DIF (*P* = 0.042). Since the number of cattle for the Charolais, composite white and Hereford were not sufficient to make any sort of conclusion in this study they will not be discussed in this section.

Table 4.20 Effect of breed type on ADG and DIF of feedlot cattle

Weight category	Breed type	N	ADG (kg)	DIF (days)
			Mean ± Std. Deviation	
Average	Brahman	71	1.21^{a} ± 0.344	218.89^{a} ± 31.346
	Charolais	7	1.83^{b} ± 0.203	138.00^{b} ± 0.000
	Composite black	38	1.41^{c} ± 0.358	185.26^{c} ± 45.978
	Composite brown	179	1.28^{ac} ± 0.345	202.25^{d} ± 37.042
	Composite white	10	1.54^{bc} ± 0.484	212.90^{ad} ± 39.739
	Hereford	5	1.20^{ac} ± 0.261	222.60^{ad} ± 60.389
	Average	310	1.30 ± 0.362	203.20 ± 39.514

$^{a, b, c, d}$ Column means with different superscript letter differ (*P* < 0.05)

Table 4.20 indicates that Brahman cattle had the second lowest ADG (1.21 ± 0.344kg/day). Elzo *et al*. (2009) stated that ADG and feed to gain ratio (F:G) decreased as the percentage of Brahman genetic influence increased. The low ADG seen in the Brahman could be related to its temperament and known sensitivity to intensive feeding. Multiple studies have shown that more excitable cattle have reduced performance, less favourable efficiency of gain and a leaner carcass when compared to their calmer counterparts (Fordyce *et al*., 1988; Burrow & Dillon, 1997; Fox, 2004, Ferguson *et al*., 2006; Behrends *et al*., 2008). Café *et al*. (2011) found that Brahman cattle are more excitable when compared to Angus who had a calmer temperament.

The composite black (249.03 ± 41.716kg) entered the feedlot with a heavier initial weight when compared to the Brahman (224.85 ± 31.786kg). The composite black also had higher ADG (1.41 ± 0.358kg/day) when compared to the Brahman (1.21 ± 0.344kg/day). Findings in this study are therefore supported by Koknaroglu *et al*. (2017) who found that the ADG increased as the initial weight increased.

Brahman's are classified as an early to medium maturing breed (Strydom 2002a). Work done by the Department of Agriculture & Rural Development (2005a) found that early maturing breeds have relatively low growth rates and require a shorter period in the feedlot to reach a good carcass finish. This statement by the Department is only partially supported by findings in this study. Early to medium maturing cattle breeds did indeed have a lower ADG; however, these cattle also spent the second longest period in the feedlot.

Another factor which could explain the higher ADG within or between breeds is genetics. Cattle which have the genetics for fast growth are normally heavier at any one time, they have a delay in fat deposition and have a final body weight which is heavier when compared with cattle which have the genetics for slower growth rate (Crouse *et al*., 1975; Laborde *et al*., 2001).

In this study it can be seen that DIF is influenced to a large degree by initial body weight as well as the target body condition. Cattle which entered the feedlot at a lower initial weight spent a longer period in the feedlot to reach their target condition. Brahman entered the feedlot at an initial weight of 224.85 ± 31.786kg. These cattle spent 218.89 ± 31.346 days in the feedlot, while the composite black entered the feedlot at 249.03 ± 41.716kg and only spent 185.26 ± 45.978 days in the feedlot. The efficiency of the cattle breed as well as ADG plays a role. The more efficient the cattle breed, the more of the energy from the feed is used for growth and less for maintenance. The faster cattle grow the shorter it takes to achieve the target market condition. These findings are supported by the following statement; "Feed efficiency is the ratio between production outputs and feed inputs" (Archer *et al*., 1999).

4.2.15 Effect of breed type on the initial and final body length measurements

Table 4.21 provides a summary of the effect of breed type on the initial and final body length measurements. Breed type had a significant effect on the initial body length measurement (*P* = 0.025) but not on the final body length measurement (*P* = 0.104). Since the number of cattle for the Charolais, composite white and Hereford were not sufficient to make any sort of conclusion in this study they will not be discussed in this section. Obtaining accurate body length measurements are difficult and therefore should not be emphasized for selection (Dyer, 1985).

Table 4.21 Effect of breed type on the initial and final body length measurements

Weight category	Breed type	N	Initial body length (cm)	Final body length (cm)
			Mean ± Std. Deviation	
Average	Brahman	71	$113.69^{a} \pm 6.502$	$126.70^{a} \pm 7.706$
	Charolais	7	$125.43^{b} \pm 4.860$	$133.71^{ab} \pm 3.352$
	Composite black	38	$120.76^{bc} \pm 8.251$	$131.47^{b} \pm 7.721$
	Composite brown	179	$117.50^{c} \pm 8.063$	$129.65^{ab} \pm 7.531$
	Composite white	10	$117.50^{abc} \pm 8.317$	$129.40^{ab} \pm 9.240$
	Hereford	5	$117.20^{abc} \pm 11.323$	$130.80^{ab} \pm 12.091$
	Average	310	117.20 ± 8.080	129.30 ± 7.780

$^{a, b, c}$ Column means with different superscript letter differ ($P < 0.05$)

Table 4.22 provides a summary of the effect of breed type on the initial weight divided by initial shoulder height measurement. Breed type did not have a significant effect on this ratio (*P* = 0.725).

Table 4.22 Effect of breed type on the initial weight divided by initial body length of feedlot cattle

Weight category	Breed type	N	Initial weight divided by initial body length (kg/cm)
			Mean ± Std. Deviation
Average	Brahman	71	1.97^{a} ± 0.212
	Charolais	7	2.23^{b} ± 0.098
	Composite black	38	2.05^{ab} ± 0.230
	Composite brown	179	2.00^{a} ± 0.216
	Composite white	10	1.96^{a} ± 0.253
	Hereford	5	1.90^{a} ± 0.307
	Average	310	2.00 ± 0.220

$^{a, b}$ Column means with different superscript letter differ (P < 0.05)

4.2.16 Effect of breed type on the initial and final shoulder height measurements

Table 4.23 provides a summary of the effect of breed type on the final and initial shoulder height measurements. The breed type did not have a significant effect on the initial (P = 0.058) and final shoulder height (P = 0.109) measurements. Although, the initial shoulder height was not significant it was very close P = 0.058.

Table 4.23 Effect of breed type on the initial and final shoulder height for feedlot cattle

Weight category	Breed type	N	Initial shoulder height (cm)	Final shoulder height (cm)
			Mean ± Std. deviation	
Average	Brahman	71	108.56^{ab} ± 4.513	116.68^{a} ± 4.188
	Charolais	7	110.00^{ab} ± 4.320	115.43^{ab} ± 3.155
	Composite black	38	110.37^{a} ± 5.180	116.79^{ab} ± 4.282
	Composite brown	179	107.52^{b} ± 4.761	114.77^{b} ± 4.177
	Composite white	10	108.20^{ab} ± 6.494	116.10^{ab} ± 3.573
	Hereford	5	107.60^{ab} ± 6.107	113.60^{ab} ± 4.159
	Average	310	108.19 ± 4.890	115.49 ± 4.232

$^{a, b}$ Column means with different superscript letter differ (P < 0.05)

Table 4.24 shows the effect of breed type on the initial weight divided by initial shoulder height measurement. Breed type did not have a significant effect on the ratio (P = 0.301).

Table 4.24 Effect of breed type on the initial weight divided by initial shoulder height measurement of feedlot cattle

Weight category	Breed type	N	Initial weight divided by initial shoulder height (kg/cm)
			Mean ± Std. Deviation
Average	Brahman	71	2.07^{a} ± 0.242
	Charolais	7	2.54^{b} ± 0.082
	Composite black	38	2.25^{c} ± 0.299
	Composite brown	179	2.19^{c} ± 0.300
	Composite white	10	2.13^{ac} ± 0.289
	Hereford	5	2.08^{ac} ± 0.427
	Average	310	2.18 ± 0.296

$^{a, b, c}$ Column means with different superscript letters differ (P < 0.05)

4.2.17 Effect of breed type on the initial and final hip height measurements

Table 4.25 provides a summary of the effect of breed type on the initial and final hip height measurement. Breed type did not have a significant effect on the initial (P = 0.271) or final hip height (P = 0.401) measurement.

Table 4.25 Effect of breed type the initial and final hip height measurement for feedlot cattle

Weight category	Breed type	N	Initial hip height (cm)	Final hip height (cm)
			Mean ± Std. Deviation	
Average	Brahman	71	$114.61^{ab} \pm 4.490$	123.23 ± 4.660
	Charolais	7	$117.43^{ab} \pm 3.690$	123.57 ± 2.637
	Composite black	38	$116.29^{a} \pm 5.699$	122.92 ± 5.159
	Composite brown	179	$113.58^{b} \pm 5.041$	121.56 ± 4.307
	Composite white	10	$114.10^{ab} \pm 7.015$	123.10 ± 4.012
	Hereford	5	$113.80^{ab} \pm 6.648$	119.00 ± 5.701
	Average	310	114.25 ± 5.138	122.16 ± 4.538

$^{a, b}$ Column means with different superscript letter differ ($P < 0.05$)

Table 4.26 provides a summary of the effect of breed type on the initial weight divided by initial hip height measurement. Breed type did not have a significant effect on the ratio ($P = 0.472$).

Table 4.26 Effect of breed type on the initial weight divided by initial hip height measurement of feedlot cattle

Weight category	Breed type	N	Initial weight divided by initial hip height (kg/cm)
			Mean ± Std. Deviation
Average	Brahman	71	$1.96^{a} \pm 0.243$
	Charolais	7	$2.38^{b} \pm 0.073$
	Composite black	38	$2.13^{bc} \pm 0.279$
	Composite brown	179	$2.08^{c} \pm 0.286$
	Composite white	10	$2.02^{ac} \pm 0.274$
	Hereford	5	$1.97^{ac} \pm 0.412$
	Average	310	2.06 ± 0.283

$^{a, b, c}$ Column means with different superscript letter differ ($P < 0.05$)

4.2.18 Effect of breed type on carcass weight, dressing percentage, carcass length and carcass compactness

Table 4.27 provides a summary of the effect of breed type on carcass weight (P = 0.001), dressing percentage (P = 0.000), carcass compactness (P = 0.007) and the carcass length (P = 0.003). Breed type had a significant effect on all these variables. Since the number of cattle for the Charolais, composite white and Hereford were not sufficient to make any sort of conclusion in this study they will not be discussed in this section.

Table 4.27 Effect of breed type on carcass weight, dressing percentage, carcass length and carcass compactness of feedlot cattle

Weight category	Breed type	N	Carcass weight (cm)	Dressing percentage (%)	Carcass length (cm)	Carcass compactness (kg/cm)
			Mean ± Std. Deviation			
Average	Brahman	71	291.86^{a} ± 40.555	60.50 ± 3.571	120.70^{a} ± 4.735	2.41^{a} ± 0.267
	Charolais	7	322.86^{ab} ± 17.531	60.74 ± 0.243	126.43^{b} ± 2.388	2.55^{ab} ± 0.121
	Composite black	38	311.26^{ab} ± 36.929	61.76 ± 4.073	123.20^{ab} ± 5.618	2.52^{ab} ± 0.217
	Composite brown	179	300.27^{ab} ± 41.051	61.24 ± 2.343	121.88^{ab} ± 4.945	2.46^{ab} ± 0.273
	Composite white	10	333.16^{b} ± 36.957	61.42 ± 0.689	124.60^{ab} ± 6.450	2.67^{b} ± 0.180
	Hereford	5	290.24^{ab} ± 23.275	59.80 ± 3.207	121.70^{ab} ± 3.962	2.39^{ab} ± 0.187
	Average	310	301.10 ± 40.473	61.11 ± 2.893	121.96 ± 5.070	2.46 ± 0.263

$^{a,\,b}$ Column means with different superscript letter differ (P < 0.05)

Cattle can be classified according to their maturity type. Cattle which are early maturing start depositing fat at an earlier age and can be market-ready at a live weight of 380kg to 400kg, while late maturing cattle can be market-ready at a live weight of 500kg (Department of Agriculture & Rural Development, 2005a). In this study, early to medium maturing cattle were slaughtered at a final live weight of 482.00 ± 58.357kg, which is above the mentioned norm.

Brahman cattle may also have a low carcass weight (291.86 ± 40.555kg) due to their temperament. In a study done by Voisinet *et al*. (1997), it was found that cattle which had Brahman breeding had a higher mean temperament rating or were more excitable when compared to animals which had no Brahman influence. This more excitable temperament causes cattle to have a decreased initial body weight, final body weight, average daily gain, hot carcass weight, yield grade, quality grade, fat thickness, loin muscle area, marbling score and mortality (Reinhardt *et al*., 2009). While in another study it was found that cattle which had a calm temperament have also been reported to have a heavier carcass (Burrow & Dillon, 1997; Cafe *et al*., 2011). These findings are consistent with the findings in this study.

Brahman which are classified as early to medium maturing (Strydom, 2002a) had a frame score of between 3 and 5 and thus would explain why these cattle had the shortest carcass length of 120.70 ± 4.735cm.

The dressing percentage varies, for lean animals it can be 49% which can increase to 60% at a high level of finish, while the mean dressing percentage varies from 54 to 56% when the fat score is 2 to 3 (Department of Agriculture & Rural Development, 2005a). In this study, the average dressing percentage was 61.11 ± 2.893% which is slightly above the 60% mentioned. This indicates that cattle were finished off at a high level.

The composite black cattle had a carcass weight of 311.26 ± 36.929kg and a carcass compactness of 2.52 ± 0.217kg/cm. It has also been said that there is variation in carcass compactness between breeds (Tatum *et al*., 1986b & Du Plessis & Hoffman, 2007). The variation between breeds can be seen in Table 4.27.

In a study done by Ralston *et al*. (1970), it was found that cattle with a small frame such as the Angus should not be fed to the same slaughter weight as a large framed cattle types such as the Charolais. The condition of the animal should be used to indicate the slaughter weight rather than the weight of the animal (Ralston *et al*., 1970). This may explain the variation which one can see between the DIF, final weight and the carcass weight. The cattle in this study were slaughtered based on the condition of cattle, rather than the final weight of the cattle.

4.3 Interactions between sheath size, breed type and weight category

When looking at the interaction between sheath size and weight category (Table 4.28) it can be seen that the interaction had a significant effect on median weight minus initial weight divided by DIF, ADG, DIF and dressing percentage ($P < 0.05$), while there was no significant effect between the other variables ($P > 0.05$). This suggests that the different sheath sizes will respond differently within the different weight categories. The use of weight will not be equally significant in all the sheath sizes.

When looking at the interaction between weight category and breed type it can be seen that there was a significant effect on the DIF and dressing percentage ($P < 0.05$), however, there were no further effects between the other variables ($P > 0.05$).This suggests that the different breeds will respond differently within the different weight categories. The use of weight will not be equally significant in all the breed types.

The interaction between sheath size and breed type had a significant effect on final weight, median weight minus initial weight divided by DIF, ADG, DIF, final body length measurement, final hip height measurement and carcass weight ($P < 0.05$) while there was no significant between the other variables ($P > 0.05$). This suggests that the different breeds will respond differently within the different sheath sizes. The use of sheath sizes will not be equally significant in all the breed types.

The interaction between sheath size, weight category and breed type had a significant effect on the median weight minus initial weight divided by DIF, ADG, DIF, dressing percentage and carcass compactness ($P < 0.05$), while there was no significant effect between the other variables ($P > 0.05$).

Table 4.28 shows the interactions between the sheath size, breed type and weight category

	Sheath size * weight category	Sheath size * breed type	Weight category * breed type	Sheath size * weight category * breed type
		***P* - value**		
Initial weight	0.471	0.403	0.928	0.791
Initial weight divided by hip height	0.696	0.302	0.988	0.616
Initial weight divided by shoulder height	0.715	0.347	0.900	0.621
Median weight	0.739	0.132	0.509	0.860
Median weight minus initial weight	0.870	0.158	0.205	0.949
Median weight minus initial weight divided by DIF	0.447	0.181	0.078	0.443
Final weight	0.308	**0.020**	0.426	0.079
ADG	**0.001**	**0.000**	0.200	**0.000**
DIF	**0.006**	**0.008**	**0.014**	**0.001**
Initial body length	0.129	0.395	0.719	0.500
Initial weight divided by body length	0.626	0.617	0.896	0.815
Final body length	0.294	**0.045**	0.825	0.167
Initial shoulder height	0.175	0.187	0.853	0.546
Final shoulder height	0.066	0.737	0.582	0.289
Initial hip height	0.314	0.273	0.646	0.565
Final hip height	0.703	**0.023**	0.797	0.643
Carcass weight	0.148	**0.045**	0.760	0.086
Dressing percentage	**0.003**	0.179	**0.000**	**0.025**
Carcass Length	0.772	0.146	0.182	0.705
Carcass compactness	0.088	0.081	0.749	**0.047**

4.4 Correlations

For this section, only the initial measurements and how they influence the important feedlot performance variables (ADG; DIF) will be discussed. The initial measurements were used to try and determine if the ADG and DIF can be predicted upon entry into the feedlot, therefore using the final measurements would be of no use. Further, only the Brahman, composite black and composite brown breed types will be discussed in this section as there were enough cattle in these groups to obtain results. For this study, the focus was to see if the ADG and DIF can be predicted by various measurements, and which measurements will be more accurate and reliable in predicting these factors. Although it is known that numerous other factors such as maturity type, nutrition, frame size, management and the environment will have an effect on both the ADG and DIF. There is a lack of previous data and therefore, more research is required to support these results.

A positive correlation is desired for ADG, because an increase in the variable will result in a higher ADG. By contrast, a negative correlation is desired for DIF, because an increase in the variable will result in a lower DIF. However, care should be taken when working with the ratios because a higher value for both variables would result in a higher ratio, however a higher initial weight and/or a lower initial hip height, body length or shoulder height will also result in a higher ratio and this might not be desirable and vice versa for a decreasing ratio.

4.4.1 Correlations for cattle for all the variables

Addendum A shows the correlations for all the variables in this study. The initial weight, initial shoulder height, initial body length , initial hip height and the various ratios had a significant association with both the ADG and DIF ($P < 0.01$). There was a positive correlation between the initial weight ($r = 0.319$, $P = 0.000$), initial shoulder height ($r = 0.228$, $P = 0.000$), initial body length ($r = 0.329$, $P = 0.000$), initial hip height ($r = 0.227$, $P = 0.000$) and ADG. When looking at the ratios between the initial weight and initial shoulder height ($r = 0.300$, $P = 0.000$), initial weight and initial hip height (r = 0.299, P = 0.000) and initial weight and initial body length (r = 0.251, P = 0.000) it can be seen that there was a positive correlation with ADG. A positive correlation for ADG is desired because it indicates an increase in the variable will result in an increase in ADG, however care should be taken when working with the ratios.

When looking at DIF it can be seen that there was a negative correlation between the initial weight ($r = -0.668$, $P = 0.000$), initial shoulder height ($r = -0.454$, $P = 0.000$), initial body length ($r = -0.586$, $P = 0.000$), initial hip height ($r = -0.449$, $P = 0.000$) and DIF. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with DIF, with respectively r = - 0.639, P = 0.000; r = - 0.634, P = 0.000; r = - 0.598, P = 0.000. A negative correlation for DIF is desired because it indicates an increase in the variable will result in a decrease in DIF, however care should be taken when working with the ratios.

The positive correlation between the initial body length and ADG, r = 0.329, P = 0.000, allows the feedlot to confidently select cattle for ADG based on this measurement. The latter measurement indicates that an increase in body length will result in an increase in ADG. While, the negative correlation between initial weight and DIF, r = - 0.668, P = 0.000, allows the feedlot to confidently select cattle based on this measurement, this will provide an accurate and practical method to select cattle for a lower DIF. As the correlation strengths from 0 to + 1 and from 0 to - 1, the initial body length and initial weight had the strongest correlation between ADG and DIF respectively. The feedlot would however, need to choose the most practical measurement, in order to increase the ADG while at the same time decreasing the DIF.

4.4.2 Correlations for cattle in the ideal weight category

Addendum B shows the correlations for the ideal weight category. The initial weight, initial shoulder height measurement, initial body length measurement, initial hip height measurement and the various ratios had a significant association with both the ADG and DIF ($P < 0.05$). There was a positive correlation between the initial weight (r = 0.391, P = 0.000), initial shoulder height (r = 0.258, P = 0.009), initial body length (r = 0.362, P = 0.000), initial hip height (r = 0.247, P = 0.012) and ADG. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a positive correlation with ADG, r = 0.373, P = 0.000; r = 0.387, P = 0.000; r = 0.345, P = 0.000 respectively. A positive correlation for ADG is desired because it indicates that an increase in the variable will result in an increase in ADG, however care should be taken when working with the ratios.

When looking at DIF it can be seen that there was a negative correlation between the initial weight (r = - 0.580, P = 0.000), initial shoulder height (r = - 0.305; P = 0.002), initial body length (r = - 0.478, P = 0.000), initial hip height (r = - 0.292, P = 0.003) and DIF. For the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with DIF, r = - 0.576, P = 0.000; r = - 0.594, P = 0.000; r = - 0.544, P = 0.000. A negative correlation for DIF is desired because it indicates an increase in the variable will result in a decrease in DIF, however care should be taken when working with the ratios.

The initial weight had a positive correlation with ADG, r = 0.391, *P* = 0.000 this indicates that an increase in initial weight will result in an increase in ADG, which is favourable. There was a negative correlation between the initial weight divided by initial hip height, r = - 0.594, *P* = 0.000. In order for this ratio to be desired, both the initial weight and initial hip height measurement should be higher, this will result in a higher ratio and shorter number of DIF. In the general linear model procedure we saw that cattle in the ideal weight category had a higher initial weight (Table 4.1) and a higher initial hip height measurement (Table 4.7) and this therefore results in a favourable ratio. As the correlation strengthens from 0 to + 1 and from 0 to - 1, the initial weight and initial weight divided by initial hip height had the strongest correlation between the ADG and DIF respectively. The feedlot would however, need to decide which measurement would be the most practical for them.

4.4.3 Correlations for cattle in the sub-ideal weight category

Addendum C shows the correlations for the sub-ideal category. The initial weight and the various ratios had a significant relationship on the ADG (*P* < 0.05). None of the variables had a significant association with DIF (*P* > 0.05). There was a negative correlation between the initial weight (r = - 0.153, *P* = 0.027) and ADG. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with ADG, r = - 0.139, *P* = 0.045; r = - 0.153, *P* = 0.027; r = - 0.177, *P* = 0.010 respectively. This is undesired, because an increase in the variable will result in a decrease in ADG.

Although, these measurements can be used to predict the ADG and DIF for cattle in the ideal weight category, they serve no purpose for cattle in the sub-ideal weight category. DIF for cattle in the sub-ideal weight category cannot be predicted. The negative correlation between the variable and ADG indicates that an increase in the variable will result in a decrease in ADG. Therefore, when selecting cattle based on these variables, care should be taken to make sure the feedlot select the cattle with the least negative correlation in order to prevent a dramatic drop in ADG. The ratio between the initial weight divided by initial shoulder height measurement had the lowest negative correlation with ADG (r = - 0.139, *P* = 0.045), however this is not a practical measurement because it is quite cumbersome to measure. Shoulder height measurements are difficult to obtain, as the measurement stick might get pushed into the ground and this would provide results which are not accurate.

4.4.4 Correlations for Brahman type cattle

Addendum D shows the correlations for the Brahman breed type. The initial weight had a significant relationship with the ADG ($P < 0.05$). While the initial weight and the various ratios had a significant association on the DIF ($P > 0.05$). There was a positive correlation between the initial weight (r = 0.239, P = 0.045) and ADG. A positive correlation for ADG is desired because it indicates an increase in the variable will result in an increase in ADG, however care should be taken when working with the ratios.

When looking at the correlations for DIF it can be seen that there was a negative correlation between the initial weight (r = - 0.406, P = 0.000). When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with DIF, r = - 0.413, P = 0.000; r = - 0.393, P = 0.001; r = - 0.409, P = 0.000 respectively. A negative correlation for DIF is desired because it indicates an increase in the variable will result in an increase in DIF, however care should be taken when working with the ratios.

The positive correlation between the initial weight and ADG, r = 0.239, P = 0.045, allows the feedlot to confidently select cattle based on this measurement. An increase in the initial weight will result in an increase in ADG. The negative correlation between initial weight divided by initial shoulder height and DIF, r = - 0.413, P = 0.000, allows the feedlot to confidently select cattle based on this measurement, however it might not result in an accurate or practical method as the stick may get pushed into the ground while taking the measurement. As the correlation strengthens from 0 to + 1 and from 0 to - 1, the initial weight and initial weight divided by initial shoulder had the strongest correlation between the ADG and DIF respectively. However, the feedlot would need to decide which variable would be the most practical for them to use, in order to increase the ADG and decrease the DIF.

4.4.5 Correlations for the brown composite type cattle

Addendum E shows the correlations for the composite brown breed type. The initial weight, initial shoulder height, initial body length , initial hip height and the various ratios had a significant association on both the ADG and DIF ($P < 0.05$). There was a positive correlation between the initial weight (r = 0.297, P = 0.000), initial shoulder height (r = 0.249, P = 0.001), initial body length (r = 0.331; P = 0.000), initial hip height (r = 0.212, P = 0.004) and ADG. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a positive correlation with ADG, r = 0.265, *P* = 0.000; r = 0.277, *P* = 0.000; r = 0.217, *P* = 0.004 respectively. A positive correlation indicates that an increase in one variable will result in an increase in another variable, care should be taken when working with ratios.

The DIF had a negative correlation between the initial weight (r = - 0.714, *P* = 0.000), initial shoulder height (r = - 0.533, *P* = 0.000), initial body length (r = - 0.651, *P* = 0.000), initial hip height (r = - 0.509, *P* = 0.000) and DIF. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with DIF, r = - 0.664 *P* = 0.000; r = - 0.666, *P* = 0.000; r = - 0.633, *P* = 0.000 respectively. A negative correlation for DIF is desired because it indicates that an increase in the measurement will result in a decrease in the number of DIF, however care should be taken when working with the ratios.

The positive correlation between the initial body length measurement and ADG, r = 0.331, *P* = 0.000, allows the feedlot to confidently select cattle based on this measurement. This measurement will result in an accurate and practical method to select cattle for ADG in the feedlot. The negative correlation between initial weight and DIF, r = - 0.714, *P* = 0.000, allows the feedlot to confidently select cattle based on this measurement, this will provide an accurate and practical method to select cattle for a lower DIF. As the correlation strengthens from 0 to + 1 and from 0 to - 1, the initial body length and initial weight have the strongest correlation between ADG and DIF respectively. However, as all the variables have a positive correlation for ADG and negative correlation for DIF the feedlot would need to decide which variable is the most practical for him to increase the ADG and decrease the DIF.

4.4.6 Correlations for the composite black type cattle

Addendum F shows the correlations for the composite black breed type. The initial weight, initial shoulder height, initial body length, initial hip height and the various ratios had a significant association on DIF (*P* < 0.05). While none of the variables had a significant effect on ADG (*P* > 0.05).

There is a negative correlation between the initial weight (r = - 0.593, *P* = 0.000), initial shoulder height (r = - 0.489, *P* = 0.002), initial body length (r = - 0.532, *P* = 0.001), initial hip height (r = - 0.445, *P* = 0.005) and DIF. When looking at the ratios between the initial weight and initial shoulder height, hip height and body length it can be seen that there was a negative correlation with DIF, r = - 0.576, *P* = 0.000; r = - 0.595, *P* = 0.000; r = - 0.566, *P* = 0.000. A negative correlation for DIF is desired because it indicates increase in the measurement will result in a decrease in the number of DIF, however care should be taken when working with the ratios. As the correlation strengthens from 0 to - 1, the initial weight divided by initial hip height had the strongest correlation for DIF. However, the feedlot would need to decide which variable is the most practical for them.

4.5 Regressions

Standard regression analyses were performed in this section. The various curves used for the different regressions were based on which mathematical equation best explained the variance of the dependent variable. For this section, only the initial measurements were used to determine if these measurements can be used to predict the ADG and DIF.

Because no feed efficiency data was collected, one cannot determine if these cattle will be more efficient or not. These measurements are merely used to determine if the ADG and DIF can be predicted for cattle. It is also understood that many factors influence the ADG and DIF, such a maturity type, frame size, nutrition, management and environment. Due to the lack of previous data in some sections, more research will be required to determine if these results are indeed valid.

4.5.1 Regression of initial weight on ADG for all the data in the study

Figure 4.1 is a regression curve explained by the quadratic equation y = 1.252743285459176 + -0.002329293906286817x + 1.039183369337763e-005x^2. R^2 explained 10.6% of the variance (P = 0.000). As only a small percentage of the variance was explained by this measurement, it may not be accurate or practical.

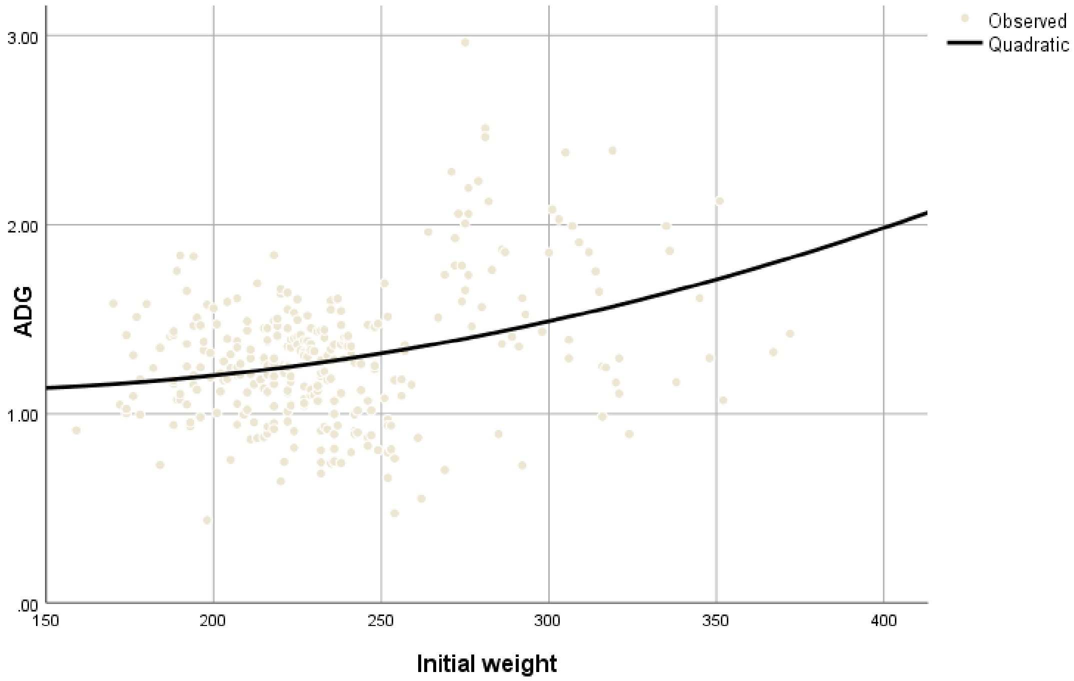


Figure 4.1 Graphic representation showing the effect of initial weight (X-axis) on ADG (Y-axis)

4.5.2 Regression of initial weight on DIF for all the data in the study

Figure 4.2 is a regression curve explained by the logistic equation y = 1 / (0 + 0.002026984535887124 x 1.003860324144068^x). R^2 = 46.3% and therefore, the logistic equation explained 46.3% of the variance (*P* = 0.000). Due to the high adjusted R^2 the feedlot can confidently select cattle based on initial weight to achieve a desired number of DIF.

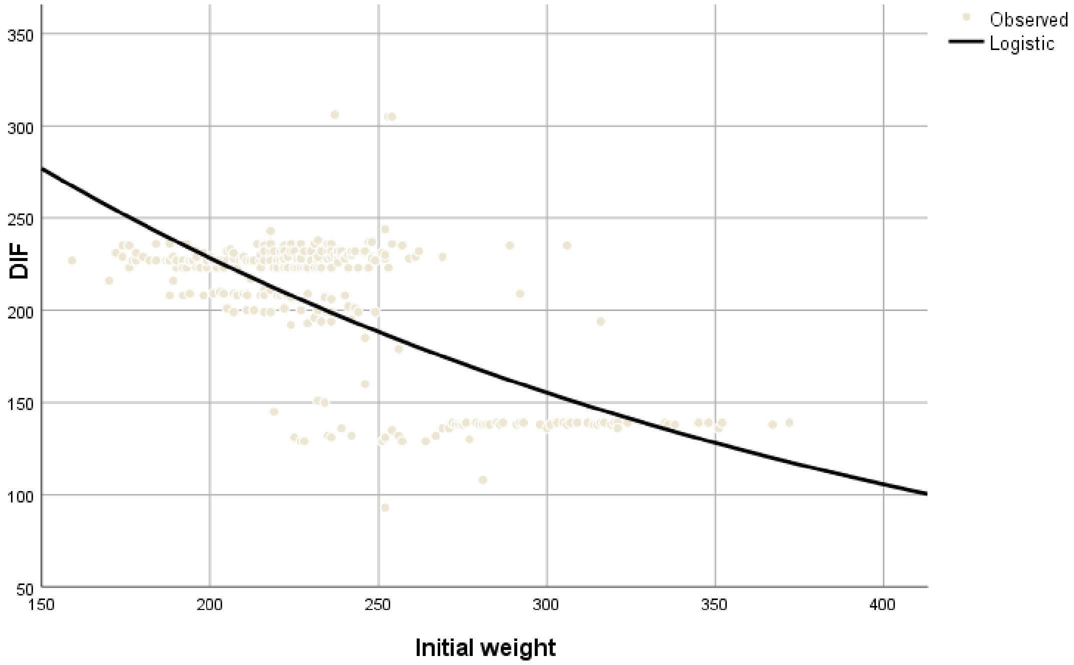


Figure 4.2 Graphic representation showing the effect of initial weight (X-axis) on DIF (Y-axis)

From Figure 4.2 it can be seen that as the initial weight increases, between 275kg - 375kg the number of DIF begins to decrease. This therefore, suggests that cattle will spend a shorter period in the feedlot. Koknaroglu *et al*., 2017 found that although the cost to purchase cattle increased as the initial weight increased, the feed costs decreased as the initial weight increased due to a shorter time on feed and, due to a lower total feed consumption.

4.5.3 Regression of initial body length on ADG for all the data in the study

Figure 4.3 illustrates the quadratic curve for the regression equation between the initial body length and ADG. The regression equations is y = 4.708515314820826 + -0.07123563475933939x + 0.0003577711841327562x^2. R^2 explained 11.7% of the variance (*P* = 0.000). As only a small percentage of the variance was explained by this measurement, it may not be accurate or practical.

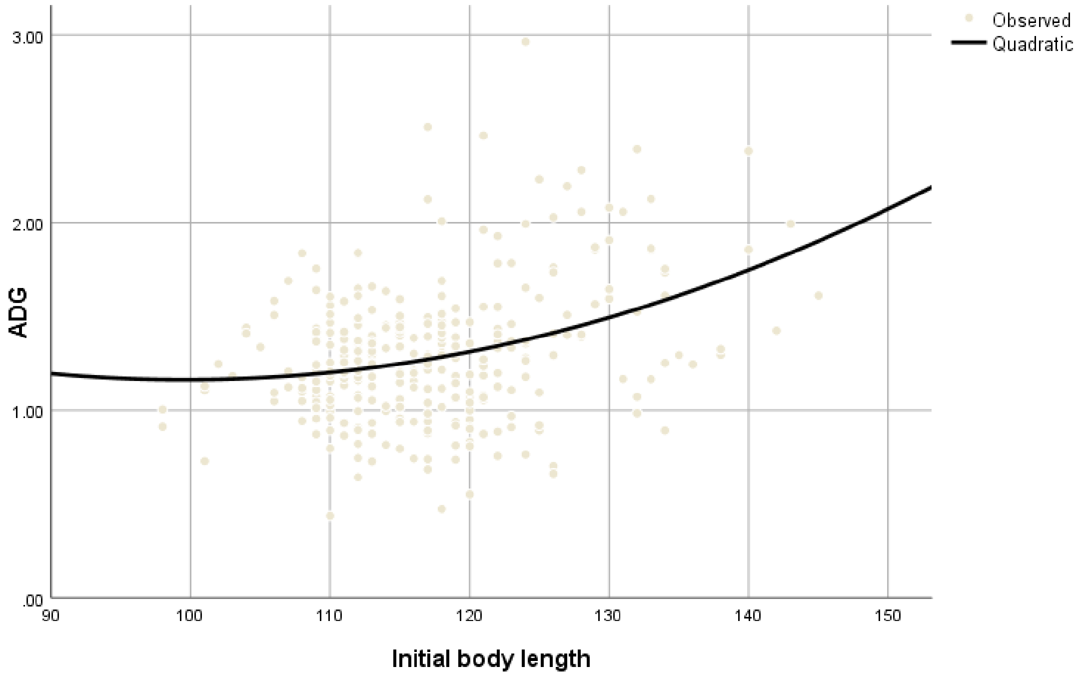


Figure 4.3 Graphic representation showing the effect of the initial body length (X-axis) on ADG (Y-axis)

4.5.4 Regression of initial body length on DIF for all the data in the study

Figure 4.4 is a regression curve explained by quadratic equation is y = -318.533791826617 + 11.48016957022802x + -0.05968689762248183x^2. R^2 explained 36.4% of the variance (*P* = 0.000). Due to the high R^2 the feedlot can confidently select cattle based on initial body length to achieve a lower number of DIF.

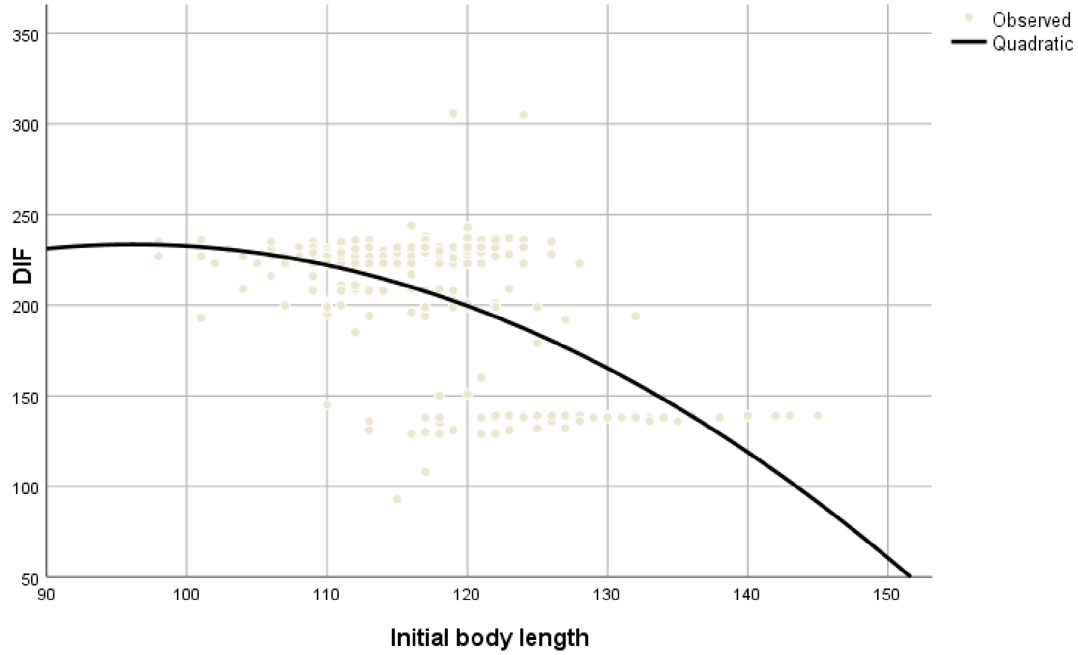


Figure 4.4 Graphic representation showing the effect of the initial body length (X-axis) on DIF (Y-axis)

Figure 4.4 shows that as initial body length increases to 128 - 145cm the number of DIF decreased dramatically to around 140 days in the feedlot. Although most cattle entered the feedlot at 115 - 125cm and these cattle had a DIF which varied between 190 - 248 days.

4.5.5 Regression of initial shoulder height on ADG for all data in the study

Figure 4.5 is a regression curve explained by the cubic equation y = 2.688098876829163 + 0x + -0.000503626977868163x^2 + 3.544530773806788e-006x^3. R^2 explained 5.8% of the variance (P = 0.000), which implies that the shoulder height is not an accurate or practical measure to predict ADG.

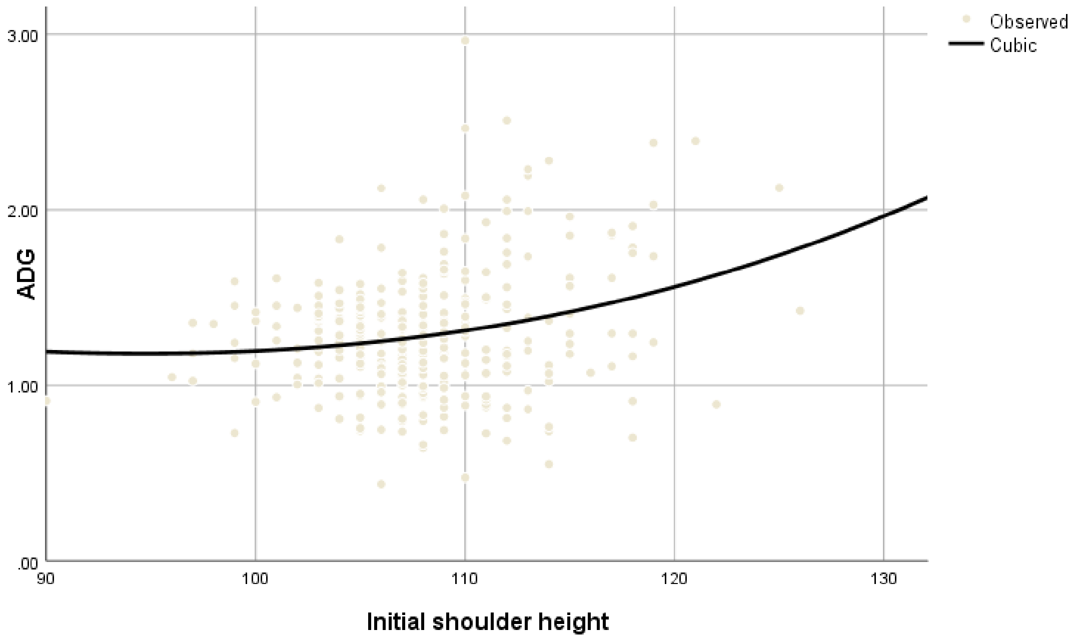


Figure 4.5 Graphic representation showing the effect of the initial shoulder height (X-axis) on ADG (Y-axis)

4.5.6 Regression of initial shoulder height on DIF for all the data in the study

Figure 4.6 illustrates the quadratic cure of the regression analyses between the initial shoulder height and DIF. The quadratic curve is y = -730.5052562165599 + 20.79951156447554x + -0.1122528691110784x^2. R^2 explained 22% of the variance (P = 0.000), the DIF can therefore, be predicted from the initial shoulder height measurement.

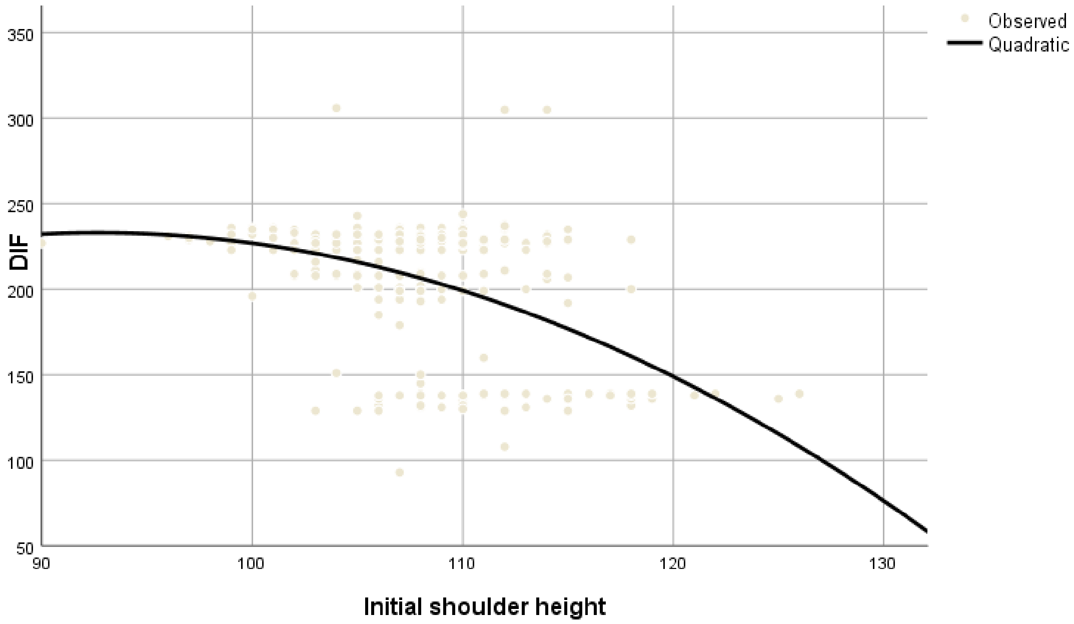


Figure 4.6 Graphic representation showing the effect of initial shoulder height (X-axis) on DIF (Y-axis)

From Figure 4.6 it can be seen that an initial shoulder height between 118cm and 126cm resulted in a lower number of DIF.

4.5.7 Regression of initial hip height on ADG for all the data in the study

Figure 4.7 is a regression curve explained by the quadratic equation y = 6.73224805646923 + -0.1106133563238734x + 0.0005506846574491079x^2. R^2 explained 5.5% of the variance (*P* = 0.000), which implies that the initial hip height measurement is not an accurate or practical method to predict ADG.

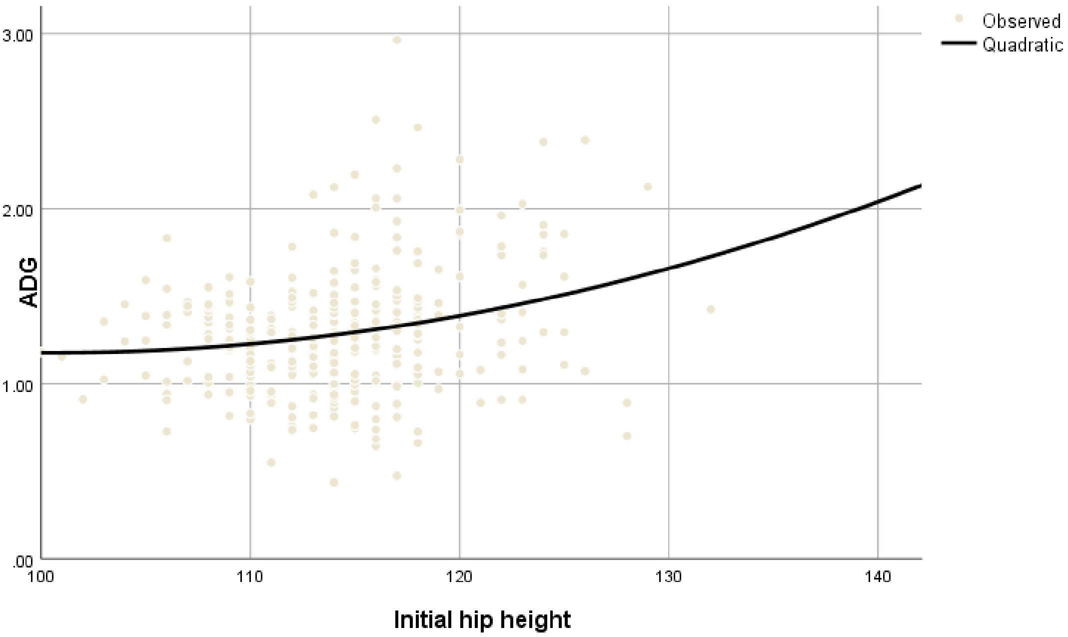


Figure 4.7 Graphic representation showing the effect of the initial hip height (X-axis) on ADG (Y-axis)

4.5.8 Regression of initial hip height on DIF for all data in the study

Figure 4.8 is a regression curve explained by the quadratic equation $y = -1045.148173704962 + 25.19491522023365x + -0.1246363063661817x^2$. The quadratic equation explained 21.8% of the variance (P = 0.000). The feedlot can therefore, use the initial hip height measurement to select cattle for a lower number of DIF.

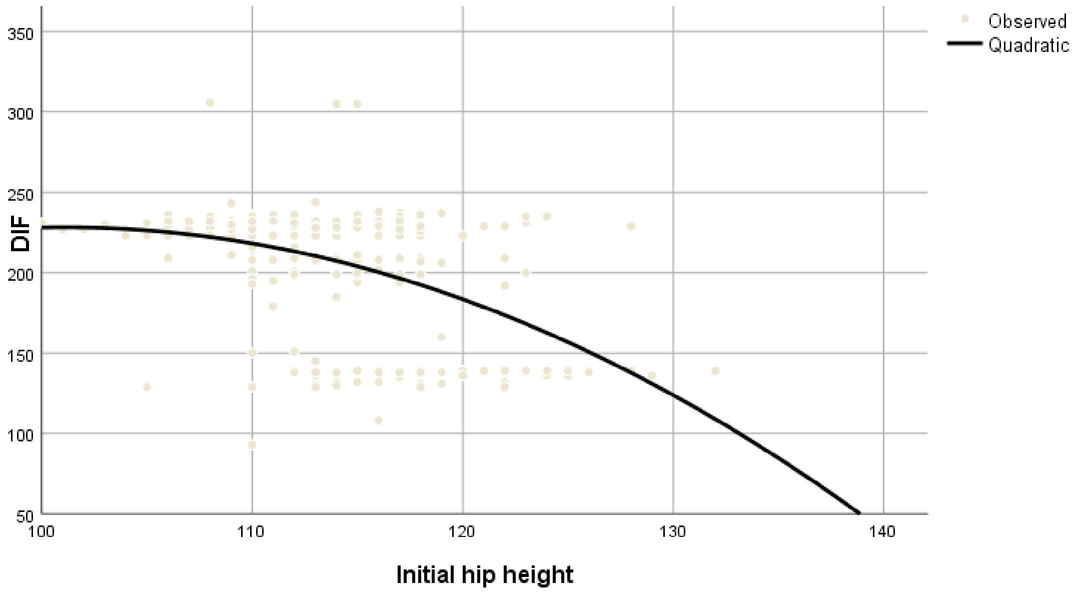


Figure 4.8 Graphic representation showing the effect of the initial hip height (X-axis) on DIF (Y-axis)

From Figure 4.8 it can be seen that an initial hip height measurement between 125cm to 132cm resulted in a decreased number of DIF. A lower number of DIF is desirable as cattle spend this time in the feedlot and therefore eat less.

4.5.9 Regression of initial weight divided by initial hip height on ADG for all data in the study

Figure 4.9 is a regression curve explained by quadratic equation y = 2.111603127502349 + -1.125853261411444x + 0.3480957887165492x^2. R^2 explained 10.1% of the variance (*P* = 0.000). As only a small percentage of the variance was explained by this measurement, it may not be accurate or practical.

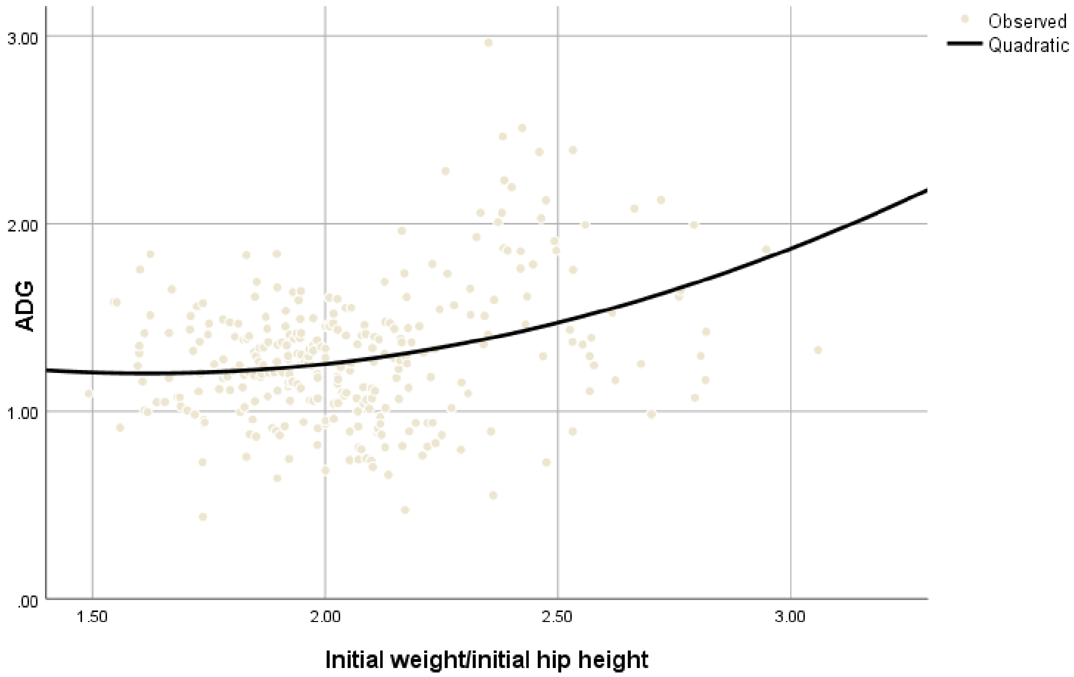


Figure 4.9 Graphic representation showing the effect of initial weight divided by initial hip height (initial weight/initial hip height) (X-axis) on ADG (Y-axis)

4.5.10 Regression of initial weight divided by initial hip height on DIF for all data in the study

Figure 4.10 is a regression curve explained by the logistic equation y = 1 / (0 + 0.001782925095169347 x 1.654659736984965^x). R^2 explained 42% of the variance (P = 0.000). The high R^2 is an indication that the feedlot can confidently select cattle based on the initial weight divided by initial hip height measurement for a lower number of DIF.

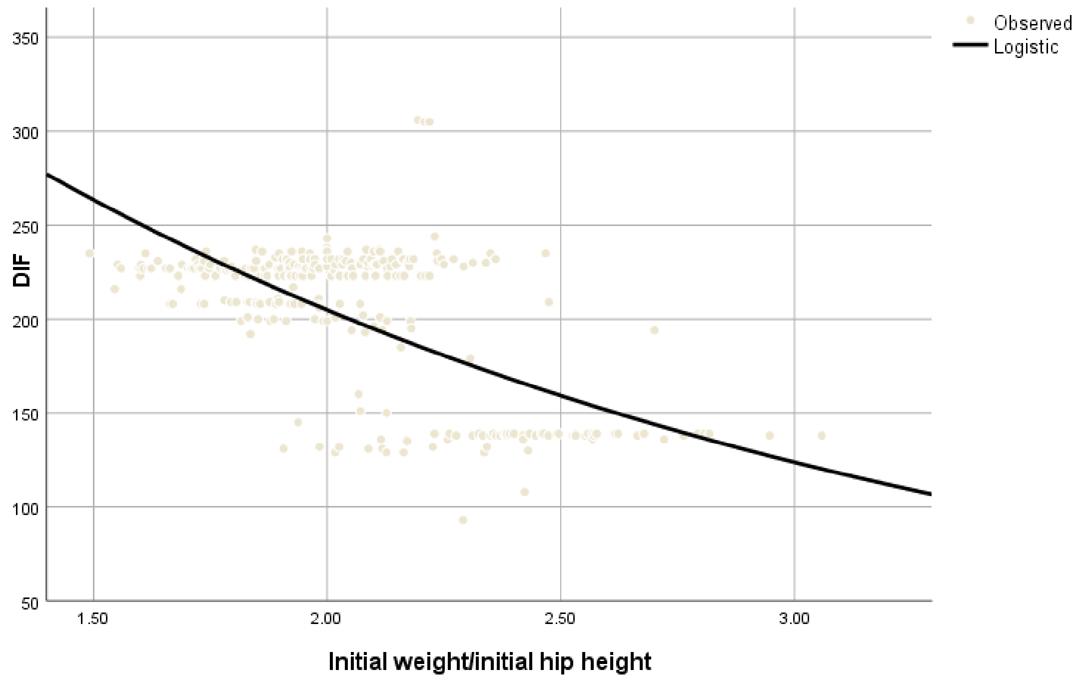


Figure 4.10 Graphic representation showing the effect of the initial weight divided by initial hip height (initial weight/initial hip height) (X-axis) on DIF (Y-axis)

From Figure 4.10 it can be seen that cattle, which had a ratio greater than 2.4kg/cm, spent less DIF. These cattle spent around 140 days in the feedlot; however, most of the cattle, which entered the feedlot, had a ratio of between 1.6kg/cm to 2.4kg/cm with a DIF of about 240 days.

4.5.11 Regression of initial weight divided by initial body length on ADG for all data in the study

Figure 4.11 is a regression curve explained by the quadratic equation y = 2.228710399828041 + -1.305608366261471x + 0.4145449230585134x^2. R^2 explained 6.9% of the variance (*P* = 0.000), which implies that the initial hip height measurement is not an accurate or practical method to predict ADG.

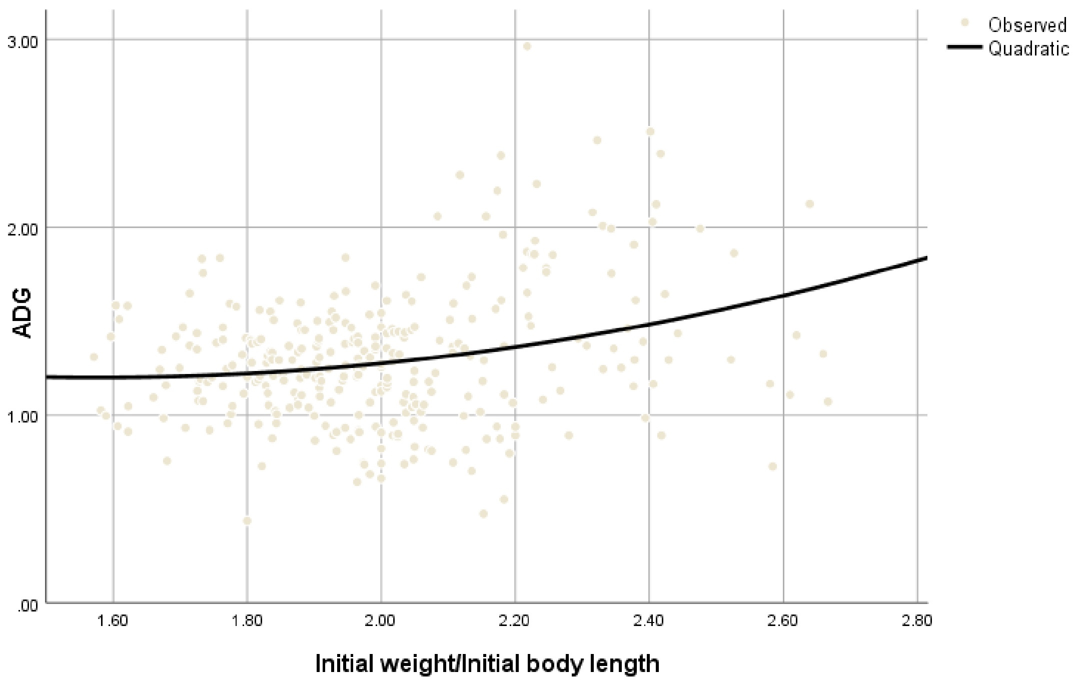


Figure 4.11 Graphic representation showing the effect of the Initial weight divided by initial body length (initial weight/initial body length) (X-axis) on ADG (Y-axis)

From Figure 4.11 it can be seen that there is no specific range in which an initial weight divided by initial body length (initial weight/initial body length) results in a higher ADG. Although as the ratio increases the ADG also increases.

4.5.12 Regression of initial weight divided by initial body length on DIF for all the data in the study

Figure 4.12 is a regression curve explained by the quadratic equation y = 94.08892574000186 + 209.4874352449494x + -76.43353322863227x^2. R^2 explained 37.4% of the variance (*P* = 0.000). The high R^2 suggests that the feedlot can confidently select cattle based on initial weight divided by initial body length to achieve a lower number of DIF

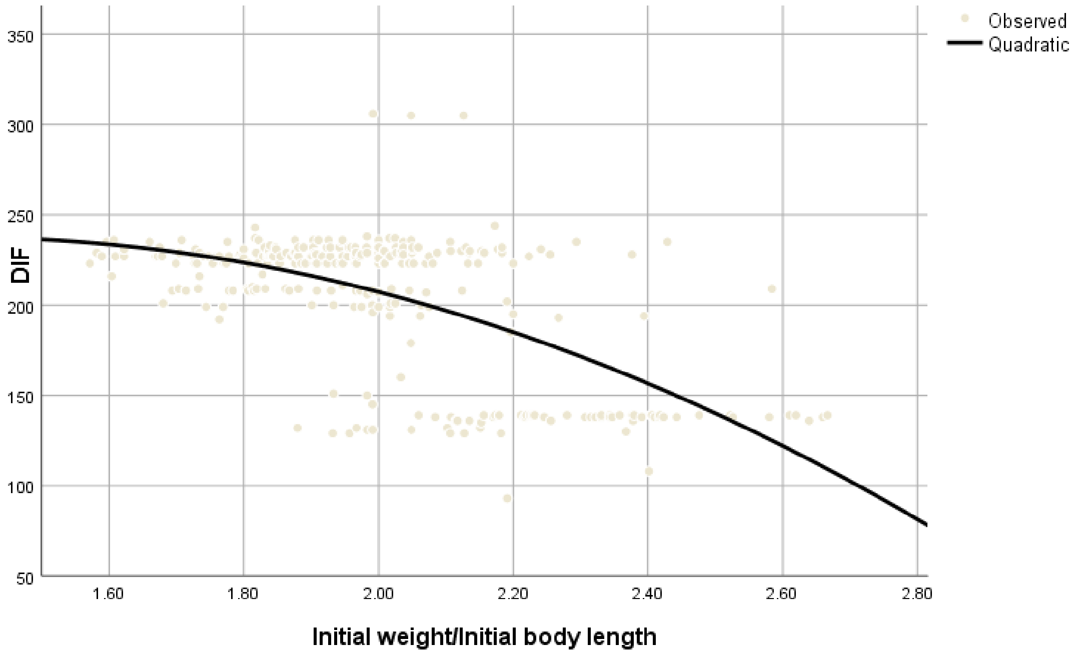


Figure 4.12 Graphic representation showing the effect of the initial weight divided by initial body length (initial weight/initial body length) (X-axis) on DIF (Y-axis)

From Figure 4.12 it can be seen that the number of DIF began to decrease to around 140 days when cattle had a ratio higher than 2.3 kg/cm. However, most cattle had a ratio of between 1.8kg/cm to 2.2kg/cm, while they spent around 230 days in the feedlot.

4.5.13 Regression of initial weight divided by initial shoulder height on ADG for all data in the study

Figure 4.13 is a regression curve explained by the quadratic equation y = 1.722414287069711 + -0.7198696745997198x + 0.2367411143070151x^2. R^2 explained 9.7% of the variance (*P* = 0.000). Although, only a small variance is explained by the measurement it can still be used to select cattle for ADG, however, it might not be accurate nor practical.

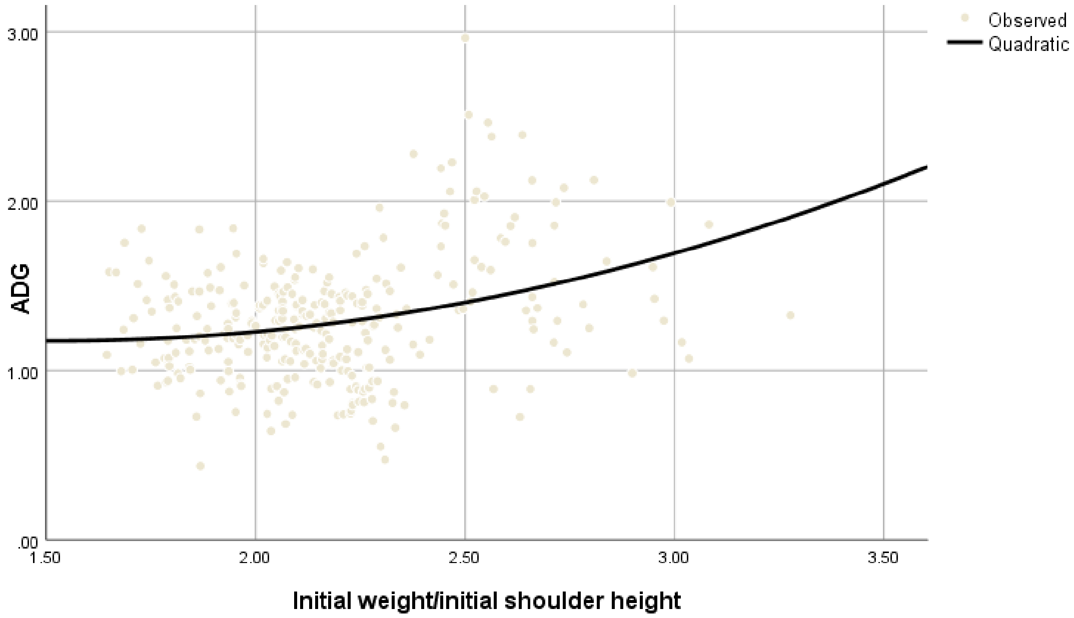


Figure 4.13 Graphic representation showing the effect of the initial weight divided by initial shoulder height (initial weight/initial shoulder height (X-axis) on ADG (Y-axis)

4.5.14 Regression of initial weight divided by initial shoulder height on DIF for all data in the study

Figure 4.14 is a regression curve by the logistic equation y = 1 / (0 + 0.001757492326277547x 1.621854858053209^x). R^2 explained 42.4% of the variance (P = 0.000). Therefore, the feedlot can confidently select cattle based on initial weight divided by initial shoulder height to achieve a lower number of DIF.

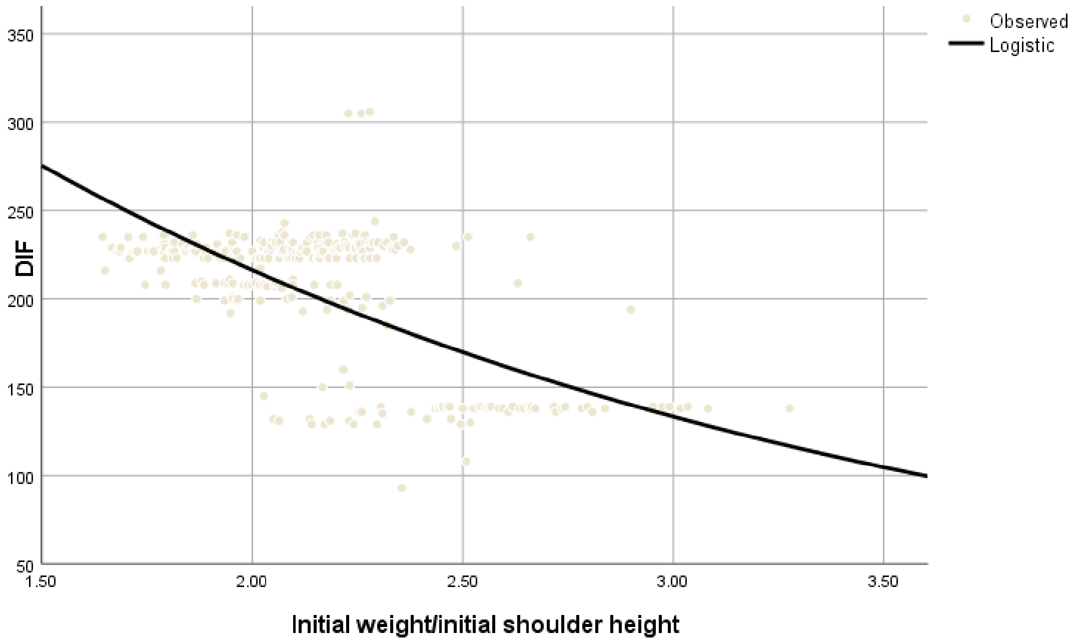


Figure 4.14 Graphic representation showing the effect of the initial weight divided by initial shoulder height (initial weight/initial shoulder height) (X-axis) on DIF (Y-axis)

From Figure 4.14 it can be seen that a measurement between 2.4kg/cm to 3.3kg/cm resulted in the least number of DIF.

Chapter 5: Conclusions

The results from this study show that cattle, which had a higher initial weight (within reason), were more economical in the feedlot in terms of, higher ADG (1.45 ± 0.491kg) and fewer DIF (156.88 ± 32.287 days) when compared to cattle in the sub-ideal weight category (ADG: 1.22 ± 0.249kg; DIF: 225.91 ± 15.704 days). Although, it is understood that there are other aspects that affect ADG and DIF such as maturity type, nutrition, frame size, management and environment. The only negative aspect of buying heavier cattle at the start of the feedlot period is the higher initial purchasing price, but this is offset by the fewer number of days spent in the feedlot and therefore a reduced feed cost.

Although, this feedlot suspected that the sheath length may influence the various variables, the lack of any significant effect indicates that there is no point in the feedlot taking this measurement. At best the tendency for cattle with a small sheath to have a numerically better initial weight, ADG, final weight and carcass weight may be explored in future research.

When considering the correlations for all the data in the study it can be said that the initial body length measurement had the highest positive correlation with ADG (r = 0.329, P = 0.000) and therefore the feedlot can confidently select cattle based on this measurement. Initial weight has the highest negative correlation with DIF (r = - 0.668, P = 0.000), so the feedlot can confidently select cattle based on this measurement for a lower DIF. The correlations can be used to select cattle in the ideal weight category, however it serves no purpose for cattle in the sub-ideal weight category. The correlations can be used to select Brahman and composite brown breed types for better performance (ADG and DIF), however the correlations can only be used to select composite black cattle for a lower DIF.

The initial body length measurement (R^2 = 11.7%, P = 0.000) explains the largest variation for ADG for all the data in the study. While the initial weight (R^2 adjusted = 46.3%, P = 0.000) explained the largest variation for DIF for all the data in the study.

Based on the results from this study, the future feedlot performance of cattle can be predicted prior to their entry into the feedlot. Therefore, measurements such as initial weight, initial hip height, initial shoulder height and initial body length as well as the various ratios can be used to predict ADG and DIF. Cattle that achieve a higher ADG and a heavier final and carcass weight together with a lower number of DIF, will result in a higher income for the feedlot due to reduced feed costs. Although, there is a lack of previous data and therefore, more research is required to support these findings.

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Addendum A Correlations for all the data in the study

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Weight_f	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.965**	.967**	.837**	.160**	.550**	.329**	.319**	-.668**	.835**	.932**	.638**	.660**	.507**	.634**	.538**	.288**	-0.076	.384**	.210**
	P		0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.181	0.000	0.000
Weight_i/HH_i	r	.965**	1.000	.987**	.787**	.117*	.498**	.315**	.299**	-.634**	.775**	.923**	.610**	.483**	.357**	.414**	.382**	.282**	-0.051	.345**	.219**
	P	0.000		0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.373	0.000	0.000
Weight_i/SH_i	r	.967**	.987**	1.000	.793**	.126*	.504**	.319**	.300**	-.639**	.780**	.922**	.610**	.450**	.345**	.455**	.396**	.288**	-0.048	.357**	.221**
	P	0.000	0.000		0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.402	0.000	0.000
Weight_m	r	.837**	.787**	.793**	1.000	.675**	.856**	.430**	.366**	-.506**	.766**	.731**	.729**	.592**	.557**	.586**	.561**	.409**	-0.013	.445**	.339**
	P	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.819	0.000	0.000
Weight_m - Weight_i	r	.160**	.117*	.126*	.675**	1.000	.801**	.331**	.230**	-0.011	.256**	0.061	.455**	.177**	.321**	.202**	.286**	.348**	0.079	.285**	.329**
	P	0.005	0.039	0.027	0.000		0.000	0.000	0.000	0.843	0.000	0.287	0.000	0.002	0.000	0.000	0.000	0.000	0.165	0.000	0.000
Weight_m - Weight_i /DIF	r	.550**	.498**	.504**	.856**	.801**	1.000	.308**	.453**	-.572**	.568**	.428**	.554**	.423**	.412**	.431**	.404**	.299**	0.025	.342**	.242**
	P	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.667	0.000	0.000
Weight_f	r	.329**	.315**	.319**	.430**	.331**	.308**	1.000	.807**	-0.046	.316**	.278**	.414**	.215**	.269**	.218**	.294**	.954**	-0.060	.779**	.903**
	P	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.422	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.296	0.000	0.000
ADG	r	.319**	.299**	.300**	.366**	.230**	.453**	.807**	1.000	-.467**	.329**	.251**	.312**	.228**	.182**	.227**	.222**	.738**	-.127*	.667**	.669**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.025	0.000	0.000
DIF	r	-.668**	-.634**	-.639**	-.506**	-0.011	-.572**	-0.046	-.467**	1.000	-.586**	-.598**	-.302**	-.454**	-.226**	-.449**	-.277**	-0.004	0.081	-.185**	0.073
	P	0.000	0.000	0.000	0.000	0.843	0.000	0.422	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.951	0.152	0.001	0.199
BL_i	r	.835**	.775**	.780**	.766**	.256**	.568**	.316**	.329**	-.586**	1.000	.584**	.699**	.632**	.471**	.620**	.537**	.284**	-0.054	.395**	.203**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.348	0.000	0.000
Weight_i/BL_i	r	.932**	.923**	.922**	.731**	0.061	.428**	.278**	.251**	-.598**	.584**	1.000	.487**	.564**	.437**	.531**	.438**	.238**	-0.077	.304**	.178**
	P	0.000	0.000	0.000	0.000	0.287	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.175	0.000	0.002
BL_f	r	.638**	.610**	.610**	.729**	.455**	.554**	.414**	.312**	-.302**	.699**	.487**	1.000	.436**	.453**	.415**	.495**	.423**	0.073	.408**	.371**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.198	0.000	0.000
SH_i	r	.660**	.483**	.450**	.592**	.177**	.423**	.215**	.228**	-.454**	.632**	.564**	.436**	1.000	.761**	.887**	.717**	.163**	-.127*	.293**	0.088
	P	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.004	0.026	0.000	0.124
SH_f	r	.507**	.357**	.345**	.557**	.321**	.412**	.269**	.182**	-.226**	.471**	.437**	.453**	.761**	1.000	.718**	.805**	.246**	-0.042	.291**	.194**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.459	0.000	0.001
HH_i	r	.634**	.414**	.455**	.586**	.202**	.431**	.218**	.227**	-.449**	.620**	.531**	.415**	.887**	.718**	1.000	.752**	.172**	-.116*	.319**	0.088
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.002	0.042	0.000	0.120
HH_f	r	.538**	.382**	.396**	.561**	.286**	.404**	.294**	.222**	-.277**	.537**	.438**	.495**	.717**	.805**	.752**	1.000	.276**	-0.029	.346**	.211**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.615	0.000	0.000
Carcass_w	r	.288**	.282**	.288**	.409**	.348**	.299**	.954**	.738**	-0.004	.284**	.238**	.423**	.163**	.246**	.172**	.276**	1.000	.240**	.771**	.968**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.951	0.000	0.000	0.000	0.004	0.000	0.002	0.000		0.000	0.000	0.000
Dressing %	r	-0.076	-0.051	-0.048	-0.013	0.079	0.025	-0.060	-.127*	0.081	-0.054	-0.077	0.073	-.127*	-0.042	-.116*	-0.029	.240**	1.000	0.053	.296**
	P	0.181	0.373	0.402	0.819	0.165	0.667	0.296	0.025	0.152	0.348	0.175	0.198	0.026	0.459	0.042	0.615	0.000		0.356	0.000
Carcass_l	r	.384**	.345**	.357**	.445**	.285**	.342**	.779**	.667**	-.185**	.395**	.304**	.408**	.293**	.291**	.319**	.346**	.771**	0.053	1.000	.591**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.356		0.000
Carcass_c	r	.210**	.219**	.221**	.339**	.329**	.242**	.903**	.669**	0.073	.203**	.178**	.371**	0.088	.194**	0.088	.211**	.968**	.296**	.591**	1.000
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.199	0.000	0.002	0.000	0.124	0.001	0.120	0.000	0.000	0.000	0.000	
	N	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000	310.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Addendum B Correlations for cattle in the ideal weight category

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Weight_f	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.963**	.960**	.885**	.482**	.614**	.627**	.391**	-.580**	.823**	.908**	.756**	.591**	.642**	.642**	.635**	.645**	0.134	.606**	.591**
	P		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.178	0.000	0.000
Weight_i/HH_i	r	.963**	1.000	.987**	.838**	.438**	.581**	.596**	.387**	-.594**	.753**	.906**	.701**	.393**	.498**	.413**	.482**	.622**	0.156	.586**	.570**
	P	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.119	0.000	0.000
Weight_i/SH_i	r	.960**	.987**	1.000	.829**	.425**	.566**	.591**	.373**	-.576**	.757**	.899**	.696**	.344**	.464**	.443**	.479**	.614**	0.145	.588**	.560**
	P	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.145	0.000	0.000
Weight_m	r	.885**	.838**	.829**	1.000	.835**	.887**	.617**	.412**	-.516**	.807**	.747**	.782**	.585**	.656**	.613**	.630**	.647**	0.157	.592**	.601**
	P	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.115	0.000	0.000
Weight_m - Weight_i	r	.482**	.438**	.425**	.835**	1.000	.942**	.420**	.313**	-.284**	.545**	.332**	.578**	.401**	.475**	.395**	.434**	.455**	0.136	.398**	.432**
	P	0.000	0.000	0.000	0.000		0.000	0.000	0.001	0.004	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.172	0.000	0.000
Weight_m - Weight_i/DIF	r	.614**	.581**	.566**	.887**	.942**	1.000	.491**	.452**	-.563**	.610**	.488**	.622**	.439**	.499**	.436**	.450**	.541**	.202*	.473**	.511**
	P	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.000
Weight_F	r	.627**	.596**	.591**	.617**	.420**	.491**	1.000	.882**	-.361**	.555**	.550**	.601**	.414**	.508**	.441**	.531**	.934**	-0.053	.802**	.877**
	P	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.595	0.000	0.000
ADG	r	.391**	.387**	.373**	.412**	.313**	.452**	.882**	1.000	-.549**	.362**	.345**	.426**	.258**	.303**	.247*	.316**	.819**	-0.045	.696**	.769**
	P	0.000	0.000	0.000	0.000	0.001	0.000	0.000		0.000	0.000	0.000	0.000	0.009	0.002	0.012	0.001	0.000	0.654	0.000	0.000
DIF	r	-.580**	-.594**	-.576**	-.516**	-.284**	-.563**	-.361**	-.549**	1.000	-.478**	-.544**	-.415**	-.305**	-.262**	-.292**	-.240*	-.421**	-.251*	-.405**	-.383**
	P	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000		0.000	0.000	0.000	0.002	0.008	0.003	0.015	0.000	0.011	0.000	0.000
BL_i	r	.823**	.753**	.757**	.807**	.545**	.610**	.555**	.362**	-.478**	1.000	.512**	.836**	.591**	.608**	.652**	.674**	.584**	0.146	.573**	.527**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.144	0.000	0.000
Weight_i/BL_i	r	.908**	.906**	.899**	.747**	.332**	.488**	.550**	.345**	-.544**	.512**	1.000	.538**	.456**	.523**	.489**	.464**	.557**	0.105	.503**	.518**
	P	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.296	0.000	0.000
BL_f	r	.756**	.701**	.696**	.782**	.578**	.622**	.601**	.426**	-.415**	.836**	.538**	1.000	.543**	.662**	.574**	.692**	.639**	0.173	.538**	.607**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.081	0.000	0.000
SH_i	r	.591**	.393**	.344**	.585**	.401**	.439**	.414**	.258**	-.305**	.591**	.456**	.543**	1.000	.828**	.881**	.763**	.408**	0.042	.347**	.383**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.002	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.678	0.000	0.000
SH_f	r	.642**	.498**	.464**	.656**	.475**	.499**	.508**	.303**	-.262**	.608**	.523**	.662**	.828**	1.000	.761**	.826**	.510**	0.065	.408**	.493**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.008	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.515	0.000	0.000
HH_i	r	.642**	.413**	.443**	.613**	.395**	.436**	.441**	.247*	-.292**	.652**	.489**	.574**	.881**	.761**	1.000	.784**	.430**	0.020	.396**	.395**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.003	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.842	0.000	0.000
HH_f	r	.635**	.482**	.479**	.630**	.434**	.450**	.531**	.316**	-.240*	.674**	.464**	.692**	.763**	.826**	.784**	1.000	.532**	0.057	.454**	.505**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.015	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.567	0.000	0.000
Carcass_m	r	.645**	.622**	.614**	.647**	.455**	.541**	.934**	.819**	-.421**	.584**	.557**	.639**	.408**	.510**	.430**	.532**	1.000	.304**	.789**	.974**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.002	0.000	0.000
Dressing %	r	0.134	0.156	0.145	0.157	0.136	.202*	-0.053	-0.045	-.251*	0.146	0.105	0.173	0.042	0.065	0.020	0.057	.304**	1.000	0.069	.381**
	P	0.178	0.119	0.145	0.115	0.172	0.041	0.595	0.654	0.011	0.144	0.296	0.081	0.678	0.515	0.842	0.567	0.002		0.493	0.000
Carcass_l	r	.606**	.586**	.588**	.592**	.398**	.473**	.802**	.696**	-.405**	.573**	.503**	.538**	.347**	.408**	.396**	.454**	.789**	0.069	1.000	.634**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.493		0.000
Carcass_c	r	.591**	.570**	.560**	.601**	.432**	.511**	.877**	.769**	-.383**	.527**	.518**	.607**	.383**	.493**	.395**	.505**	.974**	.381**	.634**	1.000
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
	N	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000	102.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Addendum C Correlations for cattle in sub-ideal weight category

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Weight_f	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.928**	.936**	.697**	0.055	0.041	.285**	-.153*	0.087	.647**	.905**	.547**	.473**	.369**	.404**	.382**	.300**	0.057	.234**	.287**
	P		0.000	0.000	0.000	0.428	0.556	0.000	0.027	0.213	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.411	0.001	0.000
Weight_i/HH_i	r	.928**	1.000	.974**	.602**	-0.011	-0.028	.261**	-.153*	0.108	.556**	.867**	.521**	.179**	0.125	0.036	0.130	.280**	0.080	.154*	.295**
	P	0.000		0.000	0.000	0.870	0.684	0.000	0.027	0.121	0.000	0.000	0.000	0.010	0.073	0.607	0.060	0.000	0.250	0.026	0.000
Weight_i/SH_i	r	.936**	.974**	1.000	.622**	0.010	0.004	.265**	-.139*	0.053	.562**	.873**	.516**	0.135	0.121	0.118	.164*	.289**	0.102	.171*	.298**
	P	0.000	0.000		0.000	0.887	0.951	0.000	0.045	0.443	0.000	0.000	0.000	0.051	0.083	0.091	0.018	0.000	0.144	0.014	0.000
Weight_m	r	.697**	.602**	.622**	1.000	.755**	.719**	.369**	0.057	0.083	.556**	.571**	.643**	.408**	.416**	.394**	.412**	.370**	-0.006	.302**	.345**
	P	0.000	0.000	0.000		0.000	0.000	0.000	0.414	0.234	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.933	0.000	0.000
Weight_m - Weight_i	r	0.055	-0.011	0.010	.755**	1.000	.963**	.253**	.219**	0.036	.183**	-0.033	.394**	0.135	.241**	.179**	.224**	.241**	-0.061	.207**	.218**
	P	0.428	0.870	0.887	0.000		0.000	0.000	0.001	0.605	0.008	0.638	0.000	0.052	0.000	0.010	0.001	0.000	0.385	0.003	0.002
Weight_m - Weight_i /DIF	r	0.041	-0.028	0.004	.719**	.963**	1.000	.195**	.237**	-.206**	.171*	-0.043	.374**	0.112	.229**	.183**	.222**	.189**	-0.029	.168*	.167*
	P	0.556	0.684	0.951	0.000	0.000		0.005	0.001	0.003	0.014	0.538	0.000	0.109	0.001	0.008	0.001	0.006	0.683	0.015	0.016
Weight_f	r	.285**	.261**	.265**	.369**	.253**	.195**	1.000	.862**	.142*	.263**	.217**	.267**	.158*	0.103	.139*	.141*	.978**	-0.114	.773**	.948**
	P	0.000	0.000	0.000	0.000	0.000	0.005		0.000	0.040	0.000	0.002	0.000	0.023	0.137	0.046	0.042	0.000	0.101	0.000	0.000
ADG	r	-.153*	-.153*	-.139*	0.057	.219**	.237**	.862**	1.000	-.176*	-0.022	-.177*	0.030	-0.060	-0.063	-0.018	-0.016	.841**	-0.102	.674**	.813**
	P	0.027	0.027	0.045	0.414	0.001	0.001	0.000		0.011	0.749	0.010	0.666	0.393	0.367	0.791	0.814	0.000	0.144	0.000	0.000
DIF	r	0.087	0.108	0.053	0.083	0.036	-.206**	.142*	-.176*	1.000	0.077	0.062	0.057	0.100	0.069	-0.031	0.005	0.114	-.150*	0.066	0.121
	P	0.213	0.121	0.443	0.234	0.605	0.003	0.040	0.011		0.271	0.375	0.413	0.151	0.319	0.661	0.944	0.102	0.031	0.343	0.081
BL_i	r	.647**	.556**	.562**	.556**	.183**	.171*	.263**	-0.022	0.077	1.000	.263**	.567**	.425**	.284**	.380**	.322**	.271**	0.031	.260**	.241**
	P	0.000	0.000	0.000	0.000	0.008	0.014	0.000	0.749	0.271		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.660	0.000	0.000
Weight_i/BL_i	r	.905**	.867**	.873**	.571**	-0.033	-0.043	.217**	-.177*	0.062	.263**	1.000	.379**	.361**	.305**	.296**	.297**	.231**	0.055	.148*	.233**
	P	0.000	0.000	0.000	0.000	0.638	0.538	0.002	0.010	0.375	0.000		0.000	0.000	0.000	0.000	0.000	0.001	0.426	0.033	0.001
BL_f	r	.547**	.521**	.516**	.643**	.394**	.374**	.267**	0.030	0.057	.567**	.379**	1.000	.257**	.209**	.197**	.252**	.281**	0.062	.261**	.248**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.666	0.413	0.000	0.000		0.000	0.002	0.004	0.000	0.000	0.377	0.000	0.000
SH_i	r	.473**	.179**	0.135	.408**	0.135	0.112	.158*	-0.060	0.100	.425**	.361**	.257**	1.000	.737**	.843**	.660**	.142*	-0.085	.241**	0.084
	P	0.000	0.010	0.051	0.000	0.052	0.109	0.023	0.393	0.151	0.000	0.000	0.000		0.000	0.000	0.000	0.041	0.221	0.000	0.229
SH_f	r	.369**	0.125	0.121	.416**	.241**	.229**	0.103	-0.063	0.069	.284**	.305**	.209**	.737**	1.000	.689**	.773**	0.087	-0.083	.178*	0.035
	P	0.000	0.073	0.083	0.000	0.000	0.001	0.137	0.367	0.319	0.000	0.000	0.002	0.000		0.000	0.000	0.212	0.232	0.010	0.612
HH_i	r	.404**	0.036	0.118	.394**	.179**	.183**	.139*	-0.018	-0.031	.380**	.296**	.197**	.843**	.689**	1.000	.710**	0.130	-0.044	.255**	0.062
	P	0.000	0.607	0.091	0.000	0.010	0.008	0.046	0.791	0.661	0.000	0.000	0.004	0.000	0.000		0.000	0.061	0.525	0.000	0.374
HH_f	r	.382**	0.130	.164*	.412**	.224**	.222**	.141*	-0.016	0.005	.322**	.297**	.252**	.660**	.773**	.710**	1.000	.143*	0.007	.239**	0.083
	P	0.000	0.060	0.018	0.000	0.001	0.001	0.042	0.814	0.944	0.000	0.000	0.000	0.000	0.000	0.000		0.039	0.925	0.001	0.236
Carcass_m	r	.300**	.280**	.289**	.370**	.241**	.189**	.978**	.841**	0.114	.271**	.231**	.281**	.142*	0.087	0.130	.143*	1.000	0.094	.795**	.967**
	P	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.102	0.000	0.001	0.000	0.041	0.212	0.061	0.039		0.176	0.000	0.000
Dressing %	r	0.057	0.080	0.102	-0.006	-0.061	-0.029	-0.114	-0.102	-.150*	0.031	0.055	0.062	-0.085	-0.083	-0.044	0.007	0.094	1.000	0.104	0.079
	P	0.411	0.250	0.144	0.933	0.385	0.683	0.101	0.144	0.031	0.660	0.426	0.377	0.221	0.232	0.525	0.925	0.176		0.134	0.257
Carcass_l	r	.234**	.154*	.171*	.302**	.207**	.168*	.773**	.674**	0.066	.260**	.148*	.261**	.241**	.178*	.255**	.239**	.795**	0.104	1.000	.616**
	P	0.001	0.026	0.014	0.000	0.003	0.015	0.000	0.000	0.343	0.000	0.033	0.000	0.000	0.010	0.000	0.001	0.000	0.134		0.000
Carcass_c	r	.287**	.295**	.298**	.345**	.218**	.167*	.948**	.813**	0.121	.241**	.233**	.248**	0.084	0.035	0.062	0.083	.967**	0.079	.616**	1.000
	P	0.000	0.000	0.000	0.000	0.002	0.016	0.000	0.000	0.081	0.000	0.001	0.000	0.229	0.612	0.374	0.236	0.000	0.257	0.000	
	N	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000	208.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Addendum D Correlations for Brahman type cattle

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Final_w	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.960**	.961**	.769**	-0.003	.290*	.391**	.239*	-.406**	.705**	.921**	.568**	.640**	.511**	.515**	.444**	.284*	-0.134	.347**	0.228
	P		0.000	0.000	0.000	0.978	0.014	0.001	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.264	0.003	0.055
Weight_i/HH_i	r	.960**	1.000	.981**	.677**	-0.100	0.191	.332**	0.196	-.393**	.627**	.916**	.503**	.461**	.339**	.259*	.260*	0.225	-0.151	.257*	0.187
	P	0.000		0.000	0.000	0.406	0.110	0.005	0.102	0.001	0.000	0.000	0.000	0.000	0.004	0.029	0.029	0.059	0.209	0.030	0.118
Weight_i/SH_i	r	.961**	.981**	1.000	.700**	-0.065	0.228	.353**	0.215	-.413**	.612**	.924**	.497**	.407**	.334**	.317**	.293*	.256*	-0.120	.294*	0.214
	P	0.000	0.000		0.000	0.593	0.056	0.003	0.071	0.000	0.000	0.000	0.000	0.000	0.004	0.007	0.013	0.031	0.317	0.013	0.073
Weight_m	r	.769**	.677**	.700**	1.000	.636**	.765**	.434**	0.218	-0.190	.684**	.623**	.664**	.589**	.622**	.579**	.520**	.422**	0.120	.447**	.372**
	P	0.000	0.000	0.000		0.000	0.000	0.000	0.068	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.319	0.000	0.001
Weight_m - Weight_i	r	-0.003	-0.100	-0.065	.636**	1.000	.847**	0.208	0.052	0.193	0.219	-0.137	.353**	0.148	.357**	.284*	.277*	.318**	.350**	.281*	.307**
	P	0.978	0.406	0.593	0.000		0.000	0.082	0.666	0.107	0.066	0.254	0.002	0.217	0.002	0.016	0.019	0.007	0.003	0.018	0.009
Weight_m - Weight_i /DIF	r	.290*	0.191	0.228	.765**	.847**	1.000	.333**	.394**	-.318**	.373**	0.147	.447**	.281*	.382**	.381**	.364**	.333**	0.128	.379**	.282*
	P	0.014	0.110	0.056	0.000	0.000		0.004	0.001	0.007	0.001	0.223	0.000	0.017	0.001	0.001	0.002	0.005	0.286	0.001	0.017
Weight_f	r	.391**	.332**	.353**	.434**	0.208	.333**	1.000	.787**	-0.186	.360**	.313**	.394**	.310**	.278*	.340**	.411**	.922**	0.124	.796**	.875**
	P	0.001	0.005	0.003	0.000	0.082	0.004		0.000	0.120	0.002	0.008	0.001	0.008	0.019	0.004	0.000	0.000	0.302	0.000	0.000
ADG	r	.239*	0.196	0.215	0.218	0.052	.394**	.787**	1.000	-.637**	0.193	0.190	.241*	0.163	0.058	0.205	.256*	.604**	-0.186	.564**	.547**
	P	0.045	0.102	0.071	0.068	0.666	0.001	0.000		0.000	0.107	0.113	0.043	0.173	0.633	0.086	0.031	0.000	0.120	0.000	0.000
DIF	r	-.406**	-.393**	-.413**	-0.190	0.193	-.318**	-0.186	-.637**	1.000	-0.191	-.409**	-0.118	-0.173	0.013	-0.175	-0.105	0.042	.491**	-0.103	0.110
	P	0.000	0.001	0.000	0.112	0.107	0.007	0.120	0.000		0.111	0.000	0.326	0.149	0.916	0.145	0.382	0.730	0.000	0.391	0.360
BL_i	r	.705**	.627**	.612**	.684**	0.219	.373**	.360**	0.193	-0.191	1.000	.378**	.678**	.644**	.560**	.532**	.514**	.301*	-0.033	.365**	.247*
	P	0.000	0.000	0.000	0.000	0.066	0.001	0.002	0.107	0.111		0.001	0.000	0.000	0.000	0.000	0.000	0.011	0.782	0.002	0.038
Weight_i/BL_i	r	.921**	.916**	.924**	.623**	-0.137	0.147	.313**	0.190	-.409**	.378**	1.000	.364**	.486**	.357**	.376**	.288*	0.205	-0.158	.246*	0.166
	P	0.000	0.000	0.000	0.000	0.254	0.223	0.008	0.113	0.000	0.001		0.002	0.000	0.002	0.001	0.015	0.086	0.188	0.039	0.168
BL_f	r	.568**	.503**	.497**	.664**	.353**	.447**	.394**	.241*	-0.118	.678**	.364**	1.000	.482**	.487**	.411**	.519**	.409**	0.170	.450**	.354**
	P	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.043	0.326	0.000	0.002		0.000	0.000	0.000	0.000	0.000	0.156	0.000	0.002
SH_i	r	.640**	.461**	.407**	.589**	0.148	.281*	.310**	0.163	-0.173	.644**	.486**	.482**	1.000	.760**	.818**	.643**	0.224	-0.119	.324**	0.160
	P	0.000	0.000	0.000	0.000	0.217	0.017	0.008	0.173	0.149	0.000	0.000	0.000		0.000	0.000	0.000	0.061	0.322	0.006	0.183
SH_f	r	.511**	.339**	.334**	.622**	.357**	.382**	.278*	0.058	0.013	.560**	.357**	.487**	.760**	1.000	.734**	.809**	.290*	0.119	.314**	.256*
	P	0.000	0.004	0.004	0.000	0.002	0.001	0.019	0.633	0.916	0.000	0.002	0.000	0.000		0.000	0.000	0.014	0.323	0.008	0.031
HH_i	r	.515**	.259*	.317**	.579**	.284*	.381**	.340**	0.205	-0.175	.532**	.376**	.411**	.818**	.734**	1.000	.741**	.293*	-0.010	.413**	0.218
	P	0.000	0.029	0.007	0.000	0.016	0.001	0.004	0.086	0.145	0.000	0.001	0.000	0.000	0.000		0.000	0.013	0.933	0.000	0.067
HH_f	r	.444**	.260*	.293*	.520**	.277*	.364**	.411**	.256*	-0.105	.514**	.288*	.519**	.643**	.809**	.741**	1.000	.442**	0.211	.478**	.390**
	P	0.000	0.029	0.013	0.000	0.019	0.002	0.000	0.031	0.382	0.000	0.015	0.000	0.000	0.000	0.000		0.000	0.077	0.000	0.001
Carcass_m	r	.284*	0.225	.256*	.422**	.318**	.333**	.922**	.604**	0.042	.301*	0.205	.409**	0.224	.290*	.293*	.442**	1.000	.497**	.822**	.978**
	P	0.016	0.059	0.031	0.000	0.007	0.005	0.000	0.000	0.730	0.011	0.086	0.000	0.061	0.014	0.013	0.000		0.000	0.000	0.000
Dressing %	r	-0.134	-0.151	-0.120	0.120	.350**	0.128	0.124	-0.186	.491**	-0.033	-0.158	0.170	-0.119	0.119	-0.010	0.211	.497**	1.000	.330**	.548**
	P	0.264	0.209	0.317	0.319	0.003	0.286	0.302	0.120	0.000	0.782	0.188	0.156	0.322	0.323	0.933	0.077	0.000		0.005	0.000
Carcass_l	r	.347**	.257*	.294*	.447**	.281*	.379**	.796**	.564**	-0.103	.365**	.246*	.450**	.324**	.314**	.413**	.478**	.822**	.330**	1.000	.692**
	P	0.003	0.030	0.013	0.000	0.018	0.001	0.000	0.000	0.391	0.002	0.039	0.000	0.006	0.008	0.000	0.000	0.000	0.005		0.000
Carcass_c	r	0.228	0.187	0.214	.372**	.307**	.282*	.875**	.547**	0.110	.247*	0.166	.354**	0.160	.256*	0.218	.390**	.978**	.548**	.692**	1.000
	P	0.055	0.118	0.073	0.001	0.009	0.017	0.000	0.000	0.360	0.038	0.168	0.002	0.183	0.031	0.067	0.001	0.000	0.000	0.000	
	N	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000	71.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Addendum E Correlations for composite brown type cattle

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Weight_f	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.965**	.967**	.835**	.154*	.565**	.300**	.297**	-.714**	.844**	.935**	.616**	.642**	.534**	.621**	.578**	.252**	-0.135	.364**	.173*
	P		0.000	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.072	0.000	0.020
Weight_i/HH_i	r	.965**	1.000	.987**	.793**	0.125	.515**	.297**	.277**	-.666**	.782**	.927**	.597**	.463**	.397**	.399**	.436**	.258**	-0.100	.329**	.194**
	P	0.000		0.000	0.000	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.181	0.000	0.009
Weight_i/SH_i	r	.967**	.987**	1.000	.790**	0.118	.508**	.293**	.265**	-.664**	.788**	.925**	.594**	.430**	.383**	.443**	.442**	.255**	-0.099	.326**	.191*
	P	0.000	0.000		0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.187	0.000	0.010
Weight_m	r	.835**	.793**	.790**	1.000	.673**	.875**	.416**	.373**	-.530**	.754**	.745**	.707**	.582**	.608**	.554**	.611**	.376**	-0.096	.410**	.310**
	P	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.201	0.000	0.000
Weight_m - Weight_i	r	.154*	0.125	0.118	.673**	1.000	.812**	.343**	.271**	0.008	.219**	0.080	.442**	.183*	.374**	.160*	.321**	.336**	0.009	.248**	.323**
	P	0.039	0.095	0.114	0.000		0.000	0.000	0.000	0.913	0.003	0.287	0.000	0.014	0.000	0.033	0.000	0.000	0.908	0.001	0.000
Weight_m - Weight_i/DIF	r	.565**	.515**	.508**	.875**	.812**	1.000	.327**	.457**	-.545**	.576**	.454**	.550**	.463**	.518**	.428**	.495**	.296**	-0.072	.359**	.230**
	P	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.336	0.000	0.002
Weight_f	r	.300**	.297**	.293**	.416**	.343**	.327**	1.000	.841**	-0.008	.288**	.252**	.364**	.182*	.283**	.166*	.246**	.970**	-0.019	.751**	.927**
	P	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.921	0.000	0.001	0.000	0.015	0.000	0.026	0.001	0.000	0.804	0.000	0.000
ADG	r	.297**	.277**	.265**	.373**	.271**	.457**	.841**	1.000	-.372**	.331**	.217**	.264**	.249**	.264**	.212**	.235**	.803**	-0.056	.727**	.727**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.004	0.000	0.001	0.000	0.004	0.002	0.000	0.459	0.000	0.000
DIF	r	-.714**	-.666**	-.664**	-.530**	0.008	-.545**	-0.008	-.372**	1.000	-.651**	-.633**	-.287**	-.533**	-.337**	-.509**	-.388**	0.033	0.129	-.236**	0.131
	P	0.000	0.000	0.000	0.000	0.913	0.000	0.921	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.663	0.084	0.001	0.080
BL_i	r	.844**	.782**	.788**	.754**	.219**	.576**	.288**	.331**	-.651**	1.000	.603**	.681**	.625**	.495**	.622**	.579**	.245**	-0.116	.370**	.162*
	P	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.121	0.000	0.030
Weight_i/BL_i	r	.935**	.927**	.925**	.745**	0.080	.454**	.252**	.217**	-.633**	.603**	1.000	.472**	.546**	.463**	.517**	.476**	.208**	-0.128	.288**	.148*
	P	0.000	0.000	0.000	0.000	0.287	0.000	0.001	0.004	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.005	0.087	0.000	0.048
BL_f	r	.616**	.597**	.594**	.707**	.442**	.550**	.364**	.264**	-.287**	.681**	.472**	1.000	.396**	.489**	.370**	.520**	.371**	0.090	.302**	.341**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.232	0.000	0.000
SH_i	r	.642**	.463**	.430**	.582**	.183*	.463**	.182*	.249**	-.533**	.625**	.546**	.396**	1.000	.746**	.882**	.726**	0.126	-.187*	.306**	0.041
	P	0.000	0.000	0.000	0.000	0.014	0.000	0.015	0.001	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.092	0.012	0.000	0.590
SH_f	r	.534**	.397**	.383**	.608**	.374**	.518**	.283**	.264**	-.337**	.495**	.463**	.489**	.746**	1.000	.687**	.789**	.257**	-0.059	.319**	.197**
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.001	0.434	0.000	0.008
HH_I	r	.621**	.399**	.443**	.554**	.160*	.428**	.166*	.212**	-.509**	.622**	.517**	.370**	.882**	.687**	1.000	.729**	0.112	-.181*	.291**	0.029
	P	0.000	0.000	0.000	0.000	0.033	0.000	0.026	0.004	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.135	0.015	0.000	0.702
HH_f	r	.578**	.436**	.442**	.611**	.321**	.495**	.246**	.235**	-.388**	.579**	.476**	.520**	.726**	.789**	.729**	1.000	.224**	-0.044	.302**	.162*
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.003	0.560	0.000	0.030
Carcass_m	r	.252**	.258**	.255**	.376**	.336**	.296**	.970**	.803**	0.033	.245**	.208**	.371**	0.126	.257**	0.112	.224**	1.000	.226**	.737**	.970**
	P	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.663	0.001	0.005	0.000	0.092	0.001	0.135	0.003		0.002	0.000	0.000
Dressing %	r	-0.135	-0.100	-0.099	-0.096	0.009	-0.072	-0.019	-0.056	0.129	-0.116	-0.128	0.090	-.187*	-0.059	-.181*	-0.044	.226**	1.000	0.029	.269**
	P	0.072	0.181	0.187	0.201	0.908	0.336	0.804	0.459	0.084	0.121	0.087	0.232	0.012	0.434	0.015	0.560	0.002		0.697	0.000
Carcass_l	r	.364**	.329**	.326**	.410**	.248**	.359**	.751**	.727**	-.236**	.370**	.288**	.302**	.306**	.319**	.291**	.302**	.737**	0.029	1.000	.553**
	P	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.697		0.000
Carcass_c	r	.173*	.194**	.191*	.310**	.323**	.230**	.927**	.727**	0.131	.162*	.148*	.341**	0.041	.197**	0.029	.162*	.970**	.269**	.553**	1.000
	P	0.020	0.009	0.010	0.000	0.000	0.002	0.000	0.000	0.080	0.030	0.048	0.000	0.590	0.008	0.702	0.030	0.000	0.000	0.000	
	N	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000	179.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Addendum F Correlations for composite black type cattle

		Weight_i	Weight_i/HH_i	Weight_i/SH_i	Weight_m	Weight_m - Weight_i	Weight_m - Weight_i /DIF	Weight_f	ADG	DIF	BL_i	Weight_i/BL_i	BL_f	SH_i	SH_f	HH_i	HH_f	Carcass_m	Dressing %	Carcass_l	Carcass_c
Weight_i	r	1.000	.971**	.975**	.862**	0.258	.531**	0.162	0.120	-.593**	.870**	.950**	.667**	.775**	.595**	.786**	.630**	0.160	-0.039	0.211	0.108
	P		0.000	0.000	0.000	0.117	0.001	0.331	0.473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.337	0.815	0.203	0.518
Weight_i/HH_i	r	.971**	1.000	.991**	.815**	0.207	.491**	0.158	0.135	-.595**	.840**	.929**	.650**	.631**	.443**	.619**	.484**	0.178	0.021	0.204	0.140
	P	0.000		0.000	0.000	0.212	0.002	0.343	0.419	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.002	0.285	0.901	0.220	0.403
Weight_i/SH_i	r	.975**	.991**	1.000	.822**	0.215	.488**	0.173	0.136	-.576**	.847**	.929**	.657**	.616**	.447**	.649**	.516**	0.183	-0.013	0.231	0.132
	P	0.000	0.000		0.000	0.194	0.002	0.299	0.417	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.001	0.271	0.937	0.164	0.431
Weight_m	r	.862**	.815**	.822**	1.000	.712**	.801**	0.286	0.175	-.441**	.757**	.806**	.782**	.706**	.601**	.728**	.660**	0.260	-0.154	0.274	0.208
	P	0.000	0.000	0.000		0.000	0.000	0.082	0.292	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.115	0.356	0.096	0.209
Weight_m - Weight_i	r	0.258	0.207	0.215	.712**	1.000	.792**	.321*	0.168	-0.018	0.238	0.220	.566**	0.273	.321*	0.299	.386*	0.274	-0.240	0.230	0.248
	P	0.117	0.212	0.194	0.000		0.000	0.049	0.313	0.913	0.151	0.185	0.000	0.097	0.049	0.068	0.017	0.096	0.147	0.165	0.134
Weight_m - Weight_i /DIF	r	.531**	.491**	.488**	.801**	.792**	1.000	-0.018	0.215	-.601**	.479**	.485**	.526**	.480**	.372*	.481**	.367*	-0.022	0.008	-0.053	-0.005
	P	0.001	0.002	0.002	0.000	0.000		0.914	0.196	0.000	0.002	0.002	0.001	0.002	0.021	0.002	0.023	0.895	0.963	0.754	0.975
Weight_f	r	0.162	0.158	0.173	0.286	.321*	-0.018	1.000	.681**	.355*	0.162	0.136	.576**	0.076	0.169	0.111	0.304	.936**	-.502**	.830**	.852**
	P	0.331	0.343	0.299	0.082	0.049	0.914		0.000	0.029	0.331	0.415	0.000	0.650	0.311	0.508	0.064	0.000	0.001	0.000	0.000
ADG	r	0.120	0.135	0.136	0.175	0.168	0.215	.681**	1.000	-0.224	0.165	0.087	.404*	0.063	0.019	0.065	0.087	.634**	-.335*	.482**	.629**
	P	0.473	0.419	0.417	0.292	0.313	0.196	0.000		0.176	0.322	0.604	0.012	0.709	0.911	0.698	0.602	0.000	0.040	0.002	0.000
DIF	r	-.593**	-.595**	-.576**	-.441**	-0.018	-.601**	.355*	-0.224	1.000	-.532**	-.566**	-0.220	-.489**	-0.225	-.445**	-0.148	0.287	-.325*	0.307	0.227
	P	0.000	0.000	0.000	0.006	0.913	0.000	0.029	0.176		0.001	0.000	0.184	0.002	0.175	0.005	0.374	0.081	0.046	0.060	0.170
BL_i	r	.870**	.840**	.847**	.757**	0.238	.479**	0.162	0.165	-.532**	1.000	.675**	.656**	.677**	.533**	.696**	.650**	0.110	-0.161	0.216	0.039
	P	0.000	0.000	0.000	0.000	0.151	0.002	0.331	0.322	0.001		0.000	0.000	0.000	0.001	0.000	0.000	0.513	0.335	0.193	0.815
Weight_i/BL_i	r	.950**	.929**	.929**	.806**	0.220	.485**	0.136	0.087	-.566**	.675**	1.000	.582**	.734**	.551**	.736**	.530**	0.168	0.051	0.181	0.133
	P	0.000	0.000	0.000	0.000	0.185	0.002	0.415	0.604	0.000	0.000		0.000	0.000	0.000	0.000	0.001	0.313	0.761	0.276	0.426
BL_f	r	.667**	.650**	.657**	.782**	.566**	.526**	.576**	.404*	-0.220	.656**	.582**	1.000	.489**	.516**	.506**	.578**	.539**	-0.280	.484**	.489**
	P	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.012	0.184	0.000	0.000		0.002	0.001	0.001	0.000	0.000	0.089	0.002	0.002
SH_i	r	.775**	.631**	.616**	.706**	0.273	.480**	0.076	0.063	-.489**	.677**	.734**	.489**	1.000	.827**	.940**	.762**	0.046	-0.079	0.096	0.006
	P	0.000	0.000	0.000	0.000	0.097	0.002	0.650	0.709	0.002	0.000	0.000	0.002		0.000	0.000	0.000	0.782	0.639	0.567	0.971
SH_f	r	.595**	.443**	.447**	.601**	.321*	.372*	0.169	0.019	-0.225	.533**	.551**	.516**	.827**	1.000	.819**	.815**	0.112	-0.200	0.230	0.030
	P	0.000	0.005	0.005	0.000	0.049	0.021	0.311	0.911	0.175	0.001	0.000	0.001	0.000		0.000	0.000	0.501	0.227	0.165	0.858
HH_i	r	.786**	.619**	.649**	.728**	0.299	.481**	0.111	0.065	-.445**	.696**	.736**	.506**	.940**	.819**	1.000	.824**	0.057	-0.161	0.164	-0.017
	P	0.000	0.000	0.000	0.000	0.068	0.002	0.508	0.698	0.005	0.000	0.000	0.001	0.000	0.000		0.000	0.733	0.333	0.324	0.920
HH_f	r	.630**	.484**	.516**	.660**	.386*	.367*	0.304	0.087	-0.148	.650**	.530**	.578**	.762**	.815**	.824**	1.000	0.217	-0.314	.341*	0.110
	P	0.000	0.002	0.001	0.000	0.017	0.023	0.064	0.602	0.374	0.000	0.001	0.000	0.000	0.000	0.000		0.190	0.055	0.036	0.509
Carcass_m	r	0.160	0.178	0.183	0.260	0.274	-0.022	.936**	.634**	0.287	0.110	0.168	.539**	0.046	0.112	0.057	0.217	1.000	-0.169	.807**	.948**
	P	0.337	0.285	0.271	0.115	0.096	0.895	0.000	0.000	0.081	0.513	0.313	0.000	0.782	0.501	0.733	0.190		0.309	0.000	0.000
Dressing %	r	-0.039	0.021	-0.013	-0.154	-0.240	0.008	-.502**	-.335*	-.325*	-0.161	0.051	-0.280	-0.079	-0.200	-0.161	-0.314	-0.169	1.000	-.323*	-0.073
	P	0.815	0.901	0.937	0.356	0.147	0.963	0.001	0.040	0.046	0.335	0.761	0.089	0.639	0.227	0.333	0.055	0.309		0.048	0.662
Carcass_l	r	0.211	0.204	0.231	0.274	0.230	-0.053	.830**	.482**	0.307	0.216	0.181	.484**	0.096	0.230	0.164	.341*	.807**	-.323*	1.000	.579**
	P	0.203	0.220	0.164	0.096	0.165	0.754	0.000	0.002	0.060	0.193	0.276	0.002	0.567	0.165	0.324	0.036	0.000	0.048		0.000
Carcass_c	r	0.108	0.140	0.132	0.208	0.248	-0.005	.852**	.629**	0.227	0.039	0.133	.489**	0.006	0.030	-0.017	0.110	.948**	-0.073	.579**	1.000
	P	0.518	0.403	0.431	0.209	0.134	0.975	0.000	0.000	0.170	0.815	0.426	0.002	0.971	0.858	0.920	0.509	0.000	0.662	0.000	
	N	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).