Determining an optimal lysine: energy ratio for lean growth in a modern commercial pig genotype

Irmarie Taljaard

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Supervisor: Dr C Jansen Van Rensburg
Co-Supervisor: Dr F Crots

DECLARATION

I, Irmarie Taljaard, hereby declare that this dissertation submitted for the obtainment of the degree MSc (Agric) Animal Science: Animal Nutrition at the University of Pretoria is my own work and has not been previously submitted by myself for a degree at any other tertiary institution.

Signature: _____

I.Taljaard

Date: _____

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Abstract

Intense genetic selection for reduced back fat thickness and improved feed utilisation in pigs has resulted in modern genotypes with high lean gain potential, which now deposit a greater amount of lean tissue at faster rates than 20 years ago. As a consequence, to allow pigs to reach their genetic potential for a high capacity of lean tissue gain, higher levels of lysine relative to energy must be fed. The lysine: energy ratio can be largely influenced by genotype, sex, age and health status of the pig. Thus, continues efforts are required to characterise the effects of increasing dietary lysine in evolving modern pig genotypes reared in commercial production environments. The objective of this study was to determine the optimal lysine: energy ratio required for lean growth of a modern pig genotype (PIC337), as well as to determine the growth performance potential under typical commercial conditions.

One-hundred-and-eighty PIC337 entire male pigs were used in an experiment with a 2x3 factorial arrangement, including 2 energy levels (2560 kcal NE/kg and 2161 kcal NE/kg) and 3 lysine levels (80%, 100%, 120% of PIC recommendations) in the feed. Thirty-six pens, with 5 pigs per pen, were randomly allocated to 6 treatments (n=6 replicates/treatment). The boars were 9 weeks (63 days) of age at the start of the trial and reared for a period of 17 weeks until slaughter under typical commercial conditions. Average feed intake per pen was measured weekly and all pigs were weighed bi-weekly along with P2 back fat measurements. Average daily feed intake (ADFI), average daily gain (ADG), and feed conversion ratio (FCR) were calculated. The trial continued until 26 weeks (182 days) of age after which all the boars were slaughtered to determine carcass characteristics, including hot carcass weight, cold carcass weight, drip loss %, pH initial, pH ultimate, carcass temperatures as well as back fat thickness.

During the grower phase (9 to 18 weeks of age), energy had a significant effect (P <0.05) on body weight gain and FCR, but had no effect (P >0.05) on ADG or ADFI. During the same phase, standardized ileal digestible (SID) lysine had no significant effect (P >0.05) on body weight gain, ADG or ADFI, but had a significant effect (P <0.05) on FCR. Lysine: NE ratio had a significant effect (P <0.05) on FCR and ADFI. During the finisher phase (18 to 26 weeks of age), energy and lysine had significant effects (P <0.05) on body weight gain, as well as FCR, but not on ADG. However, pigs from the high energy treatments (T1, T2, and T3) and the high lysine treatments (T3 and T6) had higher body weight gains and ADG as well as reduced FCR and ADFI compared to the low energy and low lysine treatments for both the grower and finisher phases. Lysine had no effect (P >0.05) on carcass characteristics, whereas energy only had significant effects (P <0.05) on the hot and cold carcass weights as well as back fat thickness. However, the low energy and the two high lysine treatments (T3 and T6) resulted in leaner carcasses compared to the high energy treatments. Similarly, back fat deposition was reduced as the SID lysine content of the diets increased. Improvements in growth performance and feed efficiency were observed as the lysine: NE ratio increased. The optimum lysine: NE level for ADG from 9 to 18 weeks and 18 to 26 weeks of age was found to be 6.06 g of SID Lys/ MCal NE and 3.67 g of SID Lys/ MCal NE, respectively. The lysine: NE ratio required to optimise FCR for boars from 9 to 18 weeks of age and 9 to 26 weeks of age was found to be 6.06 g of SID Lys/ MCal NE and 4.4 g of SID Lys/ MCal NE, respectively. The lysine: NE ratios for optimised growth performance was found to be higher compared to other available literature.

The study showed that high energy as well as high lysine levels in the diet improve growth performance but due to pig producers being paid for carcass composition as well as carcass weight, a low energy diet with high lysine levels will allow for greater return on investment as it will ultimately yield leaner as well as bigger carcasses. The study also suggests that the lysine requirements for the modern pig has increased, especially during the finishing phase.

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List of Abbreviations

AA	Amino Acids
ADFI	Average Daily Feed Intake
ADG	Average Daily Gain
AEE	Acidic Hydrolysed Ether Extract
AID	Apparent Ileal Digestibility
BW	Body Weight
BWG	Body Weight Gain
CAA	Crystalline Amino Acids
CCW	Cold Carcass Weight
CP	Crude Protein
DE	Digestible Energy
DM	Dry Matter
FCR	Feed Conversion Ratio
FHP	Fasting Heat Production
FI_0	Optimal Feeding Level
FI	Feed Intake
GLM	General Linear Model
GM	Gluteus Muscle
HCW	Hot Carcass Weight
HI	Heat Increment
ID	Ileal Digestibility
IAAend	Endogenous Ileal Amino Acid Losses
Lys	Lysine
ME	Metabolisable Energy
NE	Net Energy
NEAA	Non-essential Amino Acids
NEm	Net Energy for Maintenance
NEp	Net Energy for Production

PDmax	Maximum rate of Protein Deposition
pH_{24h}	The ultimate pH of the carcass, measured 24 hours after slaughter
pH_{45min}	The initial pH of the carcass, measured 45 minutes after slaughter
PIC®	Pig Improvement Company
FHP	Fasting Heat Production
SBM	Soybean Meal
SH	Shoulder
SID	Standardized Ileal Digestibility
Temp	Temperature
TID	Total Ileal Digestibility

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Chapter 1

General Introduction

Feed costs make up a major cost component of pig production, therefore, optimal feed intake is critical for economical and sustainable pig production. Growing pigs use feed nutrients for maintenance and growth, which includes lean muscle as well as fatty tissue growth. The aim of sustainable pig production is to efficiently produce lean meat by optimising lean and fat deposition rates. The modern consumer demands lean meat with minimal fat, therefore, lean and adipose deposition rates are two contributing factors involved in economic and sustainable production of lean meat. Swine breeding programmes have transitioned towards intense selection for leaner genotypes with the intention of meeting consumer demands (Siebrits *et al.*, 1986). Wood *et al*. (1980) observed that animals with larger mature sizes tend to fatten at heavier body weights, therefore, genetic selection for leaner genotypes was indirectly biased towards larger mature sizes and as result gave rise to the benefit of longer lean growth periods obtained by large mature size genotypes (Siebrits *et al.*, 1986).

Improvement in swine genetics and management over the past decade, as well as raised expectations for economic returns along with animal performance, heightens the need to carefully revise existing management and feeding regimes (Oresanya *et al.*, 2007). From a nutritional point of view, the increased rate of lean growth in modern pig genotypes and the increased proportion of lean on the carcass (Van Lunen & Cole, 1998), implies that previous recommendations of nutrient requirements may no longer be adequate (NRC, 2012). To develop a more precise feeding regime that allows maximum lean deposition rates, it is important for pig producers and nutritionists to realise the genetic potential of the pigs they are feeding. The genotype of the pig sets the upper limit for the lean growth that can be achieved by the pig (Coffey *et al.*, 2000). Having sound knowledge on the genetic potential of the pig is of utmost importance as the genetic merit is related to protein or more specifically, the amino acid requirements of the pig. Pigs with a high genetic merit for lean growth have a higher potential for lean deposition, not only do they reach higher peak muscle growth (Thong & Liebert, 2004a), but they also have the ability to continue laying down muscle to heavier weights compared to pigs with a low genetic merit for lean deposition (Coffey *et al.*, 2000).

Coffey *et al.* (2000) stated that pigs with a high genetic merit for lean gain often show reduced feed intake compared to pigs with lower lean deposition rates and found that feed intake may be up to 20 - 25% less than average for high lean growth pigs. Based on research findings from Henry (1985) where the author found that feed intake is reduced by a severe deficiency in the dietary limiting amino acid, one can assume that if the pig has reduced feed intake, the amino acids concentration in the diet must be increased to meet the requirements. Coffey *et al. (*2000) concluded that pigs with different rates of lean tissue deposition will have different requirements for amino acids. The lysine: energy regime can be largely influenced by genotype, sex, age and health status of the pig. Therefore, continues efforts are required to further determine the influence of increasing dietary lysine in evolving modern pig genotypes reared in commercial production environments (Thong & Liebert, 2004a; Main *et al.*, 2008). The aim of this study was, therefore, to determine the optimal lysine: energy ratio required for lean growth of a modern pig genotype, as well as to determine growth performance potential of the modern pig genotype under typical commercial conditions.

Hypothesis of the study

The null hypothesis (H_0) of this study was that the lean growth performance of a modern pig genotype will not improve with an increased lysine: energy ratio, whereas the alternative hypothesis (H_A) was that the lean growth of a modern pig genotype will improve with an increased lysine: energy ratio.

Chapter 2

Literature Review

2.1 Modern pigs and the pig industry

The definition of pork quality changed over time and for many centuries before the 1900's, the term 'improvement' was generally associated with changing pig genotypes which had an increased tendency to deposit fat. In the past, fat in pigs were seen as a beneficial characteristic, a healthy source of energy to the population and an effective source of cooking lard in the absence of readily available vegetable oils (Kyriazakis & Whittemore, 2006). However, as time progressed towards the 20th century, increased health awareness and market demands for affordable lean animal protein sources not only resulted in higher prices for leaner carcasses (Siebrits *et al.*, 2012) but also drove genetic selection of swine towards a leaner, fast growing and more efficient pig (Steyn *et al*., 2012; Jocic, 2017). The modern commercial pig has evolved through intense selection and breeding programmes, more controlled environments, improved management practices and nutrition to yield an efficient feed converting animal. This goes alongside the modern consumer who now demands lean meat with minimal fat. Therefore, protein and fat deposition rates are two major factors involved in economic production of lean meat. For the past few decades, swine breeding programmes have shifted towards intense selection of leaner genotypes in order to meet consumer demands (Siebrits *et al.*, 1986).

2.1.1 The pig industry

Pork is the most consumed meat in a global context, with over 95 million tonnes of pork produced per annum, accounting for up to 40% of the total global meat consumption and is also one of the most economical sources of animal proteins for human consumption (BFAP, 2016). Although pork is the global protein of choice, it only comprises a mere 7% of all protein consumed in South Africa (Meyer *et al*., 2013). With an increasing world population, and an increased demand for animal products the agricultural sector shifted from being a supply-driven to a demand-driven sector. Animal products have to be produced on less land due to urbanisation, placing more pressure on the industry to produce more efficiently. Pieterse *et al. (*2000) stated that improved production efficiency can be achieved in numerous ways including the production of intact males instead of females or castrates (barrows) and by increasing slaughter weights.

In South Africa, greater per capita income, increasing population along with increased urbanisation and diversifying diets of the modern consumer are some of the major factors affecting pork consumption per capita. South African pork production increased approximately 3.5 percent per annum for the past 10 years driven by increased consumer demand (BFAP, 2015). However, the number of pigs slaughtered only increased by an average rate of 2.2 percent annually from 2005 to 2015, implying that South Africa's increased pork production is attributed to slaughtering heavier pigs rather than increasing the sow herd (BFAP, 2015).

Over the past decade, economics of pig production has changed significantly as more research in South Africa has been directed towards improving gain and growth performance of pigs, while simultaneously reducing feed costs (Meyer *et al*., 2013). Feed generally comprises up to 70% of production costs, and therefore, the rapid increase in feed costs has resulted in increased production costs (Steyn *et al*., 2012). The South African pork industry is known to slaughter pigs at lower weights compared to the rest of the world. Due

to lower slaughter weights, a smaller amount of kilograms are produced per unit of fixed cost which therefore lowers the efficiency of pork production (Pieterse *et al.*, 2000). Leaner and lighter carcasses are generally favoured for the fresh meat market with average weights around 62 kg while heavier and more conditioned carcasses of approximately 76 kg or heavier are directed towards the processed market (Pieterse *et al.*, 2000). In the past, heavier slaughter weights were commonly associated with poor performance; especially reduced feed conversion efficiency and excessive fat thickness at slaughter. However, genetic selection has resulted in improved genotypes in terms of potential lean growth rates and overall carcass fatness as slaughter weights increased (Pieterse *et al.*, 2000). Levels of fatness and carcass weights are the prime determinants of value and payment received by the producer. Therefore, improved genetics give opportunity for South African producers to consider heavier carcasses. However, to exploit the benefit of improved genetics to potentially increase slaughter weights and achieve leaner carcasses, the modern pig has to be fed accordingly to reach its genetic potential.

Pork is the most consumed meat globally, however, there remains constant competition in the pork industry to attract and retain consumers world-wide. Pork price, nutritional value, convenience, eating satisfaction as well as food safety are major factors which contribute to consumer preference for a meat source (Steyn *et al*., 2012). Pork quality is influenced by on farm factors including genetics, nutrition, and management, as well as off-farm practices including transportation, slaughter and processing practices. The modern day consumer demands low levels of subcutaneous fat on pork products which has resulted in increased selection for leaner and more efficient animals (Siebrits *et al.*, 1986; Pieterse *et al.*, 2000; Steyn *et al*., 2012).

Breeding and selection of pigs is mainly done by private breeding companies to produce improved genotypes which are commercially available for production purposes (Mulder, 2015), which results in a constant improvement of pig genotypes used in pig production systems. Through intense genetic improvement pigs now deposit comparatively more protein and less fat than twenty years ago. This phenomenon is driven by consumer preference for less subcutaneous fat on pork products. Therefore, pig breeding companies also supply the commercial producers with nutrient requirements that need to be met for optimal performance of their genetic products. However, as genetics change toward improved efficiency and higher growth rates, these requirements for amino acids relative to energy has increased over time (Moore *et al.*, 2015), and has to be adapted frequently to match the improvements made by intense genetic selection.

Nutrient requirements along with other experimental studies conducted on pigs have normally been done by placing the pigs in individual pens where growth performance was often greater (de Haer & de Vries, 1993; Hacker *et al.*, 1994), and feed intake is higher (Campbell *et al*., 1984), compared to animals penned in groups. However, under commercial conditions, animals are normally penned in groups. It is therefore important to design experimental studies in such a way that results can be extrapolated to practical pig farming. There is significant competition at feeders and social stress can alter feeding behaviour and performance of animals penned in groups. These factors should be considered when making nutritional recommendations to group housed animals.

2.1.2 Modern pig genetics

In modern commercial pig production, a primary objective is lean meat yield to satisfy consumer demands. In growing-finishing pigs, lean tissue growth is closely related to daily gain, feed efficiency as well as carcass quality. Lean tissue gain is also closely related to body protein deposition which in turn determines the animals' requirements for amino acids as well as energy (NRC, 1998). To more accurately develop a feeding regime that allows maximum lean growth rate, it is important for pig producers and nutritionists to know the genetic merit of the pigs they are feeding. The genetic background of an animal, made up of heritable traits including traits for muscling, adipose deposition and growth rate provides the upper limit for the lean growth and body composition that can be achieved by the pig (Coffey *et al.*, 2000; Thong & Liebert, 2004a; Hossner, 2005). The characteristics of animal growth are heritable and contribute to the large variation observed in animal body size and growth rates (Hossner, 2005). Numerous studies have found that heritability for growth traits and carcass quality are medium to high (Petrović *et al.*, 2006; Radović *et al.*, 2013; Lo *et al.*, 2014). The modern commercial pig has evolved through intense selection and breeding programmes, more controlled environments, improved management practices and nutrition to yield a more efficient feed converting animal.

In modern days, the efficiency of pork production is more commonly measured by the efficiency of lean, muscle gain rather than total body weight gain (Webb *et al.*, 2006; Liao *et al.*, 2015). Siebrits *et al. (*1989) stated that protein and lipid deposition rates are two major contributing factors to economic production of lean meat. Intense genetic selection for reduced back fat thickness and improved feed utilisation has resulted in pigs with high lean gain potential (Campbell & Taverner, 1988), and the modern genotypes, therefore, deposit a greater amount of lean tissue at faster rates (Moore & Mullan, 2010). These modern genotypes with high potential for lean tissue gain have superior growth performance and increased peak muscle growth and therefore have the ability to continue laying down muscle to heavier weights before starting to deposit fat compared to genotypes that show medium lean gain potential (Unruh *et al.*, 1996; Coffey *et al.*, 2000). The increased muscle growth associated with the modern genotypes require a greater amount of amino acid to meet their needs for high lean growth. It is, therefore, important to understand the modern pigs' need for protein and energy to reach their genetic potential, as a deficiency in one nutrient can result in reduced gain and performance (Campbell & Taverner, 1988; Coffey *et al.*, 2000; Thong & Liebert, 2004a; McDonald *et al.*, 2010).

2.1.3 Body composition

There are genotypic differences in the mature composition of pigs and how they develop towards it (Joubert, 2004). Due to increased genetic selection for lean pigs which fatten at heavier body weights, Siebrits *et al. (*1986) stated that selection was most likely biased towards large mature sizes so that benefit could be taken of an extended lean growth phase achieved by these type of animals. Expected lean mass at maturity and the time to reach this state is the platform of growth analysis. An overall increase in lean tissue mass at maturity has been achieved through intense genetic selection for improved lean tissue deposition. The lean tissue component consists of approximately 22% protein, and the protein mass of mature modern pigs is estimated to be around 35 – 55 kg (Kyriazakis & Whittemore, 2006; Rittonori, 2014). Muscle fibre number is predominantly determined at birth and growth observed in lean tissue is due to increase in muscle fibre size (Hossner, 2005).

Growth rate is the major decisive factor for the efficiency of feed conversion into meat due to saving of feed used for maintenance. Maintenance costs for feed occurs on a daily basis, utilising feed but rendering no product. A slow growing pig will utilise the same amount of feed maintenance cost per day as a fast growing pig, but will be less productive to offset the fixed cost of that feed. Second to the rate of growth is the ratio of lean to adipose tissue growth, as adipose tissue growth has an energy feed cost three times higher to that of lean tissue growth (figure 2.1), and feed efficiency decreases as the lipid: protein ratio increases (Whittemore, 1995). Cambell & Taverner (1988) conducted a study to investigate the response of fast (strain A) and slow (strain B) growing boars and castrated male pigs at different levels of intake. They found that strain A, which showed higher protein deposition rates, had a 28% higher maintenance requirement than strain B, which deposited protein at a slower rate. However, strain A boars contained less fat than their strain B counterparts. The authors concluded that the reason for a higher maintenance requirement in the leaner pigs (strain A), was most likely due to the increased lean body mass and higher protein turnover rate than strain B and castrates. The authors also found that strain A had higher amounts of ash at 90 kg, 13% more bone and heavier viscera and organ weights and a lighter carcass weight than the strain B and castrate counterparts, which led the authors to conclude that the strain A animals were physiologically less mature at 90 kg. The results from this study also proposes that intense genetic selection of animals receiving *ad libitum* feeding had elevated the genetic ceiling for protein deposition above the upper limit for appetite.

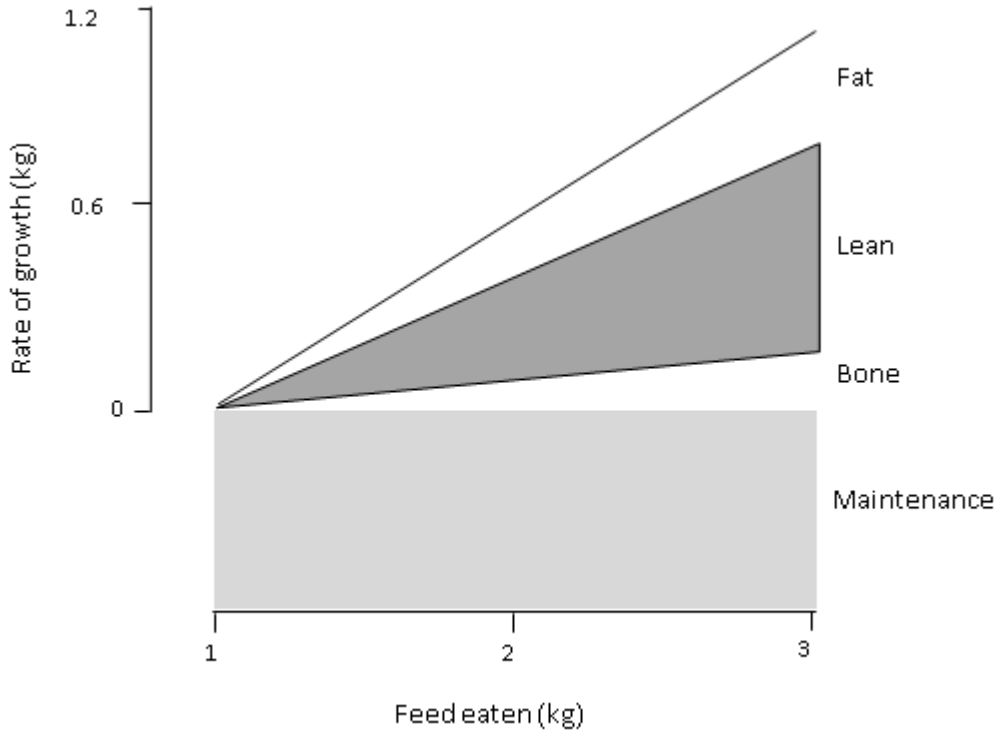

Figure 2.1 Effeciency increases with growth rate due to the fixed cost of maintenance feed being spread over a high level of productive output (Kyriazakis & Whittemore, 2006)

The relationship of bone, lean tissue and fat tissue growth affects development of the animal. Slow growing animals will have a higher bone to fat ratio at any given weight (Kyriazakis & Whittemore, 2006). The whole body chemical composition of a growing pig varies with lean: fat: bone ratio, however, averages at

approximately 3% ash, 16% lipid, 16% protein and 64% water. The intact male is leaner (60% carcass lean) compared to castrates (56%) and females (58%) at any given weight and feeding. Kyriazakis & Whittemore (2006) stated that dissected lean tissue contains 20 - 25% protein, 70 - 75% water and 5 - 15% fat. Adipose tissue contains 70 - 80% lipid, 10 - 25% water and 2% protein. Although it is generally agreed that as pigs grow in size they become fatter, the point of fattening is largely influenced by sex, genotype and level of feed.

The composition of pigs as they grow can be expressed by means of an allometric equation:

$y = ax^b$

in which Y is the weight of a tissue or organ related to X representing the whole empty body weight, a and b is referred to as the growth coefficient which indicates the relative increase of tissue (Y) in relation to increase of the reference tissue (X). Positive allometry occurs if b > 1, y is then growing faster than x. In negative allometry (b < 1) the relative increase of y is smaller than that of x. If b = 1 the components y and x grow isometrically (Walstra, 1980). According to De Greef (1992) the allometric equation is an effective tool to describe nutrient partitioning as well as the sequence at which different tissues reach maturity in the body as a whole.

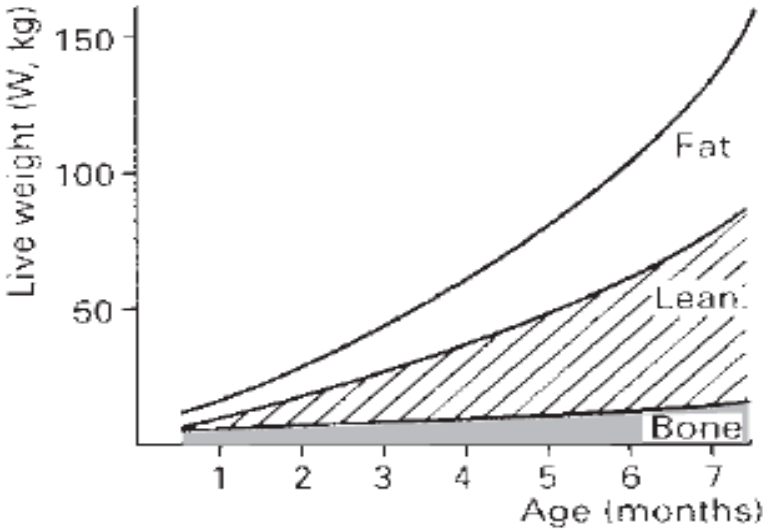

Figure 2.2 Composition of growing pigs (Kyriazakis & Whittemore, 2006)

2.1.4 Carcass characteristics

Carcass classification plays a crucial role in efficient animal production, determining meat price as well as meeting consumer demands (Webb, 2015). In South Africa, carcasses are marketed according to a relatively crude classification system, where heavier, more conditioned carcasses are favoured for the processing market, while leaner and lighter carcasses are directed towards the fresh meat market. Lean tissue is the major component in pig carcasses, which also contributes most to carcass value, and has a higher efficiency of synthesis compared to adipose tissue, due to lean tissue containing more than 70% water (Teague, 2017). Lipid deposition is known to result in lower carcass classification and is therefore economically as well as energetically inefficient.

Carcass value affects the profitability of the pork industry, therefore, numerous methods are available to determine carcass composition. Conventionally, in South Africa, the back fat thickness is measured 45 mm

from the midline (known as P1) which is incorrectly referred to as the P2 back fat measurement, making comparisons of back fat measurements to global back fat measurements taken at 65 mm, merely impossible. Research done by Bruwer (1992) found that measuring the depth of fat over the *longissimus dorsi* muscle at the P2 position provides the most accurate indicator of total body fat in swine, over a range of body weights. There are a variety of methods to measure back fat thickness, from the invasive scalpel and ruler method, to the non-invasive methods including, among others, the Renco Lean-Meater® (RLM), Sonalyser Pig Monitor (SON) and Medata Back fat Grader (MED), which makes use of ultrasonic waves to estimate the back fat thickness at the P2 position (Bruwer, 1992; Hambrock, 2005). In abattoirs, the preferred methods include the use of optical devices, including the Hennessy Grading Probe® (HGP) and Intrascope® (INT) which are known to be more accurate. However, the different methods on measuring P2 back fat thickness goes beyond the scope of this literature review.

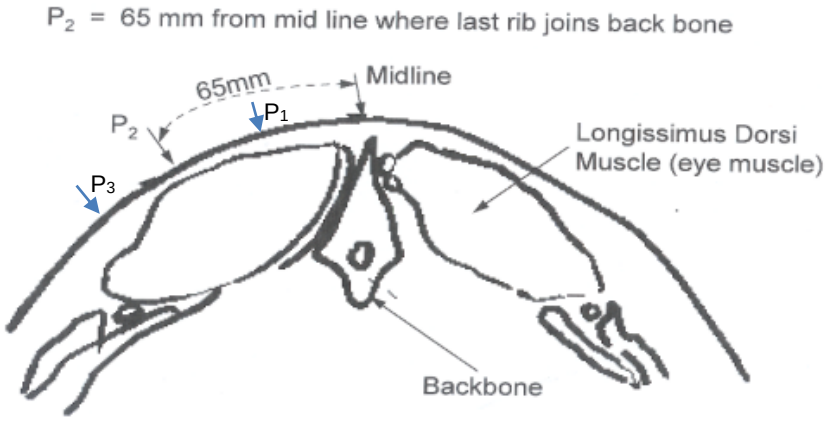

Figure 2.3 Transverse plane of a pig carcass at the last rib, indicating P2 position (Adapted from Elizabeth *et al*., 2004)

Other than measuring back fat thickness for carcass classification, numerous other sensory and olfactory traits contribute to meat quality. Meat quality has been given numerous definitions, however, meat scientists will define meat quality as those factors associated with palatability including tenderness, juiciness and flavour (Bratcher, 2019). These factors are influenced by water holding capacity, pH, colour, fat content and composition (Rosenvold & Andersen, 2003; Kim *et al.*, 2016) which in turn is influenced by genotype, age, sex, nutrition, pre-slaughter handling, slaughtering method as well as storage conditions (Pearce *et al*., 2011; Xu *et al*., 2012; Bratcher, 2019). pH post slaughter has become an important tool to evaluate pork quality (Kim *et al*., 2015) and pH taken 24 hours post mortem has been found to have the strongest correlation with pork quality traits (Bratcher, 2019). In the live pig, muscle maintains a neutral pH of 7.0 to 7.2. However, once slaughtered, there is a lack of oxygen supply to the muscles which results in lactic acid accumulation in muscle tissue and in turn results in acidification which reduces the pH of the muscle (Pearce *et al*., 2011; Kim *et al*., 2015). The rate at which the pH declines after slaughter will have an impact on colour as well as the water holding capacity of the muscle tissue. PIC (2003) recommends an initial pH (pH_{45min}) of 6.3 to 6.7 and an ultimate pH (pH_{24h}) of 5.7 to 6.1. In a study conducted by Kim *et al. (*2015), the authors examined the relationship between initial and ultimate pH as well as the rate of pH change on Berkshire's meat quality. The

authors found that a lower pH owing to high lactic acid accumulation results in protein denaturation which in turn causes a high drip loss and a low water holding capacity. The authors also found that the post-mortem pH is negatively correlated to meat colour. A high initial temperature and a low post-mortem pH are known to induce PSE (pale, soft and exudative meat) meat (Van Der Wal *et al*., 1988; Bratcher, 2019). In contrast, long term stress depletes muscle of glycogen which limits the production of lactic acid and results in a higher post-mortem pH which yields DFD (dark, firm and dry) meat (Van der Wal *et al*., 1988).

2.2 Growth

2.2.1 Growth and factors influencing growth

Growth occurs through the accretion of bone, lean and adipose tissue in the body as a result of ongoing anabolic and catabolic processes associated with tissue turnover (Kyriazakis & Whittemore, 2006). Therefore, growth can be summarised as the increase in body weight as well as body size, and change in body dimensions which can be attributed to nutritional excesses relative to the maintenance requirements of an animal which drives anabolic and catabolic pathways. Animal growth is a quantitative factor that can be measured objectively. Growth can be quantified by measuring growth parameters and the simplest and most common method to quantify whole body growth is by measuring body weight (Hossner, 2005). In the live animal, as bones elongate during linear growth, changes in body height, length and weight accompany growth. Quantitative increases in muscle mass are important for animal producers as well as quality of muscle growth determined by the ratio of adipose to muscle (Hossner, 2005). As animals grow they increase in both size and weight and the pattern by which the animals grow from conception to maturity can be represented by a sigmoid (s-shaped) curve (McMeekan, 1941; De Greef, 1992). The sigmoid growth curve is characterised by an initial exponential growth phase, when growth is rapid and the slope of the curve is at a maximal and this stage stretches from birth to puberty. This early growth is known as the self-accelerating phase. The exponential phase is then followed by an inflection point when the shape of the curve changes from the very rapid growth of young animals to a more moderate, slower growth rate known as the self-retarding phase. Finally, growth slows as animal approaches maturity and reaches a plateau and essentially ceases (McMeekan, 1941; Hossner, 2005). In practice, however, many factors including environment and nutrition, can result in growth deviations of the standard sigmoid curve (Owens *et al.*, 1993).

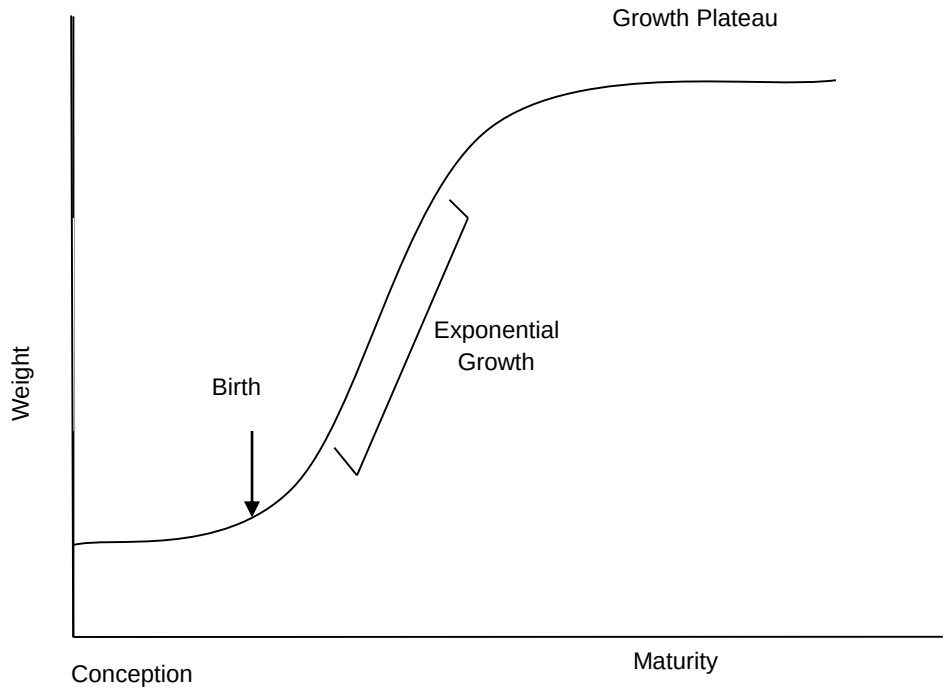

Figure 2.4 Sigmoidal growth curve (Hossner, 2005)

The main objective for rearing animals for meat is to maximise the production of the parts that generate the most income which includes lean muscle growth. Research conducted by Hammond (1932) determined varying rates of growth in different tissues as the animal changes with weight and age. Development is generally described as 'growth waves' and in early life, major tissues including brain, nerve and bone are given priority for nutrients and, therefore, grows rapidly. Later, muscle tissue gains priority and lastly followed by adipose tissue (Hammond, 1932; Owens *et al*., 1993). The order of growth is illustrated in figure 2.5 where development of different tissues is shown over time. From this figure one can interpret that as the animal matures, adipose tissue deposition accelerates at the expense of muscle development. This can be referred to as the fattening phase where producers aim to manipulate growth in order to extend the muscle deposition phase and delay the onset of the fattening phase. Prioritising nutrients for different growth waves indicates that animal nutrition and animal growth are linked and therefore the growth pattern, as well as composition of the product of growth, determines the nutrient requirements of an animal.

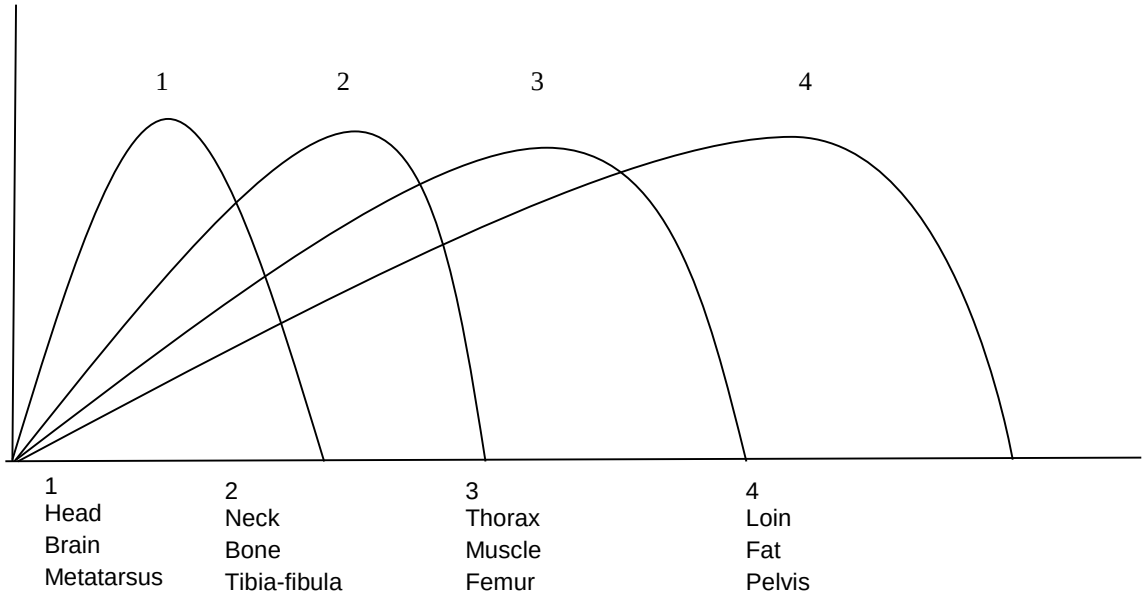

Figure 2.5 Growth rate of body tissues during development from conception to maturity adapted from Hammond, (1932)

In the past, fast growing pigs tended to deposit a greater amount of adipose tissue per unit of gain, but intense genetic selection has resulted in modern genotypes that now deposit greater amounts of lean tissue (Moore *et al.*, 2015). A rapid growth rate is desirable as it minimises fixed costs of maintenance per unit of meat produced, therefore in modern pig production, nutritionists aim to manipulate growth, in conjunction with improved genetics, to maximise lean meat production and delay or restrict adipose tissue deposition (Steyn *et al.*, 2012; Patience *et al.*, 2015).

Genetic background, sex, nutritional intake as well as environment are major contributing factors that influence animal growth as well as protein deposition. These factors also provide the fundamental basis for control and manipulation of animal growth (Irshad *et al.*, 2012; Park *et al.*, 2018). Animal nutrient requirements need to be met for maintenance and production, and a sheltered environment allows animals to perform better when they are not challenged with extreme temperatures. Genotype, sex and environment will be discussed in short, and nutrition will be discussed more extensively later in this review.

a. Genotype

Protein and lipid deposition in an animal is primarily determined by the genetic merit of the animal (Campbell & Taverner, 1988). Several literature studies have aimed to determine protein deposition and growth performance of non-superior genotypes against the superior improved genotypes (Campbell & Taverner, 1988; Schinckel *et al.*, 2007; Wiseman *et al*., 2007). Wiseman *et al. (*2007) compared two genetic lines with different lean gain potential in barrows and gilts from 20 - 125 kg body weight. The authors observed that lean tissue in high-lean pigs increased and back fat along with bone mineralisation decreased as body weight increased. In an early study conducted by Whittemore & Fawcett (1976), the authors observed a maximum protein deposition rate of 130 g/day between 75 – 100 kg live weights. Campbell & Taverner (1985) compared selected and unselected strains and found

that selected pigs not only had faster protein deposition rates but also higher slopes in the relationship between energy intake (DE) and protein deposition rates compared to unselected strains. Recent studies have also shown that new improved genotypes have higher protein deposition rates than genotypes previously used. De Greef *et al. (*1994) observed maximum protein deposition rates of 250 g/day and Van Lunen & Cole, (1998) observed maximum protein deposition rates of 236 and 176 g/day for boars and gilts, respectively. King *et al. (*2004) observed similar results with 247 and 182 g/day for boars and gilts, respectively, between 80 -120 kg live weight. It is clear that intense genetic selection for lean genotypes has increased the genetic potential for protein deposition to heavier live weights.

Historical data suggested that finisher pigs of 55 – 90 kg reached a plateau in protein deposition at approximately 35 MJ DE/day (Campbell & Taverner, 1988). King *et al. (*2004) determined the effect of energy intake on growth performance and tissue deposition in boars and gilts between 80 - 120 kg live weight, and found that boars outperformed the gilts in terms of growth, feed efficiency as well as protein deposition rates. However, there was no plateau at high energy intakes, suggesting that there is no intrinsic limit to protein deposition in these pigs up to 120 kg. King *et al. (*2004) therefore suggested that genetically improved pigs plateau at higher feed intakes or perhaps not at all, and that modern genotypes' upper limit to protein deposition cannot be reached below 80 - 90 kg body weight, particularly in boars.

b. Sex

Growth performance, maximum rate of protein deposition and nutrient requirements also differ between sexes (King *et al.*, 2000; Moore & Mullan, 2010). The difference in leanness between sex groups explain largely the differences in nutritional requirements between sexes. It is generally accepted that gilts are fatter than boars, and castrates are fatter than both gilts and boars. Research has shown that boars deposit more protein and less fat compared to gilts and castrates (Campbell & Taverner, 1988), which implies that boars contain more water and protein than gilts and this likely indicates that hormones influence body composition (Siebrits *et al.*, 1986). King *et al. (*2000) found that boars have faster growth rates, lower FCRs and higher protein deposition rates compared to gilts. Siebrits *et al. (*1986) also concluded that boars have a higher rate of protein deposition compared to gilts, where boars reached a PDmax of 156 g/day at 60 – 70 kg body weight and gilts reached a PDmax of 121 g/day at the same body weight. Eliminating castration allows improved efficiency of pork production, however, boar taint remains a matter of concern. In many countries around the world, male animals are rarely castrated and entire males are frequently sold for slaughter at all weight ranges, although entire males are generally slaughtered at less than 110 kg to limit the risk of boar taint (Whittemore, 1995).

Pork quality is determined by many factors, among which appearance and colour followed by odour / flavour and taste are some of the most influential attributes (Jocic, 2017). Odour may be negatively affected by high concentrations of a pheromonal steroid, androstenone, and a fermentation product of

l-tryptophan in the hindgut, skatole (Whittemore, 1995). Concentrations in body fat above approximately 1.0 ppm for androstenone and 0.25 ppm for skatole cause an offensive odour and flavour when eating pork. Androstenones are known to produce an urine-like odour while skatoles produce an offensive faecal-like odour (Jocic, 2017). Only about 5 to 30% of boars fall into the boar taint category but depends on the genetic constitution of the pigs. Research has also found that the accumulation of androstenone and skatoles in adipose tissue explains boar taint to a high extent (Engesser, 2015; Marro *et al.*, 2018).

c. Environment

Pig behaviour as well as production performance is greatly impacted by individual or group housing of growing and finishing pigs. Numerous studies have concluded that growth performance is higher in individually penned animals (de Haer & Merks, 1992; de Haer & de Vries, 1993; Hacker *et al*., 1994; Steyn *et al*., 2012; Quiniou & Noblet, 2012). De Haer & de Vries (1993) observed higher growth rates and back fat thickness in individually housed pigs due to higher feed intake and reduced activity levels. Gomez *et al. (*2000) conducted a trial to determine the factors that depress growth in pigs housed in groups. The authors concluded that group penned gilts had reduced back fat thickness and daily gain. It is known that competition and aggressiveness for feed and hierarchy among group penned pigs result in increased activity and chronic stress which can suppress performance of grouped pigs (Steyn *et al*., 2012). King *et al. (*2004) also stated that maximum feed intake is rarely reached, particularly in boars, due to stocking density and social behaviour which reduces the amount of time spent feeding. By providing adequate space and formulating diets that take activity and stress of group housing into account, the reduced growth rate from group housing can be overcome.

The effects of environmental temperature on growth performance have been well defined. Temperature has a significant effect on voluntary feed intake and has a direct impact on growth of the animal, as animals have to divert energy from growth and production towards maintaining their body temperature (Hossner, 2005). A $1^{O}C$ reduction of external temperature is associated with a 1 – 1.5% increase in feed intake which reduces efficiency of feed utilisation. Elevated external temperatures result in reduced feed intake which in turn reduces the amount of energy substrates available and results in protein catabolism. Once protein catabolic rate exceeds the rate of synthesis, the body enters a state of negative nitrogen balance (Hossner, 2005). Myer & Bucklin (2001) has determined that the optimal temperature range for finishing pigs ranges from 10 – 23.9 ^{O}C. White *et al. (*2008) conducted a study to determine the effects of two different housing temperatures, 23.9 ^{O}C (at thermoneutral zone) and 32.2 ^{O}C (above thermoneutral zone), and two different stocking densities of either 0.66 or 0.93 m^2/pig on growth performance and carcass characteristics. The authors found that there was a significant decrease in growth as well as carcass and bacon quality in pigs housed above thermoneutral zone. However, the authors concluded that by increasing the space available and reducing stocking density, the negative effects of thermal stress can be mitigated.

2.2.2 Protein deposition and growth models

Efficient lean meat production from pigs requires optimisation between lean and adipose tissue deposition (De Greef, 1992). Protein deposition is predetermined by the genetic potential of the pig, assuming that the diet supplies an adequate amount of well-balanced amino acids. Protein deposition rate is a predetermining factor for the pigs' requirement of daily essential amino acids as well as energy (Schinckel & De Lange, 1996; Schinckel *et al.*, 2002; NRC, 2012). Steyn *et al*. (2012) emphasised that sound knowledge on factors influencing growth and protein deposition is crucial for diet formulation of growing animals. These factors include age, weight, genotype, sex, nutrition and environment (Campbell & Taverner, 1988; De Greef, 1992). Protein and lipid deposition rates significantly determine growth and body composition, however, these components are relatively independent of one another but significantly affected by nutrition (De Greef, 1992). Research has also found that modern pig genotypes have a higher potential for protein deposition (Thong & Liebert, 2004b). Not only does protein deposition reach a maximum at a later stage in boars and lean type pigs but it also declines at slower rates thereafter (Kemm *et al*., 1991; Close, 1994). A study conducted by Siebrits *et al. (*1986) found that protein deposition rates for lean boars peaked at 60 kg at a rate of 156 g/day and obese gilts peaked at 40 kg with a rate of 101 g/day. The protein deposition rates did not only reach a maximum at a later stage, but also declined at a slower rate after the peak was reached. Kemm *et al. (*1991) found that protein deposition rates peaked at different stages for genetically lean and obese pigs. The authors determined from this study that protein deposition peaked slightly later, compared to results from Siebrits *et al. (*1986), at 51 kg in obese gilts at a rate of 103 g/day and 64 kg in lean boars at a rate of 143 g/day. The lean type pigs consumed 7.5% less DE per day but converted DE 7.2% more efficiently into live mass gain compared to obese type pigs. Kemm *et al. (*1991) concluded that the rate, composition (protein: fat ratio) and pattern of growth were influenced by type (lean vs. obese), live mass and sex of the pig. Campbell & Taverner (1988) investigated the response of fast (strain A) and slow (strain B) growing boars and castrated male pigs at different levels of intake. At *ad libitum* levels, they found higher protein deposition rates compared to Kemm *et al. (*1991) and Siebrits *et al. (*1986) where strain A peaked at 189 g/day, strain B at 128 g/day and castrates at 85 g/day. Close (1994) defined three genotypes namely, i) the superior, which are genetically improved animals with the highest protein deposition rates, ii) normal animals, and iii) the less improved animals with the lowest protein deposition rates. For the genetically improved pigs, Close (1994) has shown protein deposition rates of up to 240 g/day.

One of the early pig growth models described by Whittemore & Fawcett (1976), makes two major assumptions (figure 2.6). Firstly, it assumes that animals in a specific weight range respond to an increased energy intake, together with a sufficient supply of amino acids, in an ascending linear manner for protein deposition, up to a certain limit i.e. until a plateau is reached for protein deposition. This plateau is referred to as maximum protein deposition (PDmax), depending on genotype, age and sex (*et al.*, 1994; Thong & Liebert, 2004b), and is perceived to be an important constraint on swine growth (Moughan *et al.*, 2006). Secondly, the model assumes that for each unit of protein deposited, a minimum amount of adipose tissue is deposited and that the minimum ratio of adipose to lean deposition rate is accepted to be constant as well as independent for the intake of energy until the maximum capacity for protein deposition was reached. Kyriazakis & Whittemore (2006) explained the model (figure 2.6) based on four principals; i) as feed intake increases, the growth of lean and adipose tissue increases, ii) at low feeding levels, a small increment in feed intake will

produce a large increase in lean and adipose tissue growth in a linear fashion, iii) at a certain feed intake level, the growth response becomes broken and the growth responses gradually starts to decrease, therefore, energy intake above the level that supports PDmax will be deposited as adipose tissue, iv) the break in the growth response is determined by genetics. Whittemore (1986) stated that adipose tissue deposition will only start to increase once the genetic potential for lean gain is achieved, and therefore one can expect a relatively constant body composition over a variety of body weights which will only change once the plateau is reached (Mulder, 2015). The period before lean tissue growth stops increasing can be seen as the nutritionally limiting phase and thus, during this phase, the nutrients will be used mostly for lean tissue gain. However, the period thereafter is seen as the nutritionally unlimited phase in which most of the energy consumed above the requirement for lean tissue gain is deposited in the form of fat. Whittemore (1986) concluded from the model that animals with a higher potential for lean tissue deposition can achieve greater feed intakes and improved feed efficiency with no increase in fatness, providing that the diet is capable of supporting the genetic upper limit for protein deposition (Moughan *et al.*, 2006).

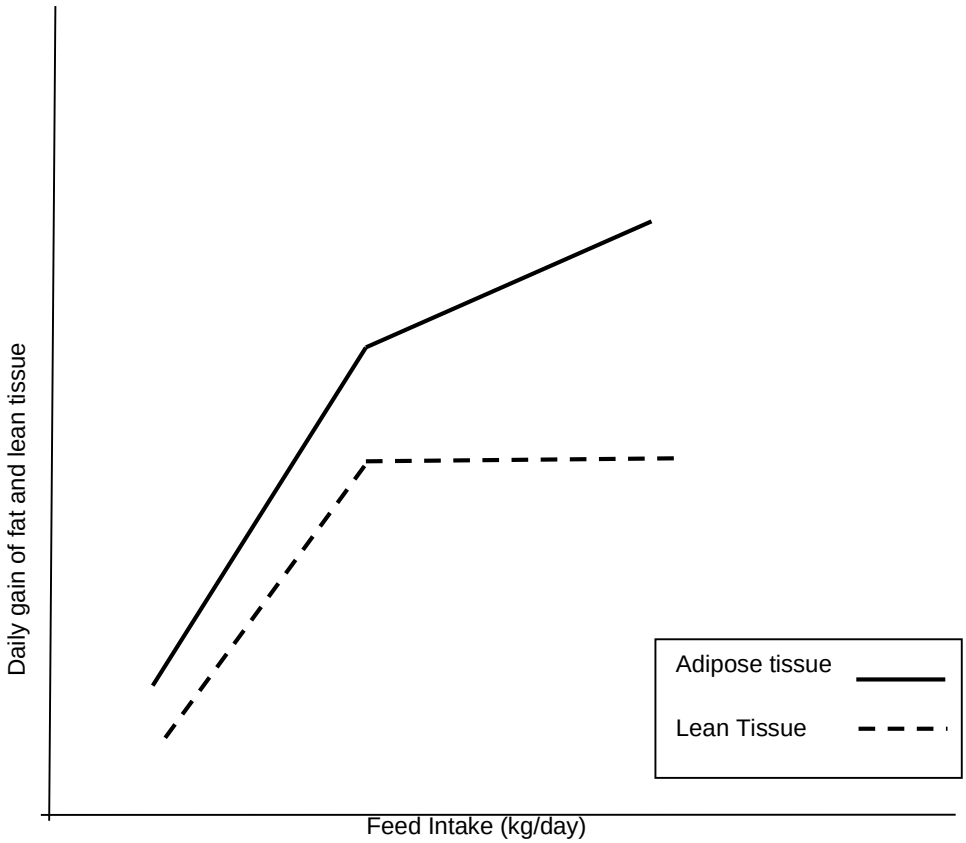

Figure 2.6 Genetic potential for lean adipose tissue deposition (Whittemore, 1986)

De Greef (1992) challenged the linear-plateau concept initially proposed by Whittemore & Fawcett (1976) to predict protein and lipid deposition. According to a study conducted by De Greef (1992), a higher energy intake below PDmax, will result in a higher lipid to protein ratio, which does not uphold the initial concept proposed by Whittemore & Fawcett (1976) of a constant partitioning between lipid and protein deposition. De Greef (1992) defined the Linear-Plateau concept as the relationship between protein and lipid deposition and

energy intake in growing pigs. The initial concept from Whittemore & Fawcett (1976) also proposes a linear increase in protein deposition with an increased energy intake until a PDmax is reached, after which the relation then plateaus. Below the plateau, a minimal amount of lipid deposition accompanies each unit of protein deposition, therefore, it is presumed that there is a minimal ratio between lipid and protein deposition. De Greef (1992), however, has proven this ratio not to be constant as previously assumed (figure 2.7). Below the PDmax, energy is divided between protein and lipid deposition according to the proposed minimal ratio. However, after the plateau for PD maxis reached, all excess energy will be converted to fatty tissue resulting in a decreased growth rate (Mulder, 2015). Therefore, the Linear-Plateau concept deals with not only the linear increase in protein deposition associated with increased energy intake up to the plateau but also with the minimal ratio between lipid and protein deposition. The model insinuates that there is a distinct optimal feeding level (FI_0), which is defined as the minimum amount of energy required to meet the intrinsic PDmax. At this point, protein deposition is maximised with minimal lipid deposition. Therefore, this model is ideal for optimising feeding strategies in practice (De Greef, 1992).

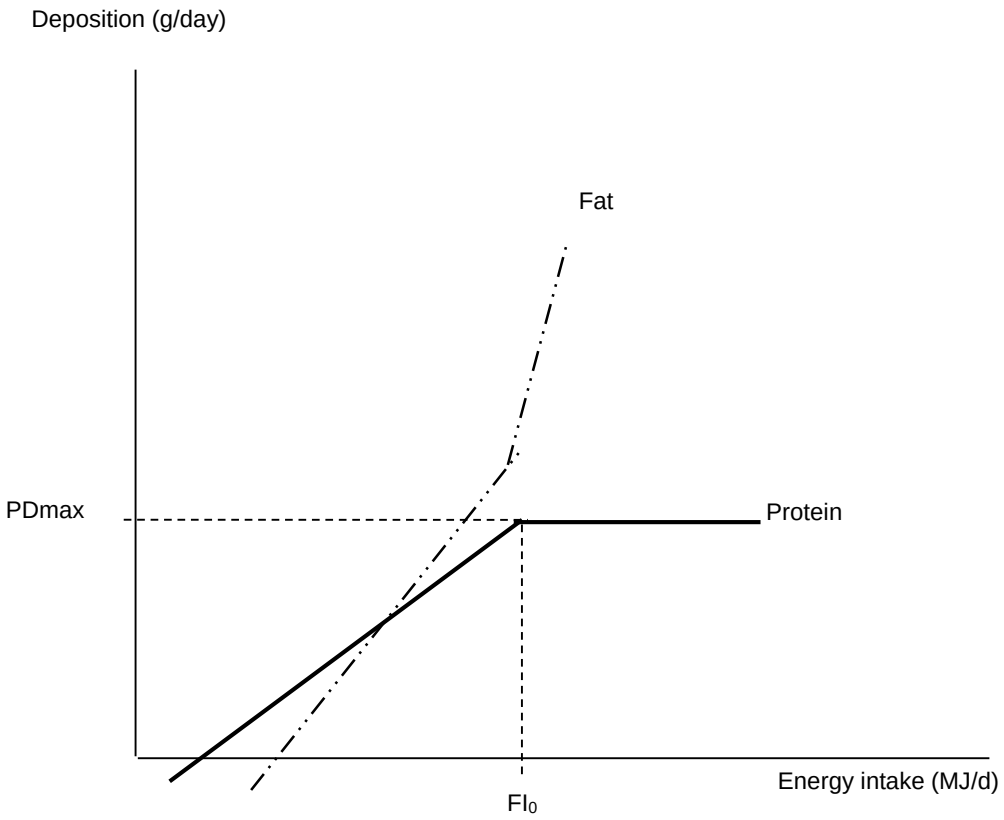

Figure 2.7 The Linear-Plateau Concept (De Greef, 1992)

2.3 Nutrient requirements of the growing pig

Nutrient deficient diets reduce animal health and performance, therefore, knowledge on nutrient content and availability in feedstuffs is critical to meet animal requirements. Pigs have a nutritional requirement for energy and protein, but more specifically for amino acids, and for vitamins and minerals (Moore & Mullan, 2010; NRC, 2012). The diet fed to the pig should contain sufficient amounts of digestible nutrients for maintenance and to grow at its optimum rate and reach its genetic potential. The two major nutrients included in diets are energy and protein and should be provided in the correct ratios to ensure lean tissue growth. The improved protein: fat ratio and greater body weight gain in faster growing pigs results in a higher dietary lysine requirement.

Siebrits *et al. (*1986) showed that feed intake is related to protein and lipid deposition rates as well as growth rate. It is commonly known that the growing pig can adjust their daily feed intake over a broad spectrum of energy concentrations in the diet to achieve a constant daily energy intake. Results obtained from an experiment conducted by Quiniou & Noblet (2012) confirmed the ability of pigs penned individually to adjust their feed intake spontaneously over a broad spectrum of NE concentrations (8.7 to 10.5 MJ/kg). Higher dietary NE concentrations were associated with a reduction in ADFI throughout the experiment and feed conversion efficiency improved as the NE concentration of the diet increased. When energy concentration of the diet decreased, pigs responded by increasing ADFI. However, this is only applicable if the maximum capacity of the digestive tract has not yet been reached (Quiniou & Noblet, 2012). On the other hand, a reduced energy concentration may lower energy intake when pigs have *ad libitum* access to feed, which may in turn lead to improved carcass leanness, depending on the growth potential of the animal (figure 2.8).

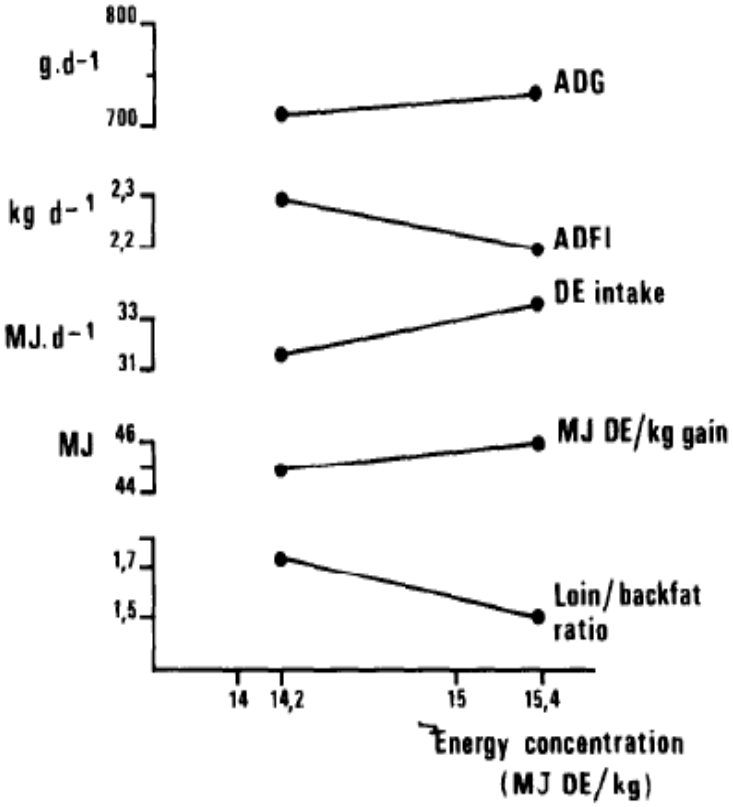

Figure 2.8 Effect of dietary energy concentration on average daily feed intake (ADFI) and energy (DE) intake (Henry, 1985)

Another adjustment of feed consumption is observed with changes in the protein (or amino acid): energy ratio for the optimum level of growth. The use of protein to source all of the amino acids can be inefficient and wasteful. Formulation of diets to minimise excesses amino acids has proven to be more cost effective. Henry, (1985) observed that the intake of protein is independently regulated from the intake of energy although both mechanisms interact to drive overall feed intake. A severe deficiency in a dietary limiting amino acid as well as an excessive supply of total protein or some essential amino acids reduced overall feed intake (Henry, 1985). However, a subclinical deficiency increased feed intake in an attempt to meet the daily requirement (figure 2.9). This increase in feed intake will result in more carcass fat deposition while an adequate protein supply allows a self-limitation of feed intake in the pig, which results in leaner carcasses (Quiniou *et al*., 1995; Ferguson *et al*., 2000; Ferguson & Theeruth, 2002).

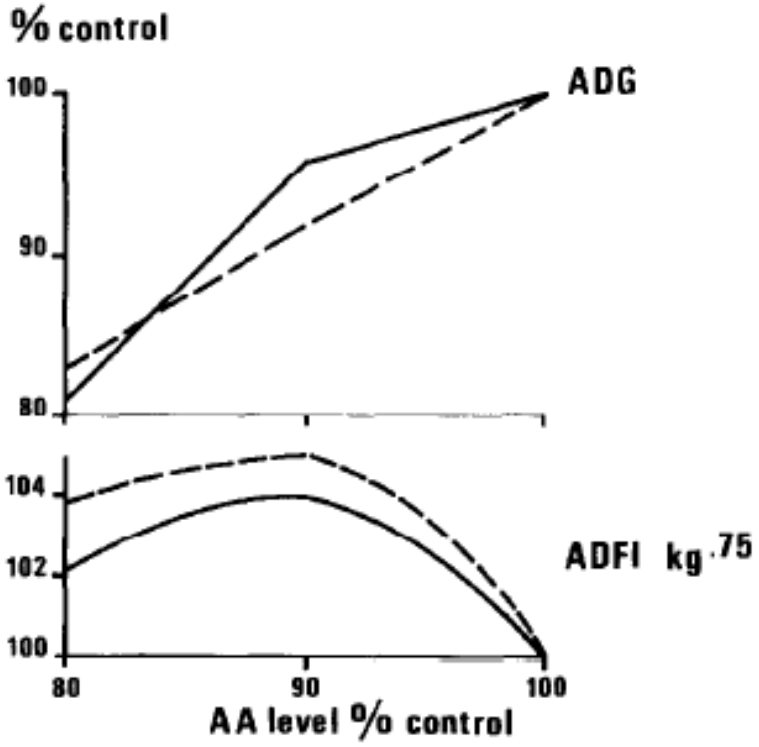

Figure 2.9 Variation in average daily gain (ADG) and average daily feed intake (ADFI) per kg metabolic weight with dietary levels of lysine (_) and threonine (- -) (Henry, 1985)

Numerous studies have been conducted to determine the lysine requirements of growing pigs (Cromwel *et al.*, 1993; Thong & Liebert, 2004a; De la Llata, 2007; Heger *et al.*, 2008; Main *et al.*, 2008; Van Milgen *et al.*, 2008; Moore & Mullan, 2010) but comparison of literature is difficult due to different experimental conditions as well as different methods and units used for estimating the requirements. Thong & Liebert (2004a) conducted a trial on 161 barrows to determine the lysine requirement and efficiency for daily protein deposition. The lysine requirements were 15.5, 18.0 and 21.1 g/day (0.77, 0.9 and 1.06 % lysine, respectively) for daily protein deposition of 130, 145, and 160g, respectively. The lysine requirement of growing pigs thus depended on the protein deposition rate. Along with increased protein deposition achieved with increased lysine levels, there was a decrease in body fat concentration. Coffey *et al. (*2000) referred to a study conducted by the University of Kentucky which examined the effects of lysine on different genotypes during the growing-finishing phase. The study made use of two genotypes with potential for high lean growth (up to 400 g lean per day) and two genotypes with medium potential for lean growth (up to 300 g lean per day). The research found that barrows with a medium potential for lean gain maximised lean growth at dietary lysine levels of 0.65%, while barrows with a high genetic potential for lean gain maximised their lean growth at 0.80 – 0.95% dietary lysine. This research clearly indicated that lysine levels have to be increased for modern improved genotypes.

2.3.1 Lysine

The digestibility of protein, its amino acid profile and the balance of amino acids in relation to the animal's requirements determines the efficiency by which the dietary protein is used by the pig. Protein is an expensive nutrient and the inefficient use of dietary protein will contribute to nitrogen excretion, increasing the impact of animal production on the environment (Van Milgen & Dourmad, 2015). Swine diets were formulated to satisfy

crude protein needs for many years, rather than to meet specific amino acid requirements. Sensible use of individual amino acid supplements in diet formulation allows for a reduction in protein concentration and thereby reduces the impact of nitrogen excretion on the environment (NRC, 2012).

It is well established that the growth and development of muscle tissue in pigs require a dietary supply of amino acids, therefore, the requirement of amino acids equals the sum of amino acids required for the functions of maintenance as well as protein retention (NRC, 2012). Amino acids are the building blocks of protein, which are composed of an amino group (-NH_2), a carboxyl group (-COOH) and a side chain specific to each amino acid (McDonald *et al.*, 2010; Van Milgen & Dourmad, 2015). Amino acids range in their capabilities of being absorbed which led to the term bioavailable amino acids, which refers to amino acids that can be absorbed and importantly be used for metabolic purposes (Ravindran *et al.*, 2005). Amino acids are required for building protein (mostly muscle tissue) and replacing proteins lost during protein turnover (maintenance) (Whittemore, 1995). The source of amino acids as well as the concentration included in a diet affects the utilisation efficiency (Colina *et al.*, 2004). Body protein can only be synthesised when the correct amino acid profile is present. Any excess amino acids will be excreted via the kidneys and urine as urea which is an energy expense to the animal.

Lysine is referred to as an essential or indispensable amino acid along with nine other amino acids including, arginine, histidine, leucine, isoleucine, methionine, valine, threonine, tryptophan and phenylalanine. These 10 amino acids are essential because the pig does not have the metabolic capacity to synthesise the carbon chains for these amino acids and, therefore, require a dietary supply of these amino acids to meet their requirements for growth and protein (Van Milgen *et al.*, 2008). In 1840, Von Liebig proposed the law of the minimum and the concept states that the rate of growth of a plant depends on the amount of the most deficient of its essential nutrients that is available to it. This concept is now broadened into a general model of limiting factors for all organisms, including the pig (figure 2.10). Therefore, the animal can only grow and utilise nutrients up to where the first nutrient becomes limiting. This concept clearly illustrates the dependency of amino acid supply on each other. The amino acid for which the dietary supply provides the lowest concentration is referred to as the first limiting amino acid (NRC, 2012). Lysine is identified as the first limiting amino acid in cereal-soybean meal based diets for growing pigs (Cho *et al.*, 2012) and the requirement for each of the essential amino acids are expressed relative to lysine (table 2.1), to achieve an optimum balance of amino acids required for maintenance and production for a clearly defined physiological state (Mitchell & Block, 1946; Moore *et al*., 2015; NRC, 2012). Any amino acids in excess of the first limiting amino acid will not be used for protein synthesis, but rather oxidised as an energy source which is an energy demanding process and reduces the efficiency of the animal (Mulder, 2015). However, Henry (1985) concluded that feed intake and growth performance will be reduced when a severe deficiency of the limiting amino acid or an excessive supply of protein and other essential amino acids occur. For this reason, lysine plays a significant role in swine nutrition (Liao *et al.*, 2015). Although the amount of each amino acid required is different, each amino acid is of equal importance.

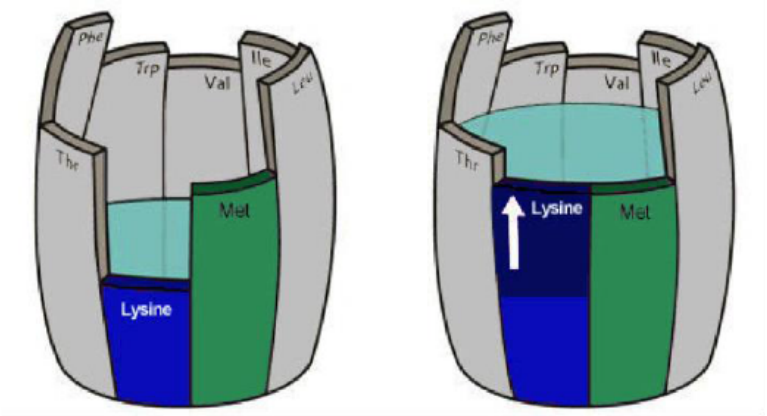

Figure 2.10 Von Liebig's barrel analogy for amino acid balance where lysine is the first limiting amino acid (Kleyn, 2013)

Table 2. 1 Amino acid profile relative to lysine for grower-finisher pigs, proposed by various research groups

Amino Acid	National Research Council (2012)	Van Milgen & Dourmad (2015)	Pig Improvement Company (2016)
Lysine	100	100	100
Met+Cys	41.8	60	58
Thr	53.1	65	64
Trp	12.8	18	18
Val	66.2	70	67
Ile	50.8	55	56
Leu	100	100	101
His	45.2	32	34
Phe+Tyr	89.9	95	95

There are multiple factors that determine the requirement for amino acids in the growing pig with the major factors being sex, genotype, body weight and level of feed intake (Campbell & Taverner, 1988; Möhn *et al.*, 2000; Butt, 2006; Main *et al.*, 2008). Through intense genetic selection, pigs now deposit relatively more lean tissue and less adipose tissue than they did 20 years ago primarily due to consumer preference for decreased fat on meat products (Moore & Mullan, 2010). As a consequence, to allow pigs to reach their genetic potential for a high capacity of lean tissue deposition, higher levels of lysine relative to energy must be fed (Loughmiller *et al.*, 1998; Moore & Mullan, 2010, NRC, 2012). Therefore, understanding the impact of increased dietary lysine on grow-finish performance is a critical component to develop cost-effective grower-finishing feeding strategies in commercial pig production (Main *et al.*, 2008). Friesen *et al. (*1994) conducted a study on high-lean-growth gilts and determined that increased dietary lysine resulted in increased ADG, improved FCR, reduced back fat thickness and greater CP accretion.

AA requirements of growing-finishing pigs are influenced by their genetic capacity to deposit body protein (NRC, 1998), and due to intense genetic selection over the past few decades, the AA requirements

have increased. Literature on the maintenance requirement for lysine in grower-finisher pigs is scarce but a study conducted by Ringel & Susenbeth (2009) determined that the lysine requirement for maintenance is 18 mg/kg BW or 71 mg/kg $BW^{0.75}$. In 1979, the NRC estimated that the lysine requirement of growing pigs (sex undefined) from 60 - 100 kg BW was 0.57% and in 1998, the NRC estimated that the lysine requirement from 50 - 110 kg BW to be an average of 0.60% TID lysine. However, in 2012, the NRC estimated the lysine requirement of growing pigs from 50 - 135 kg BW to average approximately at 0.73% SID lysine. Main *et al. (*2008) conducted a series of seven experiments to determine the lysine requirements under typical commercial conditions for grower-finisher gilts and barrows. The authors found that the equations (lysine: calorie ratio, g/MCal ME = −0.0133 × BW, kg, + 3.6944 and g/MCal ME = −0.0164 × BW, kg, + 4.004) for barrows and gilts, respectively, best described the Lys: calorie ratio that met biological requirements and optimised income over feed cost (IOFC) of the pigs in their experiments. When expressed relative to gain, the optimal SID lysine requirement was 20 g/kg of gain, which is similar to results found by De la Llata *et al*. (2007). A meta-analysis conducted by Goncalves *et al. (*2017) to determine the SID lysine requirement of finishing PIC pigs concluded that the requirements for SID lysine were 106, 103, and 132% of the NRC (2012) recommendations for barrows, gilts, and boars, respectively, and the increased requirement was attributed due to the increased lean growth rate and improved feed efficiency of these modern genotypes. The equations for SID lysine to NE ratio for PIC pigs were as follow:

(Gilts) = 0.000056 × (BW, kg × 2.2046)2 − 0.02844 × (BW, kg × 2.2046) + 6.6391
(Barrows) = 0.000042 × (BW, kg × 2.2046)2 − 0.02372 × (BW, kg × 2.2046) + 6.1452
(Boars) = 0.000046 × (BW, kg × 2.2046)2 − 0.02704 × (BW, kg × 2.2046) + 7.5417

In growing pigs, any dietary supply of AA above the maintenance requirement can be used for body protein deposition. A study conducted by Mahan & Shields (1998) to determine the AA composition of protein gain for growing-finishing pigs determined that the lysine concentration for protein gain is approximately 7.1 g lysine / 100 g of body protein gain. This clearly indicates the importance of lysine to meet the requirements for maintenance as well as protein synthesis. Numerous studies have been conducted on gilts and barrows to determine the impact of increased lysine levels on pig performance and this short meta-analysis (table 2.2) from 25 experiments conducted over the past 16 years indicates the effect of increased lysine levels on growth performance. Research on the impact of lysine on intact boars is limited.

Table 2. 2 Summary of recent available literature on the impact of increased lysine levels on pig performance

Estimated lysine requirement (%)	Weight (kg)	Sex	Diet Type	Response Criteria	Reference
0.93	80-120	gilts & barrows	wheat-sbm	Increased ADG, decreased FCR, increased protein deposition	King *et al*. (2000)
1.09	30-48	gilts & barrows	maize-sbm	Increased ADG and ADFI, improved FCR	Warnants *et al.* (2003)
1.18	27-45	gilts	maize-sbm	Increased ADG and improved FCR, improved carcass lean	De la Llata *et al*. (2007)
0.99	45-75	gilts	maize-sbm		De la Llata *et al*. (2007)
0.80	75-100	gilts	maize-sbm		De la Llata *et al*. (2007)
0.62	100-120	gilts	maize-sbm		De la Llata *et al*. (2007)
1.08	34-60	barrows	maize-sbm	Increased ADG and improved FCR, improved carcass lean	De la Llata *et al*. (2007)
0.90	60-80	barrows	maize-sbm		De la Llata *et al*. (2007)
0.71	80-100	barrows	maize-sbm		De la Llata *et al*. (2007)
0.59	100-120	barrows	maize-sbm		De la Llata *et al*. (2007)
1.04	43-70	barrow	maize-sbm	Improved ADG, FCR, IOMFC, feed cost per kg gain, decreased back fat	Main *et al*. (2008)
0.96	69-93	barrow	maize-sbm		
0.80	102-120	barrow	maize-sbm		
1.16	35-60	gilt	maize-sbm	Improved ADG, FCR, IOMFC, feed cost per kg gain, decreased back fat	Main *et al*. (2008)
1.01	60-85	gilt	maize-sbm		
0.91	78-103	gilt	maize-sbm		
0.80	100-120	gilt	maize-sbm		
1.14	20-36	gilts & barrows	maize-sbm	Improved ADG, FCR, lower back fat thickness	Main *et al*. (2008)

1.04	36-60	gilts & barrows	maize-sbm	Improved ADG, FCR, lower back fat thickness	Main *et al*. (2008)
0.94	60-86	gilts & barrows	maize-sbm	Improved ADG, FCR, lower back fat thickness	Main *et al*. (2008)
0.86	86-118	gilts & barrows	maize-sbm	Improved ADG, FCR, lower back fat thickness	Main *et al*. (2008)
1.10	38-65	gilts	maize-sbm	Improved ADG and FCR	Shelton *et al.* (2011)
0.90	55-80	gilts	maize-sbm	Improved ADG and FCR	Shelton *et al.* (2011)
0.89	85-110	gilts	maize-sbm	Improved ADG and FCR	Shelton *et al.* (2011)
0.83	58-103	barrows	maize-sbm	Improved ADG, ADFI, and FCR	Cho *et al.* (2012)

Sbm: Soybean meal
ADG: Average daily gain
FCR: Feed conversion ratio
IOMFC: Income over marginal feed cost

Endogenous AA losses

Knowledge on the proportion bioavailable AAs is essential for swine diet formulation. In most diet formulations for swine, a portion of each AA that is provided in the diet is not biologically available to the animal due to most proteins not being fully digested and absorbed. Also, not all absorbed amino acids are metabolically available (NRC, 1998). Assessing bio-availability of dietary amino acids is a critical component to evaluating the nutritional value of feed ingredients as well as to estimate the AA requirements of pigs. Batterham (1992) defined bioavailability of dietary AA as the proportion of dietary AA absorbed which are in the chemical form that allows these AA to potentially be used for metabolism and synthesis of protein. AA bioavailability is customarily determined by measuring ileal digestibility (ID) of AAs (Stein *et al.*, 2007b; Adeola *et al*., 2016). Ileal amino acid measurements are used, as the small intestine is the main site of absorption for amino acids, and not influenced by activity of gut microbes in the hindgut. This makes the ID method a more accurate estimate of AA bioavailability compared to total tract digestibility (Sauer & Ozimek, 1986; Stein *et al*., 2007a; Adeola *et al*., 2016). Endogenous amino acid losses ($\mathrm{IAA}_{\mathrm{end}}$) includes the amino acids which are secreted by the animal's gastrointestinal mucosa which are not reabsorbed (mucin protein, enzymes used for digestion and serum albumin), bacterial protein originating from the hindgut and epithelial cells which have been sloughed off from the intestines (Adeola *et al.*, 2016). The NRC (2012) published a weighted average of endogenous ileal AA losses for growing-finishing pigs fitted with ileal cannulas from 57 studies reported in literature. The weighted average of endogenous ileal lysine loss per kilogram dry matter intake was estimated to be 0.417 g.

Values of ID can be expressed as apparent (AID), true (TID) or standardised (SID) depending on which proportion of the ileal AA outflow is included in the calculations. Apparent ileal digestibility (AID) represents the net disappearance of AAs from the digestive tract prior to the distal ileum (Stein et al., 2007b). One of the major problems concerned with using AID is that the values are not always additive between individual feed ingredients. True ileal digestibility (TID) values represent the proportion of dietary AAs which disappear from the digestive tract prior to the distal ileum and excludes IAA_{end} (Stein et al., 2007b). Values for TID do not account for differences in specific IAA_{end} caused by different ingredients. This means the TID does not predict the levels of amino acids that are available to the animal for protein synthesis (Stein et al., 2007b). The ID values for AA digestibility can be calculated by subtracting the amount of AA in ileal digesta outflow from the amount ingested by the animal (Sauer & Ozimek, 1986). The ileal digesta outflow contains unabsorbed exogenous AAs which originated from the diet as well as AAs from endogenous origin (Stein *et al*., 2007a; Stein *et al*., 2007b).

The IAA_{end} (ileal endogenous AA losses) can be divided into two components (figure 2.11); i) basal losses, which are not influenced by ingredient composition of the feed and, ii) specific losses, which are induced by various feed ingredient constituents (e.g. fibre and anti-nutritional factors). Basal endogenous losses (basal IAA_{end}) represents the amount of AA which are lost from the animal irrespective of the diet fed i.e. losses not influenced by feed ingredients (Stein *et al*., 2007b). However, basal IAA_{end} is strongly influenced by total dry matter intake (DMI). Specific IAA_{end} represents the total AA losses above the basal IAA_{end}. Due to specific IAA_{end} being induced by specific feed ingredient characteristics, feeding highly digestible purified proteins will result in low specific IAA_{end} losses (Stein *et al*., 2007a), however, the opposite occurs for feed high in fibre or anti-nutritional factors which will result in specific IAA_{end} contributing more than 50% to the total IAA_{end}. By determining the basal endogenous amino acid losses which occur in monogastrics, standardised ileal digestibility values (SID) can be determined (Kong & Adeola, 2014). SID is calculated as AID minus the basal IAAend as shown:

SID (%) = [(AA intake – (ileal AA outflow – basal IAAend)) / AA intake] x 100

Due to only subtracting the basal IAAend value from the ileal outflow, any components that are feed ingredient specific are included in the calculation, therefore, SID values can distinguish between different feed ingredients inducing different levels of specific IAAend (Stein et al., 2007a; Stein et al., 2007b; NRC, 2012). This allows for SID values to be additive in mixed diets and gives SID values a distinct advantage over both the TID and AID when formulating diets.

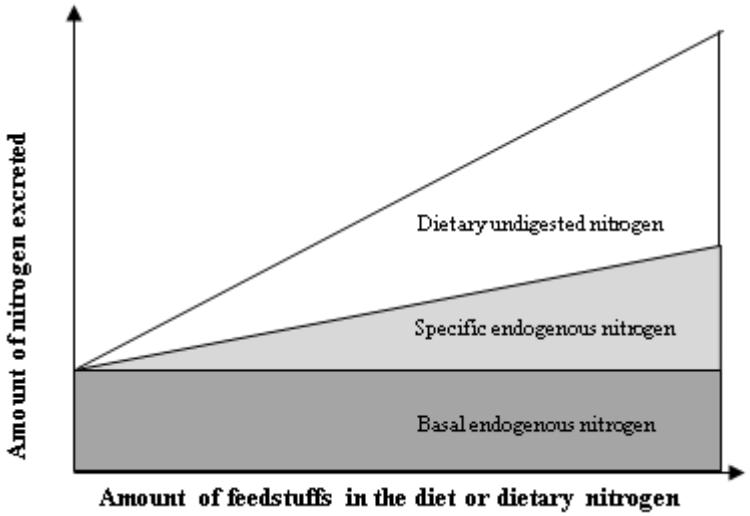

Figure 2.11 Ileal nitrogen flow partitioning (Adeola *et al*., 2016)

2.3.2 Energy

Feed costs make up a large portion of the total cost of pork production (up to 70%) with the cost of energy delivering ingredients contributing the greatest to feed costs (Noblet *et al.*, 1994; Kil *et al.*, 2013). The energy concentration is therefore often altered to not only optimise pig performance but also feed cost De la Llata *et al. (*2007). Energy is commonly described as the 'pacemaker' of animal production and fluctuations in available energy will reflect in the growth rate of the animal (McDonald *et al.*, 2010). Nitikanchana *et al. (*2015) developed a regression equation to predict change in growth rate for incremental changes in net energy (NE) intake. The equation predicts ADG provided that lysine along with the other amino acids are not limiting.

$$ADG(g) = 0.1135 \times NE + 8.8142 \times Avg\ BW\ (kg) - 0.05068 \times (Avg\ BW, kg)^2 + 275.99$$

Thus, for every 100 kcal/kg increase in NE, the ADG increased by 113.5 g/day. It is also documented in research that increasing energy concentration in the diet improves feed efficiency and reduces ADFI (Smith *et al.*, 1999; De la Llata *et al*., 2007; Nitikanchana *et al.*, 2015; Patience *et al.*, 2015). In theory, a 1% increase in dietary energy should result in a 1% improvement in feed efficiency (Euken, 2012). However, it is important to also consider the effect of increased energy concentrations on carcass characteristics as pig producers are paid based on the composition of the carcass. A review by Pettigrew & Moser (1991) indicated that added fat increases carcass fatness in grow-finish diets.

The original definition of energy relates to the potential capacity to carry out work and relates to the oxidation of organic compounds (NRC, 2012). The NRC (2012) points out that energy values are affected by the chemical and physical makeup of the ingredient and the energy requirement of the pig is determined by the physiological state of the pig. Energy is a vital component of the diet and is needed for maintenance and growth. The efficiency by which feed is utilised for maintenance and growth will be negatively influenced if energy is under or over supplied (Mulder, 2015). An under supply of energy will result in mobilisation of fat reserves along with deamination of amino acids to contribute to the energy supply for maintenance and growth. An oversupply of energy will result in excess energy being deposited as fat reserves which is an undesirable

characteristic. It is commonly accepted that energy is prioritised for maintenance first and excess energy intake above the requirement for maintenance is then retained for protein or lipid deposition (Kil *et al.*, 2013). Euken (2012) stated that about 30 – 35 % of consumed energy is used for maintenance, 20 – 25 % of consumed energy is used for protein deposition and 50% is used for lip deposition. Energy is more efficiently used for lipid deposition where efficiency of ME use for lipid reposition ranges from 0.57 – 0.81 and efficiency for protein deposition ranges from 0.36 - 0.57 (NRC, 2012). The growing pig is well known for its ability to adjust ADFI over a wide range of energy concentrations supplied by the diet to maintain a constant daily energy intake, however, due to genetic selection for improved lean growth and FCR, pigs are now associated with reduced voluntary feed intake (Cameron & Curran, 1994). This statement agrees with the delayed onset of lipid deposition and the reduced energy requirement of modern genotypes compared to genotypes in the past (Quiniou *et al.*, 1995). Both the source and the purpose for which energy is used determine the efficiency of energy utilisation (De Lange, 2007). The supply of nutrients along with adequate energy supply is of fundamental importance for optimal pig production (Kil *et al.*, 2013). Campbell & Taverner (1988) conducted a study to determine the effect of different energy levels on protein deposition in growing pigs of different strains and sex and concluded that body protein decreased with increasing energy intake and body fat content increased with increased energy intake. Fat content, however, increased to a lesser extent in strain A boars compared to strain B and castrates. There was also no intrinsic limit to protein deposition for strain A due to protein deposition increasing linearly with increased energy intake up to *ad libitum*. The authors therefore concluded that the intense selection for these animals under *ad libitum* feeding conditions has raised the genetic upper limit for protein deposition beyond the upper limit for appetite.

The classical hierarchy of energy from Birkett & De Lange (2001) is represented in figure 2.12. Gross energy (GE) is defined as the total energy in feed ingredients, which is determined by the degree of oxidation and the ratios of hydrogen, carbon and oxygen in the ingredient. GE is commonly determined by complete combustion of organic materials using bomb calorimetry (McDonald *et al.*, 2010). The digestible energy (DE) of feed ingredients represents the energy absorbed by the animal and is calculated by subtracting the GE excreted in faeces from total GE in feed consumed (Birkett & De Lange, 2001). Metabolisable energy (ME) represents energy that is available for use by the animal and is calculated as DE minus energy lost in urine and combustible gases. However, pigs produce relatively small amounts of gasses, making it difficult to measure and, therefore, gaseous energy losses are often ignored when calculating ME (Kil *et al.*, 2013). Net energy (NE) is closest representative value of “true energy” for pigs. NE values are calculated by subtracting heat increment (HI) or energy lost as heat dissipation during nutrient metabolism from ME.

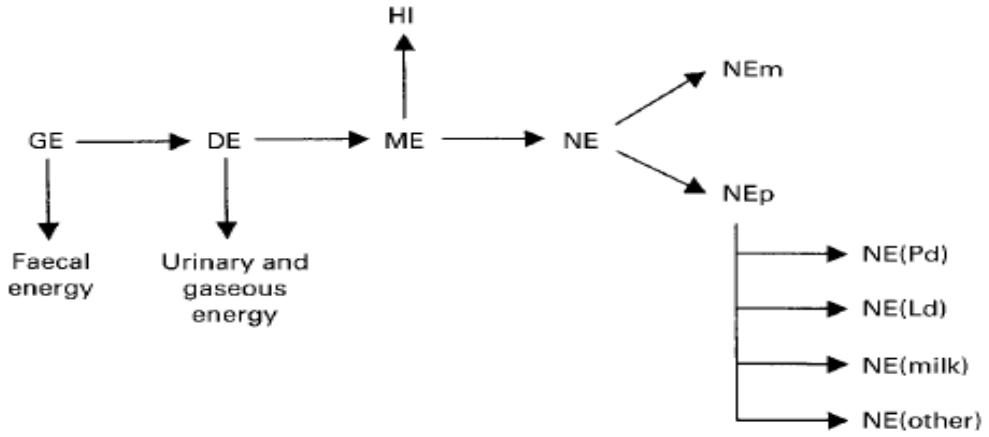

Figure 2.12 The energy hierarchy. Digestible energy (DE) is gross energy (GE) intake less faecal losses; metabolisable energy (ME) is DE less gaseous and urinary losses; net energy (NE) is ME less heat increment (HI). NE can be further subdivided into NE for production (NEp) or NE for maintenance (NEm); NEp is attributed to retained protein, retained lipid, milk and other products. Adapted from Birkett & De Lange, (2001).

There are three energy system available which provide rules that relates energy supply to energy requirements. The quality of an energy systems is determined by the ability of the system to accurately predict animal performance from a level of energy supply provided or to determine the energy supply required to achieve an appropriate level of performance (Noblet & Henry, 1993). The three energy systems, namely the DE, ME and NE systems, have all found their place within the pork production industry. Currently, the most commonly used energy systems in the swine industry include the DE and ME systems, however, these energy values do not account for variation in metabolic utilization as well as the heat increment produced between nutrients. For these two systems, the energy value of high fibre or high protein feed is overestimated while the energy value of fat and starch is underestimated (Noblet, 2007, NRC, 2012). Among the three energy system, the NE system is well recognized for providing energy values of diets as well as ingredients that most accurately estimate the energy available to the animal due to taking the heat increment from metabolism and digestive utilization of feeds into account (Kil *et al.*, 2013).

2.3.3 Lysine: energy ratio

Feed intake is the primary determinant for the amount of amino acids consumed. It is well known that pigs voluntary feed intake is influenced by the energy content of the diet, therefore, one can assume that amino acid levels of the diet is related to the energy concentration of the diet. There are strong, well established relationships and interactions between the requirements for energy and amino acids, such that amino acids will only be deposited as protein if there is a sufficient source of energy supplied. Therefore, when diets are formulated the amino acid specifications are expressed in terms of the lysine level relative to energy (Kim *et al.*, 2011; Moore *et al.*, 2015). Expressing lysine requirements as lysine: energy ratio (g of Lys/ MCal ME), enables the requirements to be suitable over a range of energy levels (Chiba *et al.*, 1991a; Main *et al.*, 2008), and is likely most relevant for growing environments where the energy level required for maximum protein deposition is not normally exceeded (Campbell & Taverner, 1988; Möhn *et al.*, 2000).

The reaction to lysine: energy ratio is expected to vary among genetic lines and production environments (Main *et al.*, 2008). Grower-finisher lysine requirements have been well studied and documented, however,

the optimum lysine: energy ratio is largely affected by genotype, sex, environment, health status, physiological age and variable methods of interpreting results and, therefore, the periodic review of amino acid requirements is essential as genetic selection for increased lean growth continuous (Campbell & Taverner, 1988; Miller *et al.*, 2008; Cho *et al.*, 2012). Many trials have been conducted to determine the effects of different lysine: energy levels on the growth performance of pigs and found that an increase in lysine: energy ratio lead to significant improvements in ADG and FCR (Chiba *et al.*, 1991a; Main *et al.*, 2008; Moore & Mullan, 2010; Cho *et al.*, 2012). In a study conducted by Castell *et al. (*1994) the authors found that an increase in the lysine: energy from 1.5 to 2.59 g Lys/MCal DE resulted in improved growth rate, increased lean content and a reduction in marbling and back fat thickness. Main *et al. (*2008) found similar results in a study where the authors conducted 7 trials (3 on barrows, 4 on gilts) with different lysine: calorie ratios. In all the trials, increasing lysine: calorie ratios significantly increased ADG, improved FCR and reduced back fat thickness. Cho *et al. (*2012) also conducted a study with different lysine: DE ratios ranging from 1.5 to 2.4 g Lys/MCal DE on finishing barrows and also found increased ADG and improved FCR, but did not influence ADFI. The authors concluded that maximum yields including ADG, gain: feed ratio, carcass weight and grade can be achieved by administrating finishing pigs with an ideal Lys: DE ratio of Lys 2.1 g/ MCal DE. Referring back to the linear-plateau model discussed earlier in this paper, Möhn *et al. (*2000) stated that energy and lysine intake have independent effects on protein deposition and is best represented in the linear-plateau model. The authors suggested that the plateau of the model represents the lysine dependent phase and the slopes represent the energy dependent phase. The results indicated that lysine intake did not affect protein deposition when energy intake was limited and energy intake did not limit protein deposition when lysine was limited.

Many of the early studies on lysine and energy were conducted on pigs in individual pens, however, literature has indicated that feed intake of pigs penned individually is often higher compared to pigs placed in group housing. Results from these early studies thus require some degree of interpretation (Campbell *et al*., 1984, Moore & Mullan, 2010). Main *et al. (*2008) therefore emphasizes that there is and will continue to be efforts required to further characterize the outcome of increased dietary lysine in evolving genetic lines.

Chapter 3

Materials and Methods

An experiment was conducted to determine the optimal lysine: energy ratio for 180 PIC337 entire males over the growing-finishing period under typical commercial conditions in South Africa. The experiment consisted of 2x3 factorial design including 2 energy levels (2560 kcal NE/kg and 2161 kcal NE/kg) and 3 lysine levels (80%, 100%, 120%; where 100% equals PIC recommendations from Goncalves *et al.*, 2017). The experiment consisted of 2 phases, a growing phase and a finishing phase. This research was approved by the Animal Ethics Committee at the University of Pretoria, reference number NAS103/2019.

3.1 Location and facilities

The experiment commenced on 10 September 2018 and continued until 28 January 2019 at PIC nucleus farm, Springtop, located in Magaliesburg, South Africa. Pigs were housed in open-sided curtain grower-finisher housing making use of natural ventilation. Pens were 4x2 m (8 m^2) and floors were half solid concrete and half slatted. Five pigs were placed per pen resulting in a stocking density of 1.6 m^2 per pig. Each pen was equipped with “Swing R3 Duo” feeders (55 cm wide). Each pen had one nipple drinker per 5 pigs to ensure *ad libitum* access to water. Each house was equipped with “LogTags” to measure minimum and maximum temperatures for the duration of the trial (table 3.1).

Table 3. 1 Temperature profile in the grow-finish houses from onset of the trial for the first batch up to slaughter of the last batch

Week	Minimum Temperature (°C)	Maximum Temperature (°C)
1	8.8	27.0
2	13.8	28.8
3	15.3	29.1
4	11.9	26.4
5	14.1	26.0
6	13.6	27.6
7	11.9	27.7
8	14.9	26.6
9	12.7	27.3
10	17.7	32.8
11	16.2	28.6
12	16.1	28.8
13	17.1	30.9
14	16.4	30.7
15	18.4	31.2
16	18.9	30.6
17	17.3	25.3
18	17.8	28.9
19	18.7	30.5
20	16.1	30.2

3.2 Animals

All pigs were born and raised on the same farm, received the same creep feed and weaner pellets to reduce variation. The farm followed a three-week batch farrowing system, therefore, two batches of 90 PIC337 entire males entered the trial 3 weeks apart at 9 weeks of age (63 days) to give a total of 180 entire males. Each batch continued in the trial for 17 weeks until slaughter at 26 weeks (182 days) of age with a target slaughter weight of 140 kg.

3.3 Experimental diets and trial design

Each pen was randomly allocated to one of 6 treatments. There was a total of 36 pens with 5 entire males per pen, giving 6 replicates per treatment. Each pen represented an experimental unit and was allocated to treatments following a complete randomized block design with two energy levels, each combined with three lysine levels.

i) Lysine (80% 100% and 120% of PIC recommendations from Goncalves *et al.*, 2017)
ii) Energy (2560 kcal NE/kg and 2161 kcal NE/kg i.e. 10.7 MJ NE/kg and 9.03 MJ NE/kg)

Data was blocked due to two batches of pigs used during the trial. Diets were maize-soybean meal based with all other amino acids included relative to the lysine level. All feeds were produced at a commercial feed mill (AFGRI Animal Feeds, Eloff, South Africa). All feeds were provided in pellet form. The lysine: NE ratio was adjusted for two feeding phases, including the grower phase (table 3.2) and the finisher phase (table 3.3). The finishing phase was implemented at the start of the 10^{th} week of the trial when the animals were 18 weeks of age. Therefore, the pigs received the grower diet for 9 weeks and finisher diet for 8 weeks. Three samples of each diet (for both the grower and finisher treatments) was analysed for nutrient content before the onset of the trial. Formulated raw material and nutrient compositions (%) of the grower diets are listed in table 3.4. Analysed nutrient and amino acid composition (%) of the grower diets are listed in table 3.5. Formulated raw material and nutrient compositions (%) of the finisher diets are listed in table 3.6. Analysed nutrient and amino acid composition (%) of the finisher diets are listed in table 3.7.

Chemical analysis of feed samples was conducted at Labworld (Philafrica Feeds, Isando, South Africa). Moisture was determined based on the AOAC official method 44 15-A (AOAC,1999) by comparing initial and final weights of samples after being dried for 24 hours in an oven at 100°C. Dry matter content was calculated by subtracting the moisture content from 100%. Protein analysis was done based on the AOAC official method 992.23 (AOAC, 2000), a dumatherm was used to determine the sample nitrogen content which was then multiplied by a factor of 6.25 to calculate the protein content. The crude fibre analysis was based on the AOAC official method 978.10 (AOAC, 2000), whereby the crude fibre content was determined using a fibretherm, followed by ashing of the sample for six hours at 550°C. Ash content was determined based on the AOAC official method 942.05 (AOAC, 2000). Crude fat analysis was based on the AOAC official method 920.39 (AOAC, 2000), whereby crude fat content was determined by heat extraction of the sample submerged in petroleum ether using a soxtherm. Calcium and phosphorus contents were determined based on the AOAC official method 976.06 (AOAC, 2000). Sodium and potassium contents were determined by absorption emission spectrometry. Amino acids were analysed using high performance liquid chromatography (HPLC) at AMINOLab (Evonik Industries, Essen, Germany) based on the AOAC official method 994.12 (AOAC, 1995).

Table 3. 2 Formulated net energy (NE) and standardised ileal digestible (SID) lysine (%) levels and Lys: NE of experimental diets (as fed) during the grower phase

Treatment	NE (kcal/kg)	SID Lysine (%)	Lys: NE
1	2560	1.03	4.02
2	2560	1.29	5.04
3	2560	1.55	6.06
4	2161	0.91	4.21
5	2161	1.14	5.28
6	2161	1.37	6.34

Table 3. 3 Formulated net energy (NE) and standardised ileal digestible (SID) lysine (%) levels and Lys: NE of experimental diets (as fed) during the finisher phase

Treatment	NE (kcal/kg)	SID Lysine (%)	Lys: NE
1	2560	0.75	2.93
2	2560	0.94	3.67
3	2560	1.13	4.41
4	2161	0.66	3.05
5	2161	0.83	3.84
6	2161	1.00	4.63

Table 3. 4 Formulated raw material and nutrient composition (as fed) of the grower diet (%)

	Treatment					
	1	2	3	4	5	6
	SID Lysine %					
	1.03	1.29	1.55	0.91	1.14	1.37
	Net Energy (kcal/kg)					
	2560	2560	2560	2161	2161	2161
Yellow maize	63.42	56.55	47.00	57.45	53.24	49.04
Soya oilcake meal 46	13.94	19.94	28.62	5.40	13.51	21.61
Sunflower oilcake (CF20-24 CP≥38)	15.00	15.00	15.00	15.00	15.00	15.00
L-Valine	0.00	0.08	0.11	0.02	0.04	0.07
Lysine HCl	0.50	0.66	0.73	0.54	0.60	0.66
DL Methionine	0.07	0.17	0.24	0.04	0.10	0.16
L-Tryptophan	0.05	0.07	0.08	0.03	0.05	0.06
L-Threonine	0.08	0.15	0.19	0.09	0.12	0.16
Soya oil	4.54	5.08	5.86	0.00	0.00	0.00
Wheat bran	0.00	0.00	0.00	19.02	15.03	11.03
Limestone	1.08	1.06	1.04	1.13	1.10	1.08
Salt	0.55	0.55	0.55	0.55	0.55	0.55
Choline Chloride Liq. LM (75%)	0.02	0.02	0.02	0.02	0.02	0.02
Monocalcium phosphate	0.36	0.28	0.16	0.32	0.24	0.16
Grower premix (AFGRI, Eloff)	0.30	0.30	0.30	0.30	0.30	0.30
Axtra PHY 1000 TPT PIGS (Danisco)	0.10	0.10	0.10	0.10	0.10	0.10
Formulated nutrient composition						
Dry matter	88.98	89.12	89.44	88.75	88.89	89.04
Moisture	11.02	10.88	10.56	11.25	11.11	10.96
Crude protein	17.19	19.4	22.98	16	18.93	21.91
Crude fat	5.52	5.9	7.09	3.04	2.91	2.78
Crude fibre	2.61	2.67	3.47	6.82	6.58	6.33
NE (MJ/kg)	10.71	10.71	10.71	9.04	9.04	9.04
Ash	4.96	5.19	5.62	5.4	5.62	5.84
Calcium	0.72	0.72	0.73	0.73	0.74	0.74
Total Phosphorous	0.39	0.4	0.44	0.58	0.57	0.56
Sodium	0.26	0.26	0.26	0.26	0.26	0.26
Potassium	0.74	0.83	0.97	0.73	0.84	0.95
Chloride	0.44	0.46	0.48	0.49	0.49	0.5

Table 3. 5 Analysed nutrient and amino acid composition (as fed) of the grower diet (%)

	Treatment					
	1	2	3	4	5	6
	SID Lysine %					
	1.03	1.29	1.55	0.91	1.14	1.37
	Net Energy (kcal/kg)					
	2560	2560	2560	2161	2161	2161
Dry Matter	89.87	89.23	89.71	89.59	88.97	89.23
Moisture	10.13	10.77	10.29	10.41	11.03	10.77
Crude protein	17.93	20.61	23.83	16.88	19.17	22.23
Crude fat	7.17	7.54	8.07	3.08	2.89	2.71
Crude fibre	5.92	5.96	6.03	7.35	7.15	6.94
Ash	4.46	4.64	4.89	4.85	4.96	5.08
Calcium	0.69	0.69	0.77	0.69	0.73	0.82
Total Phosphorous	0.44	0.44	0.48	0.59	0.59	0.58
Sodium	0.25	0.28	0.26	0.25	0.26	0.24
Potassium	0.69	0.78	0.95	0.68	0.79	0.89
Methionine	0.39	0.48	0.57	0.31	0.40	0.52
Cystine	0.29	0.31	0.36	0.28	0.32	0.36
Met + Cys	0.69	0.80	0.93	0.60	0.72	0.88
Total Lysine	1.29	1.46	1.71	0.99	1.26	1.57
Threonine	0.77	0.89	1.02	0.63	0.77	0.97
Arginine	1.15	1.29	1.57	1.04	1.27	1.57
Isoleucine	0.74	0.83	1.00	0.60	0.74	0.91
Leucine	1.62	1.72	1.93	1.35	1.52	1.77
Valine	0.88	1.03	1.21	0.76	0.92	1.12
Histidine	0.52	0.57	0.66	0.44	0.53	0.62
Phenylalanine	0.89	0.98	1.14	0.76	0.91	1.05
Glycine	0.71	0.79	0.96	0.71	0.83	0.98
Serine	0.89	0.97	1.13	0.72	0.87	1.05
Proline	1.18	1.27	1.40	1.05	1.17	1.29
Alanine	0.95	1.00	1.13	0.83	0.94	1.07
Asparagine	1.75	1.97	2.34	1.31	1.66	2.11
Glutamic acid	3.25	3.58	4.24	3.06	3.56	4.18

Amino acids presented in the table are based on the total amino acid content analysed for the diet

Table 3. 6 Formulated raw material and nutrient composition (as fed) of the finisher diet (%)

	Treatment					
	1	2	3	4	5	6
	SID Lysine %					
	0.75	0.94	1.13	0.66	0.83	1
	Net Energy (kcal/kg)					
	2560	2560	2560	2161	2161	2161
Yellow Maize	81.73	76.09	69.30	57.63	54.71	51.78
Soya oilcake meal 46	8.13	13.13	19.27	2.48	8.09	13.71
Sunflower oilcake (CF20-24 CP≥38)	5.00	5.00	5.00	5.00	5.00	5.00
L-Valine	0.00	0.05	0.09	0.00	0.01	0.04
Lysine HCl	0.42	0.51	0.57	0.37	0.43	0.49
DL Methionine	0.03	0.10	0.16	0.00	0.03	0.09
L-Tryptophan	0.05	0.06	0.07	0.03	0.03	0.04
L-Threonine	0.06	0.10	0.13	0.05	0.08	0.11
Soya oil (mixer)	1.97	2.42	2.96	0.00	0.00	0.00
Wheat bran	0.00	0.00	0.00	31.93	29.17	26.39
Limestone	1.14	1.13	1.11	1.21	1.19	1.17
Salt	0.55	0.55	0.55	0.55	0.55	0.55
Choline Chloride Liq. LM (75%)	0.02	0.02	0.02	0.02	0.02	0.02
Monocalcium Phosphate	0.51	0.44	0.36	0.34	0.28	0.23
Finisher premix (AFGRI, Eloff)	0.30	0.30	0.30	0.30	0.30	0.30
Axtra PHY 1000 TPT PIGS (Danisco)	0.10	0.10	0.10	0.10	0.10	0.10
Formulated nutrient composition						
Dry matter	88.89	89.82	90.20	88.24	88.65	89.45
Moisture	11.11	10.18	9.8	11.76	11.35	10.55
Crude protein	12.88	14.95	17.03	12.85	14.89	16.95
Crude fat	5.13	5.44	5.81	3.41	3.28	3.15
Crude fibre	3.85	3.88	3.92	6.19	6.04	5.90
NE (MJ/kg)	10.71	10.71	10.71	9.04	9.04	9.04
Ash	3.94	4.90	4.26	4.76	4.85	4.29
Calcium	0.69	0.69	0.77	0.69	0.73	0.82
Total Phosphorous	0.44	0.44	0.48	0.59	0.59	0.58
Sodium	0.26	0.26	0.26	0.26	0.26	0.26
Potassium	0.69	0.78	0.95	0.68	0.78	0.89
Chloride	0.43	0.43	0.46	0.46	0.46	0.47

Table 3. 7 Analysed nutrient and amino acid composition (as fed) of the finisher diet (%)

	Treatment					
	1	2	3	4	5	6
	SID Lysine %					
	0.75	0.94	1.13	0.66	0.83	1
	Net Energy (kcal/kg)					
	2560	2560	2560	2161	2161	2161
Dry Matter	89.78	89.82	90.20	88.24	88.65	89.45
Moisture	10.22	10.18	9.80	11.76	11.35	10.55
Crude protein	12.93	15.31	17.57	12.57	14.34	16.50
Fat	5.13	5.44	5.81	3.41	3.28	3.15
Fibre	3.84	3.88	3.92	6.19	6.04	5.90
Ash	3.94	4.90	4.26	4.76	4.85	4.29
Calcium	0.70	0.78	0.49	0.22	1.45	0.65
Total Phosphorous	0.52	0.63	0.71	0.66	0.71	0.85
Sodium	0.25	0.30	0.24	0.23	0.24	0.24
Potassium	0.52	0.63	0.71	0.66	0.71	0.85
Methionine	0.24	0.33	0.39	0.22	0.25	0.33
Cystine	0.22	0.25	0.26	0.24	0.26	0.29
Met + Cys	0.46	0.58	0.65	0.46	0.51	0.62
Total Lysine	0.93	1.06	1.18	0.75	0.95	1.13
Threonine	0.51	0.64	0.72	0.48	0.56	0.68
Arginine	0.74	0.89	0.96	0.76	0.87	1.06
Isoleucine	0.50	0.59	0.64	0.44	0.51	0.64
Leucine	1.21	1.35	1.46	1.06	1.16	1.34
Valine	0.59	0.76	0.82	0.59	0.66	0.80
Histidine	0.37	0.43	0.45	0.36	0.41	0.46
Phenylalanine	0.61	0.72	0.76	0.56	0.63	0.76
Glycine	0.49	0.59	0.61	0.56	0.62	0.71
Serine	0.61	0.70	0.77	0.56	0.64	0.76
Proline	0.88	1.01	1.05	0.87	0.95	1.05
Alanine	0.72	0.80	0.86	0.69	0.74	0.84
Asparagine	1.12	1.33	1.47	0.92	1.15	1.45
Glutamic acid	2.26	2.65	2.84	2.33	2.56	3.01

Amino acids presented in the table are based on the total amino acid content analysed for the diet

3.4 Data collection

Pigs were weighed at the onset of the trial to determine the start weight. All pigs received a microchip, subcutaneously behind the left ear, to aid with identification throughout the trial. Body weights were measured bi-weekly along with taking P2 back fat measurements using Renco Lean-Meater® 60 to 65 mm from the midline at the last rib on both sides of the midline (Greer *et al*., 1987). Feed consumption was determined weekly by daily weighing the amount of feed made available to the animals and weighing left over feed at the end of each week. The left over feed was then subtracted from the amount of feed made available to the animals. Feed intake (FI), average daily feed intake (ADFI), average daily gain (ADG), and feed conversion ratio (FCR) was estimated from bi-weekly body weight and weekly feed disappearance.

Feed conversion ratio was calculated per pen (experimental unit) as follow:

$$FCR = \frac{Feed\ (kg) consumed\ by\ pen\ for\ week\ x}{Total\ weight\ gain\ (kg)\ of\ pen\ for\ week\ x}$$

3.5 Carcass data

Pigs were slaughtered at Lynca Meats Abattoir in Meyerton, South Africa. At slaughter, pigs were stunned using a V-shaped electric stunner at 1.8 Amps for 4 seconds to render the animal unconscious. The throat was then cut within 20 seconds to ensure sufficient bleeding. The animal then entered a hot water bath at 64^{O}C for 1 minute and 50 seconds after which the animal then entered a dehairing machine for 1 minute and 50 seconds. The leftover hair was then shaved off and burned with a blowtorch. Carcasses were then washed and viscera removed. Before chilling, carcasses were weighed for hot carcass weight and P1 was measured using a Hennessey Grading probe. The Hennessey probe was used to determine meat fat % between the 2nd and 3rd last rib, 45 mm from the midline on the right-hand side (Bruwer, 1992) as is customary in South Africa. For this experiment, the following additional measurements were taken at the abattoir: Meat fat % at 65 mm (P2) between the second and third last rib on the left of the carcass (Greer *et al*., 1987) (to compare data to international research); meat fat % on the ham and thickest part of the shoulder of each carcass (Poldvere *et al*., 2015) to determine overall carcass leanness and fat distribution; meat pH 45 minutes' post slaughter (pH_{45min}). The carcasses were graded according to the PORCUS classification system and tested for boar taint by using the soldering iron method. The carcasses then entered the cool room for chilling at <10^{O}C. After 24 hours, pH 24 hours post slaughter (pH_{24h}) was measured.

3.6 Statistical analysis

Each pen represented an experimental unit and was allocated to treatments following a complete randomised block design, with two levels of energy, each combined with three levels of lysine. Due to using two batches of pigs during the trial, data was blocked into two blocks. Each block consisted of 18 pens each, thus 3 replicates per block. There were no significant differences (P >0.05) between the two blocks for any of the parameters measured. Data was statistically analysed using a Statistical Analysis System software (SAS,

2019). Linear regressions were used to determine the effect of increasing SID lysine levels (80, 100 and 120%) on each dependent variable, within each energy level. Means, standard error and significance of differences between means were determined by Fisher's test with a confidence interval of 95% (Samuals, 1989). Analysis of Variance was done using the general linear model (GLM) to determine the significance of differences (*P* <0.05) between treatments. The following equation of the linear model applied for the complete randomised block design:

$$Y_{ijk} = \mu + L_i + T_j + LT_{ij} + B_k + \varepsilon_{ijk}$$

Where Y is the variable of interest

μ is the overall population mean (general mean)

L_i is the effect of the i^{th} level (SID Lysine %)

T_j is the effect of the j^{th} treatment (NE)

LT_{ij} is the effect of the i x j interaction (Lys x NE)

B_k is the effect of the k^{th} block

ε_{ijk} is the experimental error associated with each Y

Chapter 4

Results

4.1 Effects of standardised ileal digestible (SID) lysine intake and energy level on growth performance

Tables 4.1 to 4.3 summarises the effects of standardised ileal digestible (SID) lysine and energy level on growth performance during the grower phase (table 4.1), finisher phase (table 4.2) as well as over the entire trial period (table 4.3).

Grower phase: 9 to 18 weeks of age (20 to 83 kg live weight)

The results in table 4.1 show that there were no significant (P >0.05) differences between the initial starting weights of the pigs for the different SID lysine and energy levels. During the grower phase (9 to 18 weeks of age), SID lysine had no significant (P >0.05) effect on average daily gain (ADG), cumulative average daily feed intake (ADFI) or on cumulative body weight gain (BWG). However, SID lysine had a significant (P <0.05) effect on feed conversion ratio (FCR) as well as the final BW at 18 weeks of age. Energy had a significant (P <0.05) effect on ADFI, ADG, FCR, BWG as well as the final BW at 18 weeks of age. The pigs that received the high energy treatments differed significantly (P >0.05) from those that received low energy treatments for ADFI, ADG, FCR, BWG and final BW. ADFI was lower for the high energy treatments (T1, T2, and T3) compared to the low energy treatments which had a positive effect on FCR, as the high energy treatments (T1, 2, and T3) had lower FCRs compared to the low energy treatments. High lysine treatments (T3 and T6) had greater final BWs compared to lower lysine treatments. ADG was higher for high energy treatments (T1, T2 and T3) compared to the low energy treatments.

Finisher phase: 18 to 26 weeks of age (83 to 145 kg live weight)

As shown in table 4.2, SID lysine had a significant (P <0.05) effect on body weight and FCR during the finisher phase. However, SID lysine had no significant (P >0.05) effect on ADG, cumulative ADFI or cumulative BWG. Energy had a significant (P <0.05) effect on ADFI, FCR, as well as the final BW at 26 weeks of age. Therefore, the pigs that received high energy treatments differed significantly (P >0.05) from those that received the low energy treatments for ADFI, FCR and final BW. Energy had no significant (P >0.05) effect on ADG and BWG during the finisher phase. Similar to the grower phase (9 to 18 weeks of age), high energy treatments had lower ADFI which in turn resulted in lower FCRs compared to low energy treatments. The high lysine treatments (T3 and T6) had better FCRs compared to the lower lysine treatments.

Overall growth: 9 to 26 weeks of age (20 to 145 kg)

The results in table 4.3 show that SID lysine had no significant (P >0.05) effect on ADG and ADFI over the total period of the trial. FCR and final BW was significantly (P <0.05) influenced by the SID lysine level, where the high lysine treatments (T3 and T6) had lower FCRs compared to the other lysine treatments. Energy had a significant (P <0.05) effect on ADFI, ADG, FCR, BWG as well as the final BW over the total period of the trial. The high energy treatments (T1, 2, and T3) differed significantly (P >0.05) for ADFI and FCRs compared to the low energy treatments (T4, T5 and T6). The high energy treatments also achieved greater BWG (P <0.05) and final body weights (P <0.05) compared to the low energy treatments.

Table 4.1 Effects of standardised ileal digestible (SID) lysine and energy level on growth performance from 9 to 18 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	1.03	1.29	1.55	0.91	1.14	1.37				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	4.02	5.04	6.06	4.21	5.28	6.34		Probability (P <0.05)		
							SEM	NE level	Lys level	NE x Lys
Initial BW, kg	20.55	19.90	20.40	19.73	20.70	20.27	0.16	0.880	0.870	0.130
ADFI, kg	1.83	1.72	1.73	1.82	1.84	1.82	0.02	0.004	0.193	0.054
ADG, kg	1.019	1.01	1.02	0.94	0.99	0.99	0.01	0.001	0.261	0.173
FCR	1.79[a]	1.71[ab]	1.69[ab]	1.93[c]	1.87[b]	1.85[b]	0.02	0.001	0.001	0.902
Final BW, kg	84.90[a]	83.73[a]	85.51[a]	78.17[b]	82.63[a]	83.48[a]	0.49	0.002	0.050	0.060
Gain, kg	64.16	63.48	64.48	59.26	62.21	62.15	0.47	0.001	0.260	0.170

[a - c] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy; BW: Body weight; ADFI: Average daily feed intake; ADG: Average daily gain; FCR: Feed conversion ratio

Table 4.2 Effects of standardised ileal digestible (SID) lysine and energy level on growth performance from 18 to 26 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	0.75	0.94	1.13	0.66	0.83	1.00				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	2.93	3.67	4.41	3.05	3.85	4.63				
								Probability (P <0.05)		
							SEM	NE level	Lys level	NE x Lys
Initial BW, kg	84.90[b]	83.73[ab]	85.51[a]	78.17[b]	82.63[ab]	83.48[a]	0.49	0.002	0.050	0.060
ADFI, kg	2.93	2.84	2.77	3.08	3.17	3.14	0.04	0.001	0.746	0.318
ADG, kg	1.15	1.16	1.14	1.04	1.10	1.16	0.02	0.118	0.404	0.219
FCR	2.55	2.46	2.43	2.96	2.89	2.72	0.04	0.001	0.054	0.557
Final BW, kg	148.30[a]	148.43[a]	148.02[a]	135.58[b]	143.23[ab]	148.29[a]	1.23	0.007	0.054	0.046
Gain, kg	63.40	63.78	62.51	57.42	60.60	63.70	0.86	0.118	0.408	0.219

[a, b] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy; BW: Body weight; ADFI: Average daily feed intake; ADG: Average daily gain; FCR: Feed conversion ratio

Table 4.3 Effects of standardised ileal digestible (SID) lysine and energy level on growth performance from 9 to 26 weeks of age

	Treatment									
	1	2	3	4	5	6				
	Lys: NE ratio									
	HE-LL	HE-ML	HE-HL	LE-LL	LE-ML	LE-HL		Probability (P <0.05)		
							SEM	NE level	Lys level	NE x Lys
Initial BW, kg	20.55	19.90	20.40	19.73	20.70	20.27	0.16	0.880	0.870	0.130
ADFI, kg	2.34	2.24	2.21	2.41	2.46	2.44	0.02	0.001	0.480	0.090
ADG, kg	1.081	1.078	1.076	0.989	1.041	1.067	0.01	0.008	0.203	0.132
FCR	2.17^{ab}	2.08^{a}	2.06^{a}	2.43^{c}	2.37^{b}	2.29^{b}	0.03	0.001	0.007	0.761
Final BW, kg	148.30^{a}	148.43^{a}	148.02^{a}	135.58^{b}	143.23^{ab}	148.29^{a}	1.23	0.007	0.054	0.046
Gain, kg	127.58	127.26	126.99	116.68	122.80	125.85	1.13	0.008	0.203	0.132

$^{a - c}$ Means within the same row with no common superscript differ significantly (P <0.05)

HE-LL: High energy, low lysine treatments over grower and finisher phase
HE-ML: High energy, medium lysine treatments over grower and finisher phase
HE-HL: High energy, high lysine treatments over grower and finisher phase
LE-LL: Low energy, low lysine treatments over grower and finisher phase
LE-ML: Low energy, medium lysine treatments over grower and finisher phase
LE-HL: Low energy, high lysine treatments over grower and finisher phase
SEM: Standard error of the mean; NE: Net energy; BW: Body weight; ADFI: Average daily feed intake; ADG: Average daily gain; FCR: Feed conversion ratio

4.2 Body weight (BW)

Table 4.4 and table 4.5 show the results of the various treatment effects on body weight (BW) measured according to the weighing intervals for the grower and finisher phase, respectively. Figure 4.1 provides a graphic representation of the body weights measured over time for the grower-finisher pigs that received different lysine: NE treatments. The grand mean for initial BW at 9 weeks (63 days) of age was 20.26 (± 0.945) kg and the final BW was 145.3 (± 7.4) kg. There were no differences between treatments for BW at the start of the trial at week 9. The highest BW during the grower phase was achieved when 6.06 g of SID Lys/ MCal NE was fed. Energy had a significant effect (P <0.05) on body weight from week 11 up to week 26 of age. Lysine and the lysine: NE ratio had no significant effect (P <0.05) on BW for the grower phase, however, there was a tendency for the lysine: NE ratio to have an effect on BW for the grower phase. During the finisher phase, both lysine level as well as lysine: NE ratios had significant effects (P <0.05) on body weight up to week 25 of age. Pigs from treatment 3 (6.06 g of SID Lys/ MCal NE and 4.41 g of SID Lys/ MCal NE for the grower and finisher phase, respectively) were heavier throughout the trial except during the last two weeks, where there was no increased effect on BW by increasing the Lys: NE ratio above 2.93 g of Lysine/ MCal NE on high energy treatments. However, for low energy treatments, the effect of a higher Lys: NE ratio from T6 (6.34g of Lys/ MCal NE and 4.63 g of Lys/ MCal NE, for the grower and finisher phase, respectively) persisted throughout the trial. The pigs that received the high energy treatments (T1, T2 and T3) were significantly (P <0.05) heavier compared to the pigs which received low energy treatments throughout the trial. The pigs also had heavier final BWs compared to the pigs on low energy treatments. Pigs from T6 (4.63 g of Lys/ MCal NE for the finisher phase), however, achieved the same final BW as those on high energy treatments.

Table 4.4 The effect of Lys: NE ratios on the mean bi-weekly body weight (kg) of boars during the grower phase from 9 to 18 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	1.03	1.29	1.55	0.91	1.14	1.37			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	4.02	5.04	6.06	4.21	5.28	6.34		Probability (*P* <0.05)	
AGE (weeks)							SEM	NE level	Lys Level	NE x Lys
Initial BW (9)	20.55	19.90	20.40	19.73	20.70	20.27	0.16	0.843	0.800	0.045
11	30.98	31.20	31.72	29.23	31.22	30.38	0.32	0.048	0.162	0.324
13	43.87	43.54	44.53	40.33	43.45	43.05	0.36	0.009	0.068	0.084
15	58.63	57.82	58.56	53.77	57.57	57.40	0.47	0.012	0.152	0.053
17	75.88	74.20	75.95	69.50	73.36	73.85	0.56	0.002	0.165	0.052
18	84.90[a]	83.73[a]	85.50[a]	78.73[b]	83.35[a]	83.48[a]	0.49	0.003	0.061	0.037

[a, b] Means within the same row with no common superscript differ significantly (*P* <0.05)

SEM: Standard error of the mean; NE: Net energy; BW: Body weight

Table 4.5 The effect of Lys: NE ratios on the mean bi-weekly body weight (kg) of boars during the finisher phase from 18 to 26 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	0.75	0.94	1.13	0.66	0.83	1.00			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	2.93	3.67	4.41	3.05	3.85	4.63			
AGE (weeks)							SEM	Probability (*P* <0.05) NE level	Lys Level	NE x Lys
19	91.86^{ab}	91.33^{ab}	93.86^{a}	84.17^{c}	89.62^{b}	91.60^{ab}	0.70	<0.001	0.002	0.036
21	107.88^{ab}	107.68^{ab}	111.55^{a}	99.23^{c}	104.81^{b}	107.77^{ab}	0.88	<0.001	<0.001	0.110
23	125.57^{ab}	125.12^{ab}	126.93^{a}	114.67^{c}	121.94^{b}	126.69^{ab}	0.96	0.002	0.002	0.010
25	142.10^{a}	140.78^{a}	141.90^{a}	130.93^{b}	138.42^{a}	143.22^{a}	1.00	0.018	0.018	0.012
26	148.30^{a}	148.40^{a}	148.00^{a}	135.60^{b}	143.20^{ab}	148.30^{a}	1.23	0.010	0.072	0.060

$^{a-c}$ Means within the same row with no common superscript differ significantly (*P* <0.05)

SEM: Standard error of the mean; NE: Net energy

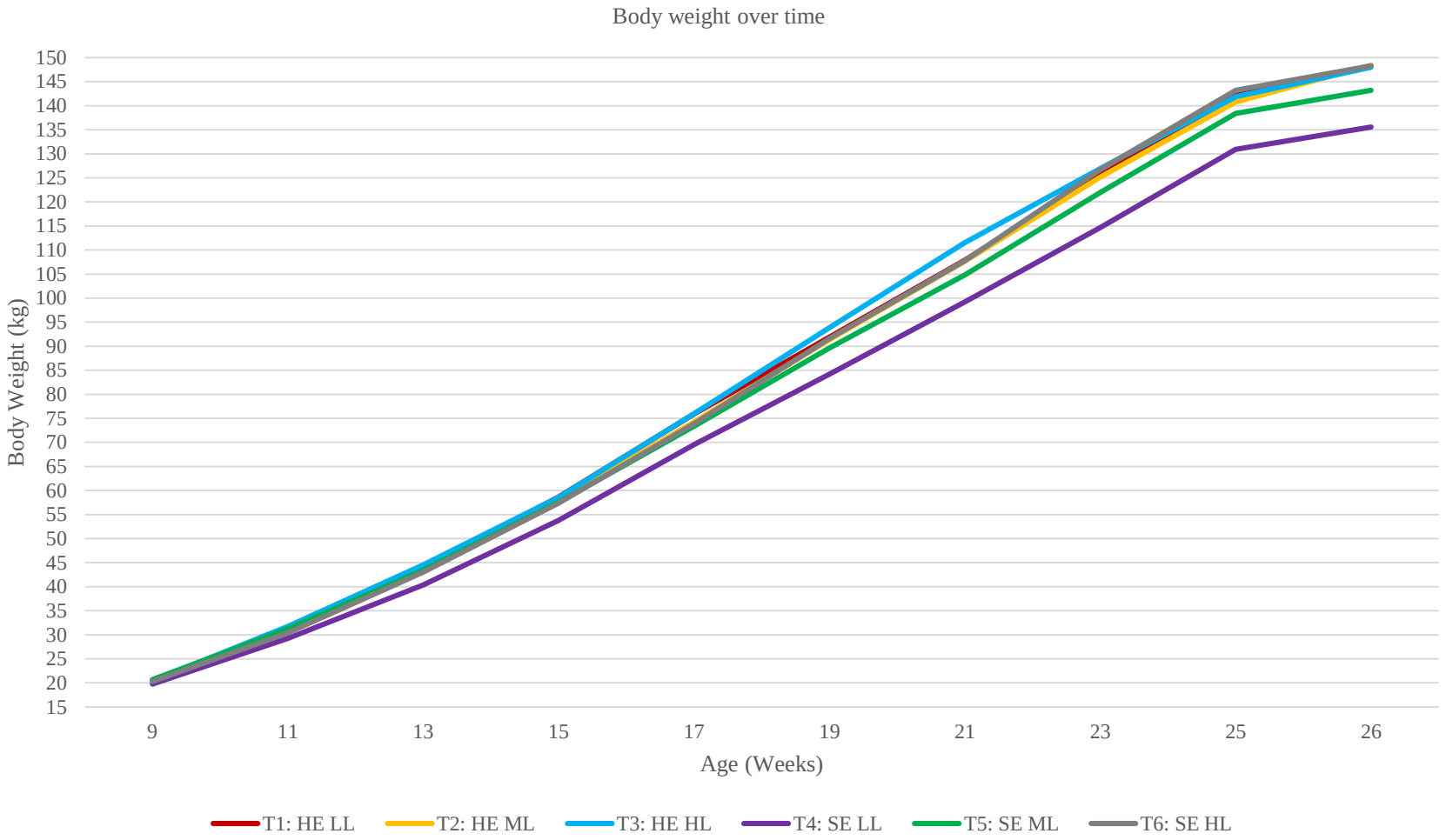

Figure 4. 1 Body weight (BW) over time for grower-finisher pigs receiving different Lys: NE ratio treatments

HE-LL: High energy, low lysine treatments over grower and finisher phase
HE-ML: High energy, medium lysine treatments over grower and finisher phase
HE-HL: High energy, high lysine treatments over grower and finisher phase
LE-LL: Low energy, low lysine treatments over grower and finisher phase
LE-ML: Low energy, medium lysine treatments over grower and finisher phase
LE-HL: Low energy, high lysine treatments over grower and finisher phase

4.3 Body weight gain (BWG)

Table 4.6 and table 4.7 show the results for the cumulative body weight gain (BWG) over the various weighing intervals for the grower and finisher phase, respectively. Figure 4.2 provides a graphic representation of the cumulative body weight gain measured over time for the grower-finisher pigs that received different lysine: NE treatments. The body weight gain was highest for pigs from T3 (6.06 g of SID Lys/ MCal NE) followed by T6 (6.34 g of SID Lys/ MCal NE) throughout the grower phase. However, the highest cumulative BWG was for pigs from T2 (3.67 g of SID Lys/ MCal NE) followed by pigs from T6 (4.63 g of SID Lys/ MCal NE) at the end of the trial. Energy had a significant effect (P <0.05) on BWG of pigs during both the grower and the finisher phases. The pigs that received high energy treatments had significantly (P <0.05) greater BWG compared to those that received the low energy treatments. Pigs from T6 (6.34g of Lys/ MCal NE and 4.63 g of Lys/ MCal NE, for the grower and finisher phase, respectively) achieved similar BWG as the pigs on the high energy treatments. Lysine had no significant effect (P >0.05) on BWG during the grower phase, but had a significant effect (P <0.05) on BWG from week 18 to week 25 of age during the finisher phase. Pigs that were fed high lysine treatments (T3 and T6) had greater BWG compared to the other lysine levels up to week 25 of the trial. The lysine: NE ratio had no significant effect (P >0.05) on BWG throughout both feeding phases.

Figures 4.3 and 4.4 indicate the relationship between cumulative body weight gain (BWG) and the level of lysine and energy over the grower and finisher period, respectively. During the grower period from 9 to 18 weeks of age (20 to 83 kg), the equation for high energy treatments was as follows: BWG (kg) = 0.008 (SID lysine %) + 63.24. The equation for the low energy treatments was as follows: BWG (kg) = 0.072 (SID lysine %) + 53.98. During the finisher period from 18 to 26 weeks of age (83 to 145 kg), the equation for high energy treatments was as follows: BWG (kg) = -0.022 (SID lysine %) + 65.455. The equation for the low energy treatments was as follows: BWG (kg) = 0.157 (SID lysine %) + 44.87.

Table 4.6 The effect of Lys: NE ratios on the cumulative body weight gain (kg) of boars during the grower phase from 9 to 18 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	1.03	1.29	1.55	0.91	1.14	1.37				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	4.02	5.04	6.06	4.21	5.28	6.34		Probability (P <0.05)		
AGE (weeks)							SEM	NE level	Lys Level	NE x Lys
9 to 11	10.43	11.30	11.32	9.50	10.52	10.78	0.24	0.021	0.008	0.763
9 to 13	22.99[ab]	23.65[a]	24.13[a]	20.60[c]	22.75[ab]	22.65[ab]	0.22	0.004	0.031	0.488
9 to 15	37.75	37.92	38.16	34.03	36.87	37.00	0.18	0.006	0.096	0.200
9 to 17	55.00	54.30	55.45	49.77	52.66	53.45	0.21	0.002	0.157	0.181
9 to 18	64.16	63.48	64.48	59.26	62.21	62.15	0.13	0.003	0.308	0.215

[a - c] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

Table 4.7 The effect of Lys: NE ratios on the cumulative body weight gain (kg) of boars during the finisher phase from 18 to 26 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	0.75	0.94	1.13	0.66	0.83	1.00				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	2.93	3.67	4.41	3.05	3.85	4.63		Probability (P <0.05)		
AGE (weeks)							SEM	NE level	Lys Level	NE x Lys
9 to 19	71.15^{ab}	71.08^{ab}	72.83^{a}	64.69^{c}	68.48^{b}	70.27^{b}	0.18	<0.001	0.022	0.202
9 to 21	87.00^{ab}	87.78^{ab}	91.05^{a}	79.50^{c}	84.23^{b}	87.37^{ab}	0.45	<0.001	<0.001	0.267
9 to 23	104.69^{ab}	105.22^{ab}	106.43^{a}	94.93^{c}	101.36^{b}	106.21^{a}	0.45	0.002	0.002	0.023
9 to 25	121.22^{a}	120.88^{a}	121.39^{a}	111.20^{b}	117.85^{a}	122.74^{a}	0.41	0.024	0.024	0.028
9 to 26	127.40	128.80	127.50	115.80	122.60	127.80	0.46	0.012	0.084	0.098

$^{a - c}$ Means within the same row with no common superscript differ significantly (P <0.05)
SEM: Standard error of the mean; NE: Net energy

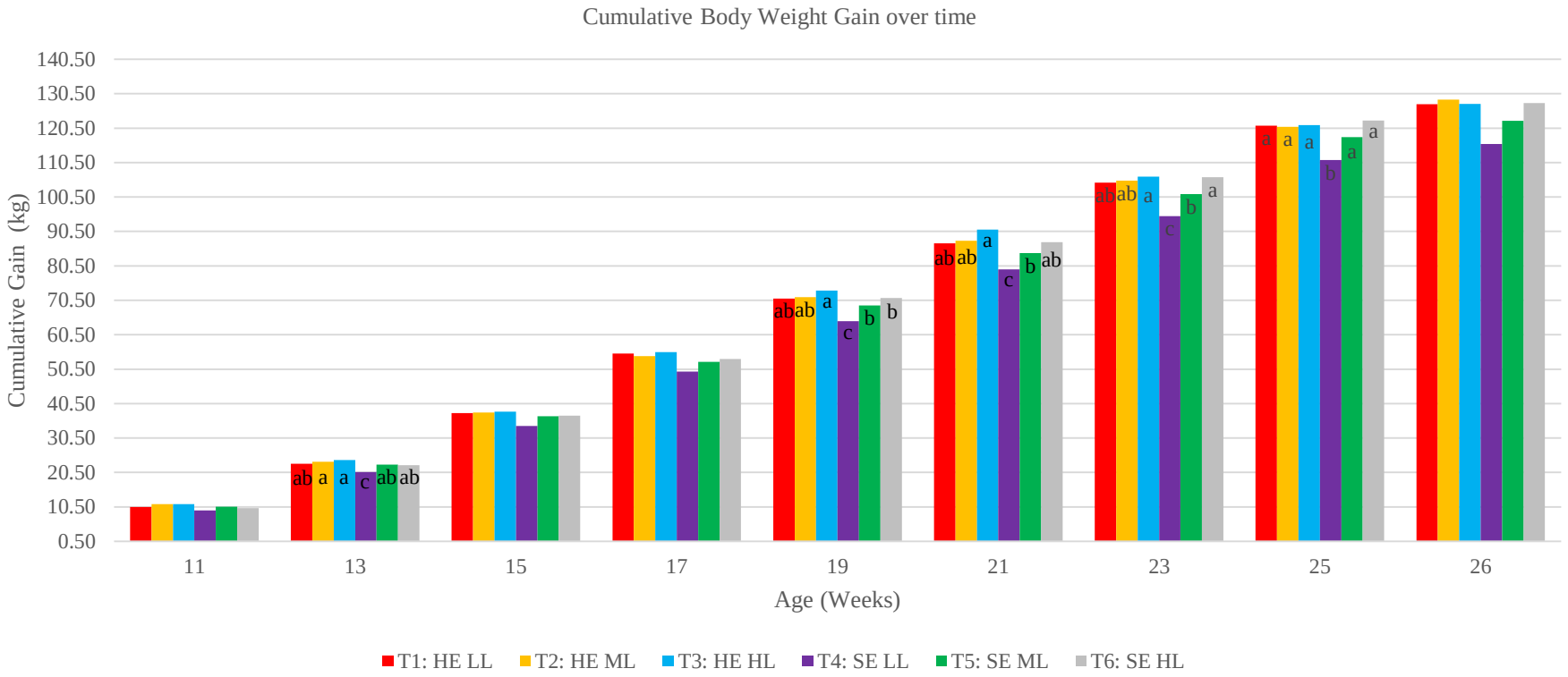

Figure 4. 2 Cumulative body weight gain (BWG) for bi-weekly weighing intervals of grower-finisher pigs receiving different Lysine: NE ratio treatments

HE-LL: High energy, low lysine treatments over grower and finisher phase
HE-ML: High energy, medium lysine treatments over grower and finisher phase
HE-HL: High energy, high lysine treatments over grower and finisher phase
LE-LL: Low energy, low lysine treatments over grower and finisher phase
LE-ML: Low energy, medium lysine treatments over grower and finisher phase
LE-HL: Low energy, high lysine treatments over grower and finisher phase

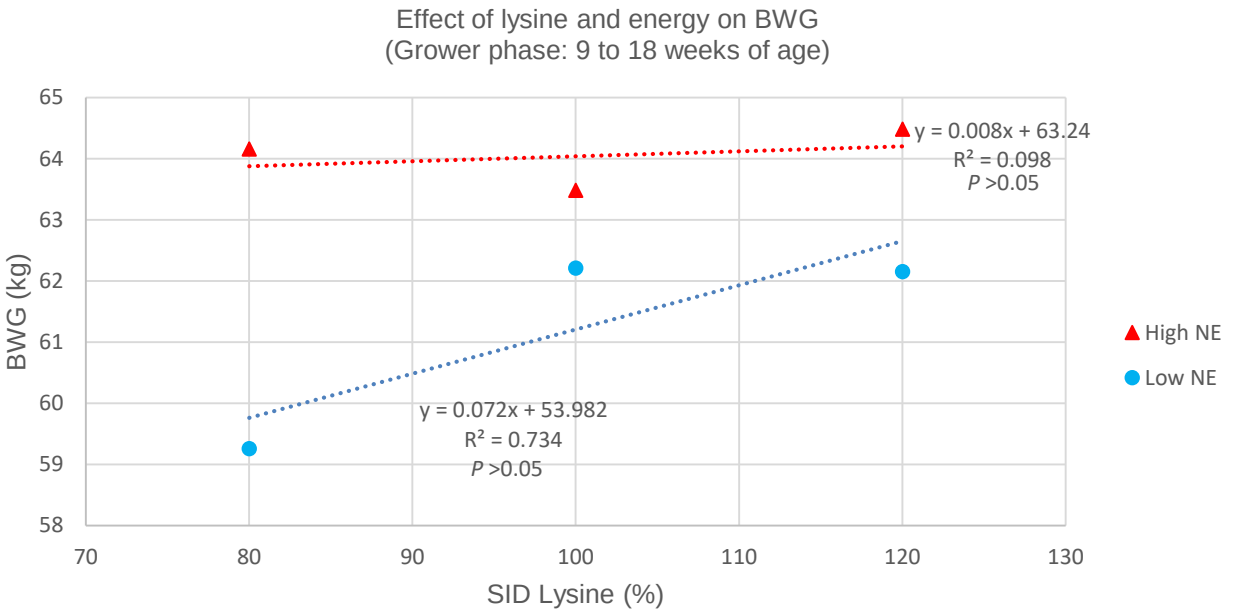

Figure 4. 3 Relationship between body weight gain (BWG) and the level of lysine and energy in grower pigs (9 to 18 weeks of age)

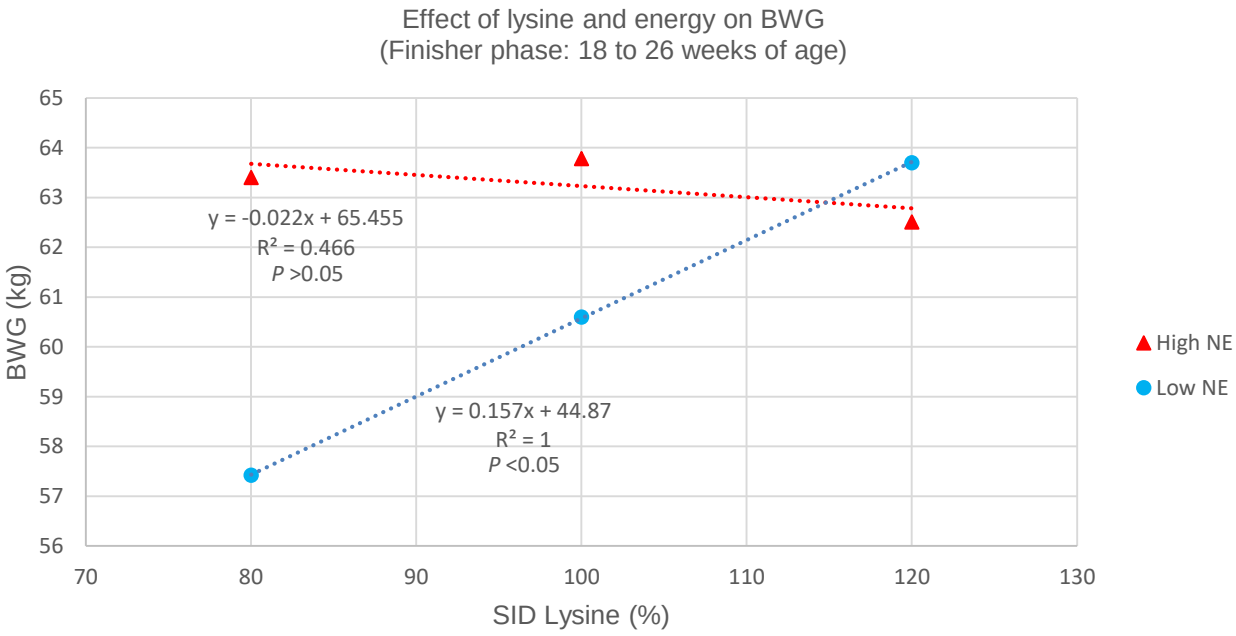

Figure 4. 4 Relationship between body weight gain (BWG) and the level of lysine and energy in finisher pigs (18 to 26 weeks of age)

4.4 Average daily gain (ADG)

Results for average daily gain (ADG) over the various weighing intervals during the grower and finisher phase, respectively, are shown in table 4.8 and 4.9. Throughout the experiment there was no significant effect (P >0.05) on average daily gain for energy level, lysine level or lysine: NE ratio. A first peak in ADG was reached at week 18 with maximum ADG reached for T6 (6.34 g of SID Lys/ MCal NE) followed by a period of slow growth until ADG reached a second peak at week 23 of age and the maximum ADG was reached for T6 (6.34 g of SID Lys/ MCal NE) again.

Figures 4.5 and 4.6 indicate the relationship between average daily gain (ADG) and the level of lysine and energy over the grower and finisher period, respectively. During the grower period from 9 to 18 weeks of age (20 to 83 kg), the equations were as follow for high energy treatments and low energy treatments, respectively: ADG (kg/day) = 0.0003 (SID lysine %) + 1.017 and ADG (kg/day) = 0.002 (SID lysine %) + 0.827. During the finisher period from 18 to 26 weeks of age (83 to 145 kg), the equation for high energy treatments was as follows: ADG (kg/day) = -0.0003 (SID lysine %) + 1.175. The equation for the low energy treatments was as follows: ADG (kg/day) = 0.003 (SID lysine %) + 0.8.

Table 4.8 The effect of Lys: NE ratios on the average daily gain (kg/day) for boars during the grower phase 9 to 18 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	1.03	1.29	1.55	0.91	1.14	1.37				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	4.02	5.04	6.06	4.21	5.28	6.34				
AGE (weeks)							SEM	Probability (P <0.05)		
								NE level	Lys Level	NE x Lys
9 to 11	0.745	0.807	0.808	0.679	0.751	0.723	0.02	0.018	0.127	0.904
11 to 13	0.869	0.882	0.915	0.793	0.874	0.895	0.02	0.171	0.064	0.498
13 to 15	1.055	1.019	1.002	0.960	1.009	1.025	0.01	0.272	0.968	0.154
15 to 17	1.232	1.170	1.176	1.124	1.128	1.175	0.02	0.122	0.714	0.390
17 to 18	1.172	1.200	1.270[a]	1.038	1.069	1.338[a]	0.05	0.104	<0.001	0.070

[a] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

Table 4.9 The effect of Lys: NE ratios on the average daily gain (kg/day) of boars during the finisher phase from 18 to 26 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	0.75	0.94	1.13	0.66	0.83	1.00			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	2.93	3.67	4.41	3.05	3.85	4.63		Probability (P <0.05)	
AGE (weeks)							SEM	NE level	Lys Level	NE x Lys
18 to 19	0.994	1.112	1.194	0.862	0.999	1.160	0.05	0.029	<0.001	0.577
19 to 21	1.145	1.168	1.264	1.076	1.085	1.155	0.03	0.036	0.107	0.913
21 to 23	1.263	1.245	1.099	1.102	1.224	1.273	0.03	0.958	0.630	0.052
23 to 25	1.212	1.183	1.034	1.171	1.132	1.192	0.03	0.677	0.479	0.205
25 to 26	1.032	1.121	1.020	0.775	0.800	0.844	0.06	0.133	0.960	0.935

SEM: Standard error of the mean; NE: Net energy

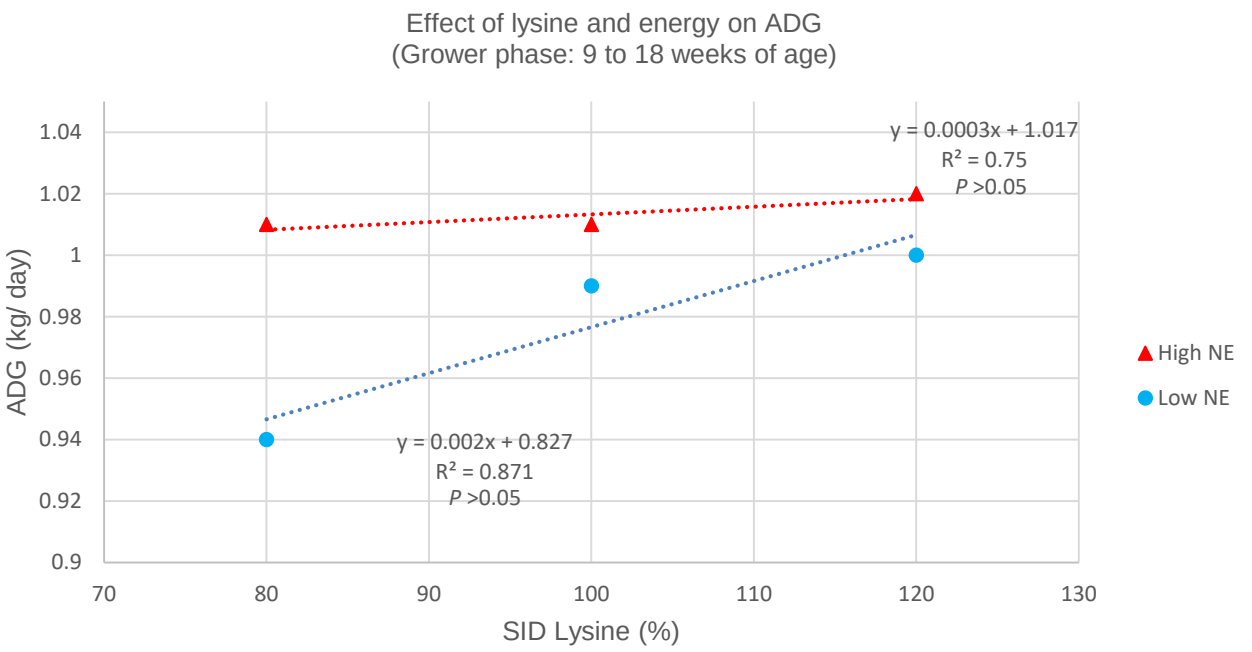

Figure 4. 5 Relationship between average daily gain (ADG) and the level of lysine and energy in grower pigs (9 to 18 weeks of age)

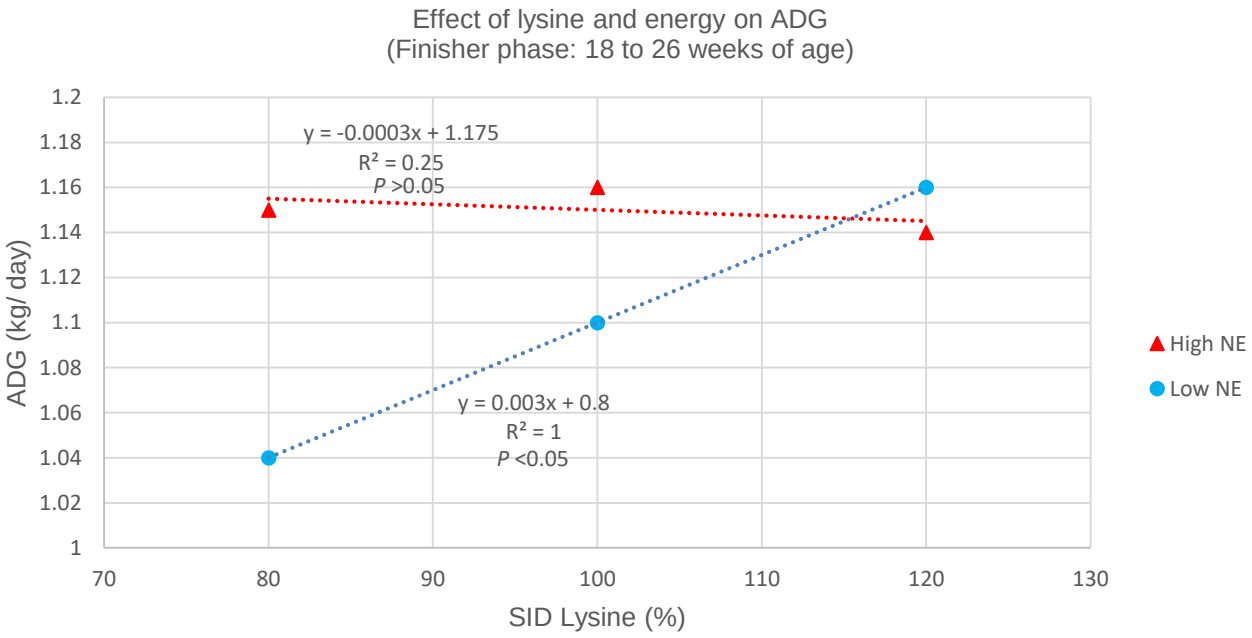

Figure 4. 6 Relationship between average daily gain (ADG) and the level of lysine and energy in finisher pigs (18 to 26 weeks of age)

4.5 Average daily feed intake (ADFI)

Results for cumulative average daily feed intake (ADFI) over the various weighing intervals for the grower and finisher phase, respectively, are shown in table 4.10 and 4.11. During the grower phase and finisher phase, energy had a significant effect (P <0.05) on ADFI of pigs. ADFI was significantly (P <0.05) lower for the pigs that received high energy treatments compared to low energy treatments. The lysine: NE ratio, however, had a significant effect (P <0.05) on ADFI during the grower phase but not throughout the entire finishing phase. SID lysine had no significant effect (P >0.05) on ADFI throughout the experiment.

The relationship between ADFI and the level of lysine and energy during the grower period (9 to 18 weeks of age) is shown in figure 4.7. During the grower period, the equations were as follow for high energy treatments and low energy treatments, respectively: ADFI (kg/day) = -0.0025 (SID lysine %) + 2.01 and ADFI (kg/day) = 0 (SID lysine %) + 1.827. The relationship between ADFI and the level of lysine and energy during the finisher period (18 to 26 weeks of age) is shown in figure 4.8. During the finisher period, the equation for high energy treatments was as follows: ADFI (kg/day) = -0.004 (SID lysine %) +3.268. The equation for the low energy treatments was as follows: ADFI (kg/day) = 0.001 (SID lysine %) + 2.98.

Table 4.10 The effect of Lys: NE ratios on the cumulative average daily feed intake (kg/day) for boars during the grower phase from 9 to 18 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	1.03	1.29	1.55	0.91	1.14	1.37			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	4.02	5.04	6.06	4.21	5.28	6.34		Probability (P <0.05)	
AGE (weeks)							SEM	NE level	Lys Level	NE x Lys
9 to 11	1.23[a]	1.17[b]	1.15[b]	1.15[b]	1.22[a]	1.22[a]	0.02	0.513	0.984	0.026
9 to 13	1.40[a]	1.29[b]	1.27[b]	1.33[ab]	1.38[a]	1.34[ab]	0.03	0.260	0.141	0.014
9 to 15	1.57[a]	1.45[b]	1.44[b]	1.52[ab]	1.57[a]	1.53[ab]	0.03	0.030	0.156	0.022
9 to 17	1.74[a]	1.61	1.63	1.71[b]	1.75[a]	1.72[b]	0.03	0.016	0.200	0.049
9 to 18	1.83	1.72	1.73	1.82	1.84	1.82	0.02	0.011	0.191	0.078

[a, b] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

Table 4.11 The effect of Lys: NE ratios on the cumulative average daily feed intake (kg/day) for boars during the finisher phase from 18 to 26 weeks of age

	Treatment									
	1	2	3	4	5	6				
	SID Lysine %									
	0.75	0.94	1.13	0.66	0.83	1.00				
	Net Energy (kcal/kg)									
	2560			2161						
	Lys: NE (g of SID Lys/ MCal NE)									
	2.93	3.67	4.41	3.05	3.85	4.63				
AGE (weeks)							SEM	Probability (P <0.05) NE level	Lys Level	NE x Lys
9 to 19	1.92	1.81	1.83	1.92	1.94	1.93	0.04	0.004	0.181	0.069
9 to 21	2.05[b]	1.93	1.95	2.05[b]	2.12[a]	2.08[a]	0.05	0.001	0.602	0.046
9 to 23	2.14	2.06	2.04	2.16	2.39	2.21	0.07	<0.001	0.713	0.063
9 to 25	2.28	2.17	2.15	2.30	2.39[a]	2.36[a]	0.10	<0.001	0.663	0.033
9 to 26	2.32	2.23	2.20	2.38	2.47	2.43	0.13	<0.001	0.677	0.095

[a, b] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

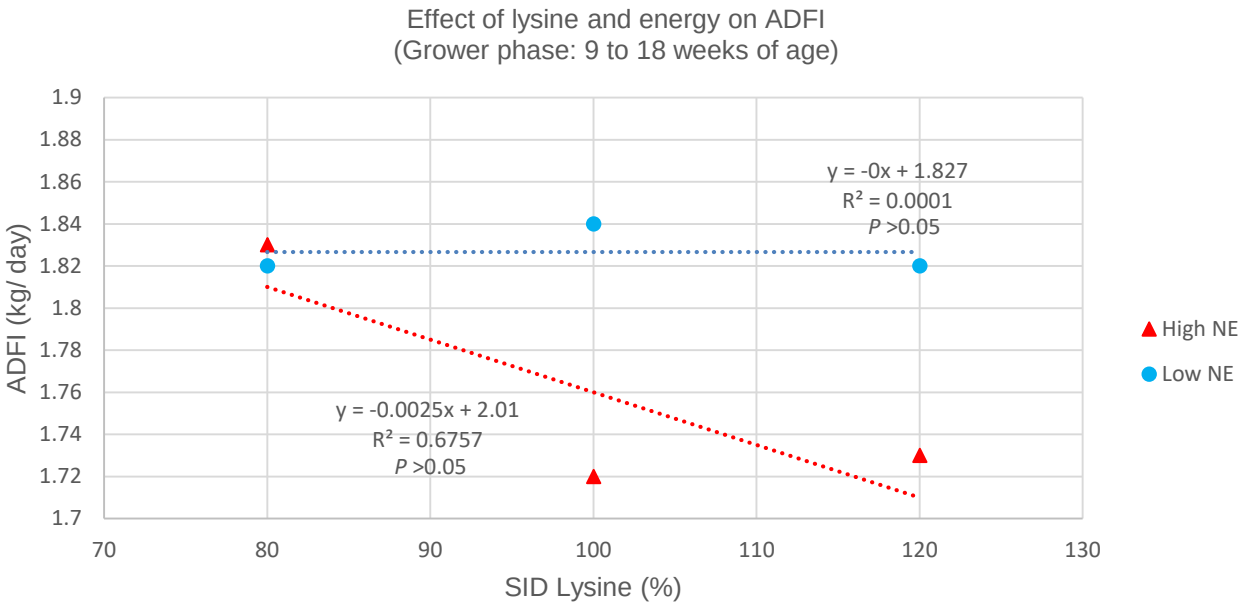

Figure 4. 7 Relationship between average daily feed intake (ADFI) and the level of lysine and energy in grower pigs (9 to 18 weeks of age)

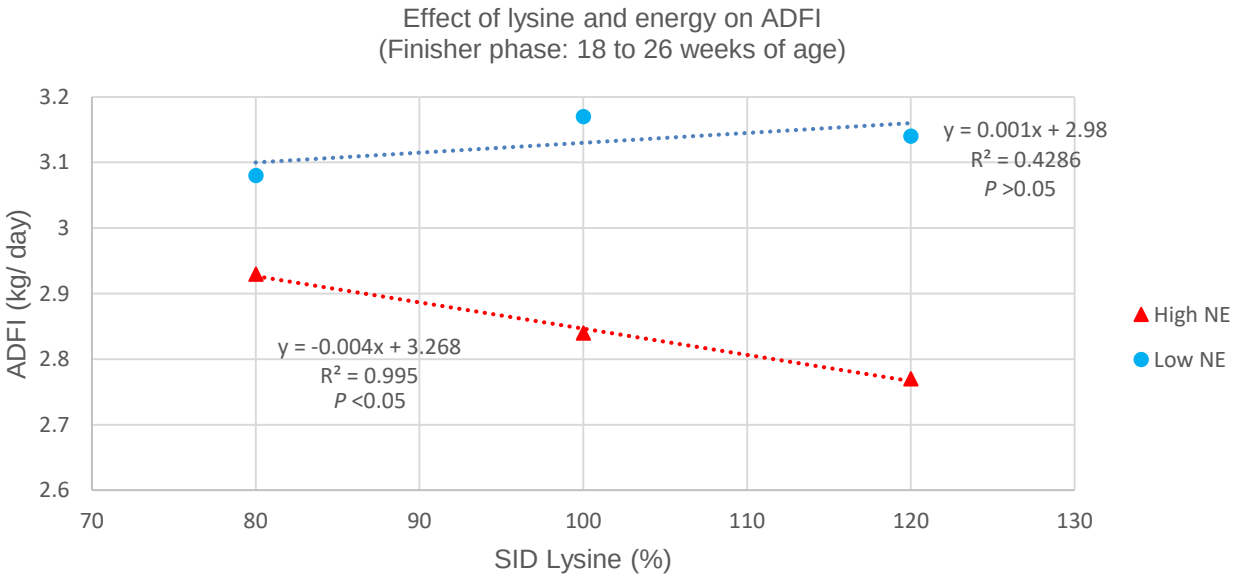

Figure 4. 8 Relationship between average daily feed intake (ADFI) and the level of lysine and energy in finisher pigs (18 to 26 weeks of age)

4.6 Feed conversion ratio (FCR)

Table 4.12 and table 4.13 show the results for the cumulative feed conversion ratio (FCR) over the various weighing intervals for the grower and finisher phase, respectively. The cumulative FCR was significantly affected (P <0.05) by energy, as well as lysine, throughout both the grower and finisher phase of the trial. The pigs that received high energy treatments had significantly (P >0.05) lower FCRs compared to those on low energy treatments. The FCR of the boars were lowest for T3 (6.06 g of Lys/ MCal NE and 4.41 g of Lys/ MCal NE, for the grower and finisher phase, respectively) and highest for T4 (4.21 g of Lys/ MCal NE and 3.05 g of Lys/ MCal NE, for the grower and finisher phase, respectively) throughout the trial. The pigs that received the two low lysine treatments (T1 and T4) had significantly higher FCRs compared to those on the lower lysine treatments. The lysine: NE ratio had no significant effect (P >0.05) on FCR of the boars.

Figures 4.9 and 4.10 show the relationship between FCR and the level of lysine and energy during the grower period (9 to 18 weeks of age) and finisher period (18 to 26 weeks of age), respectively. During the grower period, the equations were as follow for high energy treatments and low energy treatments, respectively: FCR = -0.0028 (SID lysine %) + 1.98 and FCR = -0.002 (SID lysine %) + 2.083. During the finisher period, the equations were as follow for high energy treatments and low energy treatments, respectively: FCR = -0.003 (SID lysine %) +2.78 and FCR = -0.006 (SID lysine %) + 3.457.

Table 4.12 The effect of Lys: NE ratios on the cumulative feed conversion ratio (FCR) for boars during the grower phase from 9 to 18 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	1.03	1.29	1.55	0.91	1.14	1.37			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	4.02	5.04	6.06	4.21	5.28	6.34			
AGE (weeks)							SEM	Probability (P <0.05) NE level	Lys Level	NE x Lys
9 to 11	1.67[ab]	1.45[a]	1.45[a]	1.71[b]	1.64[ab]	1.57[ab]	0.06	<0.001	<0.001	0.082
9 to 13	1.71[ab]	1.53[a]	1.48[a]	1.81[b]	1.71[ab]	1.66[ab]	0.06	<0.001	<0.001	0.457
9 to 15	1.75[ab]	1.61[a]	1.59[a]	1.88[b]	1.79[ab]	1.74[ab]	0.04	<0.001	<0.001	0.682
9 to 17	1.77[ab]	1.66[a]	1.64[a]	1.93[b]	1.86[ab]	1.80[ab]	0.05	<0.001	<0.001	0.607
9 to 18	1.78[a]	1.71[a]	1.69[a]	1.93[b]	1.87[a]	1.85[a]	0.11	<0.001	<0.001	0.891

[a, b] Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

Table 4.13 The effect of Lys: NE ratios on the cumulative feed conversion ratio (FCR) for boars during the finisher phase from 18 to 26 weeks of age

	Treatment								
	1	2	3	4	5	6			
	SID Lysine %								
	0.75	0.94	1.13	0.66	0.83	1.00			
	Net Energy (kcal/kg)								
	2560			2161					
	Lys: NE (g of SID Lys/ MCal NE)								
	2.93	3.67	4.41	3.05	3.85	4.63			
AGE (weeks)							SEM	Probability (P <0.05) NE level	Lys Level	NE x Lys
9 to 19	1.90^{ab}	1.78^{a}	1.76^{a}	2.08^{b}	1.99^{ab}	1.92^{ab}	0.15	<0.001	<0.001	0.813
9 to 21	1.98^{ab}	1.85^{a}	1.80^{a}	2.17^{b}	2.11^{ab}	2.00^{ab}	0.11	<0.001	<0.001	0.435
9 to 23	2.01^{ab}	1.92^{a}	1.88^{a}	2.23^{c}	2.17^{b}	2.04^{ab}	0.06	<0.001	<0.001	0.275
9 to 25	2.11^{ab}	2.01^{a}	1.98^{a}	2.32^{c}	2.28^{b}	2.16^{ab}	0.04	<0.001	0.001	0.414
9 to 26	2.15^{ab}	2.04^{a}	2.03^{a}	2.43^{c}	2.38^{b}	2.25^{b}	0.79	<0.001	0.004	0.311

$^{a-c}$ Means within the same row with no common superscript differ significantly (P <0.05)

SEM: Standard error of the mean; NE: Net energy

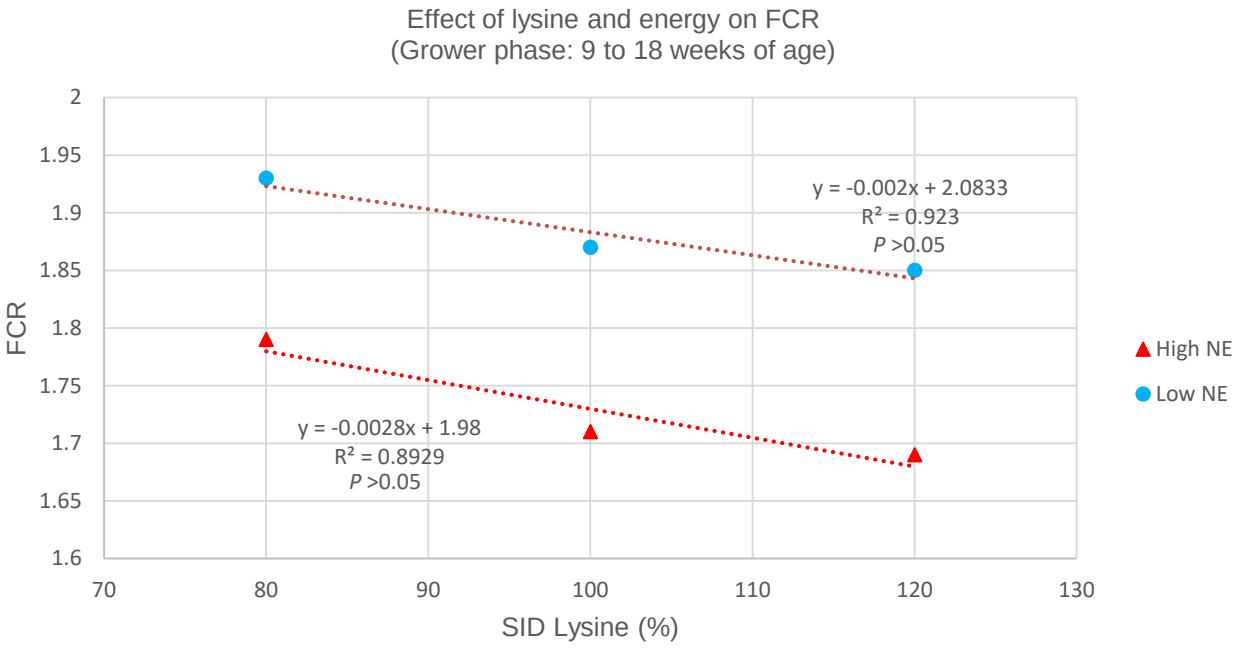

Figure 4. 9 Relationship between feed conversion ratio (FCR) and the level of lysine and energy in grower pigs (9 to 18 weeks of age)

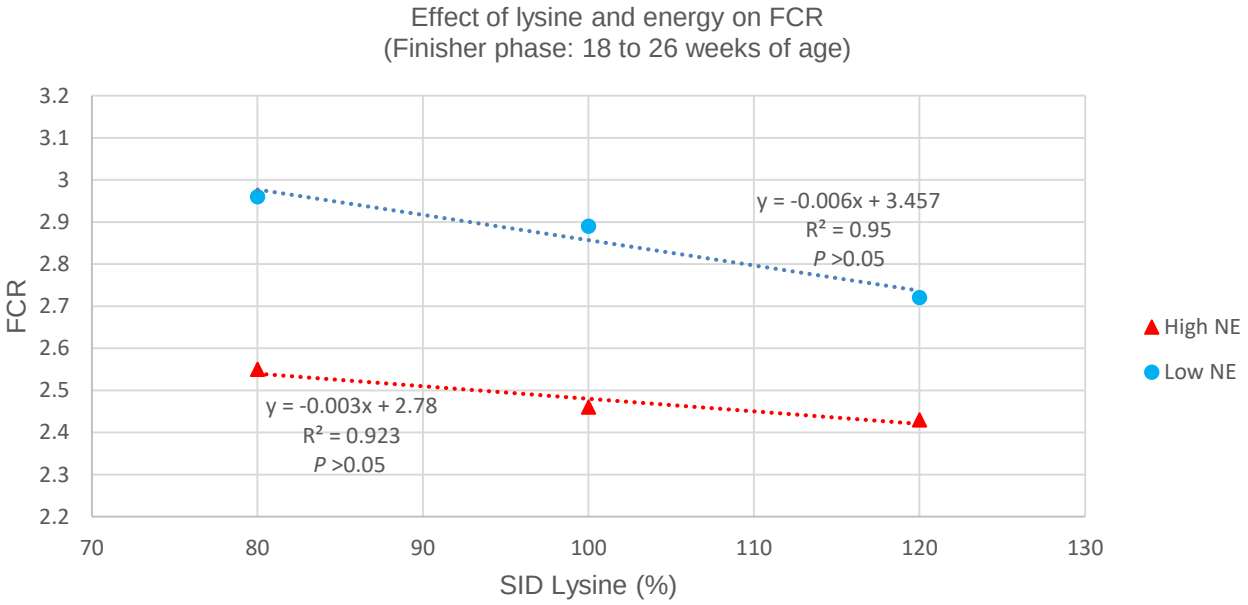

Figure 4. 10 Relationship between feed conversion ratio (FCR) and the level of lysine and energy in finisher pigs (18 to 26 weeks of age)

4.7 Carcass characteristics

Results for carcass characteristics measured at slaughter at 26 weeks (182 days) of age are shown in table 4.14. Only 175 pigs were slaughtered due to exclusion of 5 males from the trial due to injury resulting in euthanasia before slaughter age. Energy, lysine and the lysine: NE ratio had a significant effect (P <0.05) on hot carcass weights (HCW). The high energy treatments (T1, T2 and T3) as well as the low energy, high lysine treatment (T6) resulted in similar HCW's and cold carcass weights (CCW). T3 yielded the heaviest carcasses, whereas T4 yielded the lightest carcasses. Carcasses from T4 differed significantly (P <0.05) from those that received the other treatments for both HCW and CCW. Energy also had a significant effect (P <0.05) on the traditional back fat measurements (P1 and P2). Back fat thickness was lower for the pigs that received low energy treatments and also decreased as the lysine content in the treatments increased. Pigs from T4 had the leanest carcasses, whereas those from T1 had the highest back fat and was significantly fatter (P <0.05) compared to carcasses from the other treatments. Lysine, energy and the lysine: NE ratio had no significant effects (P >0.05) on any of the other carcass characteristics. Carcasses from T6 had the lowest drip loss % and those from T5 had the highest drip loss %. There were no significant differences between the treatments for both pH_{45min} and $pH_{24h.}$ There were also no significant differences between treatments for hot or cold temperatures of the carcasses, however, carcasses from T4 had lower cold temperatures due to the carcasses being smaller, allowing for faster cool down time. The carcasses were tested for the presence of boar taint by using the soldering iron method. Only one out of 175 carcasses had a slight presence of boar taint. Therefore, the treatments had no significant effect (P <0.05) on the presence of boar taint.

Table 4.14 The effect of Lys: NE ratios on the carcass characteristics after slaughter at 26 weeks (182 days) of age

	Treatment								
	1	2	3	4	5	6			
	Lysine: NE ratio								
	HE-LL	HE-ML	HE-HL	LE-LL	LE-ML	LE-HL			
								Probability (P <0.05)	
							SEM	NE level	Lys Level	NE x Lys
HCW(kg)	117.96[a]	117.75[a]	118.21[a]	106.57[b]	113.87[a]	117.10[a]	0.96	0.001	0.022	0.027
CCW (kg)	116.45[a]	114.69[a]	115.01[a]	103.94[b]	110.71[a]	114.75[a]	1.03	0.003	0.099	0.021
Drip loss %	2.86	2.60	2.78	2.76	3.10	2.15	0.06	0.724	0.293	0.115
P1 (45mm)	17.49	16.43	15.24	14.40	14.85	14.50	0.31	0.001	0.220	0.167
P2 (65mm)	19.55[a]	16.11[b]	15.65[b]	14.90[b]	15.33[b]	15.18[b]	0.14	0.004	0.066	0.019
Fat mm (GM)	22.2	21.8	21.3	15.4	21.1	19.5	1.51	0.234	0.701	0.588
Fat mm (SH)	37.14[a]	32.14[ab]	32.16[ab]	28.91[b]	32.45[ab]	36.09[a]	2.21	0.458	0.855	0.048
pH_{45min}	6.55	6.59	6.52	6.57	6.62	6.55	0.01	0.215	0.069	0.930
pH_{24h}	5.81	5.89	5.80	5.80	5.84	5.83	0.02	0.793	0.481	0.775
Warm temp (^{O}C)	39.77	39.54	39.91	39.93	39.94	39.90	0.06	0.305	0.751	0.633
Cold temp (^{O}C)	6.61	6.39	6.59	6.25	6.59	6.30	0.07	0.241	0.910	0.137

[a, b] Means within the same row with no common superscript differ significantly (P <0.05)

HE-LL: High energy, low lysine treatments over grower and finisher phase.

HE-ML: High energy, medium lysine treatments over grower and finisher phase.

HE-HL: High energy, high lysine treatments over grower and finisher phase.

LE-LL: Low energy, low lysine treatments over grower and finisher phase.

LE-ML: Low energy, medium lysine treatments over grower and finisher phase.

LE-HL: Low energy, high lysine treatments over grower and finisher phase.

SEM: Standard error of the mean; NE: Net energy; HCW: Hot carcass weight; CCW: Cold carcass weight

Chapter 5

Discussion

5.1 Growth performance data

5.1.1 Body weight and body weight gain

Numerous studies have been conducted on swine to determine the optimal lysine: energy requirement for gilts and barrows, however, limited data is available on the lysine: energy requirement of intact boars. To compare the results of this trial to other literature, some degree of extrapolation will be required, firstly due to the trial being conducted in commercial conditions and secondly, the animals being intact boars. Literature has shown that increased lysine: energy ratios result in improved growth performance of pigs (Chiba *et al.*, 1991b; Bikker *et al.*, 1994; Friesen *et al.*, 1994; Main *et al.*, 2008; Miller *et al.*, 2008; Moore & Mullan, 2010; Schneider *et al.*, 2010; Cho *et al.*, 2012). Most research trials conducted on swine have weight specific cut off points for various grower and finisher phases. For this trial, phase transitions were age specific to simulate the commercial environment in South Africa being time or age specific rather than weight specific. Therefore, one can deduct from the results of this trial, that a higher body weight at a transition point, indicated faster growth. In this study, the highest BW of 85.5 kg during the grower phase was achieved at 6.06 g of SID Lys/ MCal NE (4.43 g SID Lys/ MCal of ME). However, due to the age transition, T4 had a significantly lower (P <0.05) starting weight for the finisher phase compared to the other treatments. SID lysine level as well as the lysine: NE ratio had no significant effect (P >0.05) on BW during the grower phase at a 95% confidence level.

During the finisher phase, both SID lysine level as well as lysine: NE ratios had significant effects (P <0.05) on body weight up to week 25 of age. Energy had a significant effect (P <0.05) on body weight from week 11 up to week 26 of age (including both the grower and the finisher phase). The pigs from treatment 3 (6.06 g of SID Lys/ MCal NE and 4.41 g of SID Lys/ MCal NE for the grower and finisher phase, respectively) were heavier throughout the trial except during the last two weeks where there was no increased effect on BW by increasing the lysine: NE ratio above 2.93 g of SID Lys/ MCal NE on high energy treatments. However, for low energy treatments, the effect of increased lysine: NE ratio from T6 (6.34g of SID Lys/ MCal NE and 4.63 g of SID Lys/ MCal NE, for the grower and finisher phase, respectively) persisted throughout the trial. The high energy treatments (T1, T2 and T3) were heavier compared to low energy treatments throughout the trial and had heavier end BW's compared to the low energy treatments, however, T6 (4.63 g of SID Lys/ MCal NE for the finisher phase) achieved the same end BW as the high energy treatments. The two high lysine treatments (T3 and T6) resulted in heavier BW's compared to the lower lysine treatments. The BW results from this trial follow the same pattern as a study conducted by Colina *et al. (*2015) to evaluate the effects of different lysine levels with high energy treatments on finishing pigs, where the authors found that the final live weights of the animals increased linearly (P <0.05) with increasing lysine levels in the treatment.

The cumulative body weight gain was highest for pigs from T3 (6.06 g of SID Lys/ MCal NE) followed by pigs from T6 (6.34 g of SID Lys/ MCal NE) throughout the grower phase, however, the highest cumulative BWG at the end of the trial was for T2 (3.67 g of SID Lys/ MCal NE) followed by T6 (4.63 g of SID Lys/ MCal NE) at the end of the trial. Therefore, increasing the lysine: NE ratio above 3.67 g of SID Lys/ MCal NE after week 25 of age will be wasteful for increased BWG. Throughout the trial, all the pigs from the high energy treatments had greater BWG compared to those from the low energy treatments. However, pigs from T6 (6.34 g of SID Lys/ MCal NE and 4.63 g of SID Lys/ MCal NE, for the grower and finisher phase, respectively) achieved similar BWG to those from the high energy treatments. Energy had a significant effect (P <0.05) on BWG during the grower and the finisher phases. Campbell & Taverner (1988) observed that boars and barrows that received increasing amounts of DE from 45 to 90 kg were energy-dependent, due to growth increasing as energy increased. Bikker *et al. (*1994) found similar results on gilts from 45 to 85 kg when they fed increasing levels of energy. Lysine had no significant effect (P >0.05) on BWG during the grower phase, but had a significant effect (P <0.05) on BWG from week 18 to week 25 of age during the finisher phase. BWG increased as the SID lysine level increased throughout the finisher phase. The pigs that received high lysine treatments (T3 and T6) had greater BWG compared to the pigs that received other lysine levels up to week 25 of the trial. Figures 4.3 and 4.4. indicate that there were strong relationships between BWG and the SID lysine level for the low energy treatments during the grower phase and finisher phase (R^2 = 0.7344 and R^2 = 1, respectively) but not for the high energy treatments (R^2 = 0.0982 and R^2 = 0.4661, respectively). This indicates that the pigs that received the low energy treatments had a greater response to increased SID lysine, compared to those that received the high energy treatments. The pigs that received T4 showed poorer growth (BW and BWG) during both the grower and the finisher phase and was significantly (P <0.05) lighter than the pigs that received the other treatments during the finisher phase. This could be due to the low crude protein content of the diet. In a study conducted by Guay *et al*. (2006) to determine the effect of reduced dietary CP, replaced with crystalline amino acids (CAA), on growth and gut morphology of growing pigs, the authors reported poor growth performance in pigs when dietary CP content was reduced from 16.1% to 12.8%. This reduced growth performance could be due to insufficient total nitrogen or non-essential amino acids (NEAA).

5.1.2 Average daily gain

Throughout the experiment there was no significant effect (P >0.05) on average daily gain for energy level, lysine level or lysine: NE ratio, except during week 18 and 19 where lysine level had a significant effect (P >0.05) on ADG and week 19 to 21 where energy had a significant effect (P >0.05) on ADG. Smith *et al. (*1999) evaluated the effect of dietary energy density as well as lysine: energy ratio on growth performance of grower-finisher pigs, and found that increasing energy density improved ADG (P <0.05) in gilts from 29.5 to 72.6 kg. Cho *et al. (*2012) also concluded that increased energy density improved ADG (P <0.05) in finishing barrows from 58 to 103 kg. A similar trend was observed by De la Llata *et al. (*2007) where ADG increased when fat was added to the diets.

The increased lysine: NE ratio also improved the ADG of the boars. A first peak in ADG was reached at week 18 with maximum ADG of 1.338 kg/ d reached for boars from T6 (6.34 g of SID Lys/ MCal NE or 4.57

g of SID Lys/ MCal of ME) followed by a period of slow growth until ADG reached a second peak at week 23 of age (1.273 kg/day) for the boars from T6 (4.63 g of SID Lys/ MCal NE or 3.33 g of SID Lys/ MCal of ME) once again. In this trial, the high lysine treatments T3 and T6 (6.06 g of SID Lys/ MCal NE and 6.34 g of SID Lys/ MCal NE, respectively or 4.43 g of SID Lys/ MCal of ME and 4.57g of SID Lys/ MCal of ME, respectively) resulted in greater ADG during the grower phase up to week 23 of age when the second ADG peak was reached. After the second peak in ADG, T6 and T2 (4.63 g of SID Lys/ MCal NE and 3.67 g SID Lys/ MCal NE, respectively or 3.33 g of SID Lys/ MCal of ME and 2.69 g of SID Lys/ MCal of ME, respectively) resulted in the greatest ADG during the finisher period.

Figures 4.5 and 4.6 indicate that there were strong relationships between ADG and the SID lysine level for high and low energy treatments (R^2 = 0.75 and R^2 = 0.871, respectively) during the grower phases and for the low energy treatments during the finisher phase (R^2 = 1). There was a linear increase in ADG as the SID lysine level increases. During the grower phase, ADG was maximised at a 120% SID lysine level for the high energy treatments (figure 4.5), which equates to an optimum lysine: NE ratio of 6.06 g of SID Lys/ MCal NE (5.4 g of SID Lys/ MCal ME). During the finisher phase, ADG was maximised at a 100% SID lysine level for the high energy treatments (figure 4.6), which equates to an optimum lysine: NE ratio of 3.67 g of SID Lys/ MCal NE (3.2 g of SID Lys/ MCal ME). Therefore, the requirement for maximum ADG was higher compared to Main *et al. (*2008), where the authors found that ADG was maximised for gilts and barrows at 3.23 g of TID Lys/ MCal of ME and 2.89 g of TID Lys/ MCal of ME (approximately 2.84 g of SID Lys/ MCal of ME and 2.5 g of SID Lys/ MCal of ME), respectively, weighing less than 70kg. This could be due to the animals growing faster during the grower phase, which increases the requirement for lysine. However, in the current study the lysine: NE ratio for optimised ADG from 9 to 18 weeks of age is higher compared to results obtained by Main *et al. (*2008) where ADG was maximised for animals below 90 kg at 2.8 and 2.65 g of TID Lys/ MCal of ME (approximately 2.44 g of SID Lys/ MCal of ME and 2.3 g of SID Lys/ MCal of ME), for gilts and barrows, respectively. Lastly, they observed a maximum ADG for gilts and barrows up to 120 kg at 2.2 g of TID Lys/ MCal of ME (approximately 1.9 g of SID Lys/ MCal of ME). Shelton *et al. (*2011) found that 3.16 g of SID Lys/ MCal ME, 2.58 g SID Lys/ MCal ME and 2.55 g of SID Lys/ MCal of ME optimised ADG and FCR for 38 to 65 kg, 55 to 80 kg and 84 to 110 kg gilts, respectively. The improved effect on ADG observed from the increased lysine: NE ratios is similar to results observed by others on gilts and barrows during different growth periods (Bikker *et al.*, 1994; Friesen *et al.*, 1994; Smith *et al.*, 1999; Cho *et al.*, 2012). Furthermore, comparing the results from the current trial to other studies is difficult due to sex differences, genetic differences, growth periods, etc.

5.1.3 Average daily feed intake

Numerous research has been directed towards studying the effect of dietary energy concentration on growth performance, carcass value as well as feed intake. It is commonly known that the growing pig can adjust their daily feed intake over a wide range of dietary energy concentrations to achieve a constant daily energy intake (Henry, 1985; Chiba *et al*., 1991a; Cameron & Curran, 1994; Ferguson *et al*., 1994; NRC, 1998; Quiniou & Noblet, 2012). Animals will also attempt to grow at their absolute genetic potential and the achievement of this goal is influenced by numerous factors including environmental conditions, the state of the animal as well as nutritional and physiological factors such as gut capacity (Ferguson, 2006). For this trial,

high levels of dietary fibre was included in the low energy treatments in order to bring the energy level down. Baird *et al. (*1975) found that certain levels of dietary fibre in a diet, providing that the energy density is sufficient, will have no negative effect on growth performance. Quiniou & Noblet (2012) confirmed the ability of individually penned pigs to adjust their feed intake spontaneously over a wide range of NE concentrations (8.7 to 10.5 MJ/kg). Higher dietary NE concentrations were associated with a reduction in ADFI for the entire experiment and feed conversion efficiency improved as the dietary NE concentration increased. When the energy concentration of the diet decreased, pigs responded by increasing their ADFI. However, this implies that the maximum capacity of the digestive tract has not yet been reached (Quiniou & Noblet, 2012). During the grower phase and finisher phase of this current trial, energy had a significant effect (P <0.05) on ADFI. ADFI was lowest for the high energy treatments compared to low energy treatments. These results are in accordance with the concept that pigs adjust their daily feed intake to achieve a constant energy supply. The lowest ADFI was observed for pigs from T3 (6.06 g of SID Lys/ MCal NE and 4.41 g of SID Lys/ MCal NE, for the grower and finisher phase, respectively), which was the most concentrated treatment, and the highest ADFI was observed for pigs from T5, which was a more diluted treatment in terms of energy.

Smith *et al. (*1999) found that an increased energy concentration in the diet reduced ADFI in gilts weighing from 29.5 to 72.6 kg which therefore in turn improved FCR. In contrast, Cho *et al. (*2012) found that an increase in energy density had no effect on ADFI of barrows from 58 to 103 kg. In the current study, lysine as well as the lysine: NE ratio, had no significant effect (P >0.05) on ADFI throughout the experiment. Main *et al. (*2008) observed that an increased lysine: energy ratio had no effect on ADFI of gilts and barrows over 60 and 70 kg, respectively. Friesen *et al. (*1994) found that increased dietary lysine had no significant effect (P >0.10) on ADFI of high lean-growth gilts from 34 to 55 kg and from 55 to 72.5 kg. However, a decrease (quadratic, P <0.10) in ADFI from 34 to 72.5 kg was observed. King *et al. (*2000) observed a decrease in ADFI as lysine levels increased for pigs from 80 to 120kg. Although not significant (P >0.05), ADFI from the current study decreased slightly as the SID lysine value of the diet increased (figure 4.7 and 4.8). This trend was also observed by Main *et al. (*2008) as well as Shelton *et al. (*2011) and it is concluded that the decrease in feed intake may be due to the high proportion of soybean meal in the diet to increase the protein content. The boars from this current experiment had a lower ADFI than recorded by other literature, including the NRC (2012). Due to improved genetics, modern pigs are now consuming less feed which highlights the need to review the feeding strategies of growing pigs. Therefore, the diet formulations that are used to optimise growth performance should consider feed intake of the animals. At lower feed intakes, it is appropriate to adjust the amino acid proportions according to the energy density of the feed (Colina *et al.*, 2015). The goal, when feeding the modern pig, should be to provide the pig daily with only enough energy as well as essential and non-essential amino acids to maximise lean growth potential.

5.1.4 Feed conversion ratio

The cumulative FCR was significantly affected (P <0.05) by energy, as well as SID lysine, throughout both the grower and finisher phase of the trial. The high energy treatments resulted in significantly (P <0.05) lower FCRs compared to the low energy treatments. The FCR of the boars (table 4.12 and 4.13) was lowest

for those from T3 (6.06 g of SID Lys/ MCal NE and 4.41 g of SID Lys/ MCal NE, for the grower and finisher phase, respectively or 4.29 g of TID Lys/ MCal of ME and 3.47 g of TID Lys/ MCal of ME for the grower and finisher phase, respectively) and highest for T4 (4.21 g of SID Lys/ MCal NE and 3.05 g of SID Lys/ MCal NE, for the grower and finisher phase, respectively) throughout the trial. De la Llata *et al. (*2007) showed that FCR improved for diets with added fat for both gilts and barrows. Cho *et al. (*2012) observed the same improvement in FCR for diets with increased energy density for barrows from 58 to 103 kg. The pigs that received the two high lysine treatments (T3 and T6) had improved FCRs compared to those from the lower lysine treatments.

The lysine: NE ratio had no significant effect (*P* >0.05) on FCR of the boars. Figures 4.9 and 4.10 indicate strong relationships between FCR and the SID lysine level for high energy treatments during the grower and finisher phase (R^2 = 0.8929 and R^2 = 0.9231, respectively) and low energy treatments during the grower and finisher phase (R^2 = 0.9231 and R^2 = 0.9453, respectively). The FCR during the grower phase was optimised at a 120% SID lysine level for high energy treatments (figure 4.9), which equates to the optimum lysine: NE ratio of 6.06 g of SID Lys/ MCal NE (5.4 g of SID Lys/ MCal ME). The FCR for boars during the finisher phase was also optimised at a 120% SID lysine level for high energy treatments (figure 4.10), which equates to an optimum lysine: NE ratio of 4.4 g of SID Lys/ MCal NE (3.96 g of SID Lys/ MCal ME). Smith *et al. (*1999) found that the lysine: energy requirement for gilts from 29.5 to 72.6 kg is 3.45 g of TID Lys/ MCal of ME which is lower compared to results from the current study. In contrast, Chiba *et al. (*1991a) found that energy (linear, *P* <0.001) as well as the lysine: energy ratio (linear, *P* <0.001; quadratic, *P* <0.01) improved the FCR of the pigs from 20 to 50 kg. De la Llata *et al. (*2007) observed that an increased lysine: energy ratio improved FCR, and that FCR was maximised for gilts from 27 to 45 kg at a ratio of 3.56 g TID Lys/ MCal of ME, which is slightly higher than the requirement observed by Yen *et al. (*1986) of 3.47 g of TID Lys/ MCal of ME for 25 to 55 kg gilts. Main *et al. (*2008) also found that increased lysine: energy ratios improved the FCR of barrows and gilts. For gilts and barrows from approximately 35 to 70 kg, the authors found that FCR was lowest at 3.23 g of TID Lys/ MCal of ME (approximately 2.84 g SID lysine/ MCal of ME). From approximately 70 to 100 kg, the FCR was lowest at 2.53 and 2.65 g of TID Lys/ MCal of ME (approximately 2.2 g of SID Lys/ MCal of ME and 2.3 g of SID lysine/MCal of ME), for gilts and boars, respectively. The differences in requirements for the optimal lysine: energy ratio can be due to differences in genotype, environment, sex, amino acid profile as well as different energy densities of the diets.

5.2 Carcass data

Energy, lysine and the lysine: NE ratio had a significant effect (*P* <0.05) on hot carcass weights (HCW). Carcasses from the high energy treatments (T1, T2 and T3) as well as the low energy, high lysine treatment (T6) had similar HCW's and cold carcass weights (CCW). T3 yielded the heaviest carcasses, whereas T4 yielded the lightest carcasses and T4 differed significantly (*P* <0.05) from the other treatments for both HCW and CCW. Energy also had a significant effect (*P* <0.05) on the traditional back fat measurements (P1 and P2) causing back fat to be higher for high energy treatments. This is similar to results found by Li *et al. (*2012) where back fat thickness increased linearly (*P* <0.05) with increasing dietary ME content. Back fat thickness

at slaughter was decreased by low energy levels which contributed to a reduced final weight. In this study, the results indicated that back fat thickness was lower for the low energy treatments and also decreased as the lysine content in the treatments increased. Although not significant (*P* >0.05), increasing SID lysine levels numerically reduced the back fat thickness on carcasses. Chiba *et al. (*1999) found that when the dietary lysine content increased from 1.76 to 2.96 g of TID Lys/ MCal DE, the back fat thickness at the 10th rib decreased and the lean accretion rate increased. Low energy and lysine levels were thus not sufficient for maximising lean deposition in the barrows used in their study. These conclusions are similar to findings from Main *et al. (*2008). In the current study, T4 yielded the leanest carcasses, whereas T1 yielded carcasses with the highest back fat and was significantly fatter (*P* <0.05) compared to carcasses from the other treatments. This is in accordance with the findings from Chiba *et al. (*1999). The carcasses from the low energy treatments were leaner compared to the high energy treatments. In a paper from Ferguson *et al*. (1994) the authors refer to a situation where the animal has sufficient access to energy but protein or amino acids are limiting. In this case, the energy above that used for maintenance and maximum protein retention will be deposited as fat. This additional fat deposition will result in a fatter carcass. The boars used in the current study had P2 back fat measurements ranging from 14.85 mm to 19.55 mm at average carcass weights ranging from 106.57 kg to 117.96 kg. These carcasses were heavier compared to results from other literature, however, they had lower back fat measurements. Main *et al. (*2008) reported back fat thickness ranging from 19.3 to 20.2 mm and 17.8 to 18 mm for barrows and gilts, respectively, when slaughtered at 120 kg. Cho *et al. (*2012) had back fat thickness ranging from 14.66 mm to 21.98 mm for carcass weights ranging from 56.42 to 89.80 kg. The lower back fat thickness in the heavier animals from the current study can be due to genetic improvement, genotype, sex and higher lysine levels in the diets. Lower back fat measurements will result in increased return on investment as producers are paid more for leaner carcasses. Although treatment 4 yielded the carcasses with lowest back fat, the carcasses were smaller compared to the other treatments which would ultimately mean that less kilograms of meat will be sold per pig. It would therefore be beneficial to a producer to consider a lysine: NE ratio that will allow for lean caresses as well as bigger carcasses to increase returns per pig.

Lysine, energy and the lysine: NE ratio had no significant effects (*P* >0.05) on any of the other carcass characteristics. There were no significant differences between the treatments for both $pH4_{5min}$ and pH_{24h}. Bratcher (2019) stated that the ultimate pH taken 24 hours post mortem has the strongest correlation with pork quality traits e.g. colour, firmness and marbling. Bratcher (2019) also stated that pork with a pH_{24h} of 5.8 may predict higher pork quality. In this study, carcasses from treatment 5 had a higher pH_{45min} as well as a higher drip loss %. In a study conducted by Kim *et al. (*2016) the water holding capacity was negatively correlated with initial pH, therefore resulted in higher drip loss. Treatment 6 had the lowest drip loss % as well as lowest rigor temperature. Kim *et al. (*2016) found that higher rigour temperatures resulted in higher drip loss % and less water holding capacity. There were also no significant differences between treatments for hot or cold temperatures of the carcasses. However, T4 had lower cold temperatures due to the carcasses being smaller, allowing for faster cool down time. The carcasses were tested for the presence of boar taint by using the soldering iron method. Only one out of 175 carcasses had a slight presence of boar taint. Therefore, the treatments had no significant effect (*P* <0.05) on the presence of boar taint.

Chapter 6

Conclusion

Intense genetic selection for reduced back fat thickness and improved feed utilisation in pigs has resulted in modern genotypes with high lean gain potential, which now deposit a greater amount of lean tissue at faster rates than 20 years ago. As a consequence, to allow pigs to reach their genetic potential for a high capacity of lean tissue gain, higher levels of lysine relative to energy must be fed. From a nutritional point of view, the increased rate of lean growth in modern pig genotypes and the increased proportion of lean on the carcass suggest that previous recommendations of nutrient requirements under different management conditions may no longer be adequate. To develop a more precise feeding regime that allows maximum lean deposition rates, it is important for pig producers and nutritionists to realise the genetic potential of the pigs they are feeding. The genotype of the pig sets the upper limit for the lean growth that can be achieved by the pig, therefore, having sound knowledge on the genetic potential of the pig is of utmost importance as the genetic merit is related to protein or more specifically, the amino acid requirements of the pig. Pigs with a high genetic merit for lean growth have a higher potential for lean deposition and not only do they reach higher peak muscle growth, but they also have the ability to continue laying down muscle to heavier weights compared to pigs with a low genetic merit for lean deposition. The lysine: energy ratio can be largely influenced by genotype, sex, age and health status of the pig. Thus, continues efforts are required to characterise the effects of increasing dietary lysine in evolving modern pig genotypes reared in commercial production environments. Numerous studies have been conducted on swine to determine the optimal lysine: energy requirement for gilts and barrows, however, limited data is available on the lysine: energy requirement of intact boars.

The *aim* of this study was to determine the optimal lysine: energy ratio required for lean growth of a modern pig genotype, as well as to determine growth performance potential of the modern pig genotype under typical commercial conditions. The optimal lysine: energy ratio differs for each growth performance parameter and will be largely determined by the producers' targets. Although lysine had a non-significant (P >0.05) effect on BWG during the grower phase, it had a significant (P <0.05) effect during the finisher phase. The cumulative body weight gain was highest at 6.06 g of SID Lys/ MCal NE throughout the grower phase, however, the highest cumulative BWG at the end of the trial was at 3.67 g of SID Lys/ MCal NE. According to the dose response curve for BWG from 9 to 18 weeks of age and for BWG from 18 to 26 weeks of age, the optimum level for BWG is greater than the lysine: NE ratios used during the trial.

The lysine: NE ratio had a no significant (P >0.05) effect on ADG throughout the trial but it was clear that higher lysine: NE ratios allowed for greater ADG. The optimum lysine: NE level for ADG from 9 to 18 and 18 to 26 weeks of age was found to be 6.06 g of SID Lys/ MCal NE and 3.67 g of SID Lys/ MCal NE, respectively. The SID lysine as well energy had a significant effect (P >0.05) on the FCR of the boars. The lysine: NE ratio required to optimise FCR from 9 to 18 weeks of age was found to be 5.9 g of SID Lys/ MCal NE (5.29 g of SID Lys/ MCal ME). From 18 to 26 week old boars, FCR was optimised at 4.4 g of SID Lys/ MCal

NE (3.96 g of SID Lys/ MCal ME). The lysine: NE ratios for optimised growth performance was found to be higher compared to other available literature.

In conclusion, improvements in growth performance and feed efficiency were observed as the lysine: NE ratio increased. Similarly, back fat deposition was reduced as the SID lysine content of the diets increased. For ADFI and FCR (both grower and finisher phase) and ADG along with BWG (only for finisher phase), there were dietary treatments that appeared to be above the lysine required for maximum performance but for ADG and BWG during the grower phase, the range of lysine: NE ratios were not adequate to allow an estimate of an optimum lysine: NE ratio. It is clear from available literature that responses to lysine: NE ratios should be expected to vary among genetic lines and production environments. The study showed that high energy as well as high lysine levels in the diet improve growth performance but due to pig producers being paid for carcass composition as well as carcass weight, a low energy diet with high lysine levels will allow for greater return on investment as it will ultimately yield leaner as well as bigger carcasses.

The null hypothesis (H_0) of this study, stating that the lean growth performance of a modern pig genotype will not improve with an increased lysine: energy ratio, was rejected.

Chapter 7

Critical Review and Recommendations

A re-evaluation of the South African pork carcass classification should be considered as the current PORCUS system discriminates against heavier carcasses due to outdated findings that animals become excessively fat over a 100kg carcass weight, which is no longer the case as genetic improvement has resulted in leaner animals which have the ability to continue laying down muscle to heavier weight before starting to deposit fat.

There is a lack of research available on intact boars as well as on pigs in general reared to heavier weights above 120kg live weight in commercial conditions. More research should be directed towards these topics to allow nutritionist to be able to more accurately formulate for the animals' requirements. Extended research can be done across different breeds, age, sex and environments as these are major influencing factors to determine an optimal lysine: energy ratio for a pig. The lysine: NE ratio is not a "one-size-fits-all" concept.

The industry is shifting from ME to NE systems, and more research trials should be conducted using the NE system, which will allow for better comparison and interpretation of results among research papers.

This trial had some shortcomings as listed below:

1. More animals could have been used for the study as it was done to mimic commercial conditions.

2. More phases should have been implemented to determine lysine: NE ratios for different weight groups more closely. Although this trial aimed to mimic commercial conditions, the phase transitions should rather have been implemented at certain weights instead of age to make more sense from a scientific point of view. Complications associated with the age transitions were that not all treatments commenced with the finisher phase at the same starting weight. Initial body weight should therefore have been included as a covariate during the statistical analysis.

3. The trial should have included a serial slaughter study component to predict the lean deposition rates of the animals.

4. There were some difficulties in the abattoir due to the animals being heavier than the equipment is adjusted to. Upgraded abattoir systems should be considered if the South African market is to accept heavier carcasses.

5. It is recommended that a periodic review should be considered for the lysine: NE ratio of gilts, boars and barrows to keep up with fast changing genetics in the pig industry and in turn allow the animals to reach their genetic potential for growth.

6. Shortly after the trial commenced, the PIC nutrient recommendations were altered. Therefore, the 80, 100 and 120% values are only applicable for the PIC nutrient recommendations from Goncalves *et al*. (2017).

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