

Analyses of the variation in feed efficiency measures of MOET-produced Droughtmaster SA cattle in intensive and extensive feeding systems

by

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Declaration

I, Elandie du Preez, 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 own work and has not previously been submitted by me for a degree at any other University.



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Abstract

Feed is one of the major expenses in the beef industry, so it is beneficial to select animals that consume less feed for the same level of production. This study aimed to compare the feed efficiency and residual feed intake of Droughtmaster SA weaners of different double muscling genotypes (F94L and NT821) produced by multiple ovulation embryo transfer (MOET) between the GrowSafe system and veld. In this study, several feed efficiency measures were recorded from 150 Droughtmaster SA bulls and heifers over two years. Primary data obtained for evaluation showed that there was a positive association between the double muscling mutations and low residual feed intake (efficient animal). Sex (male and female), residual feed intake rank, double muscling mutation (F94L, NT821, None), and other efficiency variables were analysed using the General Linear Model using the SPSS Software (Version 29). The results confirmed that variations in residual feed intake do exist. The research also suggested that the ranking of efficient animals in the GrowSafe system and on veld remained the same. The results of the study validated that the GrowSafe system can identify the same bulls and heifers with low RFI as on veld, which indicated that the performance testing period can be significantly reduced and cattle can be marketed at an increased price in a shorter time frame. There was no significant difference in efficiency parameter ranking of weaners in the intensive feeding system (GrowSafe System) versus on veld, as well as no significant difference between efficiency parameter measures of different double muscling genotypes when the entire population of cattle were accounted for. Significant differences did exist between efficiency parameter measures of different double muscling genotypes within gender groups. Subsequently, this may lead to decreased reproductive efficiency, since Droughtmaster SA cattle are an early maturing breed. The results of this study may have a practical implication on breeding goals, since selecting more feed-efficient animals may result in less efficient animals in terms of reproduction.

Keywords: Double muscling; Droughtmaster SA; feed efficiency; GrowSafe system; multiple ovulation embryo transfer; reproductive efficiency; residual feed intake

List of abbreviations

ACTH	Adrenocorticotropic hormone
ADG	Average daily gain
ATP	Adenosine triphosphate
BCS	Body condition score
BMR	Basal metabolic weight
BW	Body weight
CP	Crude protein
CPD	Crude protein digestibility
DMD	Dry matter digestibility
DMI	Dry matter intake
DSP	Daily sperm production
ETC	Electron transport chain
FCR	Feed conversion ratio
GDF8	Growth differentiation factor 8
GIT	Gastrointestinal tract
HP	Heat production
HPA-axis	Hypothalamic-pituitary-adrenal axis
IGF-1	Insulin-like growth factor 1
KR	Kleiber ratio
LMI scale	Livestock Measuring Instruments scale
LM	Longissimus muscle
LW	Live weight
ME	Metabolizable energy

MOET	Multiple ovulation and embryo transfer
MSTN	Myostatin
MY	Methane yield
NDF	Natural detergent fibre
PCR	Polymerase chain reaction
PEG	Partial efficiency of growth
RADG	Residual average daily gain
RE	Retained energy
RFI	Residual feed intake
RFT	Rump fat thickness
RGR	Relative growth rate
ROS	Reactive oxygen species
SC	Scrotal circumference
SCFA	Short chain fatty acid
SNP	Single nucleotide polymorphism
TMR	Total mixed ration

Table of Contents

Declaration	ii
Acknowledgements	iii
Abstract	iv
List of abbreviations	v
List of figures	x
List of Tables	xi
Chapter 1	1
Literature review	1
1.1 Introduction	1
1.2 Measures of feed efficiency.....	3
1.2.1 Feed conversion ratio	4
1.2.2 Partial efficiency of growth.....	5
1.2.3 Relative growth rate	6
1.2.4 Kleiber ratio.....	8
1.2.5 Residual feed intake.....	8
1.2.6 Residual average daily gain.....	11
1.3 Role of embryo transfer in beef cattle for feed efficiency.....	11
1.4 Factors that cause variation in Residual feed intake on a physiological basis.....	12
1.4.1 Energy metabolism, mitochondrial function and stress physiology.....	13
1.4.2 Body composition, visceral organs and protein turnover.....	15
1.4.3 Physical activity and feeding behaviour.....	16
1.4.4 Digestibility and methane emission.....	17
1.4.5 Rumen microbiome.....	18
1.4.6 Heat production	20
1.4.7 Endocrine system	21
1.5 Economic benefit of using RFI.....	22
1.6 Environmental benefit of RFI	23
1.7 Feed efficiency on veld	25
1.8 The value of performance testing.....	27
1.9 How double muscling affects RFI.....	28
1.9.1 F94L double muscling mutation.....	29

1.9.2 NT821 double muscling mutation.....	30
1.10 Droughtmaster Cattle	31
1.11 Conclusion.....	32
Chapter 2.....	33
Materials and Methods	33
2.1 Introduction	33
2.3 Experimental location	34
2.4 Materials and Methods.....	34
2.4.1 Experimental Design	34
2.4.2 The GrowSafe system and ration provided	35
2.4.3 Procedure of Multiple Ovulation and Embryo Transfer	38
2.4.4 Real-time Ultrasound	38
2.4.5 Scrotal measurements	39
2.4.6 Hip height measurement	39
2.5 Statistical analyses	40
Chapter 3.....	41
Results and Discussion	41
3.1 Introduction	41
3.2 Descriptive Statistics of Measurements in the GrowSafe system (First phase of the study trial)	42
3.3 Measurements in the GrowSafe system (phase one) with Statistical Significance.	44
3.3.1 Residual feed intake (RFI)	44
3.3.2) RFI rank	45
3.3.3 Start weight.....	47
3.3.5 End weight	48
3.3.6 Average daily gain	49
3.3.7 Dry matter intake	51
3.4 Descriptive statistics of measurements in the veld (Second phase of the study trial).	52
3.5 Measurements on veld (phase two) with Statistical Significance.	55
3.5.1 P8 fat	55
3.5.2 Rib fat	56
3.5.3 Eye muscle area	58
3.5.4 Weight measured on veld	60
3.5.5 Daily gain on veld	61
3.5.6 Difference in weight gain between end weight in system and veld weight	62

3.5.7 Intermuscular fat percentage (IMF %)	63
3.5.8 Hip height	64
3.5.9 Scrotal size	64
Chapter 4	67
Conclusion	67
Chapter 5	69
Recommendations	69
References	70

List of figures

Figure 1.1 Residual feed intake plot in beef cattle, of predicted versus actual dry material (DM) intake (kg/day). (From: https://www.thebeefsite.com/articles/1675/residual-feed-intake-a-system-for-efficiency/ . Accessed on 28 March 2022.)	10
Figure 1.2 Factors that contribute to variation in residual feed intake (RFI). From (Herd and Arthur, 2009).	13
Figure 1.3 Effect of improved efficiency in beef cattle on environment and biodiversity. Adapted from (Terry et al., 2020).	25
Figure 2.1 Droughtmaster SA cattle in GrowSafe® system. Photo taken by Elandie du Preez in Standerton, October 2022	33
Figure 2.2 Sample of ration that cattle are fed in the GrowSafe® system. Photo taken by Elandie du Preez in Standerton, October 2022.	37
Figure 2.3 Droughtmaster SA standing at water trough. Photos taken by Elandie du Preez in Standerton, October 2022.	37
Figure 3.1 Regression line of RFI and RFI rank.	45
Figure 3.2 Regression line between ADG and RFI rank.	51
Figure 3.3 Regression line between DMI and RFI rank.	52
Figure 3.4 Regression line of RFI rank to rib fat.	58
Figure 3.5 Regression line of RFI rank and eye muscle area.	60
Figure 3.6 Regression line of IMF % and RFI rank.	63
Figure 3.7 Regression line between scrotal size and RFI rank.	66

List of Tables

Table 1.1 Genetic correlations between different measures of feed efficiency in growing beef cattle, compiled from previous research; ((Berry and Crowley, 2013) ^a ; (Carstens and Tedeschi, 2006) ^b (Arthur and Herd, 2005) ^c).	4
Table 1.2 Traits used in measuring efficiency in growing beef cattle.	7
Table 1.3 Factors that cause variation in feed efficiency and its correlation with Residual feed intake. From (Hendriks et al., 2013).	20
Table 1.4 Summary of the characteristics and traits of the Droughtmaster SA. Adapted from (Webb, 2022)	31
Table 2.1 Composition of the ration fed fed (on a dry matter basis) to cattle in the GrowSafe system (provided from TMR analyses from UP NutriLab, 1 August 2023)	36
Table 3.1 Descriptive statistics of Droughtmaster SA cattle in the GrowSafe system considering sex and double muscling mutation.	43
Table 3.2 Correlations between RFI and other variables.	44
Table 3.3 Correlations between RFI rank and other variables.	46
Table 3.4 Correlations of RFI rank to other variables with Bootstrap method.	46
Table 3.5 Pairwise comparisons of start weight.	47
Table 3.6 Correlations between end weight and other variables.	49
Table 3.7 Pairwise comparisons of average daily gain (ADG).	50
Table 3.8 Descriptive statistics of Droughtmaster SA cattle in veld considering sex and double muscling mutation.	54
Table 3.9 Test of between-subjects effects of sex on other variables.	55
Table 3.10 Pairwise comparisons between P8 fat, sex and double muscling mutation.	56
Table 3.11 Descriptive statistics of rib fat, sex and double muscling mutation.	57

Table 3.12 Pairwise comparisons between eye muscle area, sex and double muscling mutation.	59
Table 3.13 Pairwise comparisons between weight measured on veld, sex and double muscling mutation.	61
Table 3.14 Correlations between daily gain on veld and other variables.	62
Table 3.15 Correlations between the difference in weight gain between end weight in the system and veld weight, and other variables.	62
Table 3.16 Correlations between hip height in male cattle and other variables	64
Table 3.17 Correlations of scrotal size and other variables.	65

Chapter 1

Literature review

1.1 Introduction

The beef industry is an important contributor to food security, supplying several crucial nutrients, protein and energy to a growing population (Gerber et al., 2015). South Africa's beef industry consists of a non-commercial and commercial beef sector. Following the broiler industry, the beef industry is the fastest growing sector in agriculture. Recent numbers showed that the average gross value of beef produced during the last decade was R 30,2 billion per annum (Agriculture, 2022). According to statistics on beef production per province in South Africa, Mpumalanga had the largest percentage (21%) of beef production, followed by the Free State (18%) and then Gauteng (17%) (Agriculture, 2022). During the last ten years, the total amount of beef produced added up to 9,8 million tons. The commercial farmers of beef production in South Africa are approximately 22 000 and provide employment opportunities to 138 000 people. South Africa became a net exporter in terms of beef production in 2016, and the largest amount was exported to China (28%). The per capita consumption of beef in South Africa during 2017/2018, was 18.02 kg per year (Council, 2021) It is a known fact that the global population is increasing, and with a higher number of people, comes an increased demand for food. The Food and Agricultural Organisation of the United Nations predict that there will need to be an increase of no less than 70 % of global food production to sufficiently feed the estimated population of 2050 (Rahman, 2016). With a rise in food production, comes a great responsibility to sustain the environment and valuable resources, whilst still finding solutions to produce more food. An important part in efficient production is to select animals for breeding that are superior for feed efficiency.

The cost of feeding cattle is the single largest expense in the beef production industry (Herd et al., 2003a, Arthur and Herd, 2005, Carstens and Tedeschi, 2006, Kenny et al., 2018). It is thus crucial to improve efficiency, and more specifically feed efficiency, in beef production systems to reduce economic losses. Feed costs can range between 50-70% of production costs in beef enterprises (Arthur et al., 2004). By decreasing the cost of production, profitability is improved. The profit of a livestock production system is dependent on several inputs and outputs. It will be economically beneficial if the outputs are increased, whilst the same level of production and inputs are maintained (Arthur et al., 2004). The contribution of animal proteins to the global supply varies between different species and production systems. Small ruminants contribute the least, providing only 4% of global animal protein.

Pigs account for 20% of the global animal protein supply. Chickens, including both meat and eggs, supply 31% of the world's animal protein. The largest contributors are buffaloes and cattle, which together provide 45% of global animal protein (Mottet et al., 2017). The beef cattle population consists of approximately 1 billion head of cattle globally, and in comparison to other livestock species (poultry and pigs) have the poorest efficiency with regards to production (Terry et al., 2020).

General beef cattle efficiency can be indicated in two different ways. Firstly, beef cattle efficiency can be indicated by general production efficiency. This includes several aspects that will increase the output of production, for example, slaughtering of cattle at the correct weight and age, or cow-calf production efficiency that can be described as the ratio of the weight of calf weaned per unit of consumed forage (Terry et al., 2020). The second aspect would be feed efficiency, which is a multifactorial trait, that is influenced by several factors such as the environment, diet, maintenance requirements, gestation period and body size (Ojo et al., 2024). Feed efficiency can be described by several mathematical and biological characteristics of efficiency (Archer et al., 1999). Measures of feed efficiency include feed conversion ratio (FCR), maintenance efficiency, partial efficiency of growth, residual feed intake (RFI) and efficiency of lactation (Archer et al., 1999, Arthur et al., 2004, Carstens and Tedeschi, 2006). The genetic and phenotypic correlations between these measurements are high and a difference in some of the measurements of feed efficiency and other traits (growth traits) do exist (Arthur and Herd, 2005) .

There are several reasons why beef cattle are less efficient than other livestock species. This includes, amongst others, that beef cattle are fed higher fibre diets, have higher maintenance requirements, have microbial methane production and are more challenging to compare at similar body compositions (Kenny et al., 2018, Terry et al., 2020). These factors, and possible solutions, will be discussed further.

Methane is one of the most considerable greenhouse gasses that are produced by livestock, and the majority is produced during fermentation in ruminants. Livestock manure produces nitrous oxide as well as methane, and these greenhouse gases have, respectively, a 310 and 21 times greater potential towards global warming than carbon dioxide (Arthur and Herd, 2005). Global warming potential is a measure of the amount of energy one tonne of emitted gas will absorb over a set period of time, compared to that of carbon dioxide. A higher global warming potential indicates an increased warming effect on the Earth. Recent values indicate that methane has a global warming potential of 27 (100 year time period) and that nitrous oxide has a global warming potential of 273 (100 year time period) (Protocol, 2024). A more efficient animal will eat less and therefore rumen retention time will be increased, resulting in an increase in methane production per kg feed consumed. (Berry and Crowley,

2013). About 70 % of phosphorus and between 55-95 % of nitrogen ingested by livestock species are excreted through faeces/urine. The manure can either be used to fertilize veldt, but a substantial part is lost to the environment through runoff, leaching and gaseous emissions (Menzi et al., 2010). There is a considerable difference between the greenhouse gas emissions of beef cattle and dairy cattle. This can be explained by the fact that specialized beef herds produce mainly meat, while dairy herds produce milk and meat. Beef herds produce 68 kg CO₂-eq per kg of carcass weight, whereas dairy herds produce 18 kg CO₂-eq per kg of carcass weight (Gerber et al., 2015).

1.2 Measures of feed efficiency

There are several definitions to describe feed efficiency, but an important aspect to remember is that efficiency is dependent on a combination of traits and that these traits need to be expressed in the breeding herd as well as the slaughter generation (Archer et al., 1999). Efficiency can be defined as a ratio between inputs and outputs (Carstens and Tedeschi, 2006). Intake and utilization of feed by livestock include several biological processes as well as environmental interactions (Arthur and Herd, 2005).

There are a few measurements of efficiency that have been refined and are utilized to improve the efficiency of production. Many of these measurements of efficiency are genetically and phenotypically correlated, as shown in **Table 1.1**, and range from medium to high. A medium correlation typically falls between the range of 0.3-0.5 and indicates that there is either a positive or negative moderate relationship between two variables, whereas a high correlation suggests that two variables have a strong relationship with each other and usually ranges from 0.7-1. It is crucial to understand that the expression of traits for feed efficiency is dependent on the animal's stage of maturity when the trait was measured. For example, the genetic correlation of residual feed intake (RFI) is high when measured between a young animal and an adult, whereas with FCR, the genetic correlation between animals at different stages of maturity are low (Arthur and Herd, 2005).

Feed efficiency measurements can be roughly categorized into two groups. The first group consists of ratio traits, like feed conversion ratio, partial efficiency of growth, relative growth rate, and Kleiber ratio. The second group consists of residual or regression traits, such as residual feed intake and residual average daily gain.

Table 1.1 Genetic correlations between different measures of feed efficiency in growing beef cattle, compiled from previous research; ((Berry and Crowley, 2013)^a; (Carstens and Tedeschi, 2006)^b (Arthur and Herd, 2005)^c).

	FI	ADG	RFI	FCR	RADG	KR
FI	/	0.78 ^a	0.72 ^a	0.38 ^a	-0.03 ^a	-0.04 ^a
		0.54 ± 0.06 ^c	0.69 ± 0.03 ^c	0.31 ± 0.07 ^c		
ADG	/	/	0.02 ^a	-0.62 ^a	0.82 ^a	0.80 ^a
			0.00 ^b	-0.60 ^b		
			-0.04 ± 0.08 ^c	-0.62 ± 0.06 ^c		
RFI	/	/	/	0.75 ^a	-0.46 ^a	-0.19 ^a
				0.56 ^b		
				0.66 ± 0.05 ^c		
FCR	/	/	/	/	-0.89 ^a	-0.78 ^a
RADG	/	/	/	/	/	0.76 ^a
KR	/	/	/	/	/	/

FI=Feed intake; ADG=Average daily gain; RFI=Residual feed intake; FCR=Feed conversion ratio; RADG=Residual average daily gain; KR= Kleiber ratio.

1.2.1 Feed conversion ratio

Feed conversion ratio (FCR) was the preferred method of measuring feed efficiency in the past. Feed conversion ratio can be described as feed intake per unit gain in weight (Arthur et al., 2004). A more efficient animal has a lower FCR, and this measurement is used to determine the effects of the environment, management practices and diet quality on production efficiency. Feed conversion ratio is moderately heritable and has little value as a trait used for genetic improvement. The reason for this is that FCR is highly correlated ($r_g > 0.50$) with growth traits. This correlation suggests that there is a strong relationship between the efficiency of an animal to convert feed into body mass and the rate at which an animal grows (Arthur et al., 2004).

Several studies show that selection to reduce FCR after weaning would result in an increased mature size of the breeding herd as well as genetic merit for growth. Feed conversion ratio is seen as a gross measurement of feed efficiency because it does not distinguish the feed intake between growth and maintenance requirements (Carstens and Tedeschi, 2006). A feedlot

study conducted showed that a 10 % improvement in ADG resulted in an 18 % increase in profit, whereas a 10 % improvement in FCR resulted in a 43 % increase in profit (Fox et al., 2001). Overall, FCR is not used as a selection tool for efficiency, because it results in higher maintenance requirements, increased mature size, higher feed intake and economic and environmental losses (Terry et al., 2020).

A study conducted with 1783 bulls and heifers that were tested for post-weaning efficiency showed that genetic variation existed between measures of FCR, feed intake and RFI. In this study, FCR had a moderate heritability of 0.29 (Arthur et al., 2004). The inverse of FCR is gross efficiency, which is defined as the difference between production outputs and feed inputs. Gross efficiency is also highly correlated with growth traits (Archer et al., 1999, Nkrumah et al., 2007). This suggests that selection for improved gross efficiency will result in improved growth in beef cattle, but will harm the efficiency and profitability of the whole production system (Archer et al., 1999). Since gross efficiency is the inverse of FCR, a more efficient animal will have a higher gross feed efficiency ratio.

1.2.2 Partial efficiency of growth

Partial efficiency of growth (PEG) can be defined as the ratio of body weight gain to feed, after subtracting maintenance requirements. The maintenance requirements can be estimated from feeding tables that is based on an average body weight that was measured during a test period (Archer et al., 1999, Berry and Crowley, 2013). The problem with estimating maintenance requirements from feeding tables, is that it doesn't account for the variation that exists in the feed efficiency used for maintenance. The feed energy used for maintenance in a beef herd consist of 60-75 % of the sum of energy requirements of breeding cows (Montaño-Bermudez et al., 1990).

There are several difficulties with measuring maintenance efficiency. This includes that the measurement cannot be made in growing animals since the requirements for weight status have not been met (Carstens and Tedeschi, 2006). Weight status in cows refers to maintaining an appropriate body condition and weight for optimal health and productivity. An accurate measurement of maintenance requirements needs a live weight that is constant over a

specific period (two years). Another definition of PEG is the ADG per unit of DMI that is available for growth, as seen in **Table 1.2** (Carstens and Tedeschi, 2006).

1.2.3 Relative growth rate

Relative growth rate (RGR) can be described as the growth that is relative to instantaneous body size and is not used as an efficiency measure, but can be used in feed efficiency measurements if the total of tested animals are fed the same diet (Berry and Crowley, 2013). The advantage of this measurement is that it considers body weight, and is therefore, an indirect measure of the biological efficiency of an animal (Liu et al., 1991).

Table 1.2 Traits used in measuring efficiency in growing beef cattle.

Name of trait	Definition	Formula	Heritability (h ²)	Phenotype that is favourable	Reference
ADG: Average daily gain	Weight gain per day	Final weight-initial weight/ days	0.31 ± 0.014	n/a	(Berry and Crowley, 2013)
FCR: Feed conversion ratio	Feed intake per unit gain in weight	DMI/ADG	0.23 ± 0.013	low	(Berry and Crowley, 2013)
PEG: Partial efficiency of growth	ADG per unit of DMI that is available for growth	ADG ÷ (DMI – DMI _m); DMI _m = expected DMI required for maintenance	/	high	(Arthur and Herd, 2008a, Berry and Crowley, 2013)
ME: Maintenance efficiency	Feed energy required for zero body weight change	MEI - (fat gain ÷ kf) (protein gain ÷ kp) ÷ MBW [standard partial efficiency for ME for fat deposition (kf) and protein deposition (kp)]	/	low	(Archer et al., 1999, Carstens and Tedeschi, 2006, Berry and Crowley, 2013)
RGR: Relative growth rate	Growth relative to size or expressed as a percentage of change in liveweight gain	100 x (log end weight- log start weight) ÷ days on test	0.26 ± 0.041	n/a	(Carstens and Tedeschi, 2006, Arthur and Herd, 2008a)
KR: Kleiber ratio	Weight gain per unit of metabolic body weight	ADG ÷ average test period liveweight ^{0.75}	0.35 ± 0.030	n/a	(Arthur and Herd, 2008a, Berry and Crowley, 2013)
RFI: Residual feed intake	Difference between actual and predicted DMI based on metabolic body weight and ADG	Expected DMI from regression of ADG on MBW and DMI	0.33 ± 0.013	low	(Carstens and Tedeschi, 2006, Arthur and Herd, 2008a, Berry and Crowley, 2013)
RADG: Residual average daily gain	Difference between actual gain and predicted gain based on animal's metabolic body weight, intake and composition.	Expected gain from regression of ADG on MBW and DMI	0.28 ± 0.030	high	(Carstens and Tedeschi, 2006, Arthur and Herd, 2008a, Berry and Crowley, 2013)

ADG: Average daily gain; DMI: Dry matter intake; FCR: Feed conversion ratio; KR: Kleiber ratio PEG: Partial efficiency of growth; RADG: Residual average daily gain RFI: Residual feed intake; RGR: Relative growth rate.

1.2.4 Kleiber ratio

Kleiber ratio can be described as the ADG per unit of metabolic body weight (Kleiber, 1961). Kleiber ratio put in simpler terms indicates that as ADG increases, growth will increase as well, for the same metabolic body weight, without a change in the cost of maintenance energy (Berry and Crowley, 2013). It does not require measurement of feed intake and is seen as an indirect measurement of feed efficiency. This measurement is useful to compare animals that does not have the same body size. The “surface law” was proposed in 1839 by Sarrus and Rameaux and stated that heat production was rather related to surface area of species that differ in sizes, than of their body masses, if the same body temperature was maintained. This implied that small animals had a larger mass-specific rate of metabolism than a larger animal (Sarrus and Rameaux, 1839).

The “surface law” was then replaced by “Kleiber’s law”. Samuel Brody and Max Kleiber studied the relationship between body mass and basal metabolic rate (BMR) in warm-blooded species and used the log-log plot to find the slope of the relationship. Samuel Brody found the relationship to be 0.73, whilst Kleiber found it to be 0.74 (Hulbert, 2014). This indicated that with relative change, the BMR increased by 66 % for every time the body size doubled when using the scaling exponent of 0.73. The BMR increased by 68 % when the body mass increased by 100 %, when the scaling exponent was 0.74. There was variation with the BMR values found in the studies, thus Brody decided on the unit of metabolic body size to a suggested mass to the power of 0.7, whilst Kleiber decided the unit of metabolic size to a suggested mass to the power of $\frac{3}{4}$ (Hulbert, 2014). Many studies showed that the BMR scaling exponent was less than $\frac{3}{4}$.

1.2.5 Residual feed intake

Residual feed intake (RFI) was first proposed by Koch et al. (1963) and has become the preferred method of measuring feed efficiency. The main reason for this is that it allows for comparison between animals that differ in production level during the period of measurement. This indicates that RFI is independent of production on a phenotypic level (Archer et al., 1999). In other words, RFI is independent of gender, age, growth rate, body composition, fat deposition, weight and milk yield/composition (Terry et al., 2020). Residual feed intake that is described on a phenotypic level increases flexibility in the sense that the

regression can be integrated into the contemporary group to account for differences among variables as well as the diet (Berry and Crowley, 2013).

A study conducted by Kennedy et al. (1993) showed that when feed intake was used to calculate the phenotypic regression of production of RFI, that RFI was not independent of production on a genotypic level. This concluded that there was genetic variation within production traits. Kennedy et al. (1993) then suggested to use genetic covariances to acquire efficiency measures that were indeed genetically independent of production. Genotypic residual feed intake was used to reflect the possible differences in genetics within the relationship between production and feed intake (Kennedy et al., 1993). Net feed efficiency is another word for residual feed intake and is the difference between the actual and predicted feed intake of an animal. Residual feed intake can also be explained by **Figure 1.1** which indicates that the dots above the line represented animals that ate more than predicted, established by their performance, and were therefore inefficient animals. The animals (dots) below the line ate less than their predicted feed intake and were efficient animals relative to the population (Berry and Pryce, 2014). Efficient animals will have a negative RFI value (low RFI), whereas inefficient animals will have a positive RFI (Carstens and Tedeschi, 2006).

The disadvantage of measuring RFI is that there can exist heritable variation that can lead to certain errors. These errors include feed losses that can be caused by feed spilling, which ultimately lead to inaccurate feed intake measurements (Berry and Crowley, 2013). Another negative factor associated with selecting animals with a low RFI is that there can be unfavourable effects with regard to reproduction and fertility. To evaluate the relationship between fertility and feed efficiency a study was conducted with 110 crossbred beef bulls with an average age of 274 ± 2.5 d, where semen was collected and scrotal circumference was measured at the end of the test period (112 days) (Awda et al., 2013). Scrotal circumference (SC) is an important measurement of fertility since it is correlated with testes size and weight as well as age at puberty in the heifer progeny and the ability to produce sperm. The results indicated that less efficient bulls had increased and better sperm motility and larger SC than that of more efficient bulls. An explanation could be that low RFI bulls (efficient bulls) reach puberty at a slower rate than high RFI bulls, and as a result have a reproductive tract that is more immature when semen was collected. Reaching puberty at a later stage could also influence sexual behaviour and activity, which could ultimately lead to better results about RFI (Awda et al., 2013). On the contrary, a study conducted by Wang et al. (2012) with 412

animals showed that semen quality, temperament, SC, ADG, and weaning body weight were uncorrelated with RFI, except for sperm motility. This study indicated that selecting for low RFI did not have a great impact on reproductive performance (Wang et al., 2012).

Residual feed intake can also have an effect on body composition. Results of a study done by Basarab et al. (2003) indicated that low RFI animals retained less energy, had less carcass marbling, reduced intermuscular fat and lower heat production. In a study done by Crowley et al. (2011), it showed that there was a genetic correlation between muscularity and RFI and that animals that were genetically superior for RFI, was also genetically superior for muscularity. Biological variation in RFI exists and a third of the variation can be explained by heat increment, digestion and feeding activity. The remainder of the variation consists of heat production that causes differences in RFI measurements (Herd et al., 2003a). Variation can also arise from factors like feed intake, digestion, metabolism, activity and thermoregulation (Herd and Arthur, 2009). These are just a few factors that can cause variation in RFI. Selection for efficient cattle (low RFI) had correlations with reduced methane emissions and reduced feed intake with no change in growth or body weight (Terry et al., 2020).

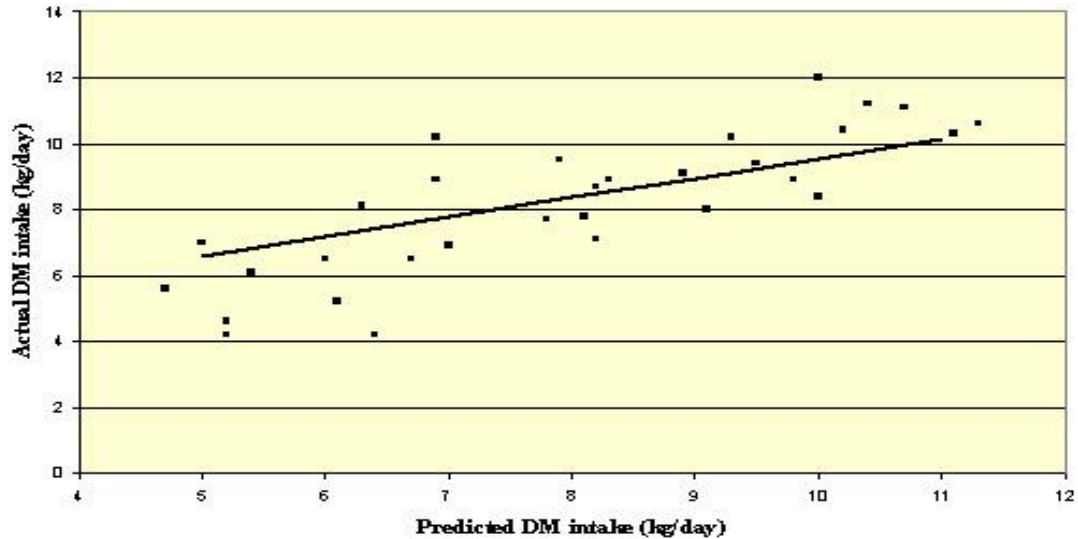


Figure 1.1 Residual feed intake plot in beef cattle, of predicted versus actual dry material (DM) intake (kg/day). (From: <https://www.thebeefsite.com/articles/1675/residual-feed-intake-a-system-for-efficiency/>. Accessed on 28 March 2022.)

1.2.6 Residual average daily gain

Residual average daily gain was also introduced by Koch et al. (1963) and was a different measure of determining variation in growing animals regarding feed efficiency (Berry and Crowley, 2013). It can be defined as the residuals from the regression of ADG on metabolic body weight and feed intake (Koch et al., 1963). An alternative and simpler definition is that RADG is the difference between the actual and predicted gain of an animal, based on intake, maintenance and body requirements. An animal with a positive RADG value is seen as an efficient animal since it gained more weight than predicted and is growing faster than expected. This measurement is correlated to growth but is independent to live weight and feed intake.

1.3 Role of embryo transfer in beef cattle for feed efficiency

To increase selection intensity and decrease the generation interval, Multiple ovulation and embryo transfer (MOET) is used in beef cattle. Embryos are collected from a genetically superior cow and transferred to a recipient cow where development is then completed (Stroud and Bó, 2011). This allows farmers to select animals based on the desired phenotype or trait, in this case animals with low RFI. The reproductive potential of a typical newborn calf is substantial, with females possessing approximately 150,000 oocytes and males producing billions of sperm. Natural breeding only makes use of a small fraction of this potential. An average herd bull sires between 15 and 50 offspring annually, while a cow typically produces one calf per year. While artificial insemination enables the extensive use of superior male genetics, the reproductive capacity of the female remains underutilized. Embryo transfer serves as a complementary technique to artificial insemination, enhancing the reproductive output of genetically valuable heifers (Kidie, 2019).

The first successful bovine embryo transfer was reported in 1949 (Umbaugh, 1949), with the first calf born from this technique in 1951 (Willett et al., 1951). The application of embryo transfer to the cattle industry started in the early 1970s with the rise of European dual-purpose cattle breeds in North America, Australia, and New Zealand. In the 1930s, embryo transfer was performed in sheep and goats, but it wasn't until the 1950s that successful transfers were reported in cattle and pigs (Rowson et al., 1969). Commercial embryo transfer in cattle began in the early 1970s, involving surgical procedures. In the late 1970's non-surgical methods were developed for embryo transfer, significantly increasing the technique's adoption. According to Fufa et al. (2016), donor cows should be selected based on three reasons. The first was being genetically superior, the second factor was improved

reproductive ability and the third factor was the market value of the offspring. There are several reasons why embryo transfer is beneficial in terms of animal production. Multiple ovulation and embryo transfer increases the number of calves produced per gestation (incidence of twinning is higher), the generation time is decreased, the selection intensity of the offspring is increased and it is a method of avoiding the transmission of genetic diseases (Mebratu et al., 2020). The formula for genetic progress per year is given below and can be increased by increasing the selection intensity (Kuhlers et al., 1990).

$$\Delta G = i * \sigma_p * h^2 / L$$

Where;

ΔG : Genetic progress

i : selection intensity

σ_p : phenotypic variability

h^2 : Trait heritability

L : generation interval

1.4 Factors that cause variation in Residual feed intake on a physiological basis

In order to select for superior cattle regarding feed efficiency, it is important to understand the factors that cause variation in the measures of feed efficiency and how this problem can be solved. There are several benefits in understanding the physiological basis for the causes of variation in feed efficiency measures. The first is that when knowing the physiological pathways, it will help to recognise correlated responses related to the selection for improved feed efficiency. Secondly, it can help to pinpoint traits that are easier and not as costly to measure. Lastly, knowing the physiological pathways can aid in alternative ways in changing the metabolism of cattle to improve feed efficiency (Archer et al., 1999). When growing cattle were compared for DMI, there was a 15 % difference between the most inefficient and efficient terciles in terms of feed efficiency (Lawrence et al., 2012). Understanding the variation in feed efficiency can also give insight into negative side effects on other traits, such as health and reproduction, that may arise when selecting for feed efficiency. Several studies have been conducted to identify the cause of animal-to-animal variation when reared in the same environmental conditions as seen in **Figure 1.2** (Cantalapiedra-Hijar et al., 2018).

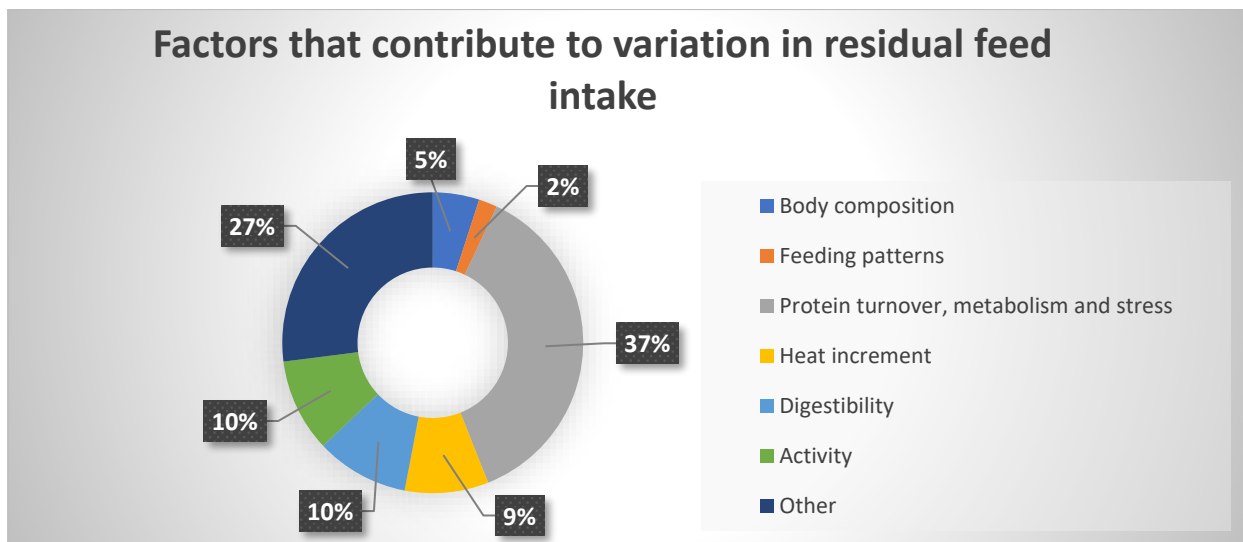


Figure 1.2 Factors that contribute to variation in residual feed intake (RFI).

From: Herd and Arthur (2009)

1.4.1 Energy metabolism, mitochondrial function and stress physiology

The feed that is ingested by an animal is partitioned into what is needed for maintenance requirements and what is used for production. Before growth can occur, maintenance requirements must be met, and this consists of basal metabolism, maintaining body temperature and involuntary body activity (Archer et al., 1999). The content of fat and muscle tissue is very important in describing the overall energy status of an animal. In a meta-analysis study done by Kenny et al. (2018) with growing beef cattle, it showed that there was no difference in the muscle accretion amongst live animals and carcasses when both high or low RFI cattle were measured. No relationship was found between back fat depth that was measured ultrasonically and RFI. It was concluded that back fat depth and carcass muscle area was not associated with RFI during the linear growth phase of cattle. One study showed that high RFI steers retained 32.1 % more energy compared to low RFI steers and that more efficient cattle had a lower percentage of carcass fat (9.9 vs. 11.3%, $P < 0.05$) (Basarab et al., 2003). Another study done by Berry and Crowley (2013) also found that RFI was positively correlated to body fat in the animal.

Animals with improved feed efficiency (low RFI) had decreased maintenance energy requirements, as well as increased partial efficiency of metabolizable energy (ME) utilization in terms of growth that resulted in higher metabolic efficiency (Cantalapiedra-Hijar et al.,

2018). More efficient animals seem to have a metabolic rate that is lower than less efficient animals. According to Cantalapiedra-Hijar et al. (2018) this was because low RFI steers had leaner carcasses (RFI and muscularity were negatively correlated) which reduced the energy costs of tissues that are rich in protein. Castro Bulle et al. (2007) found that there was less fractional protein degradation in steers with lower ME requirements. A study conducted with 27 hybrid beef steers showed that DE (digestible energy), ME (metabolizable energy) and RE (retained energy) were independent of the level of feed intake between steers with high or low RFI (Nkrumah et al., 2006).

The mitochondrion is a metabolic organelle with a double membrane that is responsible for the consumption of 80- 90 % of cellular oxygen (Carstens and Kerley, 2009). There are several factors that can lead to variation in the energy expenditure of animals, and this includes certain physiological processes such as mitochondrial proton leak, thyroid hormones, ion pumping (Na⁺/K⁺ +ATPase), IGF 1 (Insulin-like growth factor 1), leptin, sympathetic activity and lipid metabolism. According to Rolfe and Brown (1997), 20 % of the inter-animal variation in basal energy expenditure was caused by protein turnover, mitochondrial proton leak and ion pumping. Electron transfer occurs in a series through the electron transport chain (ETC) that is associated by the oxygen consumption of the mitochondria. This process is called oxidative phosphorylation, and oxidation of fuel substrates, like glucose, generates reducing equivalents. The reducing equivalents enter the ETC, which then pumps protons into the intermembrane space. The protonmotive force that is created by the ETC then activates the enzyme that produces ATP. When the protonmotive force is uncoupled, due to the presence of the uncoupling protein (UCP1), protons will leak into the mitochondrial matrix which generates heat instead of ATP (Carstens and Kerley, 2009, Cantalapiedra-Hijar et al., 2018). Bottje et al. (2002) was the first to link animal variation in terms of feed efficiency and mitochondrial function. It was found that more efficient broilers had a respiratory chain that was more tightly coupled, and consequently had less ROS (reactive oxygen species) production and electron leakage than less efficient broilers (high RFI) (Bottje et al., 2002). A study conducted by Sharifabadi et al. (2012) with lambs, showed that feed-efficient animals had better ETC coupling in the mitochondria, as well as more efficient ATP generation. This indicated that selecting animals with a low RFI resulted in less electron leakage, and thus less heat production.

Stress and stress susceptibility can be one of the causes of variation in animal feed efficiency. Stress leads to certain biological responses, such as increased energy consumption and a higher metabolic rate, as well as decreased immunity (Kelly et al., 2017). Studies showed that animals differing in RFI, had different responses to stress. Kelly et al. (2017) found that Simmental heifers with low RFI had less sensitivity to Adrenocorticotrophic hormone (ACTH) is used to stimulate the activity of the HPA axis (hypothalamic-pituitary-adrenal axis). Cortisol is seen as the principal stress biomarker, and in a study done with rams, it was found that rams with higher concentrations for cortisol also had higher RFI (Knott et al., 2010). It was also found that heifers with low RFI had a faster heart rate in response to an acute stressor compared to low RFI heifers (Munro et al., 2017).

1.4.2 Body composition, visceral organs and protein turnover

Animals that differ in body composition can cause variations in feed efficiency (Ojo et al., 2024). As animals age and slaughter weight increase, certain proportions of muscle, bone and non-carcass parts will decrease, whilst the fat in the muscle, carcass and non-carcass parts increases (Moloney and McGee, 2017). Protein has a lower energy density than fat, and thus differences in the rate of protein and fat deposition will affect feed efficiency. The deposition of protein will require less energy per unit of gain than fat. However, the higher rates of protein turnover results in the ME of protein deposition being lower compared to fat (Carstens and Kerley, 2009). There were differences in the results between studies done on RFI and body composition. One study found no relation between body measures of carcasses or live animals in cattle with low or high RFI that were fed an energy dense diet (Kenny et al., 2018). Lancaster et al. (2009) conducted a study with 341 Angus bulls and found a weak, but positive correlation between rib fat depth that was measured using ultrasound and RFI. It was also reported that more efficient bulls were leaner and that 9 % of variation in RFI was attributed to differences in carcass traits. On the other hand, Richardson and Herd (2004), found that only 5 % of variation in RFI was due to differences in carcass traits.

Certain organs, such as the liver, gastrointestinal tract (GIT) and heart, have a higher metabolic cost than others. This influences the energy requirements of an animal and can lead to variations in RFI. Several studies reported that there was a correlation between RFI and certain organs in the sense that animals with a high RFI, had a heavier liver, gastrointestinal tract, kidney, rumen and heart compared to low-RFI animals (Fitzsimons et al., 2014, Kenny et

al., 2018). A study found that less efficient cattle had an 8-10 % lower weight of the GIT, than bulls that were more efficient (Bonilha et al., 2009). This study also demonstrated that a 1 kg/day increase in RFI was linked to 1 kg increase in the weight of the reticulo-rumen. McBride and Kelly (1990) suggested that visceral organ size was not the sole reason for variation in energetic efficiency, but that certain metabolic processes, such as potassium and sodium ion transport and protein degradation and synthesis, in these tissues could be responsible.

Protein turnover is the continuous process of protein synthesis and degradation and is crucial in providing amino acid flux that implements maintenance functions, like cellular repair, metabolic regulation and adaptation to the environment (Cantalapiedra-Hijar et al., 2018). Protein turnover in growing animals can be defined in the sense that the synthesized protein is equal to the amount of degraded protein. Protein turnover can thus be assessed through the rate of protein degradation. According to Caton et al. (2000), 23 % of the total energy expenditure in ruminant animals was related to protein synthesis. A recent determinant of variation in animals performance and RFI was fractional protein turnover rate, and can be defined as the degradation of protein per unit of protein mass and time (%/day) (Richardson and Herd, 2004). Several studies showed that efficient animals had a low protein turnover strategy. In contrast, a higher protein turnover can be related to more efficient animals, considering that protein synthesis increases at a higher extent than the degradation of protein (Cantalapiedra-Hijar et al., 2018). The relationship between protein turnover and feed efficiency should be examined with caution because feed intake can affect protein turnover. Cattle that have a higher maintenance requirement, will have an increase in protein turnover. Even though efficient and non-efficient animals accrete body tissues at the same level and rate, low RFI animals have a reduced protein turnover rate (Richardson and Herd, 2004).

1.4.3 Physical activity and feeding behaviour

A meta-analyses study was conducted with growing beef cattle that was fed an energy dense and high concentrate diet. It showed that high RFI cattle spent 10.3 minutes (average=93 min) longer eating than low RFI cattle, within a 24 hour period (Kenny et al., 2018). Lancaster et al. (2009) conducted a study with 341 Angus bulls and found that RFI was positively correlated to meal frequency and duration, and that low RFI bulls spent 13 % consuming feed, as well as consumed 11 % less meals per day. It was however found that the low and high RFI bulls consumed the feed at a similar rate. There existed variation in feeding activities, and this made

up 35 % of the variation that can be noticed in feed intake that was not related to ADG, BW and carcass composition.

It was estimated that 10 % of the variation that existed in the RFI of growing beef cattle was attributed to the differences in physical activity (standing, lying and locomotion) and the energy expenditure related to these activities (Herd et al., 2004). Another study done with laying hens, showed that energy expenditures that were related to activity, accounted for 29-54 % of the differences in energy expenditure between low and high RFI hens (Luiting et al., 1991). In a study done with mice, selected based on heat loss, it was found that less efficient mice (high heat loss) were two times as active as more efficient mice, and that this caused a 36 % difference in feed intake between the two groups of mice (Mousel et al., 2001). We can conclude that low RFI bulls spend less time feeding than high RFI bulls.

1.4.4 Digestibility and methane emission

The digestion of feed will decrease as feed intake, relative to maintenance, increases. This is mainly due to the fact that the feed remains in the rumen for less time since the passage rate is faster (Nkrumah et al., 2006). The expectation would be that high RFI cattle have reduced digestibility, and there are several studies that indicate that there is a negative correlation between RFI and digestibility (Kenny et al., 2018). The reason for this could be that more efficient cattle have a slower passage rate of the feed through the rumen due to the decreased amount of feed intake. It could also be caused by differences in the diet, since the digestion of forages is less compared to concentrate-based diets. A study done by Nkrumah et al. (2006) with 306 cattle fed a high concentrate diet, showed that RFI was negatively correlated with crude protein (CP) digestibility ($r = -0.34$; $P < 0.10$) and DM digestibility ($r = -0.33$; $P < 0.10$). In the same study it was also found that apparent digestibility was 6 % higher in low RFI calves, and energy losses due to methane production was 28 % lower, compared to high RFI calves (Nkrumah et al., 2006). Johnson et al. (2019) did a study with 57 Santa Gertrudis steers and found that low RFI steers had a 6 % increase in dry matter digestibility (DMD) compared to less efficient steers. In a second study conducted with 468 Brangus heifers, it was established that RFI was negatively correlated with dry matter digestibility (DMD) ($R = -0.25$), NDF digestibility ($r = -0.21$) and CP digestibility ($r = -0.27$) (Johnson et al., 2019). It was concluded that digestion caused at least 10 % variation in RFI (Richardson and Herd, 2004). In contrast to the relationship between RFI and digestibility in cattle, it was found that in pigs, digestion

was not a significant source of variation in RFI (Barea et al., 2010). A similar result was observed with poultry in the sense that digestion was not a significant contributor to variation in RFI (Carré et al., 2008). This indicated that the biological mechanisms related to digestion, differ between species (monogastric vs. ruminant species).

Methane production (g CH₄/day) is positively correlated to dry matter intake (DMI). This means that low RFI animals will have less methane production since they consume less feed (Jones et al., 2011). However, low RFI cattle do not always produce less methane. This can be caused by two factors. The first is that low and high RFI cattle don't always show changes in DMI in digestibility measurements outside of the test period for RFI (Jones et al., 2011). The second factor is that more efficient cattle show a 4 % increase in DM digestibility, which increases the amount of feed that is available for fermentation and methanogenesis (Bonilha et al., 2017). Results in previous studies were not consistent with regards to methane yield (MY; g CH₄/kg DM intake) in beef cattle. On the contrary, Herd et al. (2016) found that reducing the feed intake of an animal, increased methane yield (MY). This could be due to the fact that smaller rumens are associated with low-RFI animals, and that more efficient animals do not have longer retention times of feed in the rumen (Fitzsimons et al., 2014). A study done by Nkrumah et al. (2006), showed significant differences between methane emission and animals of low and high RFI. The data indicated that low-RFI animals had 28 % less methane production than high RFI animals, and 24 % less methane production than medium RFI animals. It was also concluded that low RFI animals had roughly 16,100 L/year less methane production than high RFI animals and that RFI was positively correlated to methane production ($r = 0.44$; $P < 0.05$). A study with 76 Angus steers showed that more efficient animals had 25 % less methane production and ate 41 % less feed than high RFI steers (Hegarty et al., 2007).

1.4.5 Rumen microbiome

There are several studies that showed that low RFI in beef cattle was linked to changes in the bacterial composition of the rumen that enhanced feedstuff digestibility (Elolimy et al., 2018). The rumen has a range of microbes that include anaerobic fungi, bacteria, ciliate protozoa and archaea, which converts feedstuff into nutrients that is utilised by the animal (Khiaosa-Ard and Zebeli, 2014). The first to propose a link between the rumen microbiome and variation in feed efficiency was Guan et al. (2008). By using PCR-denaturing gradient gel electrophoresis

to analyse bacterial profiles, it was found that steers with high and low feed efficiency had different bacterial communities within the rumen (Greiner et al., 2003). A study done to examine the bacteria associated with RFI, showed that there was a correlation between the 16S rRNA gene of *Succinivibrio sp.* and dry matter intake, as well as daily gain in low RFI steers. *Succinivibrio sp.* utilizes hydrogen to produce succinate and thus reduces the availability of hydrogen for methanogenesis (Pope et al., 2011). *Robinsoniella sp.* was associated with feed efficiency in high RFI steers (Hernandez-Sanabria et al., 2012).

Another study showed that more efficient cattle had an abundance of *M. elsdenii* (lactate utilization), *F. succinogenes* and *E. ruminantium* ($p \leq 0.05$) and had less of *S. amylolytica* and that the total number of ruminal bacteria was less in low RFI cattle (Elolimy et al., 2018). *F. succinogenes* and *E. ruminantium* was higher in more efficient animals, because these bacteria were linked to better feed digestibility and fibre degradation. *E. ruminantium* also played a cellulolytic role within the rumen. The role of *M. elsdenii* was to produce propionate and butyrate by utilizing lactate, and this was done through reverse β -oxidation. It can be concluded that this process helped to maintain the pH of the rumen and prevent lactic acidosis. It was also proven that more efficient cattle have a greater propionate : acetate ratio. (Liang et al., 2017). It was observed that more efficient cattle had an increase in microbial fermentation, shown by an increase in short chain fatty acid (SCFA) production. The concentration of butyrate was 4 times higher in low RFI steers, suggesting that there was a shift in the bacterial population to metabolize feed substrates into products that were of higher energy value (Guan et al., 2008). The diet type could also affect the bacterial community and its influence on feed efficiency. Hernandez-Sanabria et al. (2012) did a study with high concentrate diets that differed in energy contents and found that *Eubacterium sp.* was 6 times higher in less efficient cattle when they were fed a high energy diet. When the cattle were fed a high energy/ low forage diet, the abundance of *Entodinium protozoa* doubled, *Prevotella spp.* (hemicellulose breakdown) had a 4-fold increase and *Fibrobacter succinogenes* (cellulose digestion) reduced 4.5 times (Carberry et al., 2012). This proved that microbial populations in the rumen were diet dependant.

Zhou et al. (2018) found that efficient cattle was associated with the genera *Coprococcus*, that is involved in converting lactate to propionate through the acrylate pathway. It was also shown that *Coprococcus catus* was higher in the rumen of more efficient dairy cows, and that there was an increase in the propionate and butyrate production which shifted the

fermentation and decreased the ability of metabolic hydrogen to reduce CO₂ to CH₄ (Shabat et al., 2016). Genera, such as *Veillonellaceae*, *Lachnospiraceae*, *Butyrivibrio* and *Lactobacillaceae* were linked to less efficient cattle (Myer et al., 2015, Li and Guan, 2017).

1.4.6 Heat production

A study where heat production was measured using hybrid beef steers, showed that more efficient steers (low RFI) produced 21 % less heat than high-RFI steers (Nkrumah et al., 2006). Basarab et al. (2003) found similar results using the slaughter-balance technique and estimated that high RFI steers had a 10 % increase in heat production, as well as a 7 % heavier liver mass compared to low RFI steers. It was also proved that heat production increased with 59.9 kJ as RFI increased with one unit. High RFI steers are characterized by increased heat production (HP), since maintenance costs are higher and organ weights are heavier. Visceral organs can produce up to 30-40 % of HP (Basarab et al., 2003). The largest portion of protein synthesis, and related heat production, occurs in visceral organs such as the liver and GIT (Reynolds, 2002). Lowered heat production in low RFI animals may be attributed to more efficient ATP production and decreased protein turnover (Cantalapiedra-Hijar et al., 2018). The correlation of RFI and heat production is 0.68 (**Table 1.3**). Basarab et al. (2003) found that more efficient animals retained less energy (12 %), had lower metabolizable energy intake (10.2 %) and had 9.3 % decreased heat production than high RFI cattle.

Table 1.3 Factors that cause variation in feed efficiency and its correlation with Residual feed intake. From (Hendriks et al., 2013).

Trait	Correlation with RFI
Body composition	0.375 (P <0.10)
Digestibility	-0.33 to -0.44
Activity	0.32
Protein turnover	/
Methane production	0.44
Heat production	0.68
ME requirements	0.421 (P <0.10)
Dry matter intake	0.44 (P <0.001)

1.4 7 Endocrine system

The endocrine system regulates nutrient utilization as well as feed intake and can thus play an important role in improving feed efficiency (Cantalapiedra-Hijar et al., 2018). There are several hormones that could affect feed efficiency and RFI. Leptin is produced by the adipose cells and is responsible for energy homeostasis. This is done through inhibiting hunger and controlling the intake of feed (Elias et al., 1999). In a study done with 98 Nelore cattle where two groups were formed with regards to low-RFI (n=20) and high-RFI (n=20), results showed that more efficient animals had an increased expression of leptin ($p=0.0022$). This relates back to the fact that high RFI animals consume more DMI and will have less circulating leptin (Mota et al., 2017). Foote et al. (2015) conducted a study with 473 steers to examine the relationship of serum leptin concentration and DMI as well as ADG and found that there was a positive correlation between DMI and leptin concentration ($r=0.21$).

IGF-1 is another hormone that could influence RFI. This hormone regulates cellular metabolism and growth. Nascimento et al. (2015) did a study with growing beef cattle and found that the concentration of insulin (4.45 vs. 3.70 μ IU/mL) and IGF-1 (433 vs. 399 ng/mL) were greater in low-RFI animals in comparison to high-RFI animals. Similar results were found in a study conducted with 102 lambs. More efficient lambs showed an increased concentration of IGF-1 and leptin (Montelli et al., 2021). IGF-1 was used as an indirect selection criteria for feed efficiency and aids in placing animals into low or high RFI groups by using IGF-1 as a marker in a two stage selection program (Wood et al., 2002). There were however studies that found no association between IGF-1 and RFI. This could be due to measurement of animals in different physiological stages or a difference in the amount of concentrate in the diet. Cattle that were on a high concentrate diet showed no relationship between RFI and IGF (Cantalapiedra-Hijar et al., 2018).

An alternative hormone that could be used as a marker for feed efficiency is cortisol. A study done with crossbred steers showed that low RFI was associated with higher faecal cortisol metabolites (51.1 vs. 31.2 ng/g) compared to high RFI steers (Montanholi et al., 2010). A study conducted by Richardson et al. (2004) with Angus steers, found a negative correlation between plasma cortisol concentrations and RFI ($r=-0.40$). On the contrary, a study done with finishing beef cattle demonstrated a positive correlation between RFI and plasma cortisol ($r =$

0.14) (Foote et al., 2016). The differences in results could be caused by a few factors, such as diet, age, sampling time and physiological stage.

1.5 Economic benefit of using RFI

Performance testing and measuring feed efficiency are important methods used by cattle breeders and farmers to make informed decisions regarding the herd and future progeny. A crucial part in the improvement of feed efficiency is to set breeding goals that can be met over a certain period. Phase C testing, where feed intake is measured individually and bulls and heifers are fed ad libitum, is regarded as an investment in more efficient production that will ultimately save expenses.

Recent statistics showed that the average price for bulls of all beef breeds in South Africa was R 45 000, but bulls that were tested in Phase C, had an average price that was 15 % more (Agricultural Research Council, 2021). Most of the beef produced in South Africa comes from feedlots (70 %), and as discussed previously, feed is the single largest cost in beef production systems. Statistics on feed efficiency in America showed that an improvement of 10 % in feed efficiency would reduce expenses by about 20 billion Rand/ year. A study was conducted to analyse the economic benefit of improvement in feed efficiency and selection of superior cattle based on RFI. This study was done on a herd of a 100 cattle, where the surplus heifers were sold at 18 months into the domestic market and a big percentage (80 %) of steers were sold to feedlots. The study showed that improvement of efficiency in the herd occurred slowly, but despite the initial cost of purchasing bulls that were genetically superior for feed efficiency, the ultimate rate of return was 61 % over a 25 years. (Exton et al., 2000).

When the economic gain from the selection for RFI is assessed, all the phases of the production cycle must be considered, and not just the growing phase (Arthur and Herd, 2008a). A study done by Arthur and Herd (2005), showed that it was easier when RFI was used as the feed efficiency trait when assessing the economic benefit in a production system since there was no remarkable distinction in maternal productivity in a herd that was selected for postweaning RFI, ranging from 1-2.5 generations. The amount of feed an animal requires is determined by several factors, such as maintenance requirements, production, environment and activity (Arthur and Herd, 2008b). In order to reduce expenses related to feeding, the efficiency of the herd must be improved. In a study done with 38 Angus cross beef cows, the DMI from different RFI groups were recorded during lactation as well as postweaning (no lactation), and it was found that the DMI was 6.5 % higher in inefficient animals compared to efficient animals during lactation. For postweaning DMI, it was recorded that low RFI cows had 8.9 % less DMI than high RFI cows (Walker et al., 2015).

According to Nkrumah et al. (2006) and Hegarty et al. (2007), there would be a 9-10 % decrease in maintenance costs in terms of the cow herd when animal efficiency was increased. There would also be a 10-12 % decrease in feed intake, as well as a 25-30 % reduction in methane emissions. Another study showed that low RFI animals ate 2.69 ± 1.56 kg DMI/d less feed than high RFI animals. The less efficient animals consumed 3.08 ± 1.56 kg DMI/d extra feed than what was predicted (Elolimy et al., 2018). The correlation between RFI and DMI was estimated to be 0.44. This meant that as RFI increases (less efficient cattle), feed intake would also increase. Baker et al. (2006) also reviewed the relationship between RFI and feed intake, and found that high RFI steers had increased DMI ($P=0.004$) compared to low RFI steers. Basarab et al. (2002) reported that a 5 % feed efficiency improvement would lead to an economic impact that was 4 times greater than a 5 % improvement in average daily gain. It was also found that if feed efficiency improved by 10 %, there was a 43 % return in profits (Fox et al., 2001).

Animals selected for low RFI will require less feed for the same level of production compared to high RFI animals. This means that less feed is required, and thus less money is spent on providing feed for the same production level, which makes the production system more profitable. Animals tested for low-RFI are also more likely to be valued higher compared to animals that are inefficient.

1.6 Environmental benefit of RFI

An important aspect in improving animal efficiency is to conserve valuable environmental resources as well as biodiversity. Biodiversity is seen as the variation of plant and animal life within a certain habitat. Several aspects will improve, for example, as feed production decreases, land use will also be lower and will have a less negative effect on diversity within the environment (Terry et al., 2020). Animal efficiency will increase in an area where feed provision is balanced and more adjusted towards the need of the animal. The downside is that this balance will rarely exceed 15 % in a beef cattle herd (Gerber et al., 2015). In Southern Africa, livestock grazing occurs on both communal lands and private farms. In South Africa, communal grazing areas cover only 17% of farmland but sustain 52% of cattle, 72% of goats, and 17% of sheep (Franke and Kotzé, 2022). In contrast, in Zimbabwe, Botswana, and Mozambique, 85–89% of cattle graze in communal areas (Sebina and Duvel, 1999, Tavirimirwa et al., 2019). These systems often experience high stocking densities, continuous grazing, and minimal external inputs, leading to rangeland degradation (Slayi et al., 2024). On both communal and private farms, the introduction of low RFI cattle, which are more feed-efficient, could help address some of these challenges by reducing the demand for forage and minimizing the pressure on grazing lands.

Land and water resources are mainly utilized by cattle through feed production systems. More than 60 % of the dry matter ration that is fed to cattle consist of tree leaves and grass. The remainder (40 %) is made up of crop residues and by-products (Steinfeld et al., 2006). These grains and by-products contribute to environmental issues, like water depletion and the release of pesticides into the surrounding environment (Tilman et al., 2002). According to Mekonnen and Hoekstra (2012), it was concluded that 33 % of the global water footprint was caused by beef cattle with regard to animal production. Eutrophication is another process that could be detrimental to the environment and several species. This occurs when there is an increase in the concentrations of nitrogen, phosphorus and other nutrients that are used in fertilizers for feed production (Terry et al., 2020). These fertilizers run off into aquatic ecosystems such as rivers and dams and the excessive nutrient levels increase the algae and plant growth within the water, whilst decreasing oxygen levels, which ultimately causes death of aquatic species. Animals with low RFI eat less feed than predicted, which decreases feed production and the use of fertilizers and pesticides which could negatively affect the environment and biodiversity. More efficient animals will show a decrease in land use, and this leads to a decrease in land change (Terry et al., 2020).

When there is improved efficiency within the beef production system, the animal population will decrease. There are three methods to reduce methane emissions from beef cattle herds. The first is to select animals that are superior for efficiency. Sharma et al. (2014) conducted a study with 18 Sahiwal calves and found that CH₄ emission was considerably lower in more efficient animals ($p < 0.05$). Ruminant production systems have large quantities of methane production due to rumen fermentation. Methane production appears through methanogen activity in the rumen that utilizes hydrogen to reduce CO₂. This prevents reducing equivalents from accumulating which could delay fermentation (Beauchemin et al., 2009). The second method in decreasing methane production is to manipulate the diet. By increasing the cereal grain content for finishing diets, increasing the starch content of small grains and using higher quality forages, methane production can be reduced (Beauchemin et al., 2009).

Less methane production can also be achieved through improved digestibility or reduced feed intake. More efficient cattle will have better digestibility and thus less energy loss. Methane production is seen as a source of energy loss and thus represents inefficiency (Johnson and Johnson, 1995). Decreased DMI resulted in 25 % lower methane production, which was seen in more efficient cattle (Hegarty et al., 2007). It is crucial to reduce methane production since CH₄ plays a role in global warming and causes a rise in surface temperatures. Improved efficiency also leads to decreased manure production. This will decrease the amount of run off and reduce soil and water pollution as seen in **Figure 1.3** (Terry et al., 2020). The third method in reducing methane production is to reduce

the animal's life cycle. This could be achieved through early weaning, creep feeding and feeding diets that are higher in energy (rate of gain will increase and will reduce feed intake).

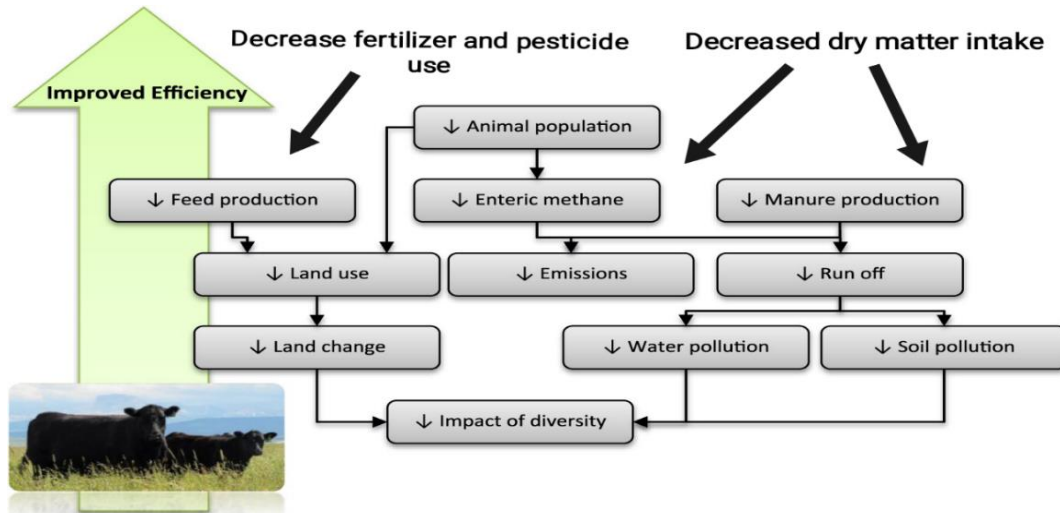


Figure 1.3 Effect of improved efficiency in beef cattle on environment and biodiversity.

Adapted from (Terry et al., 2020).

1.7 Feed efficiency on veld

Most of the research conducted on feed efficiency and RFI in beef cattle had been done where feed had been measured and delivered to the cattle. This system of measuring feed efficiency is much easier than measuring feed efficiency and RFI on veld. Several techniques have been developed to assess whether cattle that perform superior for feed efficiency (classes in low-RFI group) will perform the same in a different production system (Phase C vs. veld). It can be assumed that feed efficiency traits would remain the same between different production systems.

In a study conducted with Hereford cows that were grouped according to a low or high residual feed intake, it showed that more efficient cows had a 21 % lower average DMI than less efficient cows ($P = 0.23$) (Meyer et al., 2008). Oliveira et al. (2016) conducted a study with 73 cattle to evaluate the relationship between RFI in a feedlot and on veld, and found that in a feedlot, low RFI animals had 19.7 % lowered DMI than high RFI animals and 9.4 % lowered DMI than medium RFI animals. There was however no difference observed between low, medium and high RFI animals for DMI on veld. Enteric CH_4 was also measured during this study and gross-energy intake as well as neutral detergent fibre (NDF) intake was lower for more efficient animals. The more efficient animals also exhibited an

increase in dry matter and NDF digestibility in the feedlot. There was a substantial difference in CH₄ production on pasture between low and high RFI cattle (17.6 g CH₄/kg DMI for low RFI cattle and 13.7 for high RFI cattle). A similar result was observed in a study conducted with dairy cattle. Flay et al. (2019) did not find a positive correlation between RFI and CH₄ production when the dairy heifers consumed dry alfalfa. The results did not support previous hypotheses that stated that more efficient cattle had less methane yield. However, Jones et al. (2011) reported that low RFI cows had 27 % less CH₄ emission than high RFI cows that grazed on pasture. This difference in methane emission was only noted when the cattle grazed high-quality pasture, whereas no difference was observed for low-quality pasture between low and high RFI cows. The same results were also noted in dairy cattle. In a study done with 16 lactating Holstein-Friesian cattle that were fed ryegrass on pasture, it was found that more efficient cattle had better apparent N digestibility (77.2 %) than less efficient cattle (75.5 %), as well as better organic matter and dry matter digestibility. The low-RFI cows also had less faecal N output (138 vs. 126 g/day) (Rius et al., 2012). McDonnell et al. (2016) did a study with 86 Limousin x Friesian heifers that were fed in three different periods (period 1= grass silage, period 2= pasture, period 3= TMR) and found that there was only a significant correlation ($P < 0.05$) between DMI and RFI when the cattle were fed the TMR. As expected, CH₄ was positively correlated with DMI ($r=0.42$), but only for cattle that grazed on pasture. It was also found that more efficient animals had greater DMD and CPD (crude protein digestibility), but only when fed the grass silage. Another study concluded that more efficient cattle in a feedlot maintained their live weight (LW) better than high RFI cattle when they grazed poor-quality pasture. It was found that the average daily change in LW was higher for low RFI heifers ($p= 0.026$) (Alvarenga et al., 2020). A study was conducted with 725 bulls to evaluate trends in growth and feed efficiency and identify environmental factors affecting growth in the arid sweet bushveld of South Africa. During the test phase, live body weights were recorded every 3 weeks, while body measurements, scrotal circumference, and skin thickness were taken at the end. The results showed an increase in ADG by 3.481 g/day/year for Nguni bulls and 0.528 g/day/year for Bonsmara bulls. Corresponding feed efficiency, measured by KR, was 0.093 for Nguni and 0.059 for Bonsmara bulls. Variation in ADG was influenced by herd of origin and test year, while KR variation was affected by herd of origin, test year, start age, and start weight. The findings revealed a consistent improvement in both ADG and KR for bulls tested in the arid bushveld (Mashiloane et al., 2012).

Herd et al. (2005) conducted a study with 271 steers and found that the progeny of cattle that had genes for low RFI were heavier (2.1 % heavier) and grew at a faster rate (4.4 % faster). The results of this study linked back to the fact that low RFI cattle maintained their LW better when they were transferred from a feedlot to pasture. We can thus speculate that if a BCS is done on cattle before

being transferred to pasture and that animal maintained its LW better and had a similar BCS on pasture, that the animal was more efficient. The same can be speculated for using real-time ultrasound. Rib fat thickness and longissimus muscle area (LM area) was measured before the cattle is transferred from feedlot to pasture. The more efficient cattle will maintain their 12th and 13th rib fat thickness (cm) and LM area (cm²) better than less efficient cattle. Basarab et al. (2003) concluded that low RFI cattle had less intermuscular fat ($P = 0.06$) and less dissectible carcass fat ($P = 0.08$) than high RFI animals. As previously mentioned, low RFI animals are leaner than high RFI animals. A study done with 46 Nellore bulls showed that there was a positive correlation between RFI and final rump fat thickness (RFT) ($r=0.34$) and also RFT gain ($=0.36$) (Santana et al., 2012). Kayser and Hill (2013) reported that there was no significant difference in intramuscular fat (Angus, $P = 0.50$; Hereford, $P = 0.14$) and LM area (Angus, $P = 0.36$; Hereford, $P = 0.45$) between different RFI groups of the individual breeds. The results of the studies done were inconclusive about the relationship between RFI and carcass traits.

1.8 The value of performance testing

Performance testing in a beef production system is a method of recording the production of individual animals within the herd. This allows farmers to compare animals based on a trait of economic importance. Performance testing is not in competition with genetic tests, but rather a tool used to validate certain traits of interest (low residual feed intake), or it is used as a management strategy to improve the overall productivity of the herd. Both Phase C and Phase D performance phases assess post-weaning performance, but they differ in their testing environments and objectives. Phase C is conducted under controlled conditions in a centralized test station, allowing for standardized comparisons of growth rate, feed efficiency (FCR) and carcass traits across different bulls. Phase C is ideal for identifying superior sires based on genetic potential rather than environmental influences. In contrast, Phase D occurs on the breeder's farm, where bulls are evaluated in their natural farm conditions for weight gain, adaptability, and overall performance before sale or breeding selection.

Beef performance testing can be used to increase economic gain. These records are used to identify superior animals within the herd with regards to an economically important trait. By selecting these animals for breeding, the general performance of the herd can be improved. This also allows farmers to recognise cattle that are high-producing (superior genetics), or low producing so that culling decisions can be made (Archer et al., 2004). Performance tests are also used to provide data for

potential clients wanting to buy certain animals. In other words, performance tests aids in promoting the merit of the herd.

There are two production systems that are utilized in this study; intensive production system and extensive production system. An intensive production system is based on animals that are housed or kept in a confined space, whilst making use of purchased concentrate feed. An extensive production system is based on animals grazing in the natural veld (Ogino et al., 2016). A study conducted with 36 Charolais × Friesian bulls examined the effects of three production systems on animal performance, carcass composition, and meat quality. The systems included: (i) intensive—young bulls fed silage and concentrates, slaughtered at 19 months; (ii) conventional—steers fed silage and concentrates, slaughtered at 24 months; and (iii) extensive—steers finished on pasture, slaughtered at 29 months. Results showed that intensive animals had the highest daily gain (1.18 kg/day) and superior carcass conformation ($P < 0.001$), while the conventional system yielded higher carcass fat content ($P < 0.05$). Meat quality traits, including tenderness and juiciness, improved with heavier slaughter weights ($P < 0.05$), although extensive animals had poorer muscle colour ($P < 0.01$). Carcass output per hectare was highest in intensive and conventional systems, but the extensive system had the highest gross margin per animal and per hectare (Keane and Allen, 1998).

There are important data that needs to be collected during the testing period. This includes, amongst others, contemporary groups, initial weights, weights at specific time intervals (every month), final weight, real-time ultrasound, feed intake and scrotal circumference. An important factor to consider with performance testing is that animals that enter the test, should complete the test. Data collection should be done as accurately as possible and in the correct time frame to avoid biased results with regards to herd performance.

1.9 How double muscling affects RFI

Muscular hypertrophy is caused by mutations in the myostatin gene which is displayed by the double muscled phenotype. Myostatin, also known as growth differentiation factor 8 (GDF8) plays a significant role in the regulation of muscle mass (Vankan et al., 2010). The myostatin gene has some polymorphisms that reduces the functionally effective myostatin, and the outcome of this is muscular hypertrophy (Bennett et al., 2019). These mutations can alter the activity or production of myostatin. This gene regulates the development of skeletal muscle, and animals that are double muscled have less fat deposition and an increased gain in muscle mass, which results in leaner meat (De Smet, 2004, Aiello et al., 2018). With regards to bovine MSTN, roughly 20 types of genetic variants have been

associated with muscular hypertrophy, which includes SNP's, insertions and deletions (Grobet et al., 1997). In Droughtmaster cattle, double muscling is tested using a hair sample. Hair is usually plucked ensuring the follicles are intact and sent for Deoxyribonucleic Acid (DNA) analysis. The DNA is extracted and polymerase chain reaction (PCR) testing is used to check for mutations in the myostatin (MSTN) gene. The results show whether the animal is homozygous (M/M), heterozygous (M/N), or wild type (N/N) for the mutation.

Double muscling can have an adverse effect on certain characteristics that influences feed efficiency. A snowball effect can be noticed in an animal with muscular hypertrophy. Firstly, the conformation will be improved and the animal will be more compact. This results in a higher dressing percentage and a lower bone and fat content (Arthur et al., 1989). Double muscled animals are also characterized by smaller organs, like the lungs, liver and digestive tract (could lead to respiratory problems). The smaller digestive tract leads to a decreased intake of dry matter, similarly to low-RFI animals. This then results in a decrease in feed conversion (Fiems, 2012). Some characteristics of double muscled animals include consuming less feed, having increased digestibility, and increased protein content. There are certain negative factors with regards to double muscled animals. These cattle are more susceptible to environmental stress since they have less body fat and have reduced circulation of blood. Reproductive problems, like dystocia, can also arise with an increase in conformation. Bulls that are double muscled show decreased fertility (have smaller testes and poor semen quality). Dystocia can be caused by a small pelvic area and increased calf birth weights. Other disadvantages include having a decrease in bone weight. In a study conducted with Belgian Blue double muscled cows, it was found that caesarean section was positively correlated to calf birth weight ($r=0.164$) (Fiems et al., 2001). Cafe et al. (2014) conducted a study with Angus cattle in three different groups. Group 1 had low muscling ($n=91$), group 2 had high muscling ($n=76$), and group 3 had one copy of the myostatin mutation ($n=61$). It showed that there was a negative correlation between muscling and feed intake ($P < 0.001$) (Group 1=0.34, Group 2= -0.06, Group 3=-0.40 kg DM/day). Mutations of the myostatin gene can be a valuable tool in genetic selection as well as to increase beef yield. In this study, the focus will be placed on two mutations.

1.9.1 F94L double muscling mutation

The F94L myostatin mutation is characterized where phenylalanine is substituted by leucine at amino acid position 94 of the myostatin gene (Grobet et al., 1997). This substitution is caused by a cytosine (C) to adenine (A) transversion in exon 1. This variant

is also known as the “Profit Gene” and is the most well- known variant. What makes this variant desirable is the fact that it increases muscle fibre size without being associated with dystocia, decreased longevity or decreased fertility. This variant is partially dominant and animals that are heterozygous (only carries one allele) for this gene might show some double muscling traits. Animals that are homozygous for F94L have meat with a higher percentage of polyunsaturated fats and the meat is also more tender. A study conducted with two beef herds from separate genetic backgrounds as well as two different environments (Australia and New Zealand) were investigated for different physiological effects due to the presence of F94L. It showed that homozygous animals for the F94L allele had a 5% increase in stifle width compared to heterozygous animals, without being different in weight. It was also noted that carcass fat mass was decreased by 33 % in homozygous animals in Australia and decreased with 16 % in New Zealand. The study concluded that there was a 7,3 % increase in meat weight and a 16,5 % decrease in fat weight (Esmailzadeh et al., 2008).

1.9.2 NT821 double muscling mutation

The NT821 myostatin mutation is a recessive variant and is seen in a smaller portion of the herd. This mutation is caused by the 11-base pair deletion in the third exon of the myostatin gene (Casas et al., 2004, Menezes et al., 2022). Homozygous animals for the allele will show smaller fat depths, larger loin depths as well as rounder and wider thighs and rump. A characteristic in this double muscling mutation is that it is visibly creased between the different groups of muscles. Animals that are heterozygous (only carries one allele) will appear to be normal. The negative of this double muscling mutation is that animals have heavier birth weights and could potentially struggle with giving birth. A study conducted by Menezes et al. (2022) where data from 2044 purebred Bos Taurus animals were collected, showed that animals that were heterozygous for NT821 double muscling mutation exhibited a larger ribeye area, which meant carcass weight and cut yields were higher.

1.10 Droughtmaster Cattle

The Droughtmaster breed was originally developed in North Queensland by crossing Shorthorn cattle with Brahman cattle. The goal was to develop a breed that could withstand tropic environments (like Zebu cattle) but could also have correct proportions like several British breeds (*Bos taurus*). During 1895-1903, Australia experienced The Federation Drought. This motivated farmers to produce a breed that could withstand these harsh conditions. In the 1950's it was decided to only breed with Droughtmasters that had a red colour. This meant better adaptability to the sun and extreme heat conditions. The Droughtmaster genetics was first imported to South Africa in the early 1990's, and live animals were brought to SA in 1999. These cattle are characterised with a sleek, short coat, loose skin and is medium to large in size (**Table 1.4**). They are also resistant to ticks and bloat. The Droughtmaster also has good calving ease, mothering abilities, fertility and high milk production. This breed is highly adaptable and fertile (Webb, 2022).

Table 1.4 Summary of the characteristics and traits of the Droughtmaster SA. Adapted from (Webb, 2022)

Characteristic/ Trait	Description
Colour	Usually red in colour but can vary between dark-red and yellow-red colours. This is due to the requirement of the "only red cattle" that was specified in the Africa Droughtmaster's Standard of Excellence.
Size	Droughtmaster cattle are medium framed. <ol style="list-style-type: none"> 1. Birth weight: 35,5 ± 5,48 kg (data from 8987 cattle from 2017-2021) 2. Weaning weight: 237,54 ± 43,88 kg (data from 7943 cattle, measured at ± 200 days of age from 2017-2021) 3. Yearling weight: 317,91 ± 82,41 kg (data from 4067 cattle records, measured at ± 400 days of age from 2017-2021) 4. Final weight: 417,26 ± 106,19 kg (data from 2361 cattle records, measured at 600 days of age from 2017-2021) 5. Mature weight: 493,74 ± 78,99 kg (measured at 700 days of age between 2017-2021)
Grazing pattern	Droughtmaster SA cattle are adapted for semi-arid and arid conditions. They are bulk grazers and need little supplementation due to their hardiness and adaptability. These cattle can turn low quality pasture into protein of high quality for human consumption.
Hair coat	Droughtmaster SA cattle have good pigmentation in their hair coat. The coats are also smooth and has a red colour.
Breeding methods	These cattle were developed by means of importing Droughtmaster genetics to South Africa and implementing breeding programmes by using Embryo transfer and artificial insemination.
Normal environment	Droughtmaster SA cattle are adapted for regions in the Southern Hemisphere and areas that receive little rainfall. This includes semi-arid and arid regions as well as extensive production/grazing systems.
Performance	The Droughtmaster SA is an early maturing breed that also breeds at a young age.

-
- 1) Average age at first calving: $24,5 \pm 4,23$ months (measured from 2017-2021)
 - 2) Average inter-calving period: $381,6 \pm 45,21$ days
-

Impact on production systems and indigenous livestock	This breed of cattle is adapted to increased levels of production under conditions where there are high temperatures and humidity as well as the occurrence of external parasites. The Droughtmaster SA differs from other synthetic cattle breeds in South Africa/ Namibia, because it was bred from the <i>Bos indicus</i> (50%) x <i>Bos taurus</i> (50%).
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1.11 Conclusion

Feed efficiency in the beef industry is vital for economic stability. Residual feed intake is seen as the best measure of feed efficiency and selecting for low residual feed intake will result in less heat and manure production. Not only does cattle with increased efficiency eat less, which in turn costs less, but several other factors are also improved. Maintenance requirements will be decreased as well as the animal's susceptibility to stress. Organ size will also decrease and low-RFI cattle will have reduced protein turnover. More efficient animals also have improved digestibility, which in turn results in a great environmental benefit. There is a positive correlation between DMI and methane production, and low-RFI cattle have been found to produce substantially less methane. Selecting more efficient animals will save money and will ultimately improve the breeding value of the herd

Chapter 2

Materials and Methods

2.1 Introduction

This study aimed to evaluate if the more efficient cattle (low residual feed intake) in the Growsafe® system, where feed was measured and delivered to the animals, performed the same in terms of feed efficiency when they were transferred to veld. This provides information on whether the veld-based performance test is accurate enough to identify the same superior animals (low residual feed intake) that the GrowSafe system identified. Subsequently the variation between the bulls and heifers in terms of feed efficiency can be assessed and factors contributing to variations in residual feed intake can be investigated.

This research was conducted after the research protocol was approved by the departmental research committee and with Research Ethics approval (Approval number: NAS285/2022).



Figure 2.1 Droughtmaster SA cattle in GrowSafe® system. Photo taken by Elandie du Preez in Standerton, October 2022.

2.3 Experimental location

This study took place on a farm in the area of Val near Standerton in the province of Mpumalanga in South Africa. It is located at a latitude of -26.722532 and a longitude of 28.973957. This area has an average rainfall of 795 mm per year and has an altitude of 1550 m above sea level

The biome of Mpumalanga is classified as Grassland and is more specifically known as the Tsakane Clay Grassland (Mucina, 2006). Its landscape features include somewhat undulating plains and low hills. The vegetation is characterized by dense and short grassland that has sour grass pastures (Mucina, 2006). Sourveld can be described as grazing that is palatable in summer but unpopular in winter, and is only useful for 6-9 months out of the year (Tainton, 1999). Sour veld is highly palatable in spring and has good quality, whereas the quality and palatability declines as the plant matures. This means its feed value is very low in winter (Barnes and Dempsey, 1992). Cattle are well adapted to this biome and will have high production during the summer and spring months. Since sourveld loses its nutritional value as the plant matures, feed will need to be given to the animals during winter as well as protein-containing and non-protein-nitrogen licks. This will ensure the animals are maintained throughout the winter period. This environment also has Smutsfinger grass in late winter (Barnes and Dempsey, 1992). This grass is a perennial forage crop and is highly adaptable because of its stolons and rhizomes. It also provides good soil coverage and prevents soil erosion. It is a high-quality grass that is tolerant to fire and drought and delivers 10-20 tons of DM/hectare/season (Pieterse, 2003, Dickinson et al., 2010).

2.4 Materials and Methods

2.4.1 Experimental Design

The experimental layout consisted of 150 weaners of varying ages, including both males (average starting weight: 347.87 kg) and females (average starting weight: 320.84 kg). Animals were first assigned to an intensive feeding phase using the GrowSafe® individual feed intake system, where they were housed in pens equipped to monitor individual feed intake and bunk attendance. The intensive phase lasted 63 days, including a 14-day adaptation period and 49 days of data collection, during which feed efficiency, residual feed intake (RFI), and growth performance were recorded. To account for variability, animals were blocked by sex before treatment allocation.

This study tested two null hypotheses: (H01) that there would be no significant difference in efficiency rankings between weaners in the intensive feeding system versus those on veld, and (H02) that there would be no significant differences in efficiency measures among animals with different double muscling genotypes. Following the intensive phase, all weaners were transferred to veld grazing, allowing for continued monitoring of growth and adaptation under extensive conditions. Statistical analyses were conducted to evaluate differences in efficiency measures between feeding systems and genetic groups.

2.4.2 The GrowSafe system and ration provided

Each pen was equipped with a GrowSafe® individual feed intake system (GrowSafe® Systems Ltd., Alberta, Canada) allowing for individual intake data. This system uses RFID technology, where each animal is fitted with an electronic identification (EID) tag that allows the system to track individual visits to the feeding station and measure feed disappearance in real time. The experimental period had a duration of 63 d (14 d of adaptation to feedlot diet and environment + 49 d of data collection) (Elolimy et al., 2018). Several groups of animals (consisting of 150 bulls and heifers in different pens and groups) entered the GrowSafe® individual feed intake system. Individual bunk attendance and feed disappearance data was recorded using GrowSafe® Data Acquisition software (Lancaster et al., 2009). This data was continuously measured for different groups of weaners throughout the years of 2022 and 2023 (also measured through all seasons of the year). The GrowSafe® software continuously collects real-time data on feed intake events, including duration, frequency, and consumption per visit, ensuring accurate assessment of individual feed efficiency. The recorded data was then formatted into an Excel spreadsheet for further statistical analysis and evaluation.

The process followed before placing the cattle in the GrowSafe® system, was weighing each individual animal with an LMI (Livestock Measuring Instrument) scale (bulls and heifers are weighed separately) and attaching an Electronic Identification Device (Allflex ear tag) to the ear of each animal. Before the animals were allowed into the system, an Electronic Identification Device was placed into a test wand that was then inserted into the feeding bunk 3 times for 3 seconds, to ensure the GrowSafe® feeding bunk recognised the ear tag device and was sending the data to the GrowSafe® Data Acquisition software. The LMI scale used, was called LS2000, which was a handheld instrument that communicated with a PC and generated reports and determined average daily growth. This instrument also had a stabilizing algorithm which eliminated spikes in the measurements that could be caused by lively animals. Once the trial period started, the animals were weighed fortnightly and

this was transferred to a spreadsheet. Once inside the GrowSafe[®] system, each animal was dosed with Iver-ject Super Fluke to protect against internal/external parasites (roundworms, lice, mange mites, blue ticks etc.) as well as liverfluke. Multimin was also injected for each animal and increased the mineral status of the bulls and heifers. The bulls and heifers were vaccinated with Botuthrax that was injected subcutaneously for botulism and anthrax. The bulls and heifers were also vaccinated against diseases caused by *Clostridium perfringens* with Covexin. Bovilis Vista Once was injected to protect against respiratory diseases as well as to protect against diseases caused by bovine virus diarrhoea. A combination vaccine (Bovi-shield One Shot) was also given to protect against *Pasteurella* and to prevent respiratory diseases.

The dry matter percentage of the TMR provided ranged from 52-61 % (**Figure 2.2**).. The Dry Matter percentage was calculated by taking 100 grams of the fresh mixed ration and weighing it. It was then placed into an Air fryer for 45 minutes at 135 degrees Celsius and weighed afterwards to calculate the dry matter %. The parameters of the TMR that was fed to the cattle in the system is shown in **Table 2.2**. The GrowSafe[®] system was validated through several studies as being reliable and accurate in measuring bunk attendance, weight and feed efficiency measures (Wang et al., 2006, Mendes et al., 2011). Fresh and clean water was also provided to the animals daily and was an important factor that influenced the feed efficiency of the animals (**Figure 2.3**). Adequate water intake leads to good feed intake and is necessary for several other important processes, such as reproduction, metabolism, digestion and body temperature, as well as resulting in sufficient growth of the animal.

Table 2.1 Composition of the ration fed (on a dry matter basis) to cattle in the GrowSafe system (provided from TMR analyses from UP NutriLab, 1 August 2023).

Parameter	Composition
Dry matter (%)	95.35
Ash (%)	10.25
Crude Protein (%)	15.88
Fat (%)	3.347
NDF (%)	52.94
ADF (%)	28.64
Gross energy (MJ/Kg)	16.34
Ca (%)	0.93
P (%)	0.3



Figure 2.2 Sample of ration that cattle are fed in the GrowSafe® system. Photo taken by Elandie du Preez in Standerton, October 2022.



Figure 2.3 Droughtmaster SA standing at water trough. Photo taken by Elandie du Preez in Standerton, October 2022.

2.4.3 Procedure of Multiple Ovulation and Embryo Transfer

The Multiple Ovulation Embryo Transfer (MOET) procedure begins with superovulation, where the donor female (with the desired trait) is administered hormones such as follicle-stimulating hormone (FSH) to induce the development of multiple follicles, rather than a single follicle. This administration is conducted over several days, followed by a dose of prostaglandin to synchronize ovulation. Upon ovulation, fertilization occurs either naturally or via artificial insemination (AI) using semen of superior genetic quality. Approximately 7 days post-fertilization, embryos are collected from the donor's uterus through a catheter inserted into the uterine cavity, enabling the retrieval of embryos using a flushing solution. These embryos are then subjected to microscopic evaluation to assess their developmental stage and viability (Kidie, 2019).

Following retrieval, embryos undergo grading based on established international standards for embryo classification. High-quality embryos may be immediately transferred to synchronized recipient females or cryopreserved for future use. Cryopreservation involves freezing the embryos using cryoprotectants to maintain their viability for subsequent thawing and transfer.

Recipient females are hormonally synchronized to align their reproductive cycles with the developmental stage of the embryos through similar hormonal treatments to those administered to the donor. This synchronization maximizes the likelihood of successful implantation and pregnancy. Embryo transfer is performed using a non-surgical technique, where embryos are placed into the recipient female's uterine horn using an embryo transfer gun, similar to the procedure for artificial insemination. The embryos are deposited in the upper portion of the uterine horn to optimize conditions for implantation. Pregnancy is monitored and confirmed using ultrasonography after several weeks to assess successful embryo implantation (Kidie, 2019).

2.4.4 Real-time Ultrasound

Cattle in the GrowSafe® system and on veld was scanned using real-time ultrasound. Real-time ultrasound uses high frequency sound waves of between 2 and 10 MHz and is non-invasive technology that allows farmers to assess carcass measurements whilst the animal is still alive. A transducer was placed firmly on the animals back or side and the sound waves penetrated the tissue and reflected of the different fat, muscle layers and hide. A cross-sectional image was then generated on the monitor of the ultrasound machine (University of Georgia Extension. Using live animal carcass ultrasound in

beef cattle, 2017). The pressure of the transducer is important as this can affect fat depth measurements. It is thus crucial to maintain consistent pressure when an animal was being scanned.

2.4.5 Scrotal measurements

Scrotal circumference measurements were taken from each bull. The testes were pulled down firmly into the lower part of the scrotum and then measured around the widest point with a measuring tape. A larger scrotal circumference is related to increased semen production and producing a progeny with an earlier age at puberty. In a study conducted with twelve crossbred bulls it was found that the bulls with the higher scrotal circumference and larger testes produced a greater volume of semen that contained more spermatozoa (Latif et al., 2009).

Scrotal circumference and the weight of paired testes exhibit a strong correlation. These metrics serve as indicators for determining daily sperm production (DSP) (Coulter and Foote, 1979). DSP refers to the quantity of sperm generated per gram of testis or per bull per day. Utilizing this estimate enables the establishment of an optimal collection frequency to maximize sperm yield while ensuring a high proportion of morphologically normal sperm.

2.4.6 Hip height measurement

Hip height measurements were taken from each animal to assess skeletal growth and frame size. Measurements were recorded, ensuring consistency across all animals. The animal was positioned on a level surface, and the measurement was taken at the highest point of the hip while the animal stood in a natural posture. Hip height is a key indicator of skeletal development and overall frame size, which are associated with growth potential and mature body weight. Larger-framed animals generally exhibit greater absolute growth potential but may have higher maintenance energy requirements (Brown et al., 2004). Hip height has been correlated with feed efficiency, as animals with a greater frame size may have different metabolic demands and growth rates influencing residual feed intake

2.5 Statistical analyses

The study employed a randomized complete block design, where animals were blocked by sex (male vs. female) to account for potential differences in growth performance and feed efficiency. Within each sex group, animals were randomly assigned to pens during the intensive feeding phase, where individual feed intake and performance metrics were recorded. Following this phase, all animals transitioned to veld grazing, allowing for the assessment of post-intensive growth. Statistical analyses were conducted using mixed-model procedures, with sex and feeding phase as fixed effects and individual animal data treated as repeated measures. Analysis of variance (ANOVA) was used to assess differences between groups, with significance set at $p < 0.05$. Least squares means \pm standard error were reported for all measured variables. Data that was collected in the GrowSafe[®] system included starting weight and weight at the end of each trail for each animal. The data of the weight and feed consumed of each individual animal was then sorted and the dry matter percentage of the feed that was given to the animals was already known and RFI was automatically calculated by the software programme. A detailed spreadsheet containing the RFI, RFI rank, RADG, RADG rank, start and end weight, ADG and DMI was generated. The data was then transferred to a new Excel spreadsheet and checked for any errors or duplicates. A separate data sheet was created to record the measurements taken of the animals on veld to subsequently link the data from the GrowSafe[®] system and veld. Measurements recorded of the animals on veld included hip height, body length, skin thickness, scrotal circumference, P8 fat, rib fat, eye-muscle are and weight. The data was analysed using SPSS software.

Chapter 3

Results and Discussion

3.1 Introduction

Two data sets were analysed during this study to determine if there is a statistically significant difference ($p < 0.05$) between efficiency measures of myostatin genotypes in terms of efficiency rankings of cattle in the intensive feeding system (GrowSafe® system) and on veld. Parameters in the two datasets that were recorded in the GrowSafe® system were dry matter percentage, RFI, RFI rank, residual average daily gain, start weight and end weight in the system, ADG, DMI and days spent in the system.

Variables that were measured after the bulls and heifers were transferred from the GrowSafe® system to veld were hip height, intermuscular fat percentage (only bulls measured), scrotal circumference (only bulls measured), P8 fat, rib fat, eye muscle area, weight, and days spent on the veld after the animals were in the GrowSafe® system. The independent variables in this study were the sex of the cattle (either male or female) and their myostatin mutation (F94L, NT821, None). The effect of these different double muscling genotypes and sex on efficiency measure were analysed for significant differences ($p < 0.05$).

Rib and body wall images were captured between the 12th and 13th ribs as well as the P8 site using real-time ultrasound. In the area that was scanned, hair was clipped and cleaned prior to image collection. Once a suitable image was obtained, the image was digitized and stored on a personal computer with a video frame grabber. Four measurements were taken: P8 fat (millimetres), Rib fat (millimetres), Eye Muscle area measurement (square centimetres) and Intra-muscular fat Percentage (percentage). P8 fat measurements (millimetre) can indicate differences regarding fat distribution among animals and is negatively correlated to days to calving. This meant a bull that had a higher P8 fat measurement will likely have daughters that has shorter days to calving (more fertile). The P8 rump site is located at the intersection of the line of the inside of the pin bone with the line of the high bone. Rib fat measurements (millimetre) also indicate genetic differences between animals and is also negatively correlated to days to calving (bull with higher rib fat will have daughters with shorter days to calving). The 12/13th rib site is located at the longissimus dorsi muscle. Eye muscle area measurements (square centimetres) are taken at the 12/13th rib site, and a larger eye muscle area is more favourable (a bull with a larger eye-muscle area will produce progeny with a higher degree of

muscle expression). Intra-muscular fat percentage is measured at the 12/13th rib site and a higher fat percentage is more favourable. This indicates that an animal with a higher intra-muscular fat percentage will produce progeny that expresses more marbling. These measurements were taken by an accredited ultrasound scanner.

3.2 Descriptive Statistics of Measurements in the GrowSafe system (First phase of the study trial)

Descriptive statistics obtained from the General Linear Model (GLM) procedure showed the difference between the mean and standard deviation of sex and double muscling mutation on different feed efficiency variables within the GrowSafe[®] system. Data presented in **Table 3.1** indicate that there was a positive relationship between RFI and start weight ($r=0.053$; $p=0.582$), as well as a positive relationship between start weight and end weight ($p<0.001$) for bulls. Bulls with no double muscling mutation had the best numerical value for RFI ($\bar{X}=0.01$), but the bulls with the NT821 double muscling mutation, numerically had the heaviest start weight ($\bar{X}=354$ kg; $p<0.001$). Heifers with the F94L double muscling mutation had the numerically higher mean for start weight ($\bar{X}=332.4$ kg) and end weight ($\bar{X}=405.76$ kg). Heifers with no double muscling mutation had the highest numerical value for RFI ($\bar{X}=0.06$). The bulls with the higher numerical mean for RFI rank ($\bar{X}=11.67$) were the animals with the F94L double muscling mutation, and those bulls also had the lowest numerical value for DMI ($\bar{X}=8.931$). Heifers with the F94L double muscling mutation had the lowest numerical mean for RFI rank ($\bar{X}=8.86$) but the highest numerical mean for DMI ($\bar{X}=9.067$). A low RFI value refers to bulls and heifers that are more efficient and will thus have a low RFI Rank (rank from 1 upwards, with 1 or the lowest value being the best), while the low RFI value cattle are less efficient and will rank worse and have a higher RFI Rank. Bulls with no double muscling mutation also had the lowest numerical mean for dry matter % ($\bar{X}=54.74$), the lowest RADG ($\bar{X}=0.004$) and the lowest ADG ($\bar{X}=1.51$). Heifers with the NT821 double muscling mutation had the lowest numerical mean for dry matter % ($\bar{X}=54.36$), but the highest RADG ($\bar{X}=0.0086$). The heifers with the F94L double muscling mutation had numerically the highest mean for ADG ($\bar{X}=1.304$; $p=0.048$).

Table 3.1 Descriptive statistics of Droughtmaster SA cattle in the GrowSafe system considering sex and double muscling mutation.

Sex	Double muscling mutation	n	RFI	RFI Rank	Dry Matter %	RADG	Start weight (kg)	End weight (kg)	ADG (g)	DMI
Male	F94L	6	\bar{X} =0.02 SD=0.725	\bar{X} =11.67 SD=4.844	\bar{X} =55.70 SD=3.71	\bar{X} =0.01 SD=0.079	\bar{X} =341.328 SD=49.035	\bar{X} =426.138 SD=57.207	\bar{X} =1.522 SD=0.123	\bar{X} =8.931 SD=0.988
	None	60	\bar{X} = -0.01 SD=0.55	\bar{X} =14.10 SD=10.836	\bar{X} =54.74 SD=2.90	\bar{X} =-0.004 SD=0.202	\bar{X} =348.27 SD=45.079	\bar{X} =429.519 SD=44.936	\bar{X} =1.51 SD=0.218	\bar{X} =8.968 SD=0.9996
	NT821	9	\bar{X} =-0.06 SD=0.599	\bar{X} =12.78 SD=9.497	\bar{X} =55.70 SD=3.60	\bar{X} =0.014 SD=0.167	\bar{X} =354.00 SD=27.653	\bar{X} =438.428 SD=25.557	\bar{X} =1.55 SD=0.188	\bar{X} =9.006 SD=0.965
Female	F94L	7	\bar{X} =-0.2 SD=0.687	\bar{X} =8.86 SD=3.024	\bar{X} =55.42 SD=3.62	\bar{X} =0.0029 SD=0.185	\bar{X} =332.4 SD=24.733	\bar{X} =405.757 SD=20.050	\bar{X} =1.304 SD=0.1584	\bar{X} =9.067 SD=0.618
	None	24	\bar{X} =0.06 SD=0.711	\bar{X} =13.38 SD=9.074	\bar{X} =55.77 SD=3.57	\bar{X} =0.0033 SD=0.147	\bar{X} =304.46 SD=31.875	\bar{X} =373.295 SD=33.767	\bar{X} =1.229 SD=0.1583	\bar{X} =8.600 SD=1.040
	NT821	7	\bar{X} =-0.17 SD=0.856	\bar{X} =13.00 SD=8.926	\bar{X} =54.36 SD=2.80	\bar{X} =0.0086 SD=0.222	\bar{X} =325.66 SD=26.564	\bar{X} =394.284 SD=32.138	\bar{X} =1.260 SD=0.173	\bar{X} =8.904 SD=1.249

\bar{X} : Mean; SD: Standard Deviation; n: Population size; RFI: Residual feed intake; RADG: Residual average daily gain; ADG: Average daily gain; DMI: Dry matter intake.

3.3 Measurements in the GrowSafe system (phase one) with Statistical Significance.

3.3.1 Residual feed intake (RFI)

Residual feed intake had a significant correlation with RFI rank ($r=0.769$, $p<0.001$) suggesting that as RFI decreased the cattle ranked lower in terms of RFI rank (most efficient animal had a ranking of 1). Residual feed intake also had a moderately, positive correlation with DMI ($r=0.685$, $p<0.001$). This positive correlation indicates that as RFI decreased, DMI also decreased, because these animals were more efficient in terms of nutrient utilization for growth. Broeze et al. (2020) reported that low RFI bulls and heifers had improved digestibility, resulting in a higher efficiency of nutrient use. Broeze et al. (2020) conducted a study with 53 cows and found that the cattle with a negative RFI, consumed 11.5 % less DMI than the cattle with a positive RFI, which resulted in more profitable animals due to a lower input cost.

In the present study, a negative correlation was observed between RFI and digestibility, which agrees with that of previous studies (Broeze et al., 2020). An explanation could be that more efficient cattle has a slower passage rate of feed passing through the rumen, after the lowered dry matter intake of the cattle. It follows that feed retention time was longer so that feed had an increased amount of time to digest. It was hypothesised that the cattle with the double muscling mutation (F94L and NT821) would have a better RFI (Kenny et al., 2018). In this study, the bulls with no double muscling mutation had the best mean RFI. Residual feed intake had a negative but significant correlation with RADG ($r=-0.373$, $p<0.001$) (**Table 3.2**), suggesting that as RFI decreased, RADG increased, suggesting that more efficient animals had improved growth performance.

Table 3.2 Correlations between RFI and other variables.

Control Variables		Correlations						
		#(WGS _{end} -WGS _{start})/ (WGP _{end} - WGP _{start})	Dry Matter %	RFI	RFI Rank	RADG	Start Weight	
Weight	RFI	Correlation	-0.054	-0.023	1.000	0.769	-0.373	0.053
		Significance (2-tailed)	0.572	0.809	.	<,001	<,001	0.582
		df	110	110	0	110	110	110

#(WGS_{end}-WGS_{start})/ (WGP_{end}- WGP_{start}):Difference in weight gain between GrowSafe® system end and start weight and end and start weight on veld.

According to the regression analysis there was a positive correlation ($r=0,769$; $p < 0,001$) between RFI and RFI rank. Bulls and heifers that had a double muscling mutation had a slightly lower RFI (RFI=-1.3) than the animals with no double muscling mutation (RFI=-1). The graph (**Figure 3.1**) indicates that as RFI increased, RFI rank also improved.

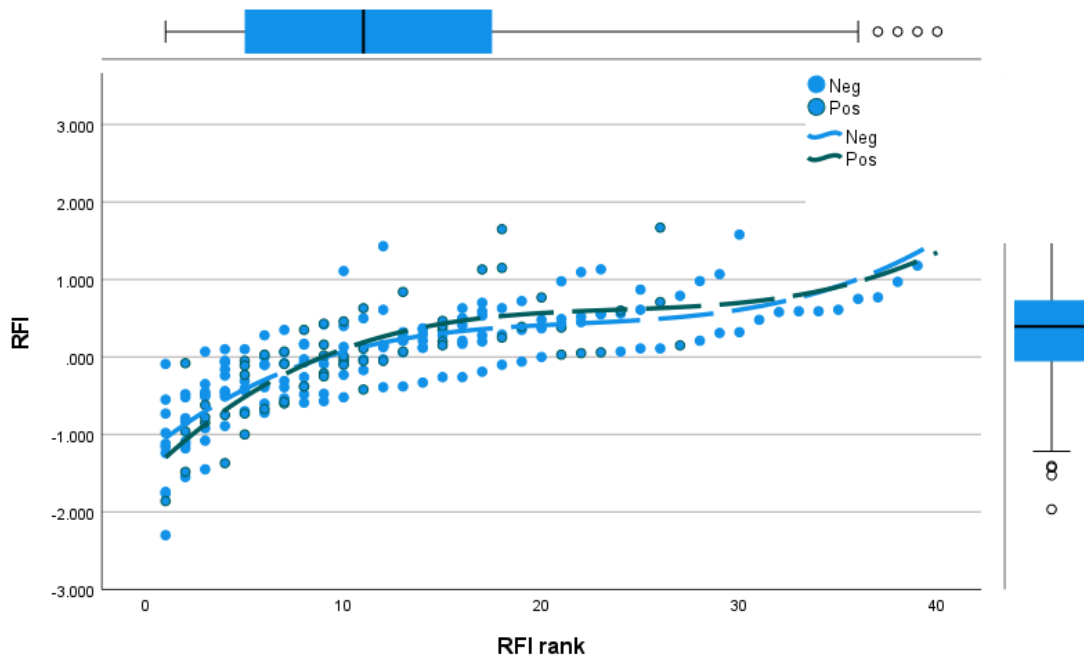


Figure 3.1 Regression line of RFI and RFI rank.
(Neg=animals with no double muscling mutation.
Pos=animals with a double muscling mutation.)

3.3.2) RFI rank

Bulls and heifers with the F94L double muscling mutation had numerically the lowest value for RFI rank, which suggested that cattle with the F94L double muscling mutation were the most efficient. This could be explained by the fact that the F94L double muscling mutation results in an increased size of muscle fibres, but with no negative effect on calving, fertility, or longevity. A study conducted with beef heifers showed that animals that were homozygous for the F94L double muscling mutation had lower maintenance energy requirements than the animals with no double muscling mutation in the myostatin gene (Hales et al., 2020). Bulls with the F94L double muscling mutation had the best numerical value for RFI rank, which suggested that these animals were the most efficient. Based on the correlations obtained in the present study, RFI rank correlated significantly with the number of

days spent on veld by the animals ($r=0.254$, $p=0.007$). There was also a significant correlation between RFI rank and dry matter intake ($r=-0.381$, $p<0.001$), a strong, positive correlation between RFI rank and RFI ($r=0.769$, $p<0.001$), as well as a significant correlation between RFI rank and RADG ($r=-0.306$, $p=0.001$) as indicated in **Table 3.3**. RFI rank had a significant correlation with DMI ($r=0.676$, $p<0.001$).

Table 3.3 Correlations between RFI rank and other variables.

Control Variables		Correlations						
		#(WGS _{end} -WGS _{start})/ (WGP _{end} - WGP _{start})	Dry matter %	RFI	RFI Rank	RADG	Start weight	
Weight	RFI Rank	Correlation	0.023	-0.381	0.769	1.000	-0.306	-0.014
		Significance (2-tailed)	0.810	<,001	<,001	.	0.001	0.881
		df	110	110	110	0	110	110

#(WGS_{end}-WGS_{start})/ (WGP_{end}- WGP_{start}): Difference in weight gain between GrowSafe system end and start weight and end and start weight on veld.

Using the Bootstrap method in correlations to exclude the influence of sex on RFI rank and other variables, there was a significant correlation between RFI rank and the number of days the animals spent on veld ($r=0.217$, $p=0.021$). This indicated that as RFI rank increased, the number of days spent on the veld by the bulls and heifers also increased. There was also a significant correlation between RFI rank and DMI using the Bootstrap method to exclude the influence of sex ($r=0.647$, $p<0.001$), suggesting that as RFI rank increased the DMI of the animals also increased, which was to be expected since the more efficient animals ranked lower and thus also had a decreased DMI (**Table 3.4**).

Table 3.4 Correlations of RFI rank to other variables with Bootstrap method.

		Correlations					
		Daily Gain on Veld	Days on Veld	RFI rank	ADG	DMI	
RFI Rank	Pearson Correlation	0.033	0.217*	1	0.025	0.647**	
	Sig. (2-tailed)	0.731	0.021		0.793	<,001	
	N	113	113	113	113	113	
Bootstrap ^c	Bias	0.002	0.000	0	-0.004	-0.002	
	Std. Error	0.097	0.075	0	0.098	0.061	
	95% Confidence Interval	Lower	-0.152	0.059	1	-0.176	0.504
		Upper	0.230	0.361	1	0.207	0.745

3.3.3 Start weight

The Tests of between-subjects effects showed that sex had a significant effect on start weight ($df=1$; $F=6.681$; $p=0.011$). Bulls weighed more than heifers for all myostatin mutations. Several studies and literature proved that bulls had a greater capacity for the conversion from feed to muscle tissue, whereas heifers reach maturity earlier which led to better finished carcasses (Purchas et al., 2002). The feeding patterns between bulls and heifers also differ. It is a known fact that bulls are heavier in weight than heifers, and this could be explained by the androgen hormones that proliferates the satellite cells, which increases protein synthesis, resulting in muscle hypertrophy. This leads to larger muscle fibres, subsequently resulting in heavier weights in male animals. Feed intake is also affected by sex. Bulls and heifers differ when it comes to nutritional requirements because of their different deposition of body tissue.

Pairwise comparisons showed that start weight had a significant effect where heifers with no double muscling mutation weighed less than bulls with no double muscling mutation (mean difference=43.810; $p<0.001$) (**Table 3.6**).

Table 3.5 Pairwise comparisons of start weight.

Pairwise Comparisons								
Dependent Variable	Double muscling mutation	(I) SEX	(J) SEX	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
							Lower Bound	Upper Bound
Start Weight	F94L	F	M	-8.928	22.131	0.687	-52.800	34.943
		M	F	8.928	22.131	0.687	-34.943	52.800
	none	F	M	-43.810*	9.607	<,001	-62.855	-24.764
		M	F	43.810*	9.607	<,001	24.764	62.855
	NT821	F	M	-28.337	20.046	0.160	-68.076	11.403
		M	F	28.337	20.046	0.160	-11.403	68.076

Start weight tended to have a significant correlation with P8 fat ($r=-0.159$, $p=0.093$). There was a significant, but weak correlation between start weight and rib fat ($r=-0.187$, $p=0.049$). Rib fat had a significant effect where heifers with no double muscling mutation had a larger rib fat than bulls with no double muscling mutation (mean difference=1.621; $p<0.001$). This suggested that the lower the start weight, the higher the rib fat would be, which in other words would relate to the heifers. There was a significant correlation between start weight and the number of days the animals spent on veld ($r=-0.284$, $p=0.002$), as well as a significant, strong, negative correlation between start weight and the

daily gain on veld ($r=-0.909$, $p<0.001$). The negative correlation indicated that a heavier start weight resulted in a decrease in the daily gain on veld. An explanation could be that heavier cattle have higher maintenance and nutrient requirements, which the veld forage cannot meet, thus leading to a decrease in daily gain and a reduction in body condition.

Correlation showed that there was a significant, strong, negative correlation between start weight and the difference in weight gain between the end weight in the system and weight measured in veld ($r=-0.936$, $p<0.001$), a significant correlation between start weight and dry matter % ($r=0.231$, $p=0.014$), and a significant correlation between start weight and RADG ($r=-0.362$, $p<0.001$).

There were significant correlations between start weight and end weight ($r=0.936$, $p<0.001$) which suggested that bulls and heifers with a heavier start weight also had a heavier end weight. There was an almost significant correlation between start weight and ADG ($r=-0.181$, $p=0.056$), and a significant correlation between start weight and DMI ($r=0.450$, $p<0.001$). This could be explained by the fact that heavier cattle have higher nutrient requirements and will consume more feed to meet those requirements, thus having a higher DMI.

3.3.5 End weight

Sex had a significant effect on end weight ($df=1$; $F=14.291$; $p<0.001$). Pairwise comparisons showed that end weight had a significant effect where heifers with no double muscling mutation weighed less than bulls with no double muscling mutation (mean difference=56.223; $p<0.001$). End weight had a significant effect where heifers with the NT821 double muscling mutation weighed less than bulls with the NT821 double muscling mutation (mean difference=44.143; $p=0.033$).

Correlations between end weight and other variables indicated that there was a significant correlation between end weight and P8 fat ($r=-0.218$, $p=0.021$). Heifers had a larger P8 fat than bulls, explaining why there was a negative correlation between the two variables since the bulls had higher end weights. There was a significant, negative, weak correlation between end weight and rib fat ($r=-0.224$, $p=0.018$). This suggested that as end weight increased, P8 fat and rib fat decreased. There was a significant correlation between end weight and the number of days the animals spent on veld ($r=-0.459$, $p<0.001$). In other words, a heavier end weight indicated that the bulls and heifers spent less days on veld, which was expected since more days on veld suggested a loss in body condition and weight since veld cannot meet the demands and requirements as the GrowSafe® system can. There was a significant strong, negative correlation between end weight and the daily gain on veld ($r=-0.961$,

$p < 0.001$) (**Table 3.7**). This related back to the fact that heavier cattle spent less days on veld and would subsequently have a decrease in daily gain on veld.

Table 3.6 Correlations between end weight and other variables.

Control Variables		Correlations					
		p8 Fat	Rib Fat	Eye Muscle	Days on Veld	Daily Gain on Veld	
Weight	End Weight	Correlation	-0.218	-0.224	-0.030	-0.459	-0.961
		Significance (2-tailed)	0.021	0.018	0.757	<,001	<,001
		df	110	110	110	110	110

Correlations in the GLM model indicated that there was a significant correlation between end weight and dry matter % ($r = 0.379$, $p < 0.001$). There was a significant strong positive correlation between end weight and start weight ($r = 0.936$, $p < 0.001$), suggesting that bulls and heifers with a heavier start weight also had a heavier end weight. There was a significant correlation between end weight and DMI ($r = 0.520$, $p < 0.001$), indicating that a heavier end weight resulted in a higher consumption of dry matter intake by the animal.

3.3.6 Average daily gain

The effect of sex on ADG ($df = 1$; $F = 26.06$; $p < 0.001$) was significant. Pairwise comparisons indicated that ADG had a significant effect where heifers with the F94L double muscling mutation gained less than bulls with the F94L double muscling mutation (mean difference = 0.217; $p = 0.048$). Average daily gain had a significant effect where heifers with no double muscling mutation gained less than bulls with no double muscling mutation (mean difference = 0.283; $p < 0.001$). ADG had a significant effect where heifers with the NT821 double muscling mutation gained less than the bulls with the NT821 double muscling mutation (mean difference = 0.286; $p = 0.004$) (**Table 3.8**). A study conducted by Hales et al. (2020) proved that heifers with two copies (homozygous) of the F94L myostatin variant had a higher average daily gain than the heifers with only one copy of the F94L allele. The homozygous heifers also had lower oxygen consumption along with a decrease in heat production, resulting in decreased maintenance energy requirements, making these animals more efficient.

Table 3.7 Pairwise comparisons of average daily gain (ADG).

Pairwise Comparisons								
Dependent Variable	Double muscling mutation	(I) SEX	(J) SEX	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
							Lower Bound	Upper Bound
ADG	F94L	F	M	-0.217*	0.109	0.048	-0.433	-0.002
		M	F	0.217*	0.109	0.048	0.002	0.433
	none	F	M	-0.283*	0.047	<,001	-0.376	-0.190
		M	F	0.283*	0.047	<,001	0.190	0.376
	NT821	F	M	-0.286*	0.098	0.004	-0.481	-0.091
		M	F	0.286*	0.098	0.004	0.091	0.481

There was a significant correlation between ADG and RADG ($r=0.731$, $p<0.001$). There was a tendency towards significance between ADG and start weight ($r=-0.181$, $p= 0.056$). There was a significant correlation between ADG and DMI ($r=0.214$, $p=0.023$). This indicated that as ADG increased, DMI also increased, which was to be expected. If an animal consumed more dry matter, this would result in an increase in daily gain.

Using the Bootstrap method in the General Linear Model to exclude the influence of sex on the variables, there was a significant correlation between ADG and the daily gain on veld ($r=0.305$, $p=0.001$). Using the Bootstrap method, there was a significant correlation between ADG and DMI ($r=0.313$, $p<0.001$). ADG also had a significant correlation with the difference in weight gain between the weight measured at the end in the GrowSafe[®] system and the veld weight ($r=0.327$, $p<0.001$).

The regression analysis indicated that at a lower RFI rank, the bulls and heifers that were positive for having a double muscling mutation had a higher ADG than the bulls and heifers that had no double muscling mutation. At an RFI rank of about 5, the ADG of cattle with and without a double muscling mutation was the same and remained constant until it reached an RFI rank of 25. At an RFI rank of 25, cattle with no double muscling mutation had a higher ADG than cattle that had a double muscling mutation (**Figure 3.2**)

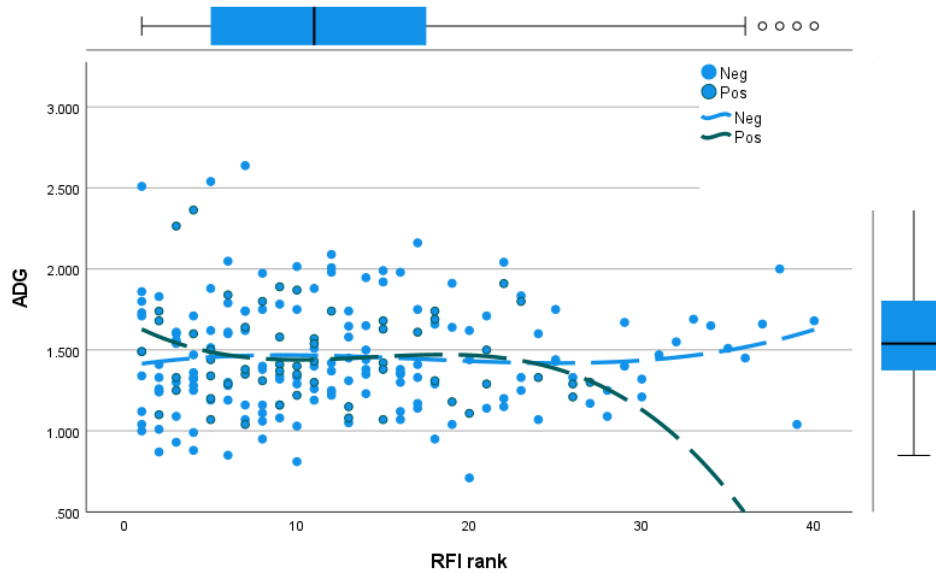


Figure 3.2 Regression line between ADG and RFI Rank.

(Neg=animals with no double muscling mutation.

Pos=animals with a double muscling mutation.)

3.3.7 Dry matter intake

Double muscling mutation and sex had no significant effect on DMI. DMI had a significant correlation with daily gain on veld ($r = -0.428$, $p < 0.001$). There was a significant correlation between DMI and the difference in weight gain between the end weight measured in the system and the weight on veld ($r = -0.520$, $p < 0.001$). There was a significant correlation between DMI and RFI ($r = 0.685$, $p < 0.001$). There was a significant correlation between DMI and RFI rank ($r = 0.676$, $p < 0.001$). The relationship between DMI and RFI had been validated through numerous studies. One study conducted with Simmental heifers proved that low RFI cattle consumed 15 % less than the high RFI cattle ($p < 0.05$) (Fitzsimons et al., 2013). There was a significant correlation between DMI and start weight ($r = 0.450$, $p < 0.001$). There was a significant correlation between DMI and end weight ($r = 0.520$, $p < 0.001$). There was a significant correlation between DMI and ADG ($r = 0.214$, $p = 0.023$).

The graph and regression analysis between DMI and RFI rank indicated that bulls and heifers with a double muscling mutation had a higher DMI at a low RFI rank. At an RFI rank of approximately 5, the DMI of both cattle with and without a double muscling mutation remained constant at a DMI of about 10. The bulls and heifers that had a double muscling mutation had a decline in DMI at an RFI rank of

approximately 23. At and RFI rank of 23, the bulls and heifers with no double muscling mutation had an increase in DMI (Figure 3.3).

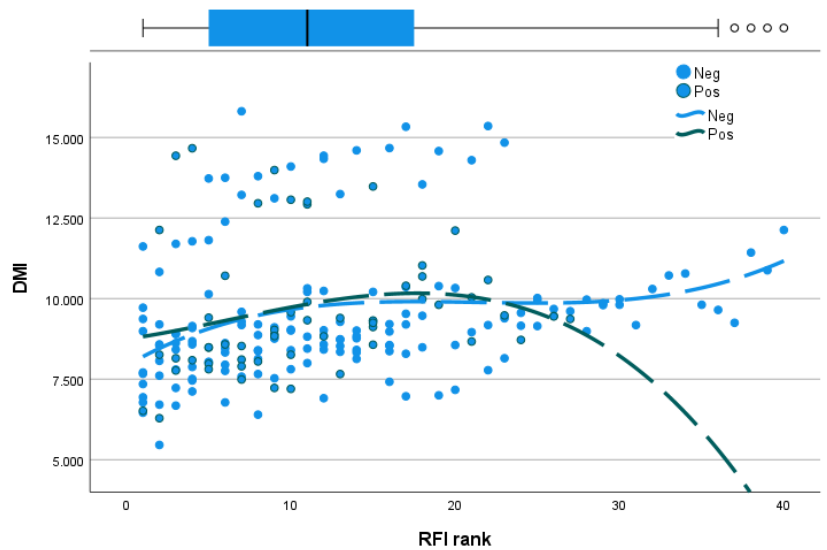


Figure 3.3 Regression line between DMI and RFI Rank.

(Neg=animals with no double muscling mutation.

Pos=animals with a double muscling mutation.)

3.4 Descriptive statistics of measurements in the veld (Second phase of the study trial).

Descriptive statistics run in the GLM model showed the difference between the means of sex and double muscling mutation on different efficiency variables measured on veld. From **Table 3.9** a relationship was noticed between the numerical values of scrotal size, eye muscle area, weight gain on veld, daily gain on veld, difference in weight gain between end weight in system and veld weight, and hip height for bulls. The bulls with the F94L double muscling mutation had the largest numerical value for scrotal size (\bar{X} =39), eye muscle area (\bar{X} =75.33; $p=0.023$), weight gain on veld (\bar{X} =503.33), daily gain on veld (\bar{X} =0.311), difference in weight gain between end weight in system and veld weight (\bar{X} =77.20), and hip height (\bar{X} =127). A relationship was noticed between the means of IMF %, P8 fat and rib fat. Bulls with no double muscling mutation had the higher numerical mean for IMF % (\bar{X} =1.78), P8 fat (\bar{X} =1.86) and rib fat (\bar{X} =1.33). The bulls with the lowest numerical mean for scrotal size were the bulls with the NT821 double muscling mutation (\bar{X} =36.39).

The heifers with no double muscling mutation had the largest numerical mean for P8 fat (\bar{X} =5.34), rib fat (\bar{X} =2.95), daily gain on veld (\bar{X} =0.13) and difference in weight gain between end weight in system

and veld weight (\bar{X} =32.83). Heifers with the F94L double muscling mutation had the largest numerical mean for eye muscle area (\bar{X} =65.86), whereas the heifers with the NT821 double muscling mutation had the numerically highest weight gain on veld (\bar{X} =421.43).

Table 3.8 Descriptive statistics of Droughtmaster SA cattle in the veld considering sex and double muscling mutation.

SEX	Double muscling mutation	n	Scrotal Size	Hip Height	IMF %	P8 Fat	Rib Fat	Eye Muscle Area	Weight on Veld (kg)	Daily Gain on Veld (g)	#(WGS _{end} -WGS _{start})/(WGP _{end} -WGP _{start})
Male	F94L	6	\bar{X} =39.0000 n=1	\bar{X} =127.0000 n=1	\bar{X} =1.6000 n=1	\bar{X} =1.417 SD=1.8552	\bar{X} =0.700 SD=1.0863	\bar{X} =75.33 SD=10.671	\bar{X} =503.33 SD=70.125	\bar{X} =0.31064 SD=0.38332 9	\bar{X} =77.19500 SD=92.608498
	None	60	\bar{X} =37.3200 SD=2.88632 n=25	\bar{X} =126.0400 SD=2.71539 n=25	\bar{X} =1.7840 SD=0.15727 n=25	\bar{X} =1.855 SD=2.3566	\bar{X} =1.333 SD=1.1386	\bar{X} =60.15 SD=10.295	\bar{X} =487.97 SD=69.249	\bar{X} =0.23424 SD=0.24798 8	\bar{X} =58.44800 SD=.312688
	NT821	9	\bar{X} =36.3889 SD=3.32395 n=9	\bar{X} =126.7778 SD=3.63242 n=9	\bar{X} =1.7222 SD=0.06667 n=9	\bar{X} =1.600 SD=1.4586	\bar{X} =1.333 SD=0.7483	\bar{X} =61.56 SD=12.471	\bar{X} =500.00 SD=75.180	\bar{X} =0.23837 SD=0.28674 4	\bar{X} =61.57222 SD=.727773
Female	F94L	7				\bar{X} =3.443 SD=1.1984	\bar{X} =1.714 SD=0.5551	\bar{X} =65.86 SD=6.012	\bar{X} =420.57 SD=25.728	\bar{X} =0.06528 SD=0.10025 8	\bar{X} =14.81429 SD=19.440495
	None	24				\bar{X} =5.342 SD=1.8500	\bar{X} =2.954 SD=0.8113	\bar{X} =54.54 SD=7.835	\bar{X} =406.12 SD=45.962	\bar{X} =0.13030 SD=0.12944 1	\bar{X} =32.82958 SD=35.372124
	NT821	7				\bar{X} =3.229 SD=1.3425	\bar{X} =1.843 SD=0.7786	\bar{X} =56.86 SD=5.815	\bar{X} =421.43 SD=29.815	\bar{X} =0.09785 SD=0.11290 2	\bar{X} =27.14429 SD=28.849096

\bar{X} : Mean; SD: Standard Deviation; n: Population size

#(WGS_{end}-WGS_{start})/(WGP_{end}-WGP_{start}): Difference in weight gain between GrowSafe system end and start weight and end and start weight on veld.

3.5 Measurements on veld (phase two) with Statistical Significance.

3.5.1 P8 fat

The test of between subject's effect showed that sex had a significant effect on P8 fat (df=1; F=19.077; $p < 0.001$). Heifers had a larger P8 fat according to the Univariate test run in the GLM model (df=2; F=4.156, $p = 0,018$). The total mean for P8 fat in heifers was 4.6 (n=38) whereas in bulls the total mean was 1.79 (n=75) (**Table 3.10**).

Table 3.9 Test of between-subjects effects of sex on other variables.

Test of between-subjects effects						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Sex	p8 Fat	82.017	1	82.017	19.077	<,001
	Rib Fat	15.903	1	15.903	15.829	<,001
	Eye Muscle	629.380	1	629.380	6.803	0.010
	Weight	95097.564	1	95097.564	24.780	<,001
	Days on Veld	140.089	1	140.089	0.047	0.829
	Daily Gain on Veld	0.386	1	0.386	7.448	0.007
	#(WGS _{end} -WGS _{start})/(WGP _{end} - WGP _{start})	24103.851	1	24103.851	8.013	0.006
	Dry matter %	0.552	1	0.552	0.054	0.816
	RFI	0.108	1	0.108	0.272	0.603
	RFI Rank	17.644	1	17.644	0.185	0.668
	RADG	5.193E-5	1	5.193E-5	0.002	0.969
	Start weight	10570.674	1	10570.674	6.681	0.011
	End weight	23447.198	1	23447.198	14.291	<,001
	ADG	0.993	1	0.993	26.060	<,001
	DMI	0.178	1	0.178	0.177	0.675

#(WGS_{end}-WGS_{start})/(WGP_{end}- WGP_{start}):Difference in weight gain between GrowSafe system end and start weight and end and start weight on veld.

It was also evident that double muscling mutation had a significant effect on P8 fat (df=2; $f=3.258$; $p=0.042$). Pairwise comparisons showed that P8 fat had a highly suggestive effect on the significance level of $p < 0.01$ where heifers with the F94L double muscling mutation was larger than bulls with the F94L double muscling mutation (mean difference=2.026; $p=0.082$). P8 fat had a significant effect where heifers with no double muscling mutation had a larger P8 fat than bulls with no double muscling mutation (mean difference=3.487; $p < 0.001$). Pairwise comparisons also showed that P8 fat had a tendency towards significance where heifers with no double muscling mutation had a larger P8 fat than heifers with the NT821 double muscling mutation (mean difference=2.113; $p=0.058$) (**Table**

3.11). The larger P8 fat in heifers in general could be explained by the fact that different sexes have different growth patterns and that bulls tend to be leaner and grow faster than heifers, explaining why bulls had a smaller P8 fat (Meyer and Graser, 1999). Correlations between P8 fat and other measures showed that P8 fat had a significant correlation with rib fat ($r=0.885$; $p<0.001$), a significant correlation with eye muscle area ($r=0.251$; $p=0.008$) and a significant correlation with daily gain on veld ($r=0.218$; $p=0.021$). The correlation between control variables weight and P8 fat showed a significant correlation with end weight of the animals ($r=-0.281$, $p=0.021$, $df=110$), and ADG ($r=-0.328$, $p<0.001$, $df=110$). This showed that as P8 fat increased, the end weight and ADG of the animals decreased, since there was a negative correlation.

Table 3.10 Pairwise comparisons between P8 fat, sex and double muscling mutation.

Pairwise Comparisons							95% Confidence Interval for Difference ^b	
Dependent Variable	SEX	(I) Mutation	(J) Mutation	Mean Difference (I- J)	Std. Error	Sig. ^b	Lower Bound	Upper Bound
p8 fat	F	F94L	None	-1.899	0.891	0.106	-4.065	0.268
			NT821	0.214	1.108	1.000	-2.481	2.910
		none	F94L	1.899	0.891	0.106	-0.268	4.065
			NT821	2.113	0.891	0.058	-0.053	4.279
		NT821	F94L	-0.214	1.108	1.000	-2.910	2.481
			None	-2.113	0.891	0.058	-4.279	0.053
	M	F94L	None	-0.438	0.888	1.000	-2.598	1.721
			NT821	-0.183	1.093	1.000	-2.841	2.475
		none	F94L	0.438	0.888	1.000	-1.721	2.598
			NT821	0.255	0.741	1.000	-1.548	2.058
		NT821	F94L	0.183	1.093	1.000	-2.475	2.841
			None	-0.255	0.741	1.000	-2.058	1.548

3.5.2 Rib fat

The test of between subject's effect showed that sex had a significant effect on rib fat ($df=1$; $f=15.829$; $p<0.001$) (**Table 3.12**). Double muscling mutation also had a significant effect on rib fat ($df=2$; $f=5.836$; $p=0.004$), and according to the Pairwise comparisons in the General Linear Model, rib fat had a highly suggestive effect where heifers with the F94L double muscling mutation had a larger rib fat area than bulls with the F94L double muscling mutation (mean difference=1.014; $p=0.072$). Rib fat had a significant effect where heifers with no double muscling mutation was larger than bulls with no double

muscling mutation (mean difference=1.621; $p<0.001$). Rib fat had a significant effect where heifers with the F94L double muscling mutation was smaller than heifers with no double muscling mutation (mean difference=1.24; $p=0.014$). Rib fat had a significant effect where heifers with the NT821 double muscling mutation was smaller than heifers with no double muscling mutation (mean difference=1.111; $p=0.034$). Control variables of weight and rib fat had correlations to P8 fat ($r=0.885$, $p<0.001$, $df=110$), and a correlation with daily gain on veld ($r=0.208$, $p=0.027$, $df=110$). This suggested that as rib fat increased, P8 fat and daily gain on veld also increased (positive correlation).

Table 3.11 Descriptive statistics of rib fat, sex and double muscling mutation.

Descriptive Statistics					
	SEX	Mutation	Mean	Std. Deviation	N
Rib fat	F	F94L	1.714	0.5551	7
		None	2.954	0.8113	24
		NT821	1.843	0.7786	7
		Total	2.521	0.9430	38
	M	F94L	0.700	1.0863	6
		None	1.333	1.1386	60
		NT821	1.333	.7483	9
		Total	1.283	1.0972	75
	Total	F94L	1.246	0.9606	13
		None	1.796	1.2832	84
NT821		1.556	0.7806	16	
Total		1.699	1.1977	113	

The regression analysis between rib fat and RFI rank (**Figure 3.4**) showed that bulls and heifers that were positive for having a double muscling mutation had a generally larger rib fat than animals that were negative for double muscling mutation (do not have a matation). At an RFI rank of approximately 7/8, the rib fat of animals with no double muscling mutation and those that had a double muscling mutation were the same (Rib fat of 5). An RFI rank of 7 and upwards indicated that cattle with no double muscling mutation had a larger rib fat, until it reached an RFI rank of 15, where cattle that were positive for having a double muscling mutation started increasing in rib fat. At the point where RFI rank is 19, cattle that had a double muscling mutation had a larger rib fat than animals with no double muscling mutation. According to Herd et al. (2003b), there is a genetic link between RFI and subcutaneous fat depth. The study indicated that more efficient steers (low RFI) had less fat on the rib and rump area, as well as a smaller eye muscle area than the less efficient steers (10.2 v 11.6mm, 13.1 v 14.8mm, 66.9 v 70.6cm²; all $P<0.05$).

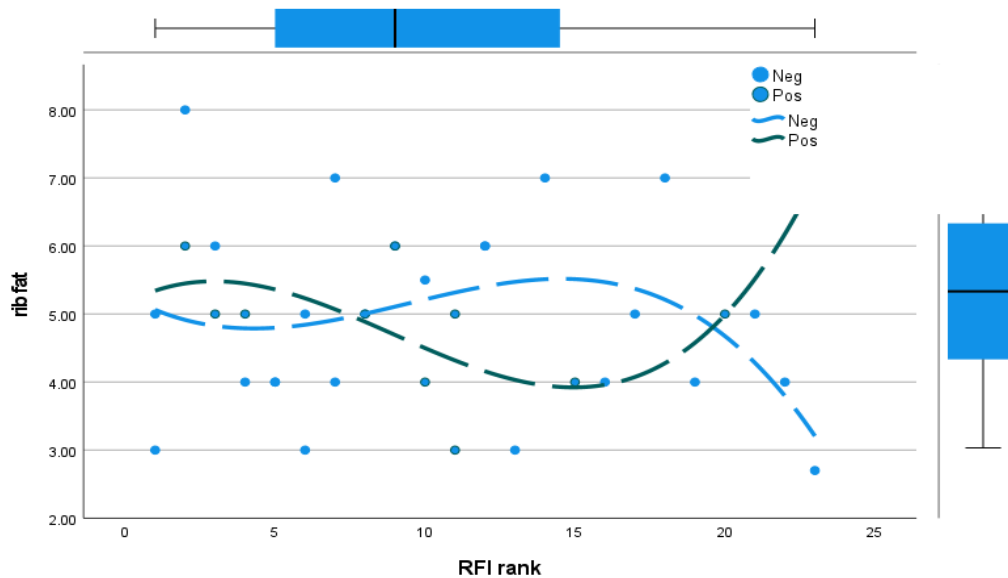


Figure 3.4 Regression line of RFI rank to Rib fat.
(Neg=animals with no double muscling mutation.
Pos=animals with a double muscling mutation.)

3.5.3 Eye muscle area

Sex had a significant effect on eye muscle area ($df=1$; $F=6.803$; $p=0.01$), and double muscling mutation also had a significant effect on eye muscle area ($df=2$; $F=10.321$; $p<0.001$). Eye muscle area had a significant effect where bulls and heifers with the F94L double muscling mutation were larger than bulls and heifers with no double muscling mutation (mean difference=13.249; $p<0.001$). Eye muscle area had a significant effect where bulls and heifers with the F94L double muscling mutation had a larger eye muscle area than bulls and heifers with the NT821 double muscling mutation (mean difference=11.389; $p=0.006$). It was also evident that eye muscle area had a highly suggestive effect where heifers with the F94L double muscling mutation had a smaller eye muscle area than bulls with the F94L double muscling mutation (mean difference=9.476; $p=0.079$). Eye muscle area had a significant effect where heifers with no double muscling mutation was smaller than bulls with no double muscling mutation (mean difference=5.608; $p=0.017$). Eye muscle area had a significant effect where heifers with the F94L double muscling mutation was larger than heifers with no double muscling mutation (mean difference=11.315; $p=0.022$). There was also a significant effect where bulls with the F94L double muscling mutation had a larger eye muscle area than bulls with no double muscling mutation (mean difference=15.183; $p=0.001$). Eye muscle area had a significant effect where bulls with the F94L double muscling mutation was larger than bulls with the NT821 double muscling

mutation (mean difference=13,778; $p=0.023$). Eye muscle was in descending order for double muscling mutations; F94L, NT821, No mutation. Bulls had a larger eye muscle area (**Table 3.13**). This was to be expected, since more efficient cattle (F94L) will convert their feed and nutrients more effectively into muscle mass, resulting in a larger eye muscle area. Eye muscle area had a negative correlation with ADG with a highly suggestive effect at the $p<0.01$ significance level ($r=-0.167$, $p=0.079$).

Table 3.12 Pairwise comparisons between eye muscle area, sex and double muscling mutation.

Pairwise Comparisons								
Dependent Variable	SEX	(I) Mutation	(J) Mutation	Mean Difference (I- J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
							Lower Bound	Upper Bound
Eye Muscle Area	F	F94L	None	11.315*	4.132	0.022	1.266	21.365
			NT821	9.000	5.141	0.249	-3.505	21.505
		none	F94L	-11.315*	4.132	0.022	-21.365	-1.266
			NT821	-2.315	4.132	1.000	-12.365	7.734
		NT821	F94L	-9.000	5.141	0.249	-21.505	3.505
			None	2.315	4.132	1.000	-7.734	12.365
	M	F94L	None	15.183*	4.118	0.001	5.167	25.200
			NT821	13.778*	5.069	0.023	1.448	26.107
		none	F94L	-15.183*	4.118	0.001	-25.200	-5.167
			NT821	-1.406	3.438	1.000	-9.768	6.957
		NT821	F94L	-13.778*	5.069	0.023	-26.107	-1.448
			None	1.406	3.438	1.000	-6.957	9.768

The regression analysis between eye muscle area and RFI rank showed that bulls and heifers that had a double muscling mutation had a lower RFI rank and a larger eye muscle area (**Figure 3.5**). As the RFI rank increased from 0 to 5, the eye muscle area for cattle that had a double muscling mutation decreased. Between an RFI rank of 5 and 16, eye muscle area for bulls and heifers with a double muscling mutation increased, until it reached an RFI rank of 17, where it then decreased to a point (RFI rank=21) where it had a smaller eye muscle area than the bulls and heifers with no double muscling mutation. Cattle that were negative for having a double muscling mutation had a generally smaller eye muscle area. As the RFI rank increased, the eye muscle area for these animals also slightly increased, until it reached a point where the RFI rank was approximately 13, then the eye muscle area for the bulls and heifers with no double muscling mutation decreased. At an RFI Rank of 21 and upwards, animals with no double muscling mutation had a larger eye muscle area than animals that had a double muscling mutation.

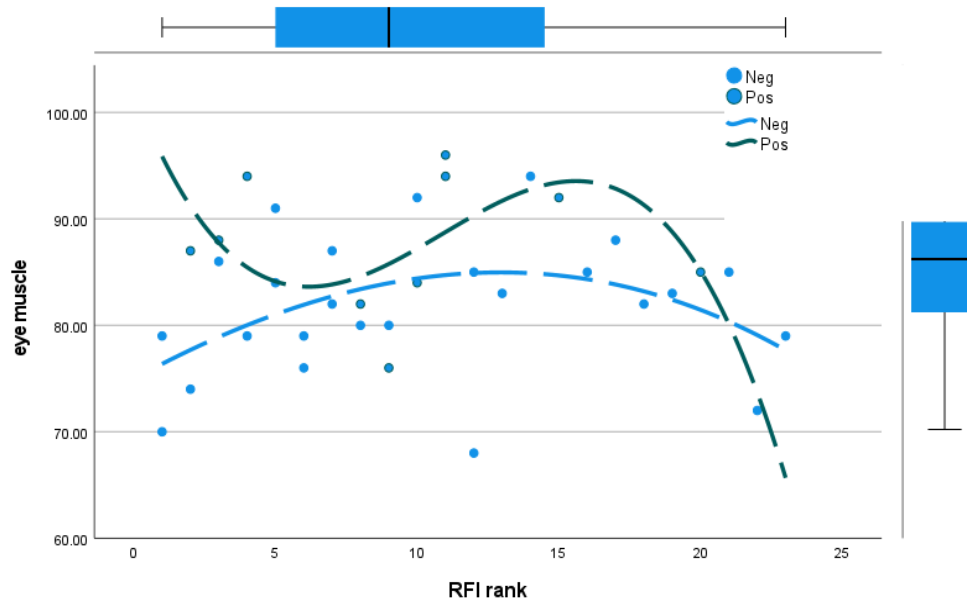


Figure 3.5 Regression line of RFI rank and Eye Muscle Area

(Neg=animals with no double muscling mutation.

Pos=animals with a double muscling mutation.)

3.5.4 Weight measured on veld

The test of between subject's effect showed that there was a significant effect of sex on the weight measured on veld ($df=1$; $F=24.78$; $p\text{-value}<0.001$). Descriptive statistics showed that bulls are numerically heavier than heifers. The total mean for the weight of bulls was 490.64 kg, whereas for heifers it was 411.61 kg. Heifers with the F94L double muscling mutation weighed less than bulls with the F94L double muscling mutation (mean difference=82.762; $p=0.018$). Weight had a significant effect where heifers with no mutation ($\bar{X} = 406.12$ kg) weighed less than bulls with no double muscling mutation ($\bar{X} = 487.97$ kg) (mean difference=81,842; $p<0.001$). Weight had a significant effect where heifers with the NT821 double muscling mutation ($\bar{X} = 421.43$ kg) weighed less than bulls with the NT821 double muscling mutation ($\bar{X} = 500$ kg) (mean difference=78,571; $p=0.013$) (**Table 3.14**).

Table 3.13 Pairwise comparisons between weight measured on veld, sex and double muscling mutation.

Pairwise Comparisons							95%	Confidence
Dependent Variable	SEX	(I) Mutation	(J) Mutation	Mean Difference (I-J)	Std. Error	Sig. ^b	Interval for Difference ^b	
							Lower Bound	Upper Bound
Weight measured on veld	F	F94L	None	14.446	26.611	1.000	-50.276	79.169
			NT821	-.857	33.113	1.000	-81.394	79.680
		none	F94L	-14.446	26.611	1.000	-79.169	50.276
			NT821	-15.304	26.611	1.000	-80.026	49.419
		NT821	F94L	0.857	33.113	1.000	-79.680	81.394
			None	15.304	26.611	1.000	-49.419	80.026
	M	F94L	None	15.367	26.525	1.000	-49.147	79.880
			NT821	3.333	32.650	1.000	-76.077	82.744
		none	F94L	-15.367	26.525	1.000	-79.880	49.147
			NT821	-12.033	22.144	1.000	-65.892	41.825
		NT821	F94L	-3.333	32.650	1.000	-82.744	76.077
			None	12.033	22.144	1.000	-41.825	65.892

3.5.5 Daily gain on veld

According to the Test of between subjects' effect, sex had a significant effect on the daily gain on veld (df=1; F=7.448; p =0.007). Pairwise comparisons showed that daily gain on veld had a tendency towards significance where heifers with the F94L double muscling mutation gained less than bulls with the F94L double muscling mutation (mean difference=0.245; p=0.055). Daily gain on veld was highly suggestive at the p<0.01 level where heifers with no double muscling mutation gained less than bulls with no double muscling mutation (mean difference=0.104; p=0.061). There was also a significant correlation between daily gain on veld and the number of days spent on veld (r=0.459; p<0.001). Daily gain on veld also had a significant correlation with end weight (r=-0.961, p<0.001) and to DMI (r=-0.428, p<0.001).

Correlation with the Bootstrap method incorporated, to take out the influence of sex, showed that daily gain on veld had a significant correlation with the days spent on veld (r=0.557, p<0.001) and to ADG (R=0.305, p=0.001). Daily gain on veld also had a significant correlation with the difference in weight gain between the end weight in the system and veld weight (r=0.981, p<0.001) (**Table 3.15**).

Table 3.14 Correlations between daily gain on veld and other variables.

		Correlations					
		Daily gain on veld	days on veld	RFI Rank	ADG	DMI	$\frac{\#(WGS_{end}-WGS_{start})}{(WGP_{end}-WGP_{start})}$
Daily gain on veld	Pearson Correlation	1	0.557**	0.033	0.305**	0.981**	0.981**
	Sig. (2-tailed)		<,001	0.731	0.001	<,001	<,001
	N	113	113	113	113	113	113
	Bootstrap ^c Bias	0	0.003	0.002	0.000	0.000	0,000
	Std. Error	0	0.054	0.097	0.006	0.006	0,006
	95% Lower Confidence Interval	1	0.446	0.967	0.967	-0.259	0,967
	Upper	1	0.657	0.990	0.990	0.069	0,990

3.5.6 Difference in weight gain between end weight in system and veld weight

Sex had a significant effect on the difference in weight gain between end weight in the GrowSafe[®] system and weight measured on veld (df=1; f=8.013; p=0.006). Pairwise comparisons showed that the difference in weight gain between end weight in the GrowSafe[®] system and weight measured on veld is significant where heifers with the F94L double muscling mutation gained less than bulls with the F94L double muscling mutation (mean difference=62.381; p=0.043). The difference in weight gain between end weight in the system and weight measured on veld was almost significant where heifers with no double muscling mutation gained less than bulls with no double muscling mutation (mean difference=25.618; p=0.056). Taking out the effect that sex had on the difference in weight gain between end weight in the GrowSafe[®] system and weight measured on veld with the Bootstrap Method, there was a significant correlation with daily gain on veld (r=0.981, p<0.001), to days spent on veld (r=0.607, p<0.001), and to ADG (r=0.327, p<0.001) (**Table 3.16**).

Table 3.15 Correlations between the difference in weight gain between end weight in the system and veld weight, and other variables.

		Correlations				
		Daily gain on veld	days on veld	RFI Rank	ADG	DMI
$\frac{\#(WGS_{end}-WGS_{start})}{(WGP_{end}-WGP_{start})}$	Pearson Correlation	0.981**	0.607**	-0.003	0.327**	-0.127
	Sig. (2-tailed)	<,001	<,001	0.975	<,001	0.181

N			113	113	113	113	113
Bootstrap ^c	Bias		0.003	0.002	-0.002	-0.001	0.000
	Standard error		0.041	0.097	0.077	0.084	0.006
	95% Confidence Interval	Lower	0.967	0.527	-0.184	0.165	-0.291
		Upper	0.990	0.690	0.199	0.467	0.042

#(WGS_{end}-WGS_{start})/ (WGP_{end}- WGP_{start}): Difference in weight gain between GrowSafe[®] system end and start weight and end and start weight on veld.

3.5.7 Intermuscular fat percentage (IMF %)

The regression analysis indicated that at a low RFI rank, IMF % for bulls with no double muscling mutation was generally lower than for bulls with a double muscling mutation (**Figure 3.6**). At an RFI rank of 3, bulls with no double muscling mutation had a higher IMF % than bulls with a double muscling mutation. These animal's IMF % increased until it reached an RFI of approximately 7, where it then started to decrease. An increase in IMF % was noticed in bulls with no double muscling mutation at an RFI rank of 17. Bulls that were positive for having a double muscling mutation had a lower IMF % in general than the bulls that have no double muscling mutation. The IMF % remained fairly constant at 1.7 for bulls with a double muscling mutation. There was a further decrease in IMF % for bulls with a double muscling mutation at an RFI rank of 16. This regression curve suggested that bulls with a double muscling mutation had reduced intermuscular fat content. A study conducted on beef quality traits in Australia and New Zealand found that the F94L allele was linked to heavier meat weights (increase of 7.3 % in Australia and 5.9 % in New Zealand; $p < 0.001$). There was also a link between the F94L allele and reduced fat depth, intermuscular fat and total fat weight of the carcass, suggesting that cattle with the F94L double muscling mutation are leaner (Esmailizadeh et al., 2008).

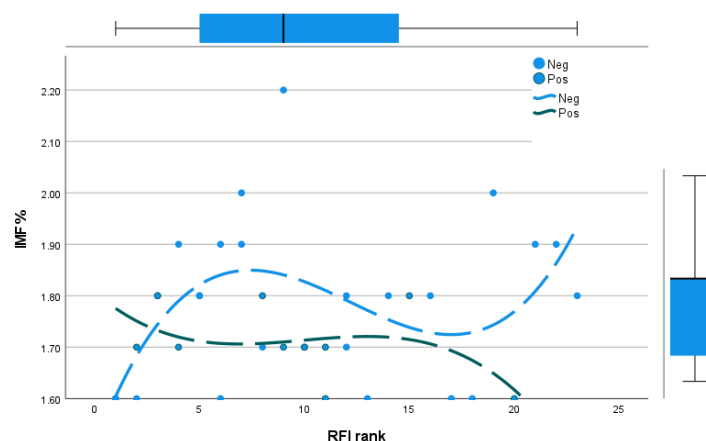


Figure 3.6 Regression line of IMF % and RFI rank.

(Neg=animals with no double muscling mutation
 Pos=animals with a double muscling mutation.)

3.5.8 Hip height

Hip height correlated significantly with scrotal size ($r=0.429$, $p=0.011$). There is a significant, positive correlation between hip height and P8 fat ($r=0.305$, $p=0.042$). There was also a tendency towards significance between hip height in bulls and rib fat ($r=0.327$, $p=0.059$) considering a significance level of $p<0.05$ (**Table 3.17**). Bulls that were positive for having a double muscling mutation had a slightly larger numerical value for hip height ($\bar{X}=126.8$) than bulls with no double muscling mutation ($\bar{X}=126.04$). These correlations suggested that hip height was not influenced by bulls ranking lower for RFI. An evaluation on hip height in a number of animal records (6 548) and contemporary groups (169) showed that the mean hip height (cm) was 132 ± 5.43 (Ceacero et al., 2016). The male cattle in this study had similar measurements with regards to their hip height.

Table 3.16 Correlations between hip height in male cattle and other variables.

			Correlations				
Control Variables			Scrotal size	hip height	p8 fat	rib fat	eye muscle
Start weight	Hip Height	Correlation	0.429	1.000	0.350	0.327	0.022
		Significance (2-tailed)	0.011	.	0.042	0.059	0.902
		df	32	0	32	32	32

3.5.9 Scrotal size

Scrotal size had a significant correlation with RFI ($r=0.455$, $p=0.007$), as well as a significant correlation with RFI rank ($r=0.390$, $p=0.023$). Scrotal size also had a highly suggestive correlation with DMI ($r=0.309$, $p=0.075$) at the significance level of $p<0.10$ (**Table 3.18**). The correlation between scrotal size, RFI and RFI rank was positive, indicating that as scrotal size increased, RFI and RFI rank also increased. This suggested that a lower RFI (more efficient bulls with a low RFI rank) had a smaller scrotal size.

Table 3.17 Correlations of scrotal size and other variables.

Control Variables		Correlations					
		Dry matter %	RFI	RFI rank	ADG	DMI	
Start weight	Scrotal Size	Correlation	.	0.455	0.390	0.100	0.309
		Significance (2-tailed)	0.007	0.023	0.576	0.075	
		df	32	32	32	32	32

According to the regression analysis between scrotal size and RFI rank, bulls that had a double muscling mutation had a generally lower RFI rank, and subsequently a smaller scrotum size. Bulls with a double muscling mutation increased in scrotal size until an RFI rank of 7 was reached. The scrotal size then remained constant (scrotal size=37.3) but increased when an RFI rank of 18 is reached. Bulls with no double muscling mutation increased in scrotal size (scrotal size=39.5) until an RFI rank of 16 was reached where it then declined until a scrotal size of 36 was reached (**Figure 3.7**). As previously mentioned, the relationship between fertility and feed efficiency was evaluated between 110 crossbred beef bulls with an average age of 274 ± 2.5 d, where semen was collected and scrotal circumference was measured at the end of the test period (112 days). Scrotal circumference (SC) is an important measurement of fertility since it is correlated with testes size and weight as well as age at puberty in the heifer progeny and the ability to produce sperm. The results indicated that less efficient bulls had increased and better sperm motility and larger SC than that of more efficient bulls. An explanation could be that low RFI bulls (efficient bulls) reach puberty at a slower rate than high RFI bulls, and as a result have a reproductive tract that is more immature when semen was collected as well as a smaller scrotal circumference (Awda et al., 2013).

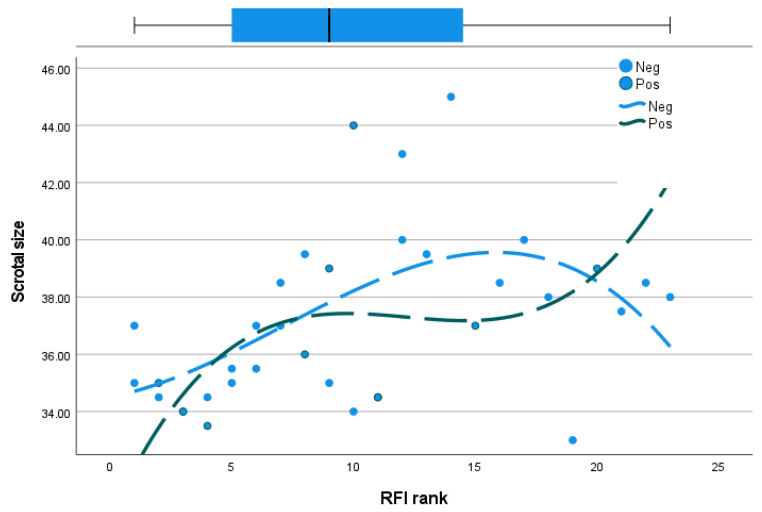


Figure 3.7 Regression line between scrotal size and RFI rank.

(Neg=animals with no double muscling mutation.

Pos=animals with a double muscling mutation.)

Chapter 4

Conclusion

The study evaluated the connection between the GrowSafe® System (Phase One) and veld conditions (Phase Two) in Droughtmaster SA cattle. Bulls with the F94L double muscling mutation were found to have the lowest mean for Residual Feed Intake (RFI) rank ($\bar{X} = 11.67$), indicating they were the most efficient. Although the differences in RFI between the various double muscling mutations in bulls were not statistically significant, the F94L mutation bulls also exhibited the lowest mean Dry Matter Intake (DMI) ($\bar{X} = 8.931$). While this difference was not statistically significant compared to other mutations, it aligns with existing research that shows efficient cattle generally have lower DMI.

The bulls with the F94L mutation had the largest eye muscle area, with significant differences noted between these bulls and those with no double muscling mutation ($p = 0.001$) and those with the NT821 mutation ($p = 0.023$). This supports the idea that efficient cattle utilize nutrients more effectively, leading to greater muscle development over fat deposition. Although the F94L bulls had the highest mean weight on veld ($\bar{X} = 503.33$; $SD = 70.125$), this difference was not statistically significant, possibly due to their better ability to maintain body condition when transitioning from intensive systems to veld. Additionally, these bulls exhibited the lowest P8 fat, rib fat, and intermuscular fat percentages, further emphasizing their leanness. They also had the largest scrotal circumference ($\bar{X} = 39.00$), highest hip height (127.00 cm), and highest daily gain on veld (0.31 kg/day), although the latter was not statistically significant.

Heifers with the F94L mutation were similarly efficient, having the lowest mean RFI rank ($\bar{X} = 8.86$), though this was not statistically significant. Unexpectedly, these heifers had the highest DMI ($\bar{X} = 9.07$) among the double muscling mutations, contrary to the bulls' lower DMI. This could be attributed to differing nutritional needs between genders, with heifers requiring more energy for reproductive functions. Despite the higher DMI, the F94L heifers had the largest eye muscle area ($\bar{X} = 65.86$), with significant differences noted between them and heifers without the mutation ($p = 0.022$). However, they did not gain the most weight on veld, with heifers carrying the NT821 mutation showing slightly higher weight gain. The F94L heifers also had the lowest rib fat ($\bar{X} = 1.71$; $p = 0.014$ compared to non-mutant heifers), consistent with their efficient and leaner carcasses. Interestingly, the F94L heifers had the lowest daily gain on veld, contrary to expectations based on their efficiency.

The study's findings led to the rejection of the H10 hypothesis, which proposed no significant difference in efficiency rankings between weaners in intensive systems versus veld. While trends

suggested similar efficiency rankings across systems, the lack of statistical significance prevents a definitive conclusion. The H2A hypothesis, which anticipated significant differences in efficiency measures between different double muscling genotypes, was also rejected. However, gender-specific analyses revealed that both bulls and heifers with the F94L mutation were the most efficient, with those carrying the NT821 mutation showing moderate efficiency and non-mutant animals being the least efficient.

Given that feed is a major expense in the beef industry, selecting animals that consume less feed for the same production level is advantageous. This study compared the feed efficiency of Droughtmaster SA weaners with different double muscling genotypes (F94L, NT821), produced through Multiple Ovulation Embryo Transfer (MOET), between the GrowSafe[®] system and veld. The analysis of 150 cattle demonstrated a clear association between RFI rank and the F94L mutation for both bulls and heifers. Despite variations in efficiency measures, particularly among heifers, the overall ranking of the most efficient animals remained consistent across both systems.

In conclusion, the GrowSafe[®] system effectively identified the same efficient cattle as those on veld, with the F94L double muscling mutation being a key factor. These findings suggest that the performance testing period could be reduced, allowing these cattle to be marketed at higher prices in a shorter timeframe. Efficient cattle, characterized by larger carcasses and greater muscle mass, can be marketed at higher prices. These findings could have a negative effect on reproductive efficiency since Droughtmaster SA cattle are an early maturing breed, which is important to consider for breeding and marketing purposes in the beef industry.

Chapter 5

Recommendations

While this study provides valuable insights into the efficiency rankings and feed intake measures of weaners under intensive and extensive production systems, several limitations should be considered. Addressing these limitations in future research would enhance the accuracy of the findings.

One notable limitation is that not all 150 weaners were produced through Multiple Ovulation and Embryo Transfer (MOET). Future studies should aim to ensure that all animals originate from the same reproductive technology to minimize genetic variability and strengthen comparisons.

Additionally, not all animals remained on the veld for the same duration. Variations in the length of the extensive production phase (veld) could have affected the accuracy of growth and efficiency assessments, as differences in adaptation periods and grazing conditions may have influenced performance outcomes. To obtain more precise and comparable data, future research should implement a standardized grazing period for all animals.

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