RESPONSES IN GROWING PIGS TO LYSINE AND THREONINE LIMITING FEEDS AND ENVIRONMENTAL TEMPERATURE.

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I HEREBY DECLARE THAT THE RESEARCH IN THIS DISSERTATION IS OF MY OWN INVESTIGATION. WHERE USE WAS MADE OF THE WORK OF OTHERS IT HAS BEEN DULY ACKNOWLEDGED IN THE TEXT.

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CONTENTS

ABSTRACT

In this thesis two experiments were conducted. The objective of the first experiment was to measure the response of a range of dietary threonine concentrations and environmental temperatures on the performance of young pigs. Large White x Landrace entire male pigs (n = 48) at 12 kg live weight were assigned to one of six dietary threonine treatments (n = 2) and one of four temperature treatments. Dietary threonine concentrations were formulated as 8.9 g Threonine/kg food (T1); 6.7 g/kg (T2); 6.2 g/kg (T3); 4.9 g/kg (T4); 3.6 g/kg (T5); 4.9 g/kg (T6). To check that threonine was limiting the most diluted diet (T5) was supplemented with synthetic threonine. The animals were fed *ad libitum* and housed in environmentally-controlled facilities. The experiment was conducted using four different temperature regimes; 18.1 (±0.38)°C, 21.9 (±0.19)°C, 26.1 (±0.50)°C and 29.9 (±0.34)°C. On reaching 25 kg live weight the pigs were slaughtered and the carcasses prepared to obtain samples for carcass analysis. There were significant differences ($P < 0.001$) in the rate of growth (ADG) between dietary treatments with the highest gains on T1 (0.571 kg/d). There were significant differences ($P < 0.01$) in ADG between temperature treatments with the highest growth rate at 22°C (0.527 kg/d) and the lowest at 30°C (0.428 kg/d). Food intakes were significantly affected by temperature ($P < 0.001$) and unaffected by dietary threonine concentrations. There was a 26.1% increase in feed intake at 18°C when compared to the feed intake at 26°C. The highest FCE was recorded at 26°C (449 g gain/kg food) and the lowest at 18°C (386 g gain/kg food). There was an 18.4% reduction in body protein content at 25 kg live weight between pigs fed on T1 as opposed to those fed on T5. Dietary treatment had a significant effect ($P < 0.001$) on the fat composition of the empty carcass. The highest fat content was on T5 (4.898 kg) and the lowest on T1 (2.041 kg). Temperature had a significant effect ($P < 0.001$) on lipid growth rates. Threonine accretion rates were higher ($P < 0.001$) for pigs fed on T1 (3.52 g/d) than those fed on T2 to T5. The lowest threonine retention was on T5 at 1.49 g/d. Linear regression of daily carcass threonine accretion on daily threonine intake resulted in an efficiency of threonine utilization for pigs between 12 kg and 25 kg live weight of 38%.

The objective of the second experiment was to measure the response of dietary lysine concentrations and environmental temperature on the performance of young pigs. Large White

x Landrace entire male pigs (n = 48) were assigned to one of six dietary lysine treatments (n = 2) and one of four temperature treatments. Dietary lysine concentrations were formulated as 12.7 g Lysine/kg food (T1); 10.8 g/kg (T2); 8.9 g/kg (T3); 7.0 g/kg (T4); 5.1 g/kg (T5); 7.0 g/kg (T6). To check that lysine was limiting, the most diluted diet (T5) was supplemented with synthetic lysine. The animals were fed *ad libitum* and housed in environmentally controlled facilities. The experiment was conducted using four different temperature regimes; 18.1 (±0.19)°C, 22.0(±0.17)°C, 25.7 (±0.32)°C and 29.6 (±0.40)°C. On reaching 25 kg live weight the pigs were slaughtered and the carcasses prepared for chemical analysis. There were significant differences ($P < 0.001$) in ADG between dietary lysine treatments, with the highest gains on T1 (0.621 kg/d) and the lowest on T5 (0.395 kg/d). There were significant differences ($P < 0.001$) in ADG between temperature treatments, with the highest growth rate at 22°C (0.588 kg/d) and the lowest at 30°C (0.466 kg/d). Food intakes were significantly affected by dietary treatment ($P < 0.05$) and environmental temperature ($P < 0.001$). The highest feed intake was on T4 (1.284 kg/d) and the lowest on T1 (1.080 kg/d). There was a 21.4% increase in feed intake at 18°C (1.394 kg/d) when compared to the feed intake at 30°C (1.096 kg/d). The highest FCE was recorded at 22°C (491 g gain/kg food) and the lowest at 18°C (417 g gain/kg food). There was an 19.9% reduction in body protein of pigs at 25 kg live weight fed on T1 (3.715 kg) as opposed to those fed on T5 (2.976 kg). Dietary treatment had a significant effect ($P < 0.001$) on the fat content of the empty carcass. There was an increase of 134% in the fat content of the empty carcass between those pigs fed on T5 as opposed to those fed on T5. The highest fat content was on T5 (4.926 kg) and the lowest on T1 (2.103 kg). There were significant differences in protein accretion rates ($P < 0.001$) between the dietary and temperature treatments. The highest PR was on T1 (91.85 g/day) and at 18°C (77.08 g/day). The highest THL ($P < 0.05$) was at 18°C (12.84 MJ/d). Lysine accretion rates were highest on T1 (6.475 g/d) and lowest on T5 (2.726 g/d). Linear regression of daily carcass lysine accretion on daily lysine intake showed that the efficiency of lysine utilization for pigs between 12 kg and 25 kg live weight was 37%.

GENERAL INTRODUCTION

A growing animal needs to be supplied with nutrients in order to meet the requirements for maintenance of the body and for the growth of the components of the body. The concept of an Ideal Protein for pigs can be defined as the perfect ratio among the essential amino acids required for maintenance and production, and this concept is becoming increasingly important in practical diet formulation for pigs. The requirement for dietary protein depends on the amino acid composition of that protein.

Feedstuffs with a high protein content are usually expensive relative to low protein-containing ingredients and thus there is a tendency to limit their inclusion in diets (Lewis, 1991). Therefore, with increasing protein prices and resultant economic pressures, it is becoming more important to adjust the content of essential amino acids or total protein in pig diets in relation to the animal's requirement. The sum of each amino acid required for the maintenance and the growth of body protein constitutes the daily requirements for each of the amino acids. In most practical pig diets, the amino acid "disproportion" of greatest concern is simply a deficiency of one or more amino acids. Feeding a diet with a marginal deficiency in an amino acid is of major economic importance for a number of reasons: firstly, the animals will have to eat more food to compensate for a deficiency in the limiting amino acid, and secondly, the animals will be fatter at a given live weight.

In order to determine the optimum dietary intakes (and hence concentrations) of amino acids at different stages of the growing period, the response of pigs to a range of dietary amino acid concentrations or intakes of each of the essential amino acids must be known, as must the effect of different dietary concentrations of an amino acid on food intake. Therefore, studying the response to an individual amino acid is of considerable practical importance. The likely responses to diets deficient in an amino acid can be determined through the use of growth response trials at different stages of the growing period. Through this knowledge one will be able to improve carcass quality by feeding better quality diets and improve our knowledge of how to feed the growing pig in a more efficient way.

Lysine is generally the first limiting amino acid and threonine the second or third limiting amino acid in practical pig diets (Cole, 1985; Saldana, Knabe, Owen, Burgoon and Gregg, 1993). There is evidence to suggest that nutrition during the early growing period may influence subsequent performance and carcass quality (Campbell and Biden, 1978). Therefore, this thesis investigates the response of young growing pigs from 12 kg to 25 kg live weight to a range of dietary concentrations of each of the above amino acids (in two separate experiments). To ensure that the above amino acids remained first limiting in all the diets used in each trial, a summit-dilution technique was used (Fisher and Morris, 1970). This involves the dilution of a high protein "summit" diet with a non-protein dilution diet. By ensuring that the amino acid being tested is first limiting in the summit diet, the response to dilution can be interpreted as a response to a single amino acid.

A second area that this thesis investigates is the environmental component. There is little or no information pertaining to the influence of heat production on the response in growing pigs fed a diet deficient in an amino acid. It is recognised that environmental temperature affects food intake, growth and heat production, but it is not known how environmental temperature interacts with dietary amino acid concentration to affect these responses. Thus the experiments were conducted using temperatures that provided environments ranging from cold to hot. Therefore, this thesis, and the experiments conducted therein, examines the response of young growing pigs to dietary amino acid concentration, environmental temperature and the dietary treatment x environmental temperature interaction. This is achieved through the use of a summit-dilution technique, different environmental temperatures and chemical carcass analyses.

The variables (i.e. the response criteria) measured or calculated in these experiments can be used to provide a series of response curves to the dietary amino acid concentration in each experiment. Thus, the response of young growing pigs to a range of dietary amino acid concentrations or intakes of each of the amino acids lysine and threonine, will be known. This is of considerable practical importance, in not only providing the likely growth responses to diets deficient in these amino acids, but also enabling one to determine the likely effects on carcass quality. Variables of importance measured or calculated in the experiments include daily growth rates, voluntary feed intakes, feed conversion efficiencies (g gain/ kg food), body tissue compositions at the end

of the trial period, body compositional gains and the efficiency of amino acid utilization. Based on one or more of a number of the response criteria measured, the amino acid supply in practical pig diets can then be adjusted to optimise performance by improving carcass quality and feeding the growing pig in a more efficient way.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Proteins contain nitrogen in a fairly fixed proportion and this relationship is used to estimate the protein content of a feed from its nitrogen content. However, pigs do not have a requirement for protein as such, but rather for an appropriate content and balance of amino acids. Most proteins contain 19 amino acids of which at least nine are considered essential for the pig (King, 1987).

The Agricultural Research Council have advocated the concept of an "ideal" protein containing an "ideal" balance of amino acids (ARC, 1981). It is implied that there is an ideal balance of essential amino acids which when supplied with adequate amounts of non-essential nitrogen constitutes the ideal protein (Taylor, Cole and Lewis, 1979). The expression of requirements in terms of a quantity of "ideal" protein to provide the needs of maintenance and lean growth accounts for individual amino acid requirements, yet simplifies the formulation of diets to meet amino acid requirements (King, 1987).

Because of the central role of lysine in most practical pig diets this ideal balance has been expressed relative to lysine. The requirement for each essential amino acid, i.e. the dietary content at which optimum performance is achieved, has been identified relative to a reference content of lysine, which is recognised as the first limiting amino acid in diets conventionally fed to growing pigs (Taylor *et al.*, 1979).

The response of the growing pig to dietary ideal protein or to lysine in the presence of an adequate supply of other essential amino acids, is influenced by a number of factors including live weight, energy intake, genotype and environmental conditions (ARC, 1981; King, 1987). In theory, any departure from the pattern of amino acids of ideal protein will lead to a reduction in pig performance, at least in terms of the efficiency with which dietary protein is utilised. In practice, however, pigs seem to be relatively tolerant of quite wide variations in the pattern of

amino acids, as long as all amino acid requirements are met. Nevertheless, if the dietary amino acid pattern deviates too far from the ideal, pig performance will be reduced (Lewis, 1991).

In most practical pig diets, the amino acid "disproportion" of greatest concern is simply a deficiency of one or more amino acids. Feedstuffs with a high protein content are usually relatively expensive and thus there is a tendency to limit their inclusion in diets. When the dietary protein content is inadequate to meet the requirements of all essential amino acids, pig performance will be restricted (Lewis, 1991). The amino acid that is present in the least amount relative to its requirement is said to be the first-limiting amino acid, and the extent to which it is adequate will determine the animals performance (Lewis, 1991). A growing animal, such as a young pig, that has been given free access to an imbalanced food, will fail to achieve its potential for growth (Kyriazakis, Stamataris, Emmans and Whittemore, 1991).

The requirements of growing animals for dietary nutrients are expected to change with time, due to systematic changes in their requirements for maintenance and growth. Also, the amount of food consumed daily by each animal increases throughout the growing period, making it difficult to calculate the optimum concentration of dietary nutrients to include in the food offered to a group of animals, considering the disparate requirements between animals on any one day, and within each animal on successive days of the growing period (Bradford and Gous, 1991). In current commercial practice, the efficiency of utilisation of dietary amino acids by the growing pig is rather low, and there is considerable scope for improvement (Moughan, 1993).

Understanding or recognising the responses of the growing pig to diets deficient in one or more amino acids, more importantly here lysine and threonine, will enable one to add to the knowledge of how to feed the growing pig in a more efficient way. This may be achieved through the formulation of diets that contain sufficient quantities of the other essential amino acids, and the response of the growing pig to the limiting amino acid can be observed through varying its concentration in the diet.

1.2 Amino Acid Requirements of Growing Pigs

1.2.1 Introduction

In the simplest terms, amino acid needs of the pig (or any other species), can be depicted in a simple flow diagram shown in Figure 1.1.

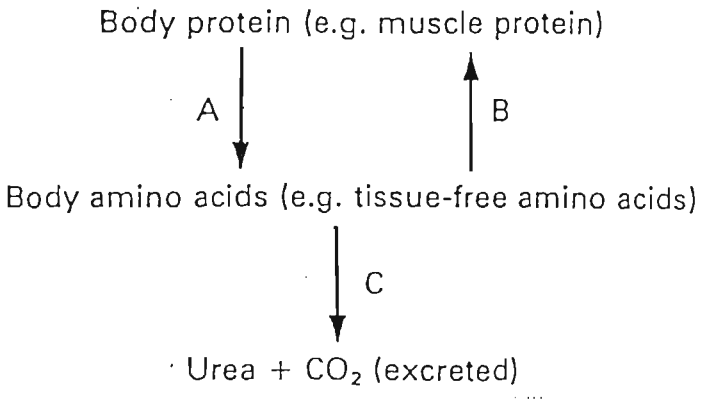

Figure 1.1 Flow diagram of amino acid requirements where A = protein degradation, B = protein synthesis and C = amino acid oxidation (from Baker, 1993).

All of the body processes (A, B and C) in Figure 1 go on continuously. It is important to note that anywhere from 60% (young animal) to 80% (adult animal) of the amino acid needs for body protein synthesis come from endogenous protein degradation. Hence, the remaining 20-40% must be supplied in the diet. Because individual amino acids have different turnover rates (lysine low, methionine high) and are therefore depleted via amino acid oxidation from tissue pools at different rates, one cannot assume that the amino acid composition of muscle tissue is predictive of the dietary amino acid requirement pattern. Requirements for individual amino acids are therefore determined by experiment (Baker, 1993).

1.2.2 Essential amino acids

Pigs are able to synthesize some amino acids and these do not need to be provided in the diet; they are referred to as nonessential amino acids. Other amino acids cannot be synthesized by swine, or at least they cannot be synthesized at a rate sufficient to permit optimum growth; they are referred to as essential (Lewis, 1991). The ARC (1981) list lysine, methionine and cystine, tryptophan, threonine and isoleucine as essential. They also list arginine, histidine, phenylalanine, leucine and valine as essential, but due to the lack of information on these amino acids no recommended requirement in the diet was given. It is of interest to note that endogenous synthesis of arginine is sufficient to enable pigs to grow at about two thirds of the normal rate, so this amino acid can be regarded as "semi-essential" like cystine and tyrosine.

Table 1.1 Amino Acid Classification for the Pig (from Cunha, 1977).

Essential Amino Acids	Nonessential Amino Acids
Lysine	Glycine
Tryptophan	Serine
Methionine	Alanine
Valine	Norleucine
Histidine	Aspartic acid
Phenylalanine	Glutamic acid
Leucine	Hydroxyglutamic acid
Isoleucine	Cystine
Threonine	Citrulline
Arginine[a]	Proline
	Hydroxyproline
	Tyrosine

[a]Partially synthesized.

1.2.3 Quality of Protein

The quality of dietary protein is determined by its content of amino acids, and by the digestibility and availability of these amino acids. Quality can be considered as the degree to which the composition of the absorbed amino acid mixture accords with the balance required by the animal (Wang and Fuller, 1989). Feeds which supply the proper proportion and amount of the various essential amino acids supply so-called good quality protein. Those feeds which furnish an inadequate amount of any of the essential amino acids have poor quality protein (Cunha, 1977). If any one amino acid is lacking in proper amount in a diet, then the response will be limited by that amino acid. It will also limit the utilization of the other amino acids in the diet (Cunha, 1977; Yen, Cole and Lewis, 1986). This means that one serious amino acid deficiency will cause the entire diet to be inadequate. For this reason, it is important that feeds low in one or more of the essential amino acids not be fed alone; otherwise the pig will make poor use of the protein supplied by that feed in performing the body functions which require protein (Cunha, 1977).

1.2.4 Food Composition

Dietary protein content affects requirements for essential amino acids (Baker, Katz and Easter,1975; Boomgaardt and Baker, 1973a). Thus, as protein content decreases, food intake generally increases as the animal attempts to meet its protein or amino acid needs (Baker, 1993). In some pig production units it is common practice to feed both a grower and a finisher food during the period 20 to 90 kg live weight. In many units the composition of the food remains constant over this entire period and is formulated to suit the requirements of a pig around 45 to 50 kg live weight. As a consequence young pigs are unable to obtain sufficient of the limiting nutrients from the food to satisfy their requirements without overconsuming other nutrients in the food (Bradford and Gous, 1991). At the end of the period of inadequate nutrition the pig will usually have a lower protein weight, and a lower or higher lipid weight than that of a similar pig treated in a non-limiting way at the same protein weight (Kyriazakis, *et al.*, 1991).

It is also recognised that the increased diversification of feed supply for pigs and the use of fibrous and Polly digestible byproducts, has introduced additional limitations in the availability of some

essential amino acids, which under certain circumstances may become limiting, thus resulting in unexpected and undesirable effects on appetite and growth performance (Henry and Seve, 1993).

1.2.5 Food Intake

Almost all the literature states that animals eat to satisfy their requirements for energy. However, a number of physiological, environmental and dietary factors influence daily feed intake and therefore daily nutrient intake (NRC, 1988). Feed intake is an important factor affecting the pig's requirements for an amino acid or the response (outputs) to inputs of nutrients. Because an animal has requirements for certain nutrients and will attempt to consume an amount of feed that will satisfy its requirements for potential growth and maintenance (Emmans and Fisher, 1986; Ferguson, 1996), food intake would be expected to deviate from the desired intake when the food is imbalanced in some way. The desired feed intake will therefore be the quantity of the diet needed to satisfy the requirements for the most limiting nutrient (Ferguson, 1996). If there is a marginal deficiency in an essential nutrient the animal may consume a sufficient amount of the imbalanced food to grow at its potential. However, if the deficiency is more severe, daily growth rates and body tissue gains (protein) would be affected. In cold environments pigs consume more feed in an attempt to meet their elevated maintenance needs (Holmes and Close, 1977). As the results of the experiments in this thesis indicate that this does occur, and at the same time lipid growth rates are higher at these lower temperatures, one can conclude that the pigs overconsume on energy which is deposited as excess lipid. This then, is a good example to prove that pigs do not eat to satisfy an energy requirement as is so often stated in the literature.

1.2.6 Body Compositional Factors

The two major components of a growing pig's requirement for protein are that for maintenance and that for tissue growth (Campbell and Biden, 1978; Campbell, Taverner and Curic, 1983). Requirements for amino acids in growing animals, expressed in terms of dietary concentration, decrease as age and weight of the animal increase (NRC, 1979; Boomgardt and Baker, 1973b). This occurs because body composition changes (e.g. more fat and less protein in the weight gain) as a growing animal matures. For amino acids, weight gain generally correlates well with nitrogen

retention in young, rapidly growing animals. After secondary sex characteristics have developed, however, body composition factors come into play such that a higher requirement is often predicted for maximal nitrogen retention than for maximum weight gain. Thus gilts and boars, because they deposit more lean in relation to fat, exhibit higher protein and amino acid requirements than is the case for castrated males. By the same token, pigs bred for leanness require higher concentrations of amino acids in their diets than those not similarly possessing a high lean:fat ratio (Batterham, Giles, Dettmann, 1985; Baker, 1993). It has been demonstrated that deposition of lysine and threonine in carcass protein have a linear relationship to amino acid intake when these amino acids are first limiting in pig diets (Batterham, Andersen, Baigent and White, 1990; Beech, Batterham and Elliot, 1991).

1.2.7 Criterion of Response.

The requirement for almost any nutrient depends to some extent on the response criteria that are measured in its establishment (Lewis, 1991). Requirements for amino acids are generally best defined in growing animals by growth data in *ad libitum* feeding studies. Part of the growth response to an essential amino acid is due to its favourable effect on metabolism; but another part of its efficacy resides in its effect on food intake (Baker, 1993). Estimates of amino acid requirements for maximal carcass leanness are usually higher than estimates for maximal rates of weight gain (Cahilly JR., Miller, Kelly and Brooks, 1963; Baker, Jordan, Waitt and Gouwens, 1967; Smith, Clawson and Barrick, 1967; Brown, Harman and Jensen, 1973a,b). Furthermore, the requirements for maximal feed efficiency are generally somewhat higher than for weight gain (Lewis, 1991).

1.3 Factors Influencing the Response in Pigs to Dietary Amino Acids

1.3.1 Introduction.

The expression of requirements in terms of a quantity of "ideal" protein to provide the needs for maintenance and lean growth accounts for individual amino acid requirements, yet simplifies the formulation of diets to meet amino acid requirements (King, 1987). Because of the central role

of lysine in most practical pig diets, the ARC (1981) expressed this "ideal" balance relative to lysine. In order to use this approach, it is necessary to be aware of the factors that influence a pig's response to lysine (or "ideal" protein) before considering how to formulate diets to supply the required amino acid concentrations.

1.3.2 Live weight.

In growing pigs, dietary amino acids are needed for the maintenance of body protein and for the synthesis of new protein such as lean tissue. When intake is sufficient to meet requirements for maintenance amino acids, the total amino acid requirement of young pigs is then determined by the rate of lean growth. The potential for lean growth rate relative to body weight and hence maximum requirement for amino acids decreases with increasing body weight (King, 1987).

1.3.3 Energy Intake.

The voluntary intake of pigs allowed *ad libitum* access to feed is influenced by the metabolizable energy (ME) concentration of the diet (Lewis, 1991). When the dietary energy concentration is low, pigs increase feed intake, and vice versa (Clawson, Blumer, Smart and Barrick, 1962; Cole, Duckworth and Holmes, 1967). As a consequence, changes in dietary ME concentration affect intakes of nutrients, including amino acids (Lewis, 1991). When other sources of energy are limited, dietary protein is diverted from anabolic pathways and oxidised to meet the body's needs for energy. To ensure that dietary protein is used to the maximum extent, large amounts of non-protein energy must be supplied (ARC, 1981).

If a constant intake of an amino acid is to be maintained when diets of different ME concentration are fed, the amino acid concentration must be adjusted (Lewis, 1991). To obviate the difficulties inherent in expressing amino acid requirements in terms of dietary concentration, some organizations (ARC, 1981) list requirements as grams of amino acid per unit of energy (digestible or metabolizable). However, the concept of a constant dietary lysine : energy value is only valid when the relationship between energy intake and rate of protein deposition is linear. For pigs between birth and 20 kg live weight, the relationship is linear and the dietary lysine : energy value

required for maximum performance is unaffected by content of energy intake. The situation for pigs of heavier body weight, however, is less clear (ARC, 1981; King, 1987).

1.3.4 Genotype

Differences in genotype can have a large effect on rate of protein deposition. This will also affect lysine : energy ratios, with higher ratios needed by those genotypes with a higher capacity for protein deposition (King, 1987). Pigs bred for leanness require higher concentrations of amino acids in their diets than those not similarly possessing a high lean:fat ratio (Batterham *et al.*, 1985; Baker, 1993).

1.3.5 Environmental Conditions

The thermal environment in which a pig is maintained influences its voluntary feed intake and the rate, efficiency and composition of gain (Verstegen, Close, Starr and Mount, 1973; Noblet and Le Dividich, 1982; Close and Stannier, 1984). The rate of an animal's heat loss is determined principally by two factors, the plane of nutrition and the environmental temperature. The environmental temperature also determines which of these two factors is primary: in the zone of thermal neutrality, the plane of nutrition is the chief determinant, with the higher heat loss occurring at the higher content of feeding (Verstegen *et al.*, 1973). Pigs housed at temperatures below their thermo-neutral zone, probably have a lower lysine : energy ratio than those housed within the thermal-neutral zone as a greater proportion of energy in the former situation is needed to maintain body temperature. The reverse should occur with pigs housed above their thermal-neutral zone (i.e. a higher lysine : energy ratio) but the situation is less clear because high temperature depresses food intake (King, 1987).

In a cold (relative to thermoneutrality) environment, pigs normally consume more feed in an attempt to meet their elevated maintenance needs without reducing body growth (Holmes and Close, 1977). In a hot (relative to thermoneutrality) environment, pigs reduce their feed intake (which reduces growth) in an attempt to minimise the burden of dissipating heat produced from digestive and metabolic processes (Schenck, Stahly and Cromwell, 1992). On amino acid

deficient diets the pigs will increase feed intakes (and hence nutrient intakes) in an attempt to compensate for the deficiency in the diet. However, the ability of the pig to compensate will depend on the maximum amount of heat the animal can lose (Ferguson, 1996). The lower the environmental temperature the more heat that can be lost. Therefore, the lowest dietary amino acid concentration in which a pig can maintain its maximum daily protein retention will depend on the ambient temperature.

1.4 The Response in Growing Pigs to Dietary Lysine and Threonine

1.4.1 Introduction

Establishing the responses of young growing pigs to varying contents of amino acids in diets fed to pigs, will enable one to formulate diets that fulfil the animals requirements, and ensure that the animal's genetic potential for growth is not affected by a deficiency in one or more amino acids.

Lysine is generally regarded as the first limiting amino acid in conventional diets for growing pigs but estimates of lysine requirement show considerable variation (Yen *et al.*, 1986). Threonine is usually the second or third limiting amino acid in practical pig diets, and it may be first-limiting when crystalline lysine is added. The threonine requirements for pigs have not been thoroughly investigated and variation exists among the reported requirements for pigs in a given weight range (Saldana, Knabe, Owen, Burgoon and Gregg, 1993).

In amino acid requirement studies it is essential that dietary contents of the amino acid range from inadequate to excess in order to provide dose response curves from which the requirement may be derived (Taylor, Cole and Lewis, 1982). The results of experiments to determine amino acid requirements will be shown, and the responses of the pigs to diets limiting in one of the amino acids discussed above, are clearly illustrated.

The principal response criteria used in most investigations into amino acid requirements of growing pigs are growth performance and carcass composition.

1.4.2 Lysine

In an experiment by Yen *et al.* (1986), the response of the growing pig (25 kg to 55 kg live weight) to dietary lysine in the presence of an adequate supply of other essential amino acids was examined. The ARC (1981) have suggested a lysine requirement of 11.9 g/kg diet for growing pigs. In the experiment described above a series of lysine concentrations in the diets were used to obtain response curves, using growth performance and carcass composition as response criteria. The response to a dietary concentration lower than that advocated by the ARC (1981) can be examined through the results of the experiment by Yen *et al.* (1986), as well as through the results of the experiment conducted by Giles, Batterham, Dettmann and Lowe (1987) who investigated the response of growing pigs (entire males on a wheat based diet) to dietary lysine from 20 kg to 50 kg live weight. In their experiment eight dietary lysine concentrations from 7.0 g dietary lysine/kg feed to 14.0 g/kg were used. The pigs in both experiments were allowed *ad libitum* access to food.

1.4.2.1 Growth performance

Dietary lysine concentration was the major significant factor influencing daily gain and food conversion ratio (Rogerson and Campbell, 1982: Yen *et al.*, 1986). Yen *et al.* (1986) found the highest growth rates were with a lysine concentration of 11.2 g lysine/kg diet for boars. An increase of 1g/kg lysine in the diet over the range of positive linear response showed an increase of 58g/day in the growth of boars. The concentration of 11.2 g/kg compares quite closely to that recommended by the ARC (1981). Giles *et al.* (1987) found the response of daily gain to lysine concentration was curvilinear increasing to a maximum with 12 g dietary lysine/kg food (Figure 1.1).

At dietary concentrations below those contents recommended in the literature, daily gain decreases steadily as the dietary concentration is decreased from 11.2 g/kg to 7.5 g/kg dietary lysine (Yen *et al.*, 1986). This would indicate that at contents where dietary lysine becomes limiting, daily gain and growth rates are affected (Figure 1.1). Bradford and Gous (1992) reported that with an undersupply of amino acids, a growth rate less than the genetic potential of

the animal may result.

Yen *et al.* (1986) found the most efficient food conversion efficiency (FCE) to be 510 g gain/kg food and was at a lysine concentration of 13.5 g/kg diet for boars. Giles *et al.* (1987) reported a maximum food conversion efficiency occurred with the maximum dietary lysine concentration in their experiment.

At lysine concentrations lower than the recommended dietary contents the food conversion efficiency (gain/food) was less favourable than at higher dietary concentrations (Figure 1.2).

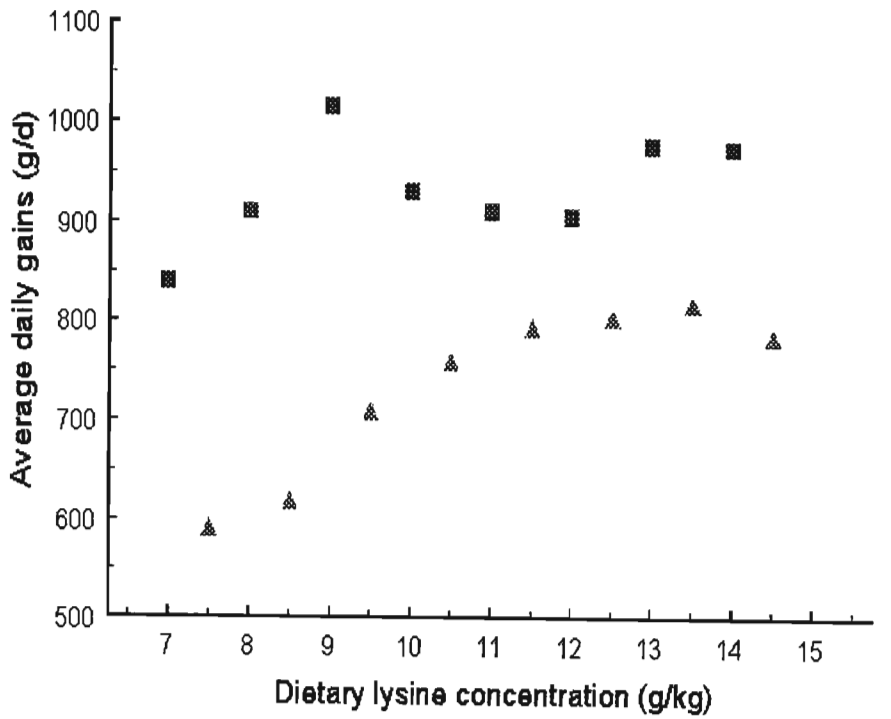

Figure 1.1 Effects of dietary lysine on daily gain of growing pigs; (▲) 25 kg to 55 kg live weight (Yen *et al.*, 1986) and (■) 20 kg to 50 kg live weight (Giles *et al.*, 1987).

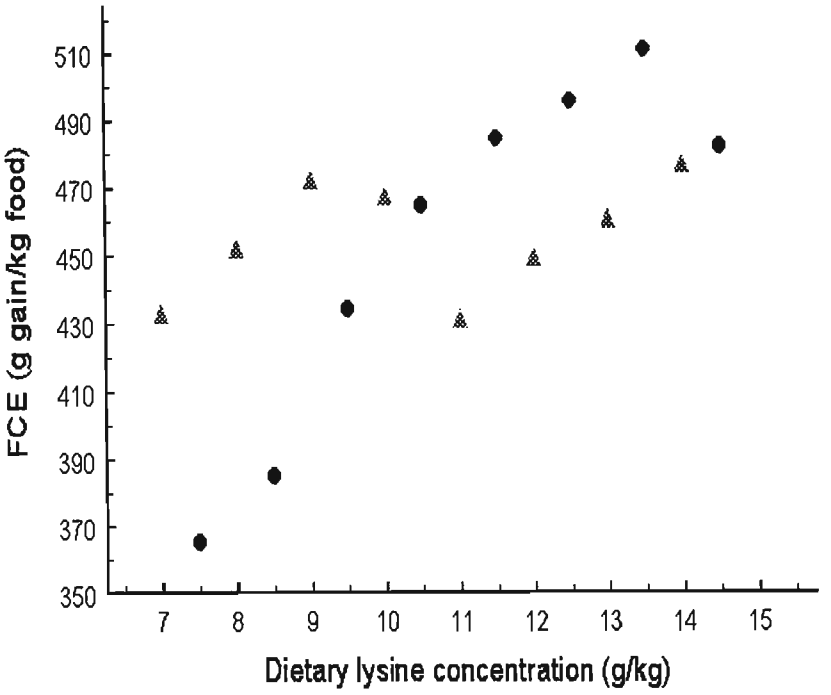

Figure 1.2: Effects of dietary lysine on food conversion efficiency of growing pigs; (●) 25 kg to 55 kg live weight (Yen *et al.*, 1986) and (▲) 20 kg to 50 kg live weight (Giles *et al.*, 1987).

In an experiment by Rosell and Zimmerman (1983) to assess the effects of graded contents of lysine on young pigs fed practical diets, the gain:feed ratio was found to have a significant linear increase with increasing dietary lysine concentration. Feed intake was not significantly affected by dietary lysine concentration. However, there was a linear decrease in average daily feed intake with increasing lysine concentration (455g at 9.5 g dietary lysine/kg food and 391g at 11.50 g dietary lysine/kg food).

1.4.2.2 Carcass performance

In the experiment of Yen *et al.* (1986) dissections of the ham joint show marked differences in lean proportion, and fat, bone and skin proportions in boars, in response to dietary lysine concentrations. Significant differences were also reported for the lean and fat proportions as a result of differences in lysine concentration ($P < 0.001$). Yen *et al.* (1986) also found that the proportion of lean increased with increasing concentrations of dietary lysine, reaching a maximum at a lysine concentrations of 10.3g/kg diet for boars, becoming constant with higher

concentrations of lysine. The response of fat in the ham to lysine concentration was opposite to that of lean. However boars had less fat than gilts. This observation is also reported by King (1987) and Lewis (1991). Giles *et al.* (1987) found that with pigs fed *ad libitum*, none of the carcass measurements were significantly affected by dietary lysine concentration. However, the proportion of fat (g/kg) in the carcass was greatest at the lowest dietary lysine concentration (Figure 1.3).

At lysine concentrations lower than the recommended contents, where lysine may be limiting, percentage lean in the ham is lower than at higher lysine concentrations (Figure 1.3). Percentage fat in the ham increases as lysine concentration decreases past a certain dietary content (Figure 1.4). The pigs may increase food intakes to compensate for the low dietary concentrations of lysine, with the result that they may overconsume on energy with a concomitant excessive lipid gain (Bradford and Gous, 1992).

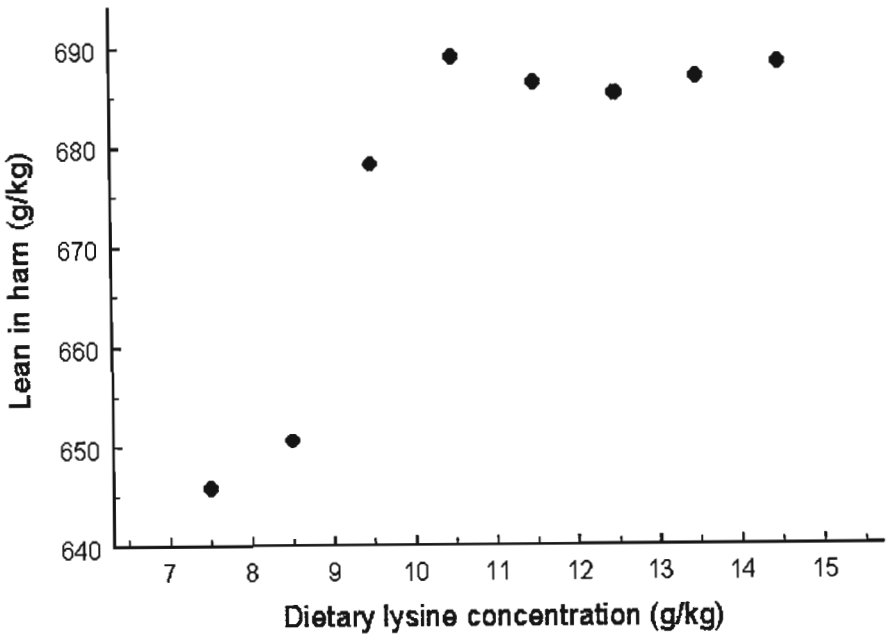

Figure 1.3 Effects of dietary lysine on lean in the ham joint of growing pigs from 25 kg to 55 kg live weight (from Yen *et al.*, 1986).

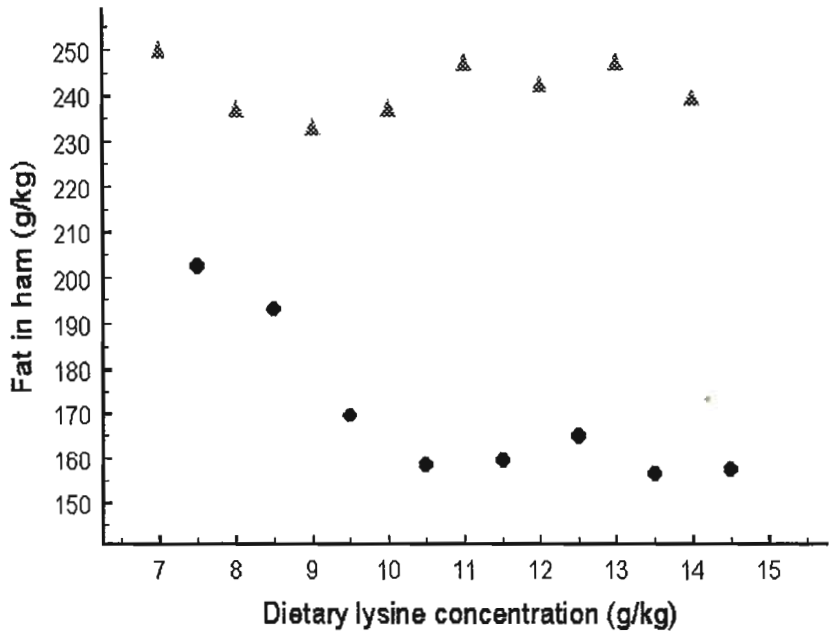

Figure 1.4 Effects of dietary lysine on fat in the ham joint of growing pigs from 25 kg to 55 kg live weight (from Yen *et al.*, 1986) and (▲) 20 kg to 50 kg live weight (Giles *et al.*, 1987).

1.4.2.3 The Efficiency of Lysine Utilization

The two major components of a growing pig's requirement for protein are that for maintenance and that for tissue growth. The efficiency with which dietary protein is used for maintenance and tissue growth will affect the amount of dietary protein that must be supplied (Adeola, 1995). This efficiency does not necessarily equal that for individual amino acid utilization (Baker, 1991; Chung and Baker, 1992). Hence, in a study by Adeola (1995) two experiments were conducted. They were to determine the efficiency of lysine and threonine deposition in carcass protein of pigs in the live weight range of 10-20 kg . The experiments were part of a project to study amino acid utilization from free and intact protein sources.

Average daily gains, feed intakes and gain:feed were found to increase linearly with increasing dietary lysine concentration. A similar response in increasing protein retention with increasing dietary lysine concentration was obtained. Lysine deposition rate in the carcass was higher in pigs fed a diet containing 8 g dietary lysine/kg than in diets containing 6 or 7 g lysine/kg. The rate of carcass lysine deposition was a linear function of daily lysine intake. A linear regression of daily carcass lysine deposition on daily lysine intake indicated that the above-maintenance efficiency of dietary lysine utilization for carcass lysine deposition in pigs raised from 10 kg to 20 kg was 0.72. The regression equation was:

$$LYSR = -1.29 + 0.72 \times LYSI \quad \text{(g/day)} \quad (1.1)$$

where LYSR = Lysine retention (g/d)
LYSI = Lysine intake (g/d)

Utilizing dietary lysine with an efficiency of 72% in this study indicates that 28% of the dietary lysine was either undigested or catabolized after absorption. The loss of lysine during the normal physiological process of growth, conversion of lysine to methylated and hydroxylated derivatives, absorption of lysine in forms unsuitable for protein synthesis, and lysine oxidation account, in major part, for the efficiency of dietary lysine utilization being less than 100% (Adeola, 1995).

1.4.3 Threonine

The recommended dietary concentration proposed by the ARC (1981) is 7.1 g/kg of diet for growing pigs, although a concentration of 5.6 g/kg was shown to be adequate (Taylor *et al.*, 1982). The amount of published information regarding optimal dietary threonine contents is limited.

It is essential in an amino acid-requirement study that dietary contents of the amino acid should range from inadequate to excess in order to provide dose response curves from which the requirement may be derived (Taylor *et al.*, 1982). In a previous experiment a threonine concentration of 4.7 g/kg of the basal diet was found to be inadequate. By using the same formulation, Taylor *et al.*, (1982) supplied the basal diet to growing pigs in combination with supplements of synthetic threonine, to give a range of theoretical threonine contents up to 6.5 g/kg. It is therefore possible to recognize the responses of young growing pigs to a diet limiting in threonine by evaluating growth performance and carcass composition data.

1.4.3.1 Growth performance

In the experiment by Taylor *et al.* (1982) daily gain showed a positive response to raising the dietary threonine content from a content where threonine was limiting in the diet. The positive response was to the first two increments of supplementary threonine, thereafter further additions did not improve performance, thus forming a plateau (Figure 1.5). An increase of 96 g/day for an increment of 1 g dietary L-threonine per kg up to a maximum growth rate of approximately 700 g/day, was recorded. At a content where dietary threonine was inadequate daily live weight gain was affected as was the food conversion efficiency. At inadequate contents of dietary threonine the food conversion efficiency (gain/food) was lower, than when further increments of threonine were added to the diet. Results for food conversion efficiency followed similar trends to growth rate (Figure1.6).

Saldana *et al.* (1993) in an experiment to determine digestible threonine requirements of pigs, evaluated the effect of dietary threonine content on the performance of starter pigs. The average

daily growth rate and feed intake increased quadratically as the threonine content increased from 6 g/kg to 7.6 g/kg. There was a significant linear increase in the gain/feed ratio as the content of dietary threonine increased.

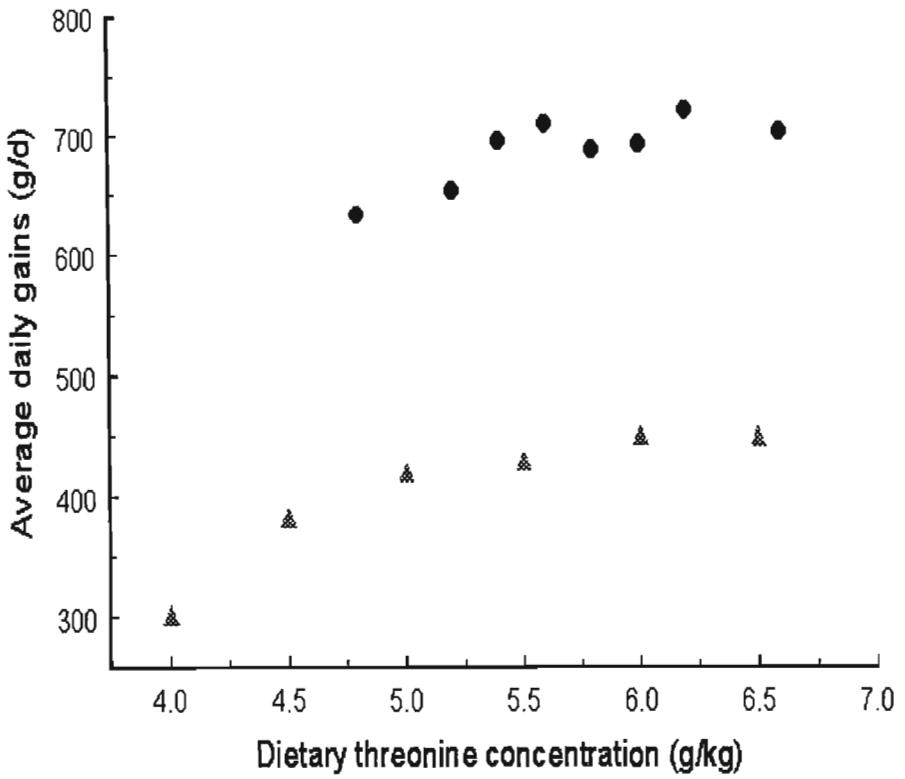

Figure 1.5 Effects of dietary threonine content on daily live weight gain of growing pigs; (●) 25 kg to 55 kg live weight (Taylor *et al.*, 1982) and (▲) 10 kg to 29 kg live weight (Kovar*et al.*, 1993).

Schutte, Bosch, Lenis, de Jong and van Diepen (1990) found that by increasing the threonine content of the feed from 5.6 g/kg to 7.4 g/kg for young growing pigs in the weight range 20 kg to 40 kg, significantly improved the growth rate up to 6.8 g /kg feed. A further increase did not improve the growth rate. Optimum feed conversion was obtained at 7.4 g/kg. Over the range 5.6 to 7.4 g threonine/kg food, the feed conversion ratio (kg feed/kg gain) decreased with increasing threonine content.

Kovar, Lewis, Radke and Miller (1993) assessed the effect of graded contents of threonine on the performance of young pigs from 10.9 g/kg live weight for 21 days. Average daily feed intakes, average daily gains (Figure 1.5) increased to increasing contents of dietary threonine from 4.0 g/kg to 6.5 g/kg. Gain/food increased with increasing dietary threonine content of the diet (Figure 1.6).

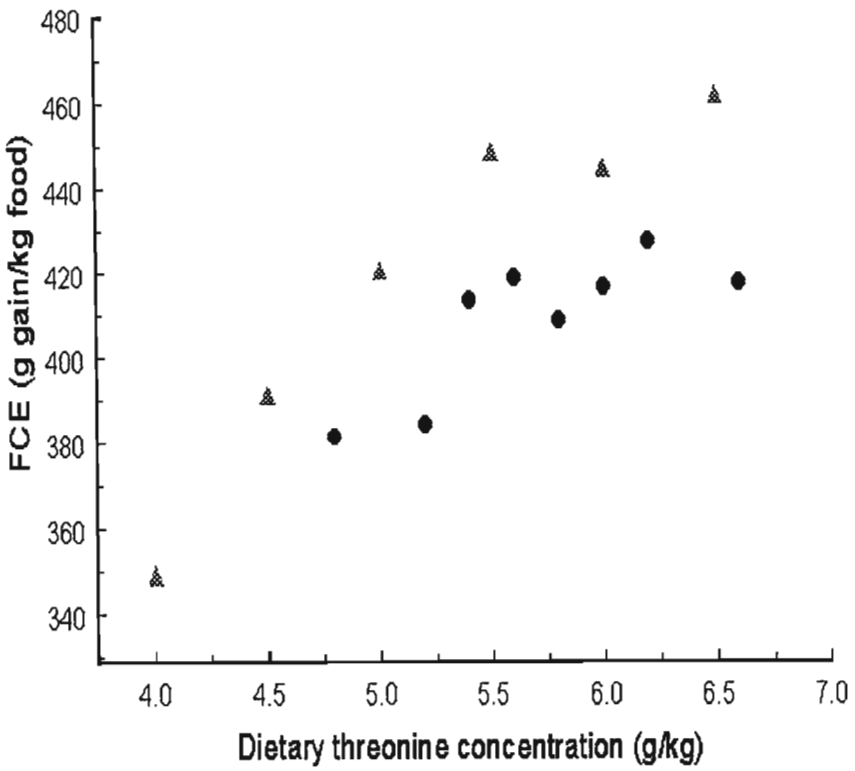

Figure 1.6 Effects of dietary threonine content on food conversion efficiency of growing pigs; (●) 25 kg to 55 kg live weight (Taylor *et al.*, 1982) and (▲) 10 kg to 20 kg live weight (Kovar *et al.*, 1993).

1.4.3.2 Carcass performance

In the experiment by Taylor *et al.* (1982) dietary threonine content was shown to significantly influence the lean content ($P < 0.01$) and fat content ($P < 0.05$) of the middle joint. Lean content increased linearly from an inadequate dietary threonine content with the first two increments of supplementary threonine; thereafter the response was erratic and followed no obvious pattern

(Figure 1.7). Results for fat content of the middle joint were inversely proportional (Figure 1.8).

The area of the *longissimus dorsi* muscle was significantly ($P < 0.01$) affected by the threonine content of the diet. As threonine was increased from 4.8 g/kg (threonine limiting in the diet) to 5.2 g/kg there was a positive response.

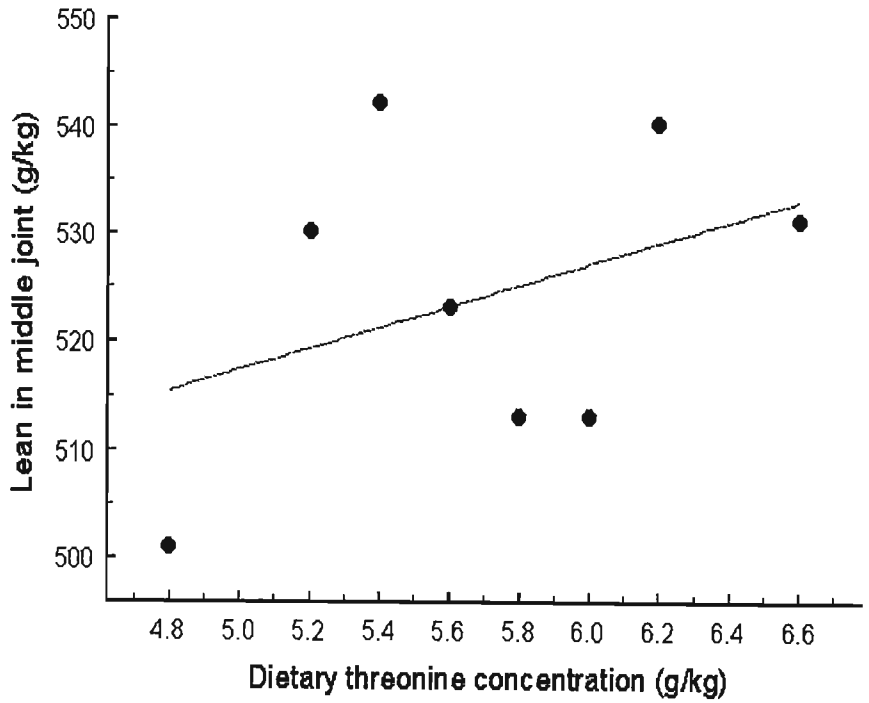

Figure 1.7 Effects of dietary threonine content on the lean content of the middle joint of growing pigs (from) Taylor *et al.*, 1982).

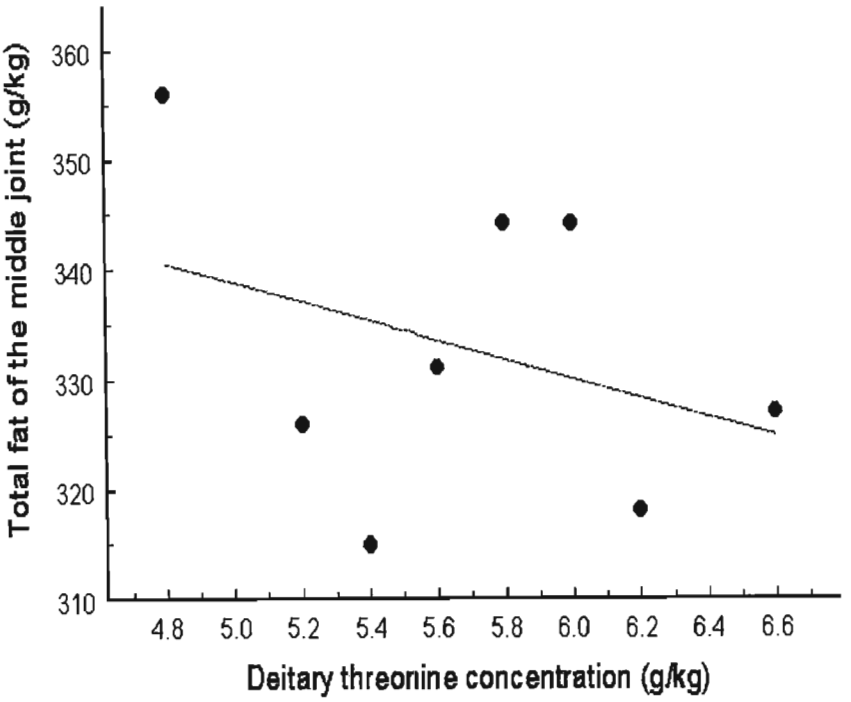

Figure 1.8 Effects of dietary threonine content on the fat content of the middle joint of growing pigs (from Taylor *et al.*, 1982)

1.4.3.3 Efficiency of threonine utilization

In the experiment by Adeola (1995) weight gain was greater when pigs were fed the diet containing 5.3 g threonine/kg than that when pigs were fed the diet containing 4 g threonine/kg. Dietary threonine concentration between 4 g/kg and 5.3 g/kg did not affect feed intake. Gain:feed ratio was higher in pigs fed 5.3 g of threonine/kg diet than in the other dietary treatments. Carcass threonine deposition rate was higher ($P < 0.05$) in pigs fed the diet containing 5.3 g threonine/kg diet than in pigs fed 4 g threonine/kg diet. The rate of threonine deposition in carcass protein was a linear function of daily threonine intake. Based upon the linear regression of daily carcass threonine deposition on daily threonine intake, the efficiency of dietary threonine utilization, above maintenance, for carcass threonine deposition was 0.60. The regression equation was:

$$THRR = -0.88 + 0.6 \times THRI \quad (g/d) \qquad (1.2)$$

where THRR = Threonine retention (g/d)
THRI = Threonine intake (g/d)

1.5 Discussion

The ARC (1981) have advocated the concept of an "ideal" protein containing an "ideal" balance of amino acids. The expression of requirements in terms of a quantity of "ideal" protein to provide the needs of maintenance and lean growth accounts for individual amino acid requirements, yet simplifies the formulation of diets to meet amino acid requirements. This "ideal" balance or ratio is usually expressed relative to lysine, the first limiting amino acid in conventional pig diets. Deviations from this "ideal" balance of amino acids in a diet, most importantly a deficiency in an amino acid, will result in animals, given free access to the imbalanced food, failing to achieve their potential growth rates.

Lysine, usually the first-limiting amino acid, and threonine, usually the second or third limiting amino acid in conventional pig diets both have a significant effect on the growing pig's performance when supplied below the animals requirement. This is clearly shown by the growth performance and carcass composition data and results presented in this paper from research by various investigators. The responses to diets where the content of the amino acid under investigation is supplied at an inadequate content, are clearly shown.

Lysine and threonine when supplied at a concentration where they become limiting in the diet, have a notable effect on daily growth rates, feed conversion ratios and the percentage lean and fat in the carcass. These have important consequences for the producer, and it is important to recognise these responses (from dose response curves) so that one can formulate diets that supply the correct balance of amino acids and that fulfil the pig's requirements, to ensure that the pig is fed in a more efficient way.

From the review of literature it is seen that there have been a number of attempts to measure the response of growing pigs to feeds deficient in the amino acids lysine and threonine. However, the results have been inconsistent and in some cases contradictory. In these experiments feeding

techniques and dietary composition have varied, and there has been little control over the prevailing environmental temperature, which is known to have an affect on voluntary feed intake. There is little or no information pertaining to the influence of heat production on the response in growing pigs fed a diet deficient in an amino acid. The response criteria measured have varied between experiments, making accurate comparisons of the data difficult. In most of the experiments protein and fat content of the ham or middle-joint was determined. This gives no indication of the pig's whole body composition, making calculations of the body compositional gains difficult. The growing periods in each experiment have also varied, making comparisons of the data impractical.

It is with this in mind that the experiments in this thesis were designed. The growing period to be studied was within the live weight range 12 kg to 25 kg live weight, and as explained earlier, was chosen due to there being evidence that nutrition during the early growing period (post-weaning) may influence subsequent performance and carcass quality. The response criteria measured included daily growth rates, voluntary feed intakes, feed conversion efficiencies, body tissue compositional gains, efficiencies of amino acid utilization and total heat loss. The experiments were conducted using various environmental temperatures to study the effect of temperature on the response in young growing pigs to diets deficient in an amino acid. A summit-dilution technique was used ensuring that the amino acid under test was limiting in the summit diet. Chemical analyses of carcass samples for protein, fat, moisture and ash content was also performed ensuring accurate estimates of whole body composition.

CHAPTER 2

THE RESPONSE IN GROWING PIGS TO DIETARY THREONINE AS INFLUENCED BY ENVIRONMENTAL TEMPERATURE.

2.1 Introduction

Due to recent and rapid improvements in the potential for lean tissue deposition, the influence of dietary amino acid balance on feed intake, growth performance and carcass characteristics is now a major concern in pig feeding. It is reported that there is now strong evidence that fast growing, lean genotypes are more sensitive to dietary amino acid imbalance than conventional types in respect of increased amino acid requirements (Henry and Seve, 1993). The increase in the ARC's (1981) recommendations may reflect a change in the pig's need for amino acids as a result of genetic selection for lean meat development (Batterham, Giles and Dettman, 1985).

It is therefore of great practical importance to measure how animals respond to a range of feeds that are increasingly deficienct in an amino acid. Such responses enable one to determine the likely growth response to diets given to a specific genotype thereby determining the optimum feed composition to maximise profit and improve the carcass quality by feeding better quality diets. These diets will be formulated not only to promote optimum performance but will place a greater emphasis on their effect on carcass quality.

There have been a number of attempts to measure the response of young growing pigs to feeds deficient in various amino acids but the results have been contradictory and inconsistent (Taylor *et al.*, 1982; Rosell and Zimmerman, 1985; Yen *et al.*, 1986; Goodbrand, Hines, Nelssen and Thaler, 1988; Henry and Seve, 1993). The two major reasons for not elucidating the response to the deficient amino acid are because of the diet (feed ingredients) and the feeding technique (restricted vs. *ad lib* feeding) used, and because little control has been excercised over the prevailing environmental temperature. It has been recognised that the increased diversification of feed supply for pigs and the use of fibrous and poorly digestible byproducts, has introduced additional limitations in the availability of some essential amino acids, namely threonine,

tryptophan and methionine, which under certain circumstances may become limiting, thus resulting in undesirable effects on appetite and growth performance (Henry and Seve, 1993). Another reason is the environments in which the experiments have been conducted have been different and therefore no account has been taken of the confounding effect of the growth-environment interaction. In many instances the environmental temperature is not even recorded in the publication.

In this experiment these problems were proposed to be overcome by using a summit-dilution technique and by growing the animals in controlled-environment chambers at fixed temperatures. This will allow one to measure the responses in hot and cold environments and determine how the animal responds to a deficiency in an amino acid notwithstanding the effect of the environment. The thermal environment in which a pig is maintained influences its voluntary feed intake and the rate, efficiency, and composition of gain (Verstegen *et al.*, 1973; Noblet and LeDividich, 1982; Close and Stannier, 1984). The environment is therefore of considerable practical importance, because of the wide variation in summer/winter temperatures and the large diurnal variation experienced in South Africa, there will be large variations in feed intake and growth performances which can adversely affect productivity. By knowing how the animal will respond to a deficiency in amino acids in different environments one can improve our knowledge of how to feed the growing pig in a more efficient way.

The work reported here can be regarded as examining the response of the growing pig to deficiencies in the amino acid threonine, in the presence of an adequate supply of other essential amino acids, when the pigs are kept in four different temperature regimes.

2.2 Materials and Method

2.2.1 Animals and Experimental Design

Fifty-one entire male Large White x Landrace pigs were used in this experiment. The experiment was a 6 x 4 factorial design, the respective factors being four temperatures 18°C, 22°C, 26°C and 30°C, and six dietary threonine concentrations ranging from 8.9 g/kg to 3.6 g/kg. For the

experiment 51 pigs were purchased at approximately 10 kg live weight. To determine initial body composition of all the pigs at the start of the experiment, three pigs were assigned to an initial slaughter group and slaughtered at the start of the experiment On reaching 12 kg live weight the remaining pigs were randomly allocated to one of six dietary treatments and one of four temperature treatments, ensuring two animals per treatment. All animals were kept on their respective treatments until they reached 25 kg live weight, whereafter they were slaughtered for carcass analysis.

2.2.2 Housing and Management

The pigs were penned individually in controlled-environment chambers, each chamber containing 12 pens. Each pen measured 0.6m² and had its own nipple drinker and metal feed bin. The four temperatures used were 18.1 (±0.38)°C, 21.9 (±0.19)°C, 26.1 (±0.50)°C and 29.9 (±0.34)°C. These temperatures provided environments ranging from cold to hot. All animals were allowed free and continuous access to food and water. All animals were weighed every Thursday starting at 09h30. Feed wastage was recorded daily, starting at 08h00. Feed levels in the hoppers were checked twice daily. Feed intakes were calculated by determining the difference in the weight of the feeder at the beginning and end of each week. As there were only two chambers available the four different temperature treatments were spread over two different periods.

2.2.3 Diets and Feeding

A summit-dilution technique (Fisher and Morris, 1970) was used to formulate six dietary treatments. The summit diet was formulated to contain 14.5 MJ DE/kg feed, and >140% of the requirements of all the essential amino acids except the amino acid threonine, which was formulated to contain no more than 110% of requirement, thereby ensuring that this was the limiting amino acid in the feed (Table 2.1).

A non-protein dilution diet was formulated to contain the same concentrations of energy and all nutrients in the summit diet, other than the amino acids (Table 2.1).

Table 2.1 Constituents and calculated chemical composition of the Summit and Dilution diets.

Ingredient	Summit (g/kg)	Dilution (g/kg)
Wheat	409.63	-
Sunflower oilcake	248.84	-
Ground nut meal	134.01	-
Maize gluten meal 60%	100.23	-
Sunflower oil	38.51	38.00
Sugar	-	590.00
Starch	-	150.00
Sunflower husks	-	160.00
Limestone	15.69	10.00
Monocalcium phosphate	32.97	45.00
Lysine HCl	10.73	-
Tryptophan	10.00	-
Methionine DL	1.89	-
Vitamin & Mineral premix	5.00	2.50
Salt	2.50	5.00
Calculated composition (g/kg)		
DE (MJ/kg)	14.50	14.57
Crude protein (N X 6.25)	273.50	0.00
Threonine	8.94	0.00

Feeds were blended in the following proportions (Summit:Dilution); 100:0, 85:15, 70:30, 55:45, 40:60 and 40:60 + Supplemental Threonine (Table 2.2).

Table 2.2 Dilution of Summit diet and the expected threonine concentration and % of requirements of the dietary treatments.

Treatment	Dilution (%)	% of requirement	Threonine Concentration (g/kg)
1	0	110	8.9
2	15	94	7.6
3	30	77	6.2
4	45	61	4.9
5	60	44	3.6
6	60+Suppl.	44+Suppl.	4.9

To check that threonine was the most limiting nutrient it was necessary to supplement the most diluted diet (T5) with synthetic threonine. If there is a positive response in growth it can be concluded that threonine was the most limiting nutrient.This diet was blended with the summit diet in the above-mentioned proportions to obtain the six dietary treatments. Vitamins and minerals were included at 1.5 times the normal rate to ensure that these were not limiting. The summit diet, dilution diet and the mixed dietary treatments were analysed for DE (energy values were determined by bomb calorimetry), crude protein (determined by a calorimetric method done on an auto analyser) and the amino acids threonine, lysine, methionine, valine, histidine, isoleucine, leucine, phenylalanine, arginine, tyrosine, cystine, serinine, proline, glycine, alanine, aspartic acid and glutamic acid (Beckman amino acid analyser) (Table 2.3).

Table 2.3 The analysed chemical compositions of the Summit, Dilution and blended diets.

Nutrient (g/kg)	Summit T1	T2	T3	T4	T5	T6	Dilution
18 & 22°C							
Digestible Energy (MJ/kg)[a]	15.7	15.3	15.6	15.0	15.0	15.0	14.3
Metabolizable Energy (MJ/kg)[b]	14.9	14.6	15.1	14.5	14.6	14.6	14.2
Crude Protein	250.6	221.5	159.6	137.8	103.9	102.9	-
Total Threonine	8.1	6.2	5.2	4.3	3.4	4.3	-
Total Lysine	16.7	12.6	10.3	8.6	5.6	6.1	-
Total Methionine	6.0	5.8	5.2	3.4	2.6	2.4	-
ME:DCP (MJ/kg)[c]	74.2	82.3	118.1	131.8	175.9	177.8	-
26 &30°C							
Digestible Energy (MJ/kg)[a]	15.7	14.4	14.5	14.1	14.4	14.6	14.3
Metabolizable Energy (MJ/kg)[b]	14.9	13.8	14.0	13.6	14.0	14.2	14.2
Crude Protein	250.6	200.0	170.2	165.9	115.9	111.5	-
Total Threonine	8.1	6.6	5.5	5.2	3.8	4.8	-
Total Lysine	16.7	13.7	11.3	10.4	7.0	7.0	-
Total Methionine	6.0	4.7	4.2	3.6	2.5	2.5	-
ME:DCP (MJ/kg)[c]	74.4	86.5	102.6	102.2	151.1	159.3	-

[a] DE = 3.77 - (0.019*(NDF*10) + (0.758*GE)) MJ/kg

[b] ME = DE*(0.997-0.000189*CP) (ARC, 1981)

[c] ME:DCP = ME (MJ/kg) / (CP(kg/kg) x protein digestibility) where protein digestibility = 0.80

Based on the principle of the summit-dilution method (Fisher, 1970), a linear regression of dietary threonine content on the percentage summit in each treatment (Figure 2.1) was performed for the dietary treatments at all temperatures (Emmans, personal communication). To facilitate the following discussion and for the purpose of description the threonine contents of T1 to T6 are expressed as calculated (or fitted values) following the linear regression described above. This produced a series of standard dietary threonine contents, as well as determining more accurately

the threonine content of the six dietary treatments at all temperatures (Table 2.4).

The regression equation was:

$$\text{THR CONC} = 0.657 + 0.0711 \times \%\text{SUMMIT} \quad \text{(g/kg)} \qquad (2.18)$$

where THR CONC = Threonine concentration (g/kg)

%SUMMIT = Proportion of summit diet in dietary treatment

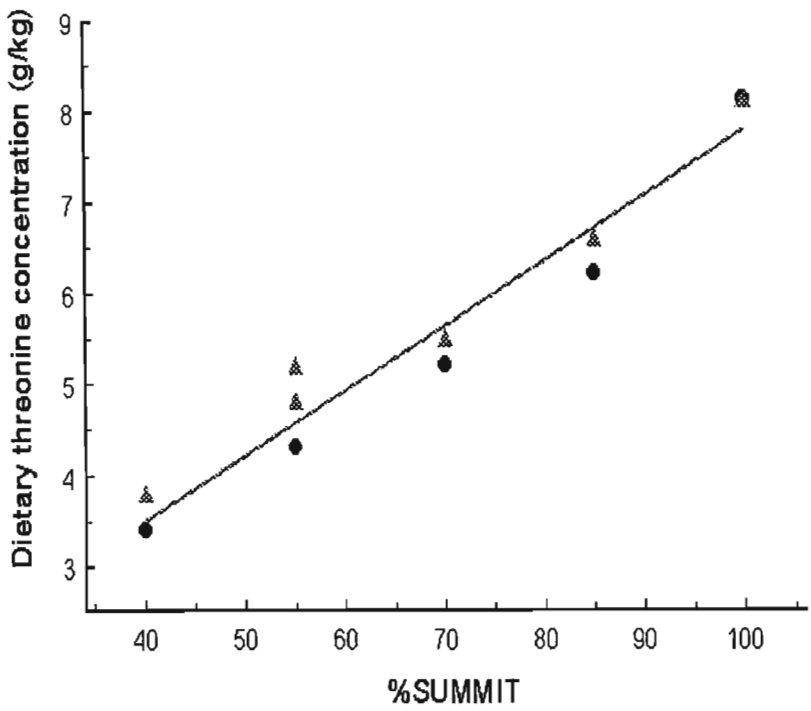

Figure 2.1 The relationship between dietary threonine concentration and summit dilution at 18°C & 22°C (●) and 26°C & 30°C (▲).

In T6 the proportion of summit diet was taken to be the same value as in T4. The concentration of threonine in T6 was formulated and calculated to be the same as in T4.

Table 2.4 Dilution of summit diet and dietary threonine concentrations (fitted values) for T1 to T6.

Treatment	Summit:Dilution	Threonine Concentration (g/kg)
1	100:0	7.8
2	85:15	6.7
3	70:30	5.6
4	55:45	4.6
5	40:60	3.5
6	55:45	4.6

2.2.4 Slaughter procedure and carcass analysis

Pigs were killed by an intra peritoneal injection of 20 ml Pentobarbitone Sodium 20% m/v (Euthatal™, Rhône Poulenc group). The intestinal tract was removed from the pig and the contents of the stomach and intestines were emptied. The carcass was portioned and together with the gastrointestinal tract was stored in a plastic bag and frozen at -20°C. The frozen portions were homogenized in a mincer. Samples were then collected in duplicate from each pig and used in the laboratory for proximate analysis. The three pigs slaughtered at 12 kg live weight were analysed in triplicate. The dry matter content of each sample was determined by freeze drying the samples for 24 hours. The protein content was calculated as nitrogen x 6.25, where nitrogen content of the dry matter was determined by auto analysis. Lipid content was determined by Soxhlet extraction of the freeze dried samples with petroleum ether at 40 - 60°C for 6 hours. Ash was determined by burning the samples at 550°C for 4 hours in a muffle furnace. Duplicate results were combined to provide a single result for each pig.

2.2.5 Statistical analysis

The results were analysed by analysis of variance using a factorial design with threonine concentration and temperature as factors. Data were analysed using Minitab (1994).

2.3 Results and Discussion

The average starting weight of the animals on all treatments was 12.94 ±0.90kg and the average slaughter weight was 25.41 ±0.67kg. The average live weight of three pigs used for determining the initial condition of the experimental pigs was 12.64 ±0.54kg . Empty body weight of these pigs was 11.49±0.56kg. The composition of this initial slaughter group was 1.76 ±0.08kg protein, 1.03 ±0.04kg lipid, 8.04 ±0.35kg moisture and 0.42 ±0.02kg ash. See Appendix 1 for detailed results (average daily gains, food intakes, body composition, body tissue growth rates) of each pig in this particular experiment. See Appendix 2 for the regression equations for each of the response curves plotted.

2.3.1 *Food intake and live weight changes*

The response in empty body weight (EBW), gut fill (GF), voluntary feed intake (FI), average daily gain (ADG) and feed conversion efficiency (FCE) to the threonine dietary treatments and temperature are shown in Table 2.5. There were no significant differences in EBW and GF across the dietary and temperature treatments. The highest GF was found at 18°C. At 18°C the environmental heat demand, associated with an ambient temperature below the comfort zone (Ferguson, 1996), will cause the animal to increase its voluntary food intake (Verstegen *et al*, 1982) and hence an increase in GF. GF was found to increase linearly with increasing concentrations of threonine in the diet. In the diets with the lower threonine concentrations there was a greater proportion of dilution diet, and hence more sugar and starch. Both sugar and starch are very soluble and readily digestible ingredients which will result in an increase in the rate of passage through the digestive tract. This also results in a lower gut fill:food intake ratio (GF index in Table 2.4). There were significant differences ($P < 0.05$) in GF index between the treatments. The GF index also increased linearly with an increase in dietary threonine concentration. As the dietary threonine concentration decreased there appeared to be a trend for a more rapid movement of digesta through the digestive tract.

The daily food intake over the live weight range of 12 kg to 25 kg increased as the dietary threonine concentration decreased from treatments 8.1 to 3.4 g/kg (Figure 2.2). The pigs

appeared to attempt to maintain a constant threonine intake as the threonine content of the feed was reduced in an effort to grow at their potential. In so doing they would have overconsumed energy and could therefore have been expected to deposit increasing amoumts of fat in the gain. Temperature had a significant effect ($P < 0.001$) on feed intake. There is considerable evidence supporting the effect of environmental temperature on voluntary feed intake (Fuller and Boyne, 1971; Close and Stanier, 1978; Rinaldo and Le Dividich, 1991; Schenck *et al.* 1992). At the comfort temperature of 26°C food intake was lower than at the other temperatures. Feed intake at lower threonine concentrations at18°C was higher than at the other environmental temperatures.

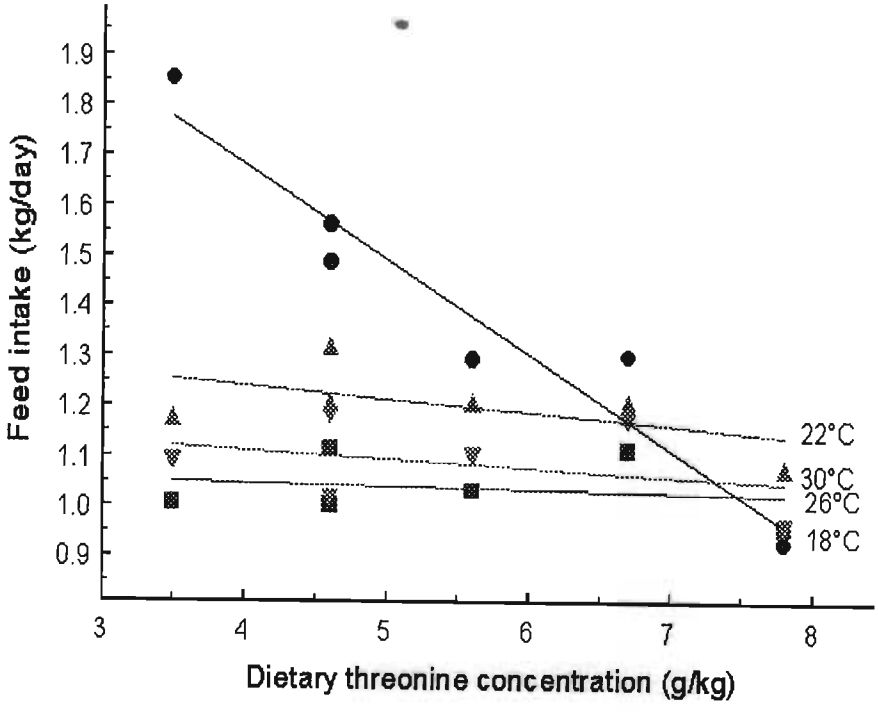

Figure 2.2 The effect of dietary threonine concentration on the food intake of growing pigs from 12 kg to 25 kg live weight using four different temperature regimes, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

A linear regression of feed intake on dietary threonine concentration at 18, 22, 26 and 30°C was performed on data from the current experiment (Figure 2.2) as a means of assessing the effect of environmental temperature on food intake. At 18°C there was a marked effect of temperature on

feed intakes. At low dietary threonine concentrations the pigs were able to increase feed intakes dramatically to compensate for the deficiency in the first limiting nutrient. This is due to the pigs being able to dissipate the extra heat produced on these poor quality diets together with increased digestive and metabolic processes. Feed intakes are lowered at higher temperatures and this was clearly seen at 26°C and 30°C. However, at the comfort temperature of 26°C food intake was lower than at the other temperatures. At this temperature on poor quality diets the pigs are able to utilize dietary threonine more efficiently as less feed was required to improve daily growth rates as seen in Figure 2.4.

It is interesting to note that the dietary treatment with the highest total heat loss (T5) also had the highest feed intake, indicating that one of the most important factors regulating voluntary feed intake is the maximum amount of heat that an animal can dissipate. It is also noted that the temperature (18°C) with the highest total heat loss (THL) also had the highest feed intake, therefore the lower the ambient temperature the more heat the animal can dissipate. The pig will attempt to grow at its potential growth rate, and is prevented from doing this at low dietary threonine concentrations due to the amount of feed that has to be consumed to satisfy its requirements. On feeds with low threonine contents the pig cannot dissipate all the heat that is produced in consuming what would be needed. At low temperatures they can dissipate more heat and in so doing they can get closer to the desired threonine intake. In this experiment at 18°C, on an adequate threonine feed, feed intake is the same as at the higher environmental temperatures, but it increases beyond the others as the dietary threonine concentration is reduced. The thermal environment in which a pig is maintained influences its voluntary feed intake (Close and Stanier, 1984): in a cold (relative to thermoneutrality) environment, pigs would need to consume more feed in an attempt to meet their maintenance energy needs. Whereas increasing the temperature above the thermoneutral zone results in a reduction in feed intake (Close and Stanier, 1984; Rinaldo and Le Dividich, 1991; Schenck, Stahly and Cromwell, 1992). Similar results were obtained in this experiment (Table 2.5). There was a 26.1% increase in feed intake at 18°C (1.401 kg/d) when compared to the feed intake at 26°C (1.036 kg/d).

Table 2.5 The response in empty body weight (EBW), food intake (FI), average daily gain (ADG), and food conversion efficiency (FCE) of growing pigs from 12 kg to 25 kg live weight to six dietary threonine concentrations and four temperatures.

Temperature	Dietary Treatment	EBW (kg)	Gut Fill (kg)	FI (kg/d)	Gut Fill Index[a]	ADG (kg/d)	FCE[b]
18°C	T1	23.19	2.18	0.925	2.40	0.550	596
	T2	22.98	1.88	1.295	1.45	0.540	417
	T3	22.97	2.31	1.290	1.79	0.560	434
	T4	22.78	2.59	1.485	1.91	0.455	327
	T5	22.23	1.73	1.850	0.97	0.335	183
	T6	24.79	1.56	1.560	1.07	0.525	356
22°C	T1	23.41	1.99	1.075	1.88	0.655	605
	T2	23.77	1.81	1.205	1.51	0.630	523
	T3	22.59	2.14	1.205	1.80	0.480	393
	T4	23.82	1.68	1.205	1.40	0.450	374
	T5	23.07	1.86	1.175	1.61	0.400	344
	T6	23.59	1.92	1.315	1.46	0.545	420
26°C	T1	23.78	2.22	0.955	2.37	0.575	612
	T2	23.39	2.21	1.110	2.05	0.560	508
	T3	23.86	2.04	1.030	1.97	0.460	447
	T4	24.28	1.70	1.115	1.53	0.470	377
	T5	22.63	2.20	1.005	2.19	0.335	333
	T6	23.76	1.56	1.000	1.55	0.420	420
30°C	T1	23.15	2.32	0.960	2.47	0.505	524
	T2	23.66	2.06	1.170	1.80	0.480	417
	T3	24.19	1.76	1.100	1.61	0.435	395
	T4	22.80	2.23	1.015	2.19	0.370	366
	T5	23.50	1.96	1.090	1.80	0.305	279
	T6	24.22	1.83	1.180	1.62	0.470	399
SEM		0.50	0.24	0.145	0.34	0.043	39
Main Effects and SEM of:							
Temperature							
18°C		23.16	2.04	1.401	1.595	0.494	386
22°C		23.37	1.90	1.197	1.608	0.527	443
26°C		23.61	1.99	1.036	1.941	0.470	449
30°C		23.58	2.03	1.086	1.912	0.428	397
SEM		0.20	0.10	0.059	0.14	0.018	16
Dietary Treatment:							
T1		23.38	2.18	0.979	2.27	0.571	584
T2		23.45	1.99	1.195	1.70	0.553	466
T3		23.40	2.06	1.156	1.79	0.484	417
T4		23.42	2.05	1.205	1.75	0.436	361
T5		22.86	1.94	1.280	1.64	0.344	285
T6		24.09	1.71	1.264	1.42	0.490	399
SEM		0.25	0.12	0.072	0.17	0.021	20
Significance of:							
Temperature (Temp)		NS	NS	***	NS	**	**
Dietary Treatment (T)		NS	NS	NS	*	***	***
Temp X T		NS	NS	NS	NS	NS	NS

[a] Gut fill index = Gut fill / FI

[b] FCE = g gain / 1000 g food

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

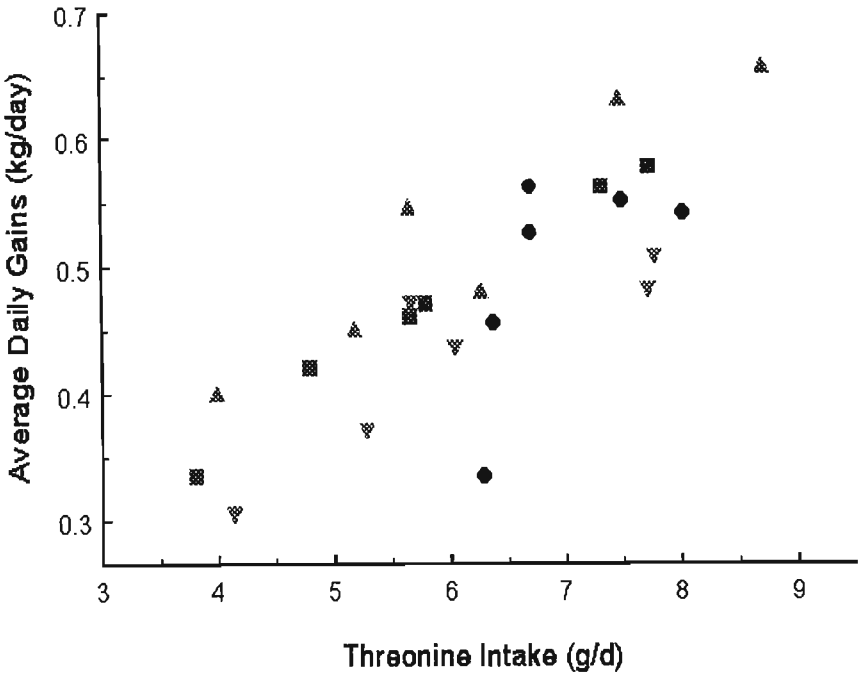

Figure 2.3 The effect of threonine intake on the average daily growth rate of pigs from 12 kg to 25 kg live weight at four different environmental temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

There were significant differences ($P < 0.001$) in the rate of growth (ADG) between dietary treatments, with the highest gains being recorded on T1 (0.571 kg/d). Decreasing the threonine concentration of the diet (and hence decreasing nutrient intakes) resulted in significant decreases ($P < 0.001$) in ADG irrespective of the ambient temperature (Figure 2.4). The response to dietary threonine was linear between T1 to T5. However, there was an increase in the ADG in T6 from T5, indicating that threonine was limiting in the summit food, there being no protein in the dilution food. The maximum ADG was on T1 (0.571 kg/d) which was 0.227 kg/d greater than on animals fed T5. There appeared to be a linear response to increasing dietary threonine intake, with increasing ADG (Figure 2.3).

There were significant differences ($P < 0.01$) in ADG between temperature treatments with the highest growth rate at 22°C (0.0527 kg/d) and the lowest at 30°C (0.428 kg/d). It appears that above 26°C growth is depressed. In a hot (relative to thermoneutrality) environment, pigs reduce their feed intake (which reduces growth) in an attempt to minimize the burden of dissipating heat produced from digestive and metabolic processes (Schenck *et al*, 1992).

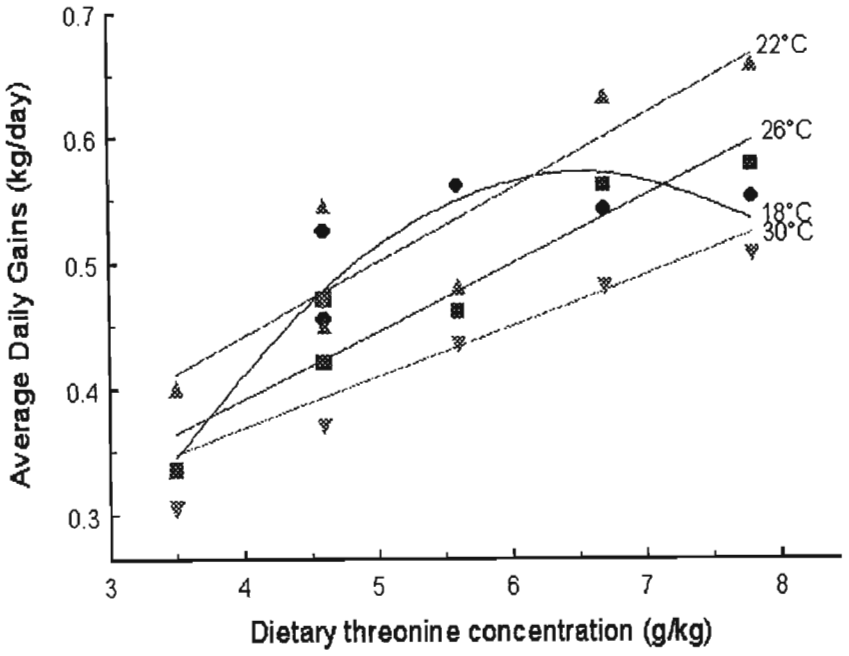

Figure 2.4 The response in daily growth rates in growing pigs from 12 kg to 25 kg live weight to dietary threonine concentration at 18°C, 22°C, 26°C and 30°C.

There was no dietary threonine x temperature interaction in liveweight gain for ADG indicating that the response to temperature was independent of dietary threonine content. Similarly the response in ADG to dietary threonine was independent of environmental temperature. However, it is known that environmental temperature has a direct effect on voluntary food intake (Sugahara, Baker, Harmon and Jensen, 1970; Schenck *et al.* 1992) and therefore on the rate, efficiency, and composition of gain in growing pigs. In the current experiment a regression of average daily gains on dietary threonine content at each environmental temperature was performed (Figure 2.4). From Figure 2.4 it is apparent that at the low environmental temperatures of 18°C and 22°C daily growth rates were generally higher than at 26°C and 30°C. This is due to the fact that at low environmental temperatures the animals were able to increase their feed intakes, and on diets deficient in threonine the animals were able to lose more heat produced as a result of the high heat increment of feeding on these poor diets. This resulted in improved growth rates compared with those at higher environmental temperatures, where feed intakes were depressed. At 30°C there was a marked depression of growth rates, compared with those at lower temperatures. However, at 18°C the growth rate of the pigs decreased with increasing dietary threonine concentration. This response is contradictory to the theory that at cold exposure, the elevated nutrient intakes

increase the growth rates of young pigs (Schenck *et al.* 1992). From Figure 2.4 it therefore appears that temperature has had an effect on the response in daily growth rates to dietary threonine content. This effect was especially evident at low dietary threonine concentrations, where at lower environmental temperatures the pigs were able to compensate for the deficiency by increasing feed intakes but at high environmental temperatures the pigs were not able to compensate for any deficiency due to a depressed feed intake.

An increase in the supply of threonine in the diet resulted in significant increases ($P < 0.001$) in the amount of gain per unit of food. The lowest FCE was recorded at 18°C (385.52 g gain / kg food) and the highest at 26°C (449.43 g gain / kg food). This indicates once again that in a cold environment pigs will need to consume more feed in an attempt to meet their elevated maintenance needs (maintaining homeothermy) which must take place before any growth can take place. The desired food intake will depend on the content of the first limiting nutrient in the feed. The lowest FCE was on T5 (284.95 g gain/ kg food) and the highest on T1 (584.28 g gain / kg food). As the threonine content increased (from T5 to T1) so less food was required for maximum growth, resulting in an increase in the FCE (Figure 2.5). An increase in the FCE with the addition of supplemental threonine is seen in T6. There was no significant dietary threonine x temperature interaction indicating that the response in FCE to dietary threonine concentration was independent of the environmental temperature.

The response in feed conversion efficiencies (FCE: g gain/1000g feed) to dietary threonine content and temperature follow similar trends as discussed with ADG and feed intakes. However, on lower dietary threonine concentrations at 18°C at the same level of feed intake, the pigs exhibited lower feed conversion efficiencies (Figure 2.5). This was due to the fact that at low temperaures more energy went into heat production and there was less net energy available for tissue deposition (decreased growth rates), therefore decreasing feed conversion efficiencies. There were similar responses in feed conversion efficiencies to dietary threonine content at 22°C and 26°C, though those were slightly higher at 26°C. At higher dietary threonine concentrations there was a higher FCE at 18°C than at 30°C. This was due to the increased feed intakes at 18°C and better growth rates.

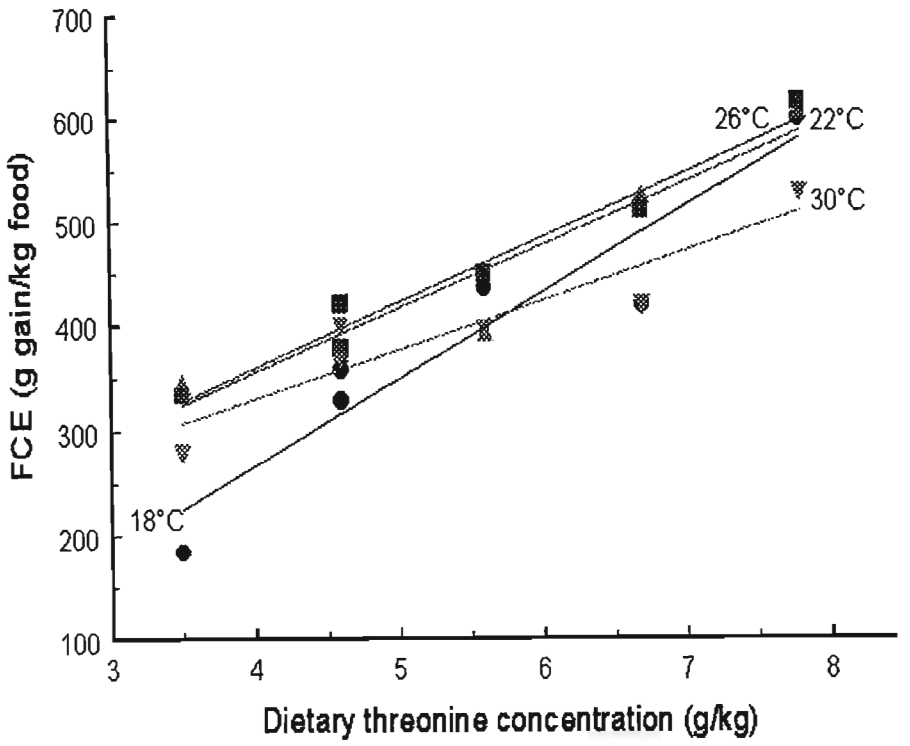

Figure 2.5 The effect of dietary threonine concentration on the feed conversion efficiency of growing pigs from 12 - 25 kg live weight at four different environmental temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

2.3.2 *Body composition*

The chemical composition of the pigs at 25 kg live weight is shown in Table 2.6. The proportion of protein in the empty body at 25 kg live weight decreased dietary threonine concentration ($P < 0.001$). An increase in protein in the empty body with T6 compared with that on T5 once again demonstrates that threonine was limiting in the dilution series. There was an 18.4% reduction in body protein between pigs fed on T1 (3.860 kg) as opposed to those fed on T5 (3.151 kg). The changes in body protein composition which accompanied the decrease in dietary threonine from 8.1 g/kg on T1 to 3.4 g/kg on T5 (dietary protein concentrations from 259 g/kg on T1 to 104 g/kg on T5) were typical of those which have been reported previously for growing pigs (McCracken, Eddie and Stevenson, 1980; Campbell and Dunkin, 1983; Zhang, Partridge, Keel and Mitchell, 1984; Campbell and Taverner, 1988).

There was no statistically significant temperature x dietary treatment interaction indicating that

the response to decreasing dietary threonine concentrations was independent of the environmental temperature. However, there was a significant effect ($P < 0.05$) of environmental temperature on the protein content of the empty carcass. At 18°C (cold) and 22°C (cool) the protein content of the carcasses were lower and the fat content was higher than at the higher temperatures. This effect was most pronounced at 18°C. In an attempt to maintain homeothermy, the additional feed consumed resulted in additional energy consumption and an increase in the lipid content of the empty body weight at these two temperatures. This was contrary to the expectation that less net energy would be available for lipid deposition in cold conditions as energy was repartitioned into cold thermogenesis.

There were significant differences ($P < 0.05$) in the protein contents of the empty body over the four different temperatures, with body protein content decreasing as environmental temperature decreased. There was no significant effect of environmental temperature on the lipid content of the empty carcass, nor was there a significant temperature x dietary treatment interaction. However, there was a significant effect ($P < 0.001$) of dietary threonine concentration on the lipid content of the empty body weight.

The lipid content decreased linearly from T5 (4.898 kg) to T1 (2.041 kg). The increased feed intake on the treatments with low dietary threonine resulted in the overconsumption of energy and an increase of 140% in the lipid content of the empty carcass. The fat content of the empty carcass decreased from T5 to T6 with the addition of supplemental threonine. The fat content of the empty carcass is expressed as:

$$\text{Lipid content (\%)} = \text{(Lipid weight / EBW) X 100} \qquad (2.1)$$

where, $$\text{Lipid weight / EBW} = \text{Initial Lipid} + \text{Lipid gain / Initial EBW} + \text{EBW Gain} \qquad (2.2)$$

To illustrate the effect of dietary threonine concentration on the lipid component of the growing pig lipid gain as a percentage of total EBW gain was plotted against threonine content to provide a more dramatic illustration of the effect of dietary threonine concentration on fat content over the live weight range 12 kg to 25 kg live weight than merely plotting lipid content of the carcass

(Figure 2.4). This eliminated the effect of initial lipid and initial EBW, which tended to "dilute" the overall impression of the effect of dietary threonine concentration on the fat content of the growing pig as it provided an illustration of fat content of the empty carcass at 25 kg live weight as affected by dietary threonine concentration.

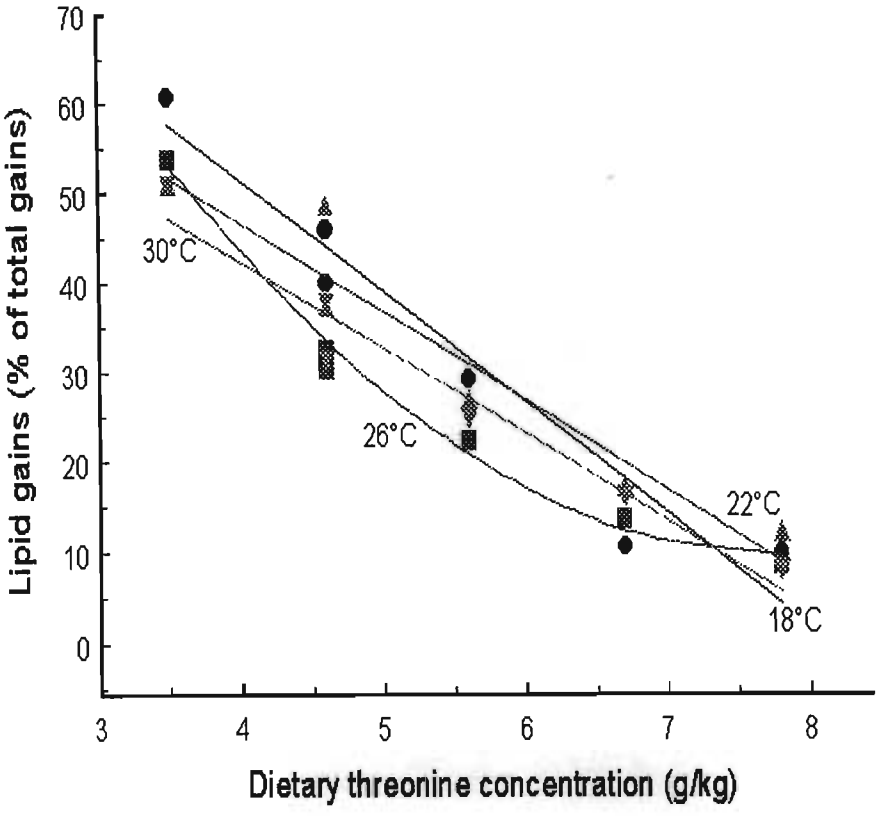

Figure 2.6 The effect of dietary threonine concentration on the lipid content (gains) of the total gains of growing pigs from 12 kg to 25 kg live weight at four different temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

Environmental temperature appeared to have no significant effect on the response in lipid gains to dietary threonine concentration (Figure 2.6). However, at 18°C at low dietary threonine concentrations lipid gains were higher than at the other temperatures. This could be due to increased feed intakes at this temperature and low dietary threonine concentrations resulting in an overconsumption of energy and increased lipid gains. Over a range of dietary threonine concentrations the lipid gains at the comfort temperature of 26°C appeared lower than at the other

temperatures. This seems to indicate that at 26°C the pigs will attain a lower carcass fatness on these dietary threonine concentrations. Other than the response in lipid gain at 18°C and 26°C mentioned above there appeared to be no significant effect of temperature on this response. This was especially evident at high dietary threonine concentrations where there appeared to be no significant effect of temperature on lipid gains.

Moisture content of the empty carcass decreased linearly from T1 to T5. There were significant differences ($P < 0.001$) in the moisture contents at the various dietary threonine concentrations. Temperature had a significant effect ($P < 0.05$) on body moisture content. This is as a result of the lower body moisture weights attained at 18°C and 22°C.

Table 2.6 Table showing the protein weight, lipid weight, moisture weight and ash weight in the empty body weight of pigs at 25 kg live weight when fed diets with different threonine concentrations at four different environmental temperatures.

Temperature	Dietary Treatment	Protein (kg)	Lipid (kg)	Moisture (kg)	Ash (kg)
18°C	T1	3.785	2.075	16.030	0.760
	T2	3.680	2.090	15.925	0.755
	T3	3.570	3.510	14.790	0.705
	T4	3.290	3.995	14.195	0.750
	T5	3.030	5.195	12.930	0.670
	T6	3.515	5.165	14.820	0.795
22°C	T1	3.770	2.245	16.025	0.835
	T2	3.675	2.780	15.890	0.740
	T3	3.430	3.240	14.620	0.685
	T4	3.665	4.130	14.735	0.755
	T5	3.160	4.485	13.875	0.690
	T6	3.095	4.770	14.285	0.720
26°C	T1	4.035	1.995	16.485	0.785
	T2	3.735	2.390	16.035	0.765
	T3	3.620	3.280	15.655	0.770
	T4	3.620	3.940	15.450	0.780
	T5	3.125	4.780	13.555	0.690
	T6	3.600	3.840	15.155	0.705
30°C	T1	3.850	1.850	16.190	0.700
	T2	3.790	2.635	15.980	0.720
	T3	3.820	3.445	15.695	0.730
	T4	3.430	3.575	14.535	0.720
	T5	3.290	5.130	13.905	0.715
	T6	3.610	4.385	14.940	0.680
SEM		0.125	0.234	0.345	0.034
Main effects and SEM of:					
Temperature					
18°C		3.478	3.672	14.782	0.739
22°C		3.466	3.608	14.905	0.738
26°C		3.623	3.371	15.389	0.749
30°C		3.632	3.503	15.208	0.711
SEM		0.051	0.096	0.141	0.014
DietaryTreatment:					
T1		3.860	2.041	16.183	0.770
T2		3.720	2.474	15.958	0.745
T3		3.610	3.369	15.190	0.723
T4		3.501	3.910	14.729	0.751
T5		3.151	4.898	13.566	0.691
T6		3.455	4.540	14.800	0.725
SEM		0.062	0.117	0.173	0.017
Significance of:					
Temperature (Temp)		*	NS	*	NS
Dietary Treatment (T)		***	***	***	NS
Temp X T		NS	NS	NS	NS

SEM standard error of means; NS not significant: * P < 0.05; ** P < 0.01; *** P < 0.001

2.3.3 *Protein and lipid retention*

In the growing animal the consumption of food is associated with increments in both protein and fat formation (Close, Mount and Brown, 1978). The effects of dietary threonine content on protein and fat deposition are shown in Table 2.7. The responses in body tissue deposition to ambient temperature are also shown.

Protein retention (PR) decreased significantly ($P < 0.001$) as dietary threonine concentration decreased (Figure 2.7) . Similarly, as dietary threonine intake decreased, PR decreased (Figure 2.8). Protein retention increased when T5 was supplemented with threonine (T6), showing a positive growth response to the addition of supplemental threonine in T6. This positive growth response again verifies the fact that threonine was limiting in treatment 1 to 5.

There was no significant environment x dietary treatment interaction. This is possibly due to the fact that only two animals were used per replicate, resulting in a high standard deviation. One would not expect this to be so as on poor quality diets deficient in one of the essential amino acids, the extra food consumed to attain maximum protein growth rates would mean the environment would be important due to the extra heat increment of feeding on these poor quality diets. On T5 the highest PR was 44.40 g/day at 22°C. The lowest was at 30°C with a protein growth rate of 36.83 g/day on T5. The response in PR to temperature in animals fed a threonine-deficient diet does suggest that animals can only achieve maximum protein growth on threonine limiting diets if the environment is sufficiently cool to allow the extra heat increment of feeding to be dissipated.

The main effect of temperature had no significant effect on PR. The highest PR was at 22°C (71.46 g/day) and the lowest at 30°C (62.67 g/day). Similar responses were shown by Rinaldo and Le Dividich (1991) between 25°C and 31.5°C. One explanation for the reduction in PR a t high temperatures is the decrease in feed intake and a reduction in the net energy available for tissue deposition.

Table 2.7 Table showing the protein (PR), lipid (LR), moisture (MR) and ash (AR) deposition of the empty body of pigs grown between 12 kg and 25 kg live weight when fed feeds with different threonine concentrations at different environmental temperatures.

Temperature	Dietary Treatment	PR (g/d)	LR (g/d)	MR (g/d)	AR (g/d)
18°C	T1	82.9	41.4	325.0	13.8
	T2	84.4	47.2	348.4	15.0
	T3	79.6	113.0	297.0	13.0
	T4	53.2	110.4	212.5	11.5
	T5	37.8	117.2	147.9	7.7
	T6	67.1	156.8	260.9	14.5
22°C	T1	103.2	64.4	408.8	21.2
	T2	92.0	83.3	378.6	15.7
	T3	66.3	91.1	264.4	10.4
	T4	66.5	114.4	228.7	11.6
	T5	44.4	120.1	182.6	8.3
	T6	56.3	161.4	263.4	12.8
26°C	T1	99.2	40.7	361.3	15.5
	T2	74.3	51.8	300.8	12.9
	T3	64.2	75.4	264.0	12.5
	T4	58.5	91.4	232.7	11.6
	T5	37.0	103.9	149.4	7.3
	T6	60.5	97.7	232.6	9.0
30°C	T1	83.4	33.2	320.2	11.1
	T2	74.4	60.3	288.2	11.0
	T3	67.5	80.8	249.5	10.1
	T4	49.2	77.9	191.6	8.8
	T5	36.8	95.3	142.9	7.3
	T6	64.7	118.6	240.6	9.2
SEM		6.89	12.91	26.80	1.36
Main effects and SEM of:					
Temperature					
18°C		67.5	97.7	265.3	12.6
22°C		71.5	105.8	287.7	13.4
26°C		65.6	76.8	256.8	11.5
30°C		62.7	77.7	238.8	9.6
SEM		2.81	5.27	10.94	0.56
Dietary Treatment:					
T1		92.2	44.9	353.8	15.4
T2		81.3	60.7	329.0	13.6
T3		69.7	90.1	268.7	11.5
T4		56.9	98.5	216.4	10.9
T5		39.0	109.1	155.7	7.7
T6		62.1	133.6	249.4	11.4
SEM		3.44	6.46	13.40	0.68
Significance of:					
Temperature (Temp)		NS	***	*	***
Dietary Treatment (T)		***	***	***	***
Temp X T		NS	NS	NS	NS

SEM standard error of means; NS not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

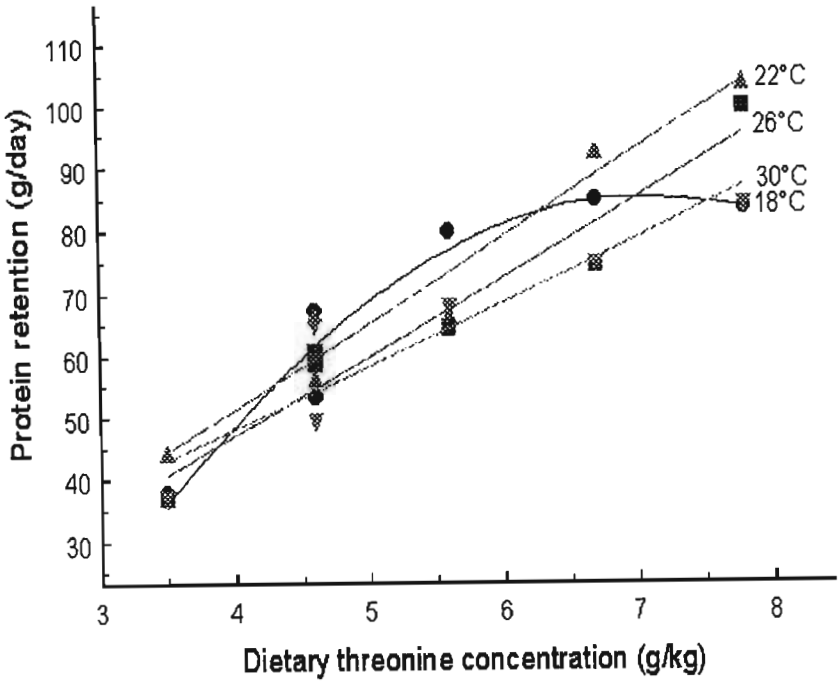

Figure 2.7 The response in protein growth rate of growing pigs between 12 kg and 25 kg live weight to dietary threonine concentration at 18°C, 22°C, 26°C and 30°C.

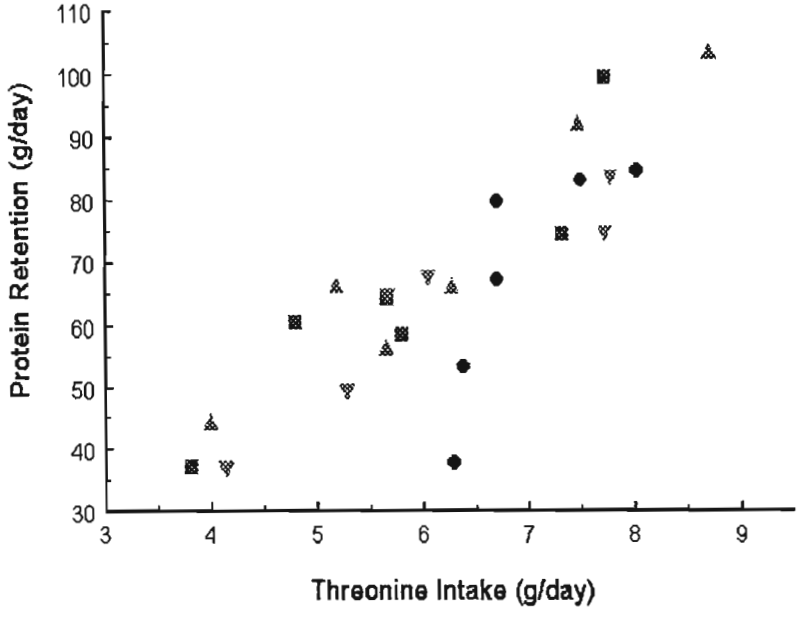

Figure 2.8 The effect of threonine intake on the protein growth rate of growing pigs from 12 kg to 25 kg live weight at four different environmental temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

There was a highly significant effect of temperature ($P < 0.001$) on lipid retention (LR). This may be attributed to the high lipid growth rate at 22°C. There was a 27.35% decline in LR between 22°C (105.75 g/day) and 26°C (76.83 g/day). At cool temperatures the pigs overconsume on energy due to increased feed intakes to maintain homeothermy resulting in increased fat deposition. At 22°C less energy would be partitioned into cold thermogenesis than at 18°C, resulting in the higher LR at 22°C (105.75 g/day) than at 18°C (97.66 g/day).

There was a significant increase ($P < 0.001$) in LR as the dietary concentration of threonine decreased from T1 to T5. This was to be expected due to the overconsumption of energy on the poorer diets.

There was a significant decrease in ash retention ($P < 0.001$) with decreasing dietary threonine concentration to T5. The threonine shortage in T5 might have impaired the formation of bone matrix with a consequent lower mineralization.

2.3.4 *Heat loss*

On the assumption that heat storage in young pigs is negligible (Ferguson, 1996), total heat lost is equal to total heat produced. Total heat loss (THL) is calculated from the equations:

$$ER = (23.8 \times PR) + (39.6 \times LR) \quad \text{(MJ/d)} \qquad (2.3)$$

where, ER = Energy Retained (MJ/d)
PR = Protein Retention (kg/d)
LR = Lipid Retention (kg/d)

$$Ei = ME \times Fi \quad \text{(MJ/d)} \qquad (2.4)$$

where, Ei = Energy Intake (MJ/d)
ME = Metabolizable Energy (MJ/kg)
FI = Food Intake (kg/d)

where,

$$ME = DE \times (0.997 - 0.000189 \times CP) \text{ (MJ/kg)} \qquad (2.5)$$

where, DE = Digestible Energy (MJ/kg)
CP = Crude Protein (g/kg)

$$THL = Ei - ER \qquad (MJ/d) \qquad (2.6)$$

The results for Total Heat Loss (THL) are shown in Table 2.8.

There were significant differences ($P < 0.001$) in THL between the temperature treatments. There were no significant differences in THL between the dietary treatments. Maximum THL occurred on T5 (13.141 MJ/d). The response in THL across both the dietary and temperature treatments followed the same trends as observed with the response in food intake.

The similarities in response to THL and feed intake indicate that food intake is strongly influenced by the amount of heat an animal can lose to its environment. Similar responses have been observed by Schenck *et al.* (1992) and Close and Stanier (1984), who found that the thermal environment in which a pig is maintained influences its voluntary feed intake. From the results it can be seen that the lower the temperature, the greater the amount of heat the animal can lose. The potential exists for such animals to lose more heat at 18°C, when fed a diet with a high heat increment of feeding such as T5, than those kept at higher temperatures.

The highest THL was on T5 (13.1 MJ/d) at 18°C and T2 (12.6 MJ/d) at 30°C. At higher temperatures the animals are unable to lose sufficient heat to the environment, and are thus prevented from achieving the desired intake of the threonine deficient diet. It is clear from the results that pigs attempt to increase their intakes of a feed which is made increasingly limiting in threonine in order to meet their requirement for the limiting nutrient.

Table 2.8 Table showing the Total Heat Loss (MJ/d) for pigs between 12kg and 25kg live weight when fed diets differing in threonine concentration at four different environmental temperatures.

Temperature	Dietary Treatment	Total Heat Loss (MJ/d)
18°C	T1	10.15
	T2	15.02
	T3	13.07
	T4	16.01
	T5	21.49
	T6	15.03
22°C	T1	10.97
	T2	12.08
	T3	12.98
	T4	11.44
	T5	11.37
	T6	11.50
26°C	T1	10.23
	T2	11.53
	T3	9.87
	T4	10.11
	T5	9.07
	T6	8.89
30°C	T1	10.97
	T2	12.03
	T3	10.57
	T4	9.53
	T5	10.63
	T6	10.54
SEM		1.94
Main effects and SEM of:		
Temperature		
18°C		15.13
22°C		11.72
26°C		9.95
30°C		10.71
SEM		0.79
Dietary Treatment:		
T1		10.58
T2		12.66
T3		11.62
T4		11.77
T5		13.14
T6		11.49
SEM		0.97
Significance of:		
Temperature (Temp)		***
Dietary Treatment (T)		NS
Temp X T		NS

SEM standard error of means; NS not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

2.3.5 *Efficiency of protein utilisation*

The two major components of a growing pig's requirements for protein are that for maintenance and that for tissue growth. The efficiency with which dietary protein is used for maintenance and tissue growth will determine the amount of dietary protein that must be supplied in the diet (Adeola, 1995). The amount of dietary protein which is available for metabolism is dependent upon the essential amino acid supply within the protein. The body uses mixtures of essential and non-essential amino acids for purposes of synthesizing proteins, and does not use the supplied amino acids as individual entities. Thus the balance between the essential amino acids is critical in optimizing protein utilisation. The value of a given dietary protein dependes on the essential amino acids required to make up ideal body protein on the one hand, and the balance of amino acids supplied from the diet on the other hand (Whittemore, 1993). Calculation of protein value (v) requires a strict definition of the essential amino acid balance in ideal protein for pigs. The required balance of amino acids in ideal protein for growing pigs is that which is required by the body, so reflects the amino acid content of body protein. Whittemore (1993) determined the quantity of the amino acid threonine in ideal protein as 45 g/kg ideal protein.

With decreasing dietary threonine concentration from 8.1 g/kg on T1 to 3.4 g/kg on T5 (dietary protein concentrations from 259 g/kg on T1 to 104 g/kg on T5) the efficiency of protein utilization can be assessed by determining the ratio of protein retained and digested ideal protein intake (DIPI), where DIPI is determined from the equation as defined by Kyriazakis and Emmans (1992a), *viz*:

$$DIPI = FI \times CP \times v \times d_{cp} \qquad (g/d) \qquad (2.7)$$

where FI = Food intake (g/d)
CP = Crude protein (N X 6.25) content of the food (g/g)
d_{cp} = digestibility of CP (0.80)

A protein value (v) was calculated for all diets as:

$$v = (TC/CP)/45 \qquad (2.8)$$

where TC = Threonine content of the dietary treatment (g/kg)
CP = Crude protein content of the diet (g/g)
45 = 45 g threonine/kg ideal protein

Figure 2.9 illustrates the relationship between protein retention (PR) and digestible ideal protein intake (DIPI). The regression equation fitted to the data was:

$$PR = - 0.2 + 0.610 \times DIPI \qquad (g/d) \qquad (2.9)$$

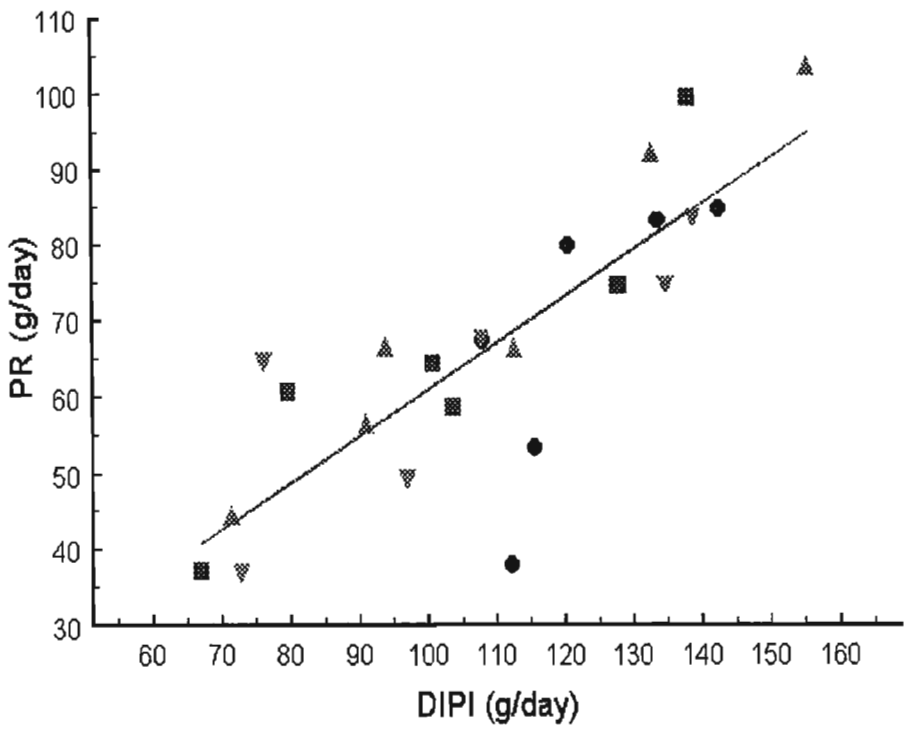

Figure 2.9 The daily rates of protein retention in pigs grown from 12 kg to 25 kg live weight against digestible ideal protein intake on diets differing in dietary threonine concentration and housed at four different ambient temperatures; (●) 18°C; (▲) 22°C; (■) 26°C; (▼) 30°C. Solid line (-) represents fitting of regression equation.

The slope of the fitted line (0.610) provides an estimate of the apparent efficiency of ideal protein utilization on diets differing in threonine concentration. The efficiency with which dietary protein is used for maintenance and tissue growth will affect the amount of dietary protein that must be supplied in the diets.

The net efficiency of ideal protein utilization (e_p) above maintenance can be calculated from the equation of Kyriazakis and Emmans (1992b):

$$e_p = PR/(DIPI - MP) \qquad (2.10)$$

where PR = Protein retained (g/d)
DIPI = Digestible ideal protein intake (g/d)
MP = Maintenance protein

The maintenance protein requirement is calculated on an ideal protein basis rather than on a CP basis from the equation:

$$MP = 4.00 \times P \quad (g/d) \qquad (2.11)$$

where P = Protein weight of the pig (kg)

The e_p values calculated from equation 2.10 for the six dietary threonine treatments and four temperatures are shown in Table 2.9.

There were significant differences ($P < 0.05$) in efficiencies of protein utilization as the dietary threonine concentration decreased from T1 to T5 (and crude protein contents decreased from T1 to T5). As feed intakes decreased from T5 to T1 and digestible ideal protein intakes increased, there was a significant increase ($P < 0.001$) in protein retention. There was an increase in e_p over the same treatments (T5 to T1), except for T2 where there was a slight decrease. It appears that the first limiting nutrient, threonine, affected the efficiency with which the pigs could utilise the digestible ideal protein content in each diet. As threonine concentration increased the e_p values also increased as did the digestible ideal protein intakes. This is clearly seen in T6 with the supplementation of threonine in this diet, indicating that where an amino acid is the limiting nutrient the supplementation of poor diets with the limiting amino acid may improve the efficiency with which the pigs utilize the dietary protein content.

Table 2.9 The efficiencies of protein utilization (e_p) of growing pigs between 12 kg and 25 kg live weight at six dietary threonine concentrations and four environmental temperatures.

Temperature	Dietary Treatment	e_p
18°C	T1	0.704
	T2	0.662
	T3	0.751
	T4	0.589
	T5	0.385
	T6	0.766
22°C	T1	0.733
	T2	0.780
	T3	0.665
	T4	0.840
	T5	0.767
	T6	0.728
26°C	T1	0.836
	T2	0.653
	T3	0.752
	T4	0.656
	T5	0.677
	T6	0.938
30°C	T1	0.669
	T2	0.636
	T3	0.731
	T4	0.609
	T5	0.616
	T6	1.048
SEM		0.093
Main effects and SEM of:		
Temperature		
18°C		0.643
22°C		0.752
26°C		0.752
30°C		0.718
SEM		0.038
Dietary Treatment:		
T1		0.735
T2		0.683
T3		0.725
T4		0.673
T5		0.611
T6		0.870
SEM		0.047
Significance of:		
Temperature (Temp)		NS
Dietary Treatment (T)		*
Temp X T		NS

SEM standard error of means; NS not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

There was no significant effect of temperature on the efficiency of protein utilization. The lowest e_p was at 18°C. This result is supported by that of Ferguson (1996) who also found the lowest e_p to be at 18°C in an experiment where diets differed in digestible ideal protein content. The explanation offered is that at low temperatures the increased demand for energy results in an overconsumption of protein and a reduction in the efficiencies of protein utilization.

2.3.6 *Efficiency of threonine utilization*

It has been stated that the efficiency of protein utilization is not necessarily equal to that of individual amino acids (Baker, 1991; Chung and Baker, 1992). Hence, protein utilization does not necessarily provide knowledge on the efficiency of utilization of individual amino acids (Adeola, 1995). Where an amino acid is the first limiting nutrient in a diet, the determination of the efficiency of utilization of the amino acid for carcass growth will provide more accurate information for the development of models to better predict animal performance and response under a variety of nutritional situations. This is especially important here, where the results for the efficiency of protein utilization data above, appear to be influenced by the dietary level of the first limiting amino acid threonine.

In order to predict the efficiency of threonine utilization it is necessary to determine threonine retention in the carcass protein of the growing pigs. In this experiment an estimate of the threonine concentration (g/kg crude protein) of the whole body of pigs was used. Kyriazakis, Emmans and McDaniel (1993) estimated this concentration to be 38.2 g threonine/kg body protein. The protein retention data obtained in the present study were used to determine the threonine retention at each dietary threonine concentration and at each environmental temperature. Hence, the threonine retention for each threonine intake was used to determine the efficiency of threonine utilization. Regression analysis was conducted using individual data points to determine the relationship between deposition rates and intakes. The daily rates of threonine deposition and intake are shown in Table 2.10. There were significant differences ($P < 0.001$) in threonine intakes between the dietary treatments. Threonine intakes showed a linear response, with decreasing intakes as the dietary threonine concentration decreased. There was no significant effect of temperature on threonine intakes.

Table 2.10 The daily rates of threonine intake and threonine retention of growing pigs between 12 kg and 25 kg live weight at six dietary threonine levels and four different environmental temperatures.

Temperature	Dietary Treatment	Threonine Intakes (g/d)	Threonine Retention (g/d)
18°C	T1	7.50	3.17
	T2	8.03	3.23
	T3	6.71	3.04
	T4	6.39	2.04
	T5	6.29	1.44
	T6	6.71	2.57
22°C	T1	8.71	3.94
	T2	7.47	3.51
	T3	6.27	2.54
	T4	5.19	2.54
	T5	4.00	1.70
	T6	5.66	2.15
26°C	T1	7.74	3.80
	T2	7.33	2.84
	T3	5.67	2.45
	T4	5.80	2.23
	T5	3.82	1.42
	T6	4.56	2.31
30°C	T1	7.78	3.19
	T2	7.73	2.85
	T3	6.06	2.58
	T4	5.28	1.88
	T5	4.15	1.41
	T6	5.67	2.47
SEM		0.69	0.26
Main effects and SEM of:			
Temperature			
18°C		6.94	2.58
22°C		6.21	2.73
26°C		5.82	2.51
30°C		6.11	2.39
SEM		0.28	0.11
Dietary Treatment:			
T1		7.93	3.52
T2		7.64	3.11
T3		6.17	2.65
T4		5.66	2.17
T5		4.56	1.49
T6		5.65	2.37
SEM		0.35	0.13
Significance of:			
Temperature (Temp)		NS	NS
Dietary Treatment (T)		***	***
Temp X T		NS	NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

There were significant differences ($P < 0.001$) between the threonine deposition rates at different dietary threonine contents. They showed a linear response with increasing threonine retention as the dietary threonine content increased. It has been shown that the deposition of a limiting amino acid in carcass protein is linearly related to amino acid intake in pig feeds (Batterham Andersen, Baigent and White, 1990; Beech, Batterham and Elliot, 1991).

In the present experiment, threonine deposition was a linear function of daily threonine intake. A linear regression of daily carcass threonine deposition on daily threonine intake (Figure 2.10) indicated that the efficiency of dietary threonine utilization for carcass threonine deposition in pigs raised from 12 kg to 25 kg live weight was 0.72 ($r^2 = 0.97$).

The regression equation was determined using mean values of all pigs on treatments 3, 4, 5 and 6 for 18, 22, 26 and 30°C, assuming that the dietary threonine contents on T1 and T2 adequately satisfied the pigs requirements for this amino acid i.e. that threonine was not limiting in these two feeds. This provides an estimate of the efficiency of threonine utilization for carcass threonine deposition when a diet deficient in this amino acid is fed to young growing animals between 12 kg and 25 kg live weight. The regression equation fitted to these data is:

$$THRR = -1.79 + 0.719 \times THRI \quad (g/d) \qquad (2.12)$$

where THRR = Threonine retention (g/d)
THRI = Threonine intake (g/d)

Over the range of dietary threonine contents from T3 to T6, the utilization of threonine for carcass threonine deposition was essentially constant. This illustrates that amino acids other than threonine, the first limiting amino acid, had no effect on threonine utilization. This is confirmed by the previous work of Batterham *et al.* (1990).

Utilising dietary threonine with an efficiency of 0.72 in the current study indicates that 0.28 of the dietary threonine was either undigested or catabolized after absorption. Adeola (1995) explains that the loss of threonine during the normal physiological process of growth, absorption of threonine in forms unsuitable for protein synthesis, and threonine oxidation accounts, in major part, for the efficiency of dietary threonine utilization being less than 100%.

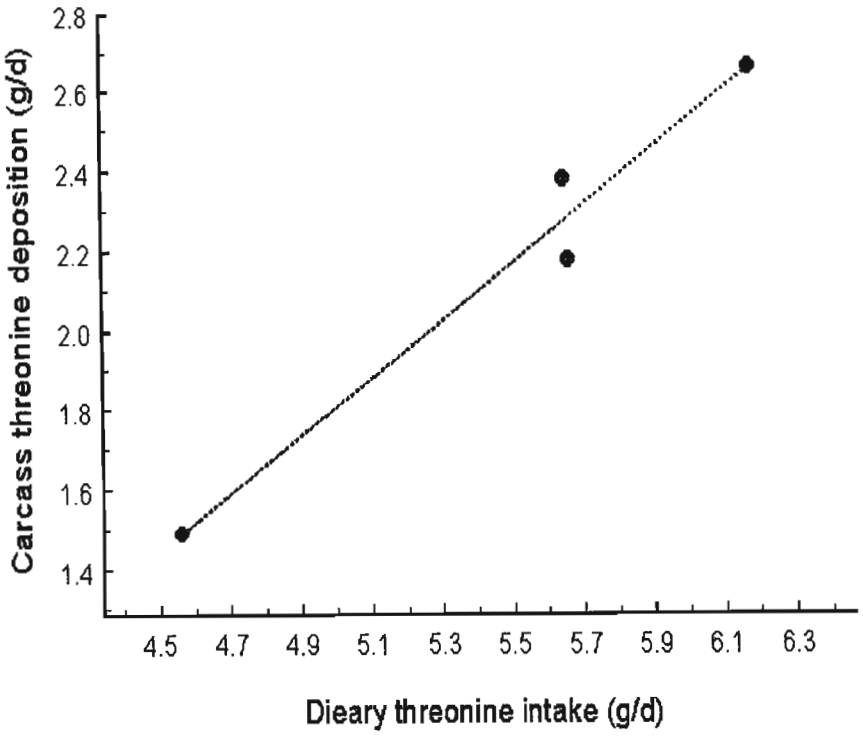

Figure 2.10 Relationship between threonine deposition rate in the carcass and daily dietary threonine intake of pigs fed on diets containing graded levels of threonine from 12 kg to 25 kg live weight. Straight line (-) represents fitting of regression equation.

The estimate of the efficiency of threonine utilization presented above was found to be significantly higher than in the literature. Adeola (1995) found the efficiency of threonine utilization in growing pigs from 10 kg to 20 kg live weight to be 0.60. Beech, Batterham and Elliot (1991) estimated the efficiency of threonine utilization over the live weight range 20 kg to 45 kg to be between 0.34 - 0.55. The estimate in the present study is therefore remarkably high and may be rather biased due to the pooling of the individual data points into means and using these means to obtain the regression equation. The result was a regression of carcass threonine on dietary threonine intake using four data points, i.e. only two degrees of freedom. When all the data points for T1 to T6 at 18, 22, 26 and 30°C were used, the regression equation was then determined from the 48 data points ($r^2 = 0.57$) was:

$$THRR = 0.204 + 0.375 \times THRI \quad (g/d) \quad (213)$$

where THRR = Threonine retention (g/d)
THRI = Threonine intake (g/d)

The linear regression of daily carcass threonine deposition on dietary threonine intake indicates that the efficiency of dietary threonine utilization was only 0.38 (Figure 2.11). This estimate seems to be more in line with that obtained by Beech *et al.* (1991), but lower than that estimated by Adeola (1995). This best fit estimate may appear rather low but is a more reliable estimate than the one presented above, because more data points were used to estimate the regression equation. In Figure 2.7 95% confidence limits have been included and although the best fit estimate of efficiency of threonine utilization has been plotted, this efficiency, determined by the slope of the regression line, may vary within the bounds of the confidence limits shown. However, the reliability of any of the estimates of efficiency presented here must be viewed with caution as an estimate of carcass threonine retention was made using an estimated value for threonine content of the protein of the whole body of the pig. It would be more appropriate to use values determined by chemical analysis for carcass amino acid concentration. The efficiency estimate may be further improved by determining the availability of the amino acid threonine in the diets used in the present experiment.

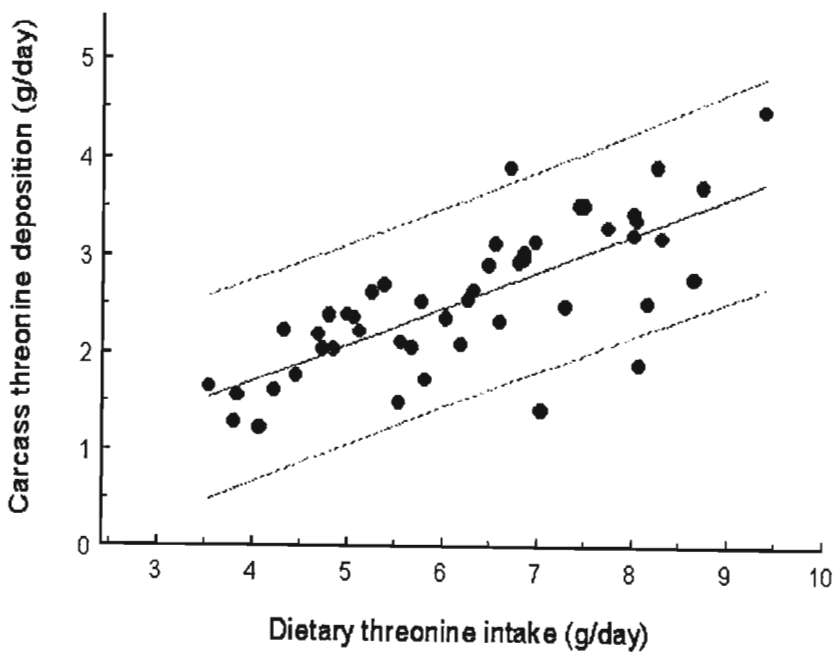

Figure 2.11 The relationship between carcass threonine deposition and dietary threonine intake in growing pigs between 12 kg and 25 kg live weight when fed six dietary threonine treatments at four different temperatures.

To assess the effect of temperature on the efficiency of threonine utilization a linear regression of daily carcass threonine deposition on daily threonine intake at each temperature was performed. The regression equations were determined from 12 data points at each temperature, using all dietary threonine treatments (T1 - T6). The results indicated that the efficiency of threonine utilization for carcass threonine deposition in these pigs was highest at 18°C with an efficiency of 0.84 ($r^2 = 0.65$), and lowest at 30°C with an efficiency of 0.43 ($r^2 = 0.89$). The relationship between carcass threonine deposition and dietary threonine intake at each temperature is shown in Figure 2.9. The regression equations are;

18°C: $$THRR = -3.27 + 0.844 \times THRI \quad (g/d) \quad (214)$$
$r^2 = 0.65$

22°C: $$THRR = -0.264 + 0.482 \times THRI \quad (g/d) \quad (215)$$
$r^2 = 0.92$

26°C: $$THRR = -0.086 + 0.459 \times THRI \quad (g/d) \quad (216)$$
$r^2 = 0.85$

30°C: $$THRR = -0.240 + 0.431 \times THRI \quad (g/d) \quad (217)$$
$r^2 = 0.89$

where, THRR = Threonine retention (g/d)
THRI = Threonine intake (g/d)

Figure 2.12 illustrates that at low dietary threonine intakes (on diets deficient in threonine) the temperature treatment with the lowest carcass threonine retention appears to be 18°C and the treatment with the highest carcass threonine deposition is 26°C. At higher threonine intakes the threonine retention at 18°C is dramatically improved. With higher feed intakes (and hence higher threonine intakes) at 18°C the environment is sufficiently cool to allow the extra heat increment of feeding to be dissipated, therefore allowing the animals to utilise dietary threonine more efficiently for carcass threonine deposition as the dietary threonine intakes increased.

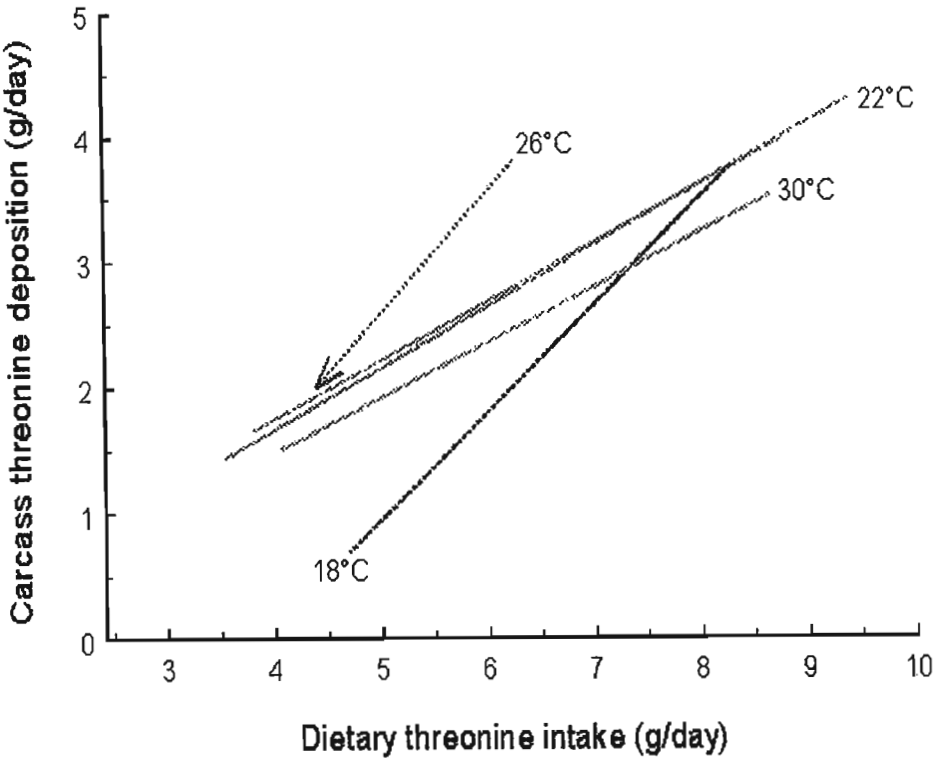

Figure 2.12 The relationship between dietary threonine intake and carcass threonine deposition of pigs grown at 18°C, 22°C, 26°C and 30°C on diets with graded levels of threonine from 12 kg to 25 kg live weight.

The coefficient of threonine intake, 0.844 (the estimate of efficiency of threonine utilization), has associated with it a very high standard deviation of 0.312. This is due to outlying data points used to plot the regression equation at 18°C. Very poor growth was exhibited by the pigs at these points. It is seen from Table 2.7 and Table 2.10 at 18°C, the pigs on T5 on a similar dietary threonine intake (though only slightly less) to T3 and T4 showed poorer protein growth rates and lower carcass threonine deposition rates. The regression equation fitted to the data may be the best fit line, but does not exhibit a true estimate of the efficiency of threonine utilization. The estimate of efficiency at 18°C is very high when compared to estimates in the literature, as discussed earlier. These estimates of efficiency at each temperature must therefore be regarded with caution.

2.4 Conclusion

Diets deficient in an amino acid will influence the response in growth, feed intake and body composition in young growing pigs. Pigs fed a diet deficient in threonine will attempt to maintain threonine intake by increasing feed intakes. Pigs will attempt to satisfy their requirements for the first limiting nutrient. The extent to which the pig can satisfy these requirements will depend on the amount of heat the animal can lose. As environmental temperature decreases the pigs are able to increase feed intakes and hence increase threonine intakes on poor quality diets. The lower the ambient temperature the more heat the animal can lose. Therefore at lower environmental temperatures pigs are able to compensate better for a deficiency in an amino acid in a diet.

CHAPTER 3

THE RESPONSE IN GROWING PIGS TO DIETARY LYSINE AS INFLUENCED BY ENVIRONMENTAL TEMPERATURE.

3.1 Introduction

There is evidence to suggest that nutrition during the early growing period may influence subsequent performance and carcass quality. For many years diets for growing pigs were formulated to promote optimum performance with little emphasis on their effect on carcass quality (Campbell and Biden, 1978). These diets were formulated to satisfy crude protein requirements rather than to meet requirements for specific amino acids (Lewis, 1991). The influence of dietary amino acids on voluntary feed intake and growth performance is now a major concern in pig feeding due to recent and rapid changes in growth capabilities for lean tissue deposition (Henry and Seve, 1993). With the present knowledge of the amino acid requirements of pigs and the amino acid composition of feedstuffs, the formulation of diets on the basis of amino acids rather than crude protein is a much more precise approach (Lewis, 1991). The utilisation of amino acids for lean tissue growth is dependent on the content of dietary amino acids in the feed (Adeola, Lawrence and Cline, 1994).

Lysine and threonine are essential amino acids in pig nutrition. In most practical pig diets lysine is the first limiting amino acid and threonine the second or third limiting amino acid (Gatel and Fekete, 1989: Adeola *et al*, 1994; Saldana *et al*, 1994). There have been a number of experiments to determine the optimum dietary lysine requirements based on protein accretion rate or carcass leanness potential. However, the range of live weights studied, the average performance of pigs, the dietary contents of amino acids tested and the criteria used to assess the optimum lysine content of the diet has varied between investigations. Brown, Harnon and Jensen (1973a,b) have indicated that dietary lysine requirements to optimise feed efficiency and carcass leanness are greater than those for average daily gains. These data suggest that current standards may underestimate the growing-finishing pigs lysine requirement for maximum carcass leanness.

More information is required on the response of growing pigs to dietary lysine content and it is recognised that different parameters respond differently to given inputs of lysine. The objective of the current experiment was to measure the response of growing pigs in controlled-environment chambers to dietary lysine using a summit-dilution technique. From such responses it is then possible to determine the dietary lysine concentration at different environmental temperatures that will optimise weight gain, food conversion efficiency, carcass leanness or any of the other criteria measured as responses to dietary lysine in this experiment.

3.2 Materials and Method

3.2.1 Animals and Experimental Design

Forty-eight entire male Large White x Landrace pigs of approximately 10 kg live weight were purchased for this experiment. The experiment was a 6 x 4 factorial design with four temperatures 18°C, 22°C, 26°C and 30°C and six dietary lysine concentrations ranging from 12.7 g/kg to 5.1 g/kg. At 12 kg live weight the pigs were randomly allocated to one of six dietary treatments and one of four temperature treatments, ensuring two animals per treatment. All animals were kept on their respective treatments until they reached 25 kg live weight, whereafter they were slaughtered for carcass analysis.

3.2.2 Housing and Management

The pigs were penned individually in controlled-environment chambers, each chamber containing 12 pens. Each pen measured 0.6 m^2 and had its own nipple drinker and metal feed bin allowing the pigs free and continuous access to food and water. The four temperatures used were 18.1 (±0.19)°C, 22.0 (±0.17)°C, 25.7 (±0.32)°C and 29.6 (±0.40)°C.. All animals were weighed each Thursday starting at 09h30. Temperatures and feed wastage were recorded daily starting at 08h00. The amount of food in the metal feed bins was checked twice daily and any feed required was weighed out and recorded. Feed intakes were calculated by determining the difference in weight of the feeder at the beginning and end of each week, less the feed wastage. The four different temperature treatments were spread over two different time periods due to space

restrictions.

3.2.3 Diets and Feeding

A summit-dilution technique (Fisher and Morris, 1970) was used to produce the six dietary treatments. The summit diet was formulated to contain 14.5 MJ DE/kg feed, and >140% of the requirements of all the essential amino acids other than the amino acid lysine, which was formulated to contain no more than 110% of requirement, thereby ensuring that this was the limiting amino acid in the feed.

A non-protein dilution diet was formulated to contain the same concentrations of energy and all nutrients as in the summit diet, other than the amino acids (Table 3.2).The dilution diet was blended with the summit diet in different proportions to obtain the six dietary treatments (Table 3.1). Vitamins and minerals were included at 1.5 times the normal rate to ensure that these were not limiting.

Table 3.1 Dilution of Summit diet and the expected lysine concentration and % of requirements of the dietary treatments.

Treatment	Dilution (%)	% of requirement	Threonine concentration (g/kg)
1	0	106	12.7
2	15	90	10.8
3	30	74	8.9
4	45	58	7.0
5	60	42	5.1
6	60+Suppl.	58+Suppl.	7.0

To check that lysine is the most limiting nutrient it is necessary to compare the response to the most diluted diet (T5) with that same diet supplemented with synthetic lysine (T6) (Table 3.1). The summit diet, dilution diet and the mixed dietary treatments were analysed for all the nutrients as in the previous experiment (Table 3.3).

Table 3.2 Constituents and calculated chemical composition of the Summit and Dilution diets.

Ingredient	Summit (g/kg)	Dilution (g/kg)
Maize	316.54	-
Sunflower oilcake	200.00	-
Soya oilcake	255.75	-
Maize gluten meal (60 g protein/kg)	113.86	-
Sunflower oil	44.71	38.00
Sugar	-	590.00
Starch	-	150.00
Sunflower husks	-	160.00
Limestone	12.23	10.00
Monocalcium phosphate	34.97	45.00
Fishmeal	14.44	-
Threonine	5.00	-
Vitamin & Mineral premix	5.00	2.50
Salt	2.50	5.00
Calculated composition (g/kg)		
DE (MJ/kg)	14.50	14.57
Crude protein (N X 6.25)	298.70	0.00
Lysine	12.69	0.00

Table 3.3 Chemical composition of the Summit, Dilution and blended diets determined by analysis.

Nutrient (g/kg)	Summit T1	T2	T3	T4	T5	T6	Dilution
18 & 22°C							
Digestible Energy (MJ/kg)[a]	14.5	14.5	14.3	13.0	14.1	14.3	14.3
Metabolizable Energy (MJ/kg)[b]	13.7	13.8	13.7	12.5	13.6	13.9	14.2
Crude Protein	297.7	246.0	226.5	189.7	140.8	127.5	-
Total Lysine	13.9	11.0	10.1	8.7	6.4	7.3	-
Total Threonine	15.5	11.9	10.6	8.5	6.5	6.2	-
Total Methionine	5.6	4.3	3.9	3.0	2.5	2.3	-
ME:DCP (MJ/kg)[c]	57.4	70.2	75.4	82.6	121.0	136.3	-
26 &30°C							
Digestible Energy (MJ/kg)[a]	14.5	14.1	14.8	15.2	15.4	13.7	14.3
Metabolizable Energy (MJ/kg)[b]	13.7	13.4	14.2	14.7	15.0	13.4	14.2
Crude Protein	297.7	245.0	197.8	151.9	117.2	99.9	-
Total Lysine	13.9	10.5	8.9	6.5	5.2	5.8	-
Total Threonine	15.5	11.6	9.3	7.3	5.6	5.0	-
Total Methionine	5.6	4.6	3.0	2.7	1.5	1.5	-
ME:DCP (MJ/kg)[c]	57.5	68.3	89.8	121.0	160.3	167.4	-

[a] DE = 3.77 - (0.019*NDF*10) + (0.758*GE)) MJ/kg

[b] ME = DE*(0.997-0.000189) (ARC, 1991)

[c] ME:DCP = ME (MJ/kg) / (CP (kg/kg) X protein digestibility) where protein digestibility = 0.80

Based on the principle of the summit-dilution method (Fisher, 1970), a linear regression of dietary lysine content on the percentage summit diet in each treatment (Figure 3.1) was performed for all dietary lysine treatments at all temperatures (Emmans, personal communication). This was done to facilitate the comparison of the response curves to dietary lysine content at each temperature, as well as more accurately determine the concentration of lysine in each dietary treatment. The regression equations for each response were determined using the calculated (or fitted) dietary lysine concentration values (Table 3.4) for each treatment. The regression equation for dietary lysine concentration was:

$$\text{LYS CONC} = -0.046 + 0.134 \times \%\text{SUMMIT} \quad \text{(g/kg)} \qquad (3.11)$$

where LYS CONC = Lysine concentration (g/kg)

%Summit = Proportion of summit diet in dietary treatment

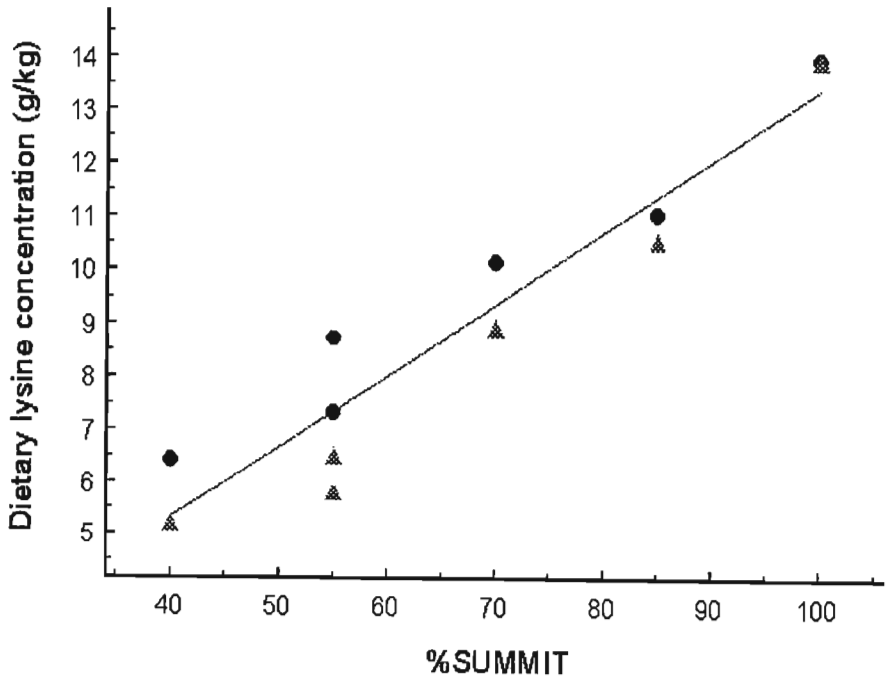

Figure 3.1 The relationship between dietary lysine concentration and summit dilution at 18°C & 22°C (●) and 26°C & 30°C (▲).

The concentration of lysine in T6 was formulated and calculated to be the same as in T4.

Table 3.1 Dilution of summit diet and dietary lysine concentrations (fitted values) for T1 to T6.

Treatment	Summit:Dilution	Lysine Concentration (g/kg)
1	100:0	13.4
2	85:15	11.3
3	70:30	9.3
4	55:45	7.3
5	40:60	5.3
6	55:45	7.3

3.2.4 Slaughter Procedure and Carcass Analysis

Pigs were killed by an intra peritoneal injection of 20 ml Pentobarbitone Sodium 20% m/v (Euthatal™, Rhône Poulenc group). Following slaughter the pigs were chilled overnight at 0°C. The pigs were then dissected and the stomach, intestines and bladder were removed and weighed full, then stripped of their contents and weighed empty. Gut fill was calculated by difference. The carcass was then portioned and together with the gastrointestinal tract was stored in a plastic bag and frozen at -20°C. The whole pig was then minced and sub-sampled. The samples were collected in duplicate and used in the laboratory for proximate analysis.

The dry matter content of each sample was determined by freeze drying the samples for 24 hours. The protein content was calculated as nitrogen x 6.25, where nitrogen content of the dry matter was determined by auto analysis. Lipid content was determined by Soxhlet extraction of the freeze dried samples with petroleum ether at 40 - 60°C for 6 hours. Ash was determined by burning the samples at 550°C for 4 hours in a muffle furnace. Duplicate results were combined to provide a single result for each pig.

3.2.5 Statistical analysis

The results were analysed by analysis of variance using a factorial design with lysine concentration and temperature as factors. Data were analysed using Minitab (1994).

3.3 Results and Discussion

The average starting weight of the animals on all treatments was 12.94 ±0.65 kg and the average slaughter weight was 25.56 ±0.58 kg. See Appendix 3 for detailed results (daily growth rates, food intakes, chemical composition, tissue deposition rates etc.) of each pig in this experiment. See Appendix 4 for the regression equations of each of the response curves plotted in this experiment.

3.3.1 *Food intake and live weight changes*

The response in empty body weight (EBW), gut fill (GF), voluntary feed intake (FI), average daily gain (ADG) and feed conversion efficiency (FCE) to the dietary lysine treatments and to environmental temperature are shown in Table 3.5. There were no significant differences in EBW or GF across either dietary treatments or temperature. The highest GF over all treatments was found at 30°C. This result is in contradiction to the result obtained in the previous experiment, where the highest GF was at 18°C, the explanation being that the environmental heat demand associated with such low temperatures will cause the animals to increase voluntary food intake and hence increase GF. However, in the present experiment it is seen that the highest GF is at 22°C on T1. At this dietary treatment there is a slower rate of passage of digesta through the digestive tract than on the treatments with low lysine concentrations and a higher proportion of sugar and starch (ingredients of the dilution diet). Sugar and starch are readily digestible ingredients which will result in an increase in the rate of passage of these ingredients through the digestive tract. Therefore on T1 GF is expected to be higher than on the other dietary treatments. As this GF is highest at 22°C it does lend some support for the result obtained in the previous experiment. The GF index (gut fill:food intake) is expected to decrease with decreasing lysine concentration (increasing proportion of dilution diet in the dietary treatment) due to increased rate of passage of digesta through the digestive tract. The results show a linear decrease in GF index with decreasing dietary concentration, with the lowest GF index on T5. There were significant differences in GF index between the dietary treatments ($P < 0.01$) and temperature treatments ($P < 0.001$). The highest GF index was at 30°C and could be attributed to lower feed intakes at this temperature. In a hot environment pigs reduce their feed intake to minimise the burden of

dissipating heat produced from metabolic and digestive processes (Schenck *et al.* 1992).

Table 3.5 The response in empty body weight (EBW), food intake (FI), average daily gains (ADG) and food conversion efficiency (FCE) of growing pigs from 12 kg to 25 kg live weight to six dietary lysine concentrations and four different temperatures.

Temperature	Dietary Treatment	EBW (kg)	Gut Fill (kg)	FI (kg/d)	Gut Fill Index[a]	ADG (kg/d)	FCE[b]
18°C	T1	23.56	2.11	1.215	1.74	0.590	486
	T2	22.87	2.61	1.300	2.01	0.700	540
	T3	22.98	2.20	1.470	1.56	0.605	436
	T4	22.77	2.06	1.335	1.64	0.500	376
	T5	23.71	1.76	1.570	1.14	0.485	309
	T6	23.33	1.73	1.475	1.23	0.525	362
22°C	T1	23.11	2.66	1.030	2.58	0.695	675
	T2	23.36	2.29	1.105	2.07	0.620	562
	T3	23.62	2.52	1.245	2.03	0.650	522
	T4	23.36	1.95	1.325	1.57	0.510	386
	T5	22.95	2.21	1.350	1.76	0.440	327
	T6	23.31	2.25	1.300	1.73	0.615	477
26°C	T1	23.49	2.20	1.000	2.21	0.635	638
	T2	23.27	2.33	1.075	2.17	0.665	627
	T3	24.31	2.29	1.315	1.75	0.595	452
	T4	23.79	2.17	1.350	1.68	0.525	387
	T5	22.90	1.88	0.965	1.95	0.310	320
	T6	23.57	2.20	1.310	1.67	0.555	424
30°C	T1	23.73	2.56	1.075	2.38	0.565	526
	T2	23.72	2.28	1.010	2.34	0.495	490
	T3	22.78	2.41	1.090	2.24	0.485	450
	T4	23.34	2.37	1.125	2.17	0.455	409
	T5	22.63	2.50	1.160	2.17	0.345	299
	T6	23.57	2.06	1.115	1.85	0.450	404
SEM		0.38	0.21	0.105	0.21	0.036	40
Main Effects and SEM of:							
Temperature							
18°C		23.20	2.08	1.394	1.55	0.568	418
22°C		23.28	2.30	1.226	1.96	0.588	491
26°C		23.55	2.18	1.169	1.9	0.548	474
30°C		23.29	2.36	1.096	2.19	0.466	429
SEM		0.16	0.08	0.043	0.09	0.015	17
Dietary Treatment:							
T1		23.47	2.38	1.080	2.23	0.621	581
T2		23.30	2.38	1.123	2.15	0.620	554
T3		23.42	2.35	1.280	1.89	0.584	465
T4		23.31	2.14	1.284	1.76	0.498	389
T5		23.04	2.09	1.261	1.75	0.395	314
T6		23.44	2.06	1.300	1.62	0.536	416
SEM		0.19	0.10	0.053	0.11	0.018	20
Significance of:							
Temperature (Temp)		NS	NS	***	***	***	*
Dietary Treatment (T)		NS	NS	*	**	***	***
Temp X T		NS	NS	NS	NS	NS	NS

[a] Gut fill index = Gut fill / FI

[b] FCE = g gain / 1000 g food; SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

There were significant differences ($P < 0.05$) in feed intake between the dietary treatments. Feed intake increased with decreasing dietary lysine concentration (Figure 3.2). Thus the pigs, in an attempt to maintain lysine intake, will increase their feed intakes on diets with low lysine concentrations. The highest feed intake over any dietary treatment was recorded on T4 at 1.28 kg/d. Temperature had a significant effect ($P < 0.001$) on feed intake. The highest feed intake over any temperature was at 18°C (1.39 kg/d). Voluntary feed intake increased at this temperature as the pigs consumed more feed in an attempt to maintain homeothermy through increased heat production. At 30°C feed intake was lowest (1.10 kg/d) and once again shows that at high environmental temperatures feed intake is depressed as the pigs attempt to minimise the burden of dissipating the extra heat produced from metabolic and digestive processes. At 18°C the total heat loss was also higher than on the other temperature treatments, showing that the lower the ambient temperature the more heat that can be lost and the more feed that the animal can consume. There was a 21.4% increase in feed intake at 18°C (1.39 kg/d) when compared to the feed intake at 30°C (1.10 kg/d). Similar results were obtained in the previous experiment.

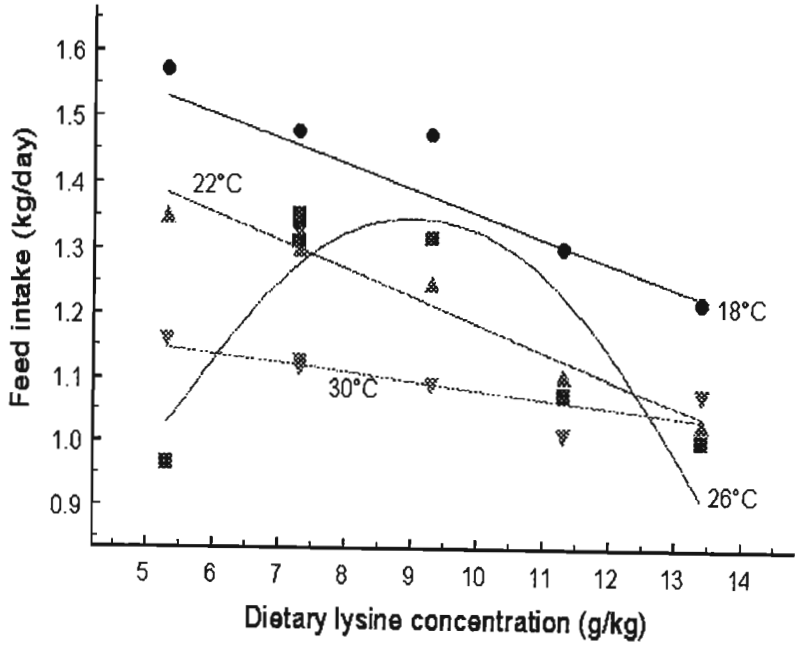

Figure 3.2 The effect of dietary lysine concentration on the food intake of growing pigs from 12 kg to 25 kg live weight using four different temperature regimes, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

It is clearly seen from Figure 3.2 that there appears to be a temperature x dietary treatment interaction with the animals at 18°C, with the response in feed intake. On diets with low dietary lysine concentrations the pigs were able to increase feed intakes considerably, in order to compensate for the deficiency in lysine, due to the lower environmental temperature. The animals were able to dissipate the extra heat produced, this heat coming from increased digestive and metabolic processes through increased feed intakes and the high heat increment of feeding associated with the poor quality diets. At higher environmental temperatures (26°C and 30°C) feed intakes were lower especially on diets with low dietary lysine concentrations. The animals may have decreased feed intakes in order to reduce the burden of dissipating the extra heat produced on the poorer quality diets. At the comfort temperature of 26°C and at low dietary lysine concentrations, for example 6 g lysine/kg feed, lower feed intakes at this temperature achieved better daily growth rates than at 30°C. From these results there appears to be a temperature x dietary treatment interaction with the response in feed intake.

There were significant differences ($P < 0.001$) in the daily growth rates (ADG) between dietary lysine treatments, with the highest gains on T1 (0.621 kg/d). With decreasing lysine concentration there was a linear decrease in ADG (Figure 3.3). On T6 with supplemental lysine there was an increase in ADG from T5. This positive growth response confirms that lysine was the most limiting nutrient in the summit feed (or in the dilution series). The lowest ADG was on T5 at 0.395 kg/d. There were significant differences ($P < 0.001$) in ADG between the temperature treatments. The highest ADG was at 22°C (0.588 kg/d) and the lowest at 30°C (0.466 kg/d). Similar results were obtained in the previous experiment when threonine was the most limiting amino acid. At 30°C depressed growth rates are expected due to depressed feed intakes and lowered nutrient intakes. There was no significant dietary lysine x temperature interaction indicating that the response to dietary lysine was independent of temperature. Similarly the response to environmental temperature was independent of dietary lysine concentration. However, it is seen at 18°C the pigs are more able to increase feed intakes (and improve growth) on the poor quality diets with high heat increments of feeding, than at the other temperatures. Temperature therefore appears to have an effect on the response in ADG to dietary threonine concentration although this difference is not statistically significant.

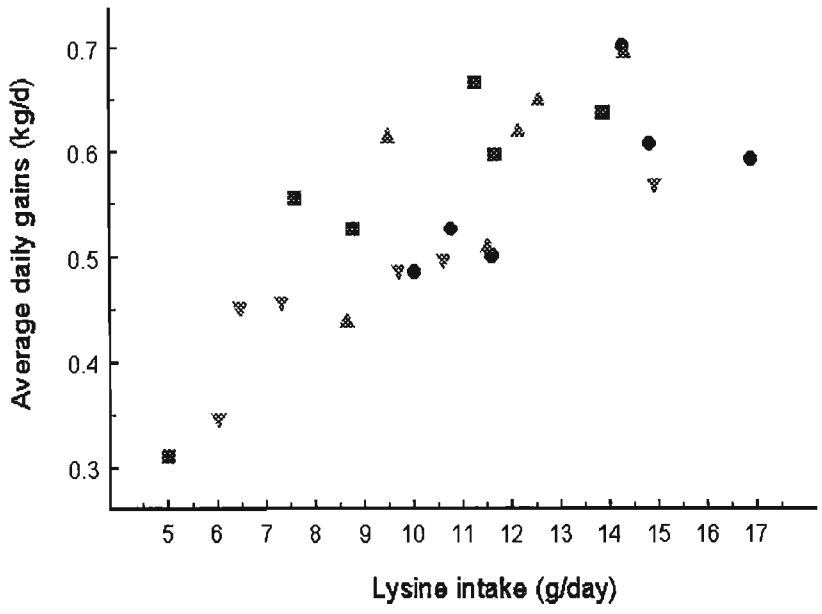

Figure 3.3 The effect of lysine intake on the average daily growth rate of growing pigs from 12 kg to 25 kg live weight a four different environmental temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

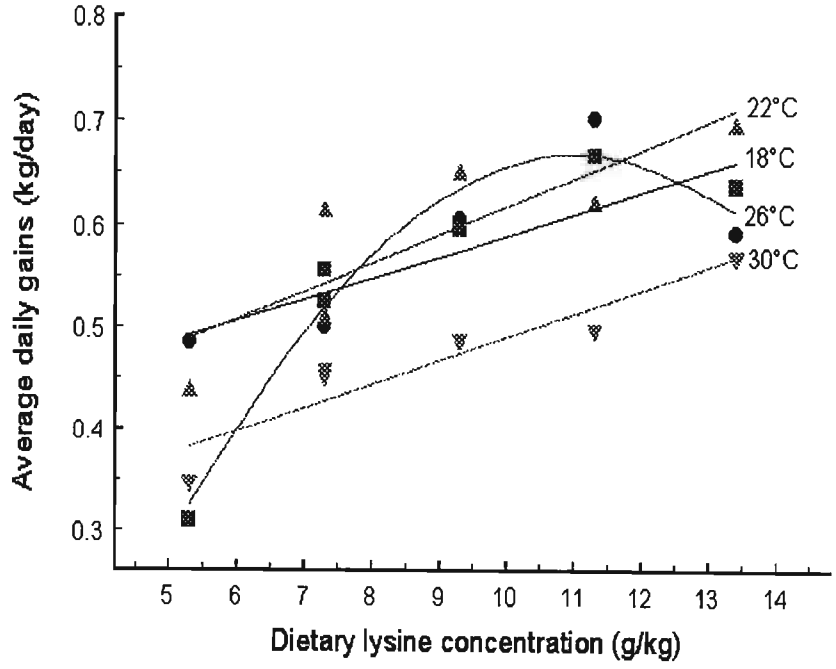

Figure 3.4 The response in daily growth rates in growing pigs from 12 kg to 25 kg live weight to dietary lysine concentration at (●) 18°C, (▲) 22°C, (■) 26°C and (▼) 30°C.

A regression of average daily gains on dietary lysine concentration was performed at each environmental temperature (Figure 3.4). From Figure 3.4 it is apparent that at low environmental temperatures (18°C and 22°C) daily growth rates were higher than at 26°C and 30°C. This trend was observed on low dietary lysine concentrations and at high dietary lysine concentrations. Similar trends were observed in the previous experiment where threonine was the first limiting amino acid in the feeds. These results indicate that on diets deficient in an amino acid, better growth rates will be exhibited by those pigs that are grown at lower environmental temperatures. This is may be due to the fact that at lower environmental temperatures the animals were able to increase feed intakes and dissipate the extra heat produced from feeding. This is important on poor quality feeds deficient in an amino acid, where the animals will have to consume more food in an attempt to meet their requirements for the limiting amino acid. The animals were then able to dissipate the extra heat produced as a result of the high heat increment of feeding on these poor diets. This resulted in improved growth rates compared with those at higher environmental temperatures. As a result of reduced feeds intakes at high environmental temperatures (30°C) the pigs exhibited poorer growth rates than at the other temperatures. It therefore appears that the temperature x dietary treatment interaction has had a marked effect on the response in daily growth rates, especially at low dietary lysine concentrations and low environmental temperatures.

An increase in the supply of lysine in the diet resulted in significant increases ($P < 0.001$) in the amount of gain per unit of food (Figure 3.5). Similar effects on FCE with graded levels of lysine have been reported previously (Blair, Dent, English and Raeburn, 1969; Rosell and Zimmerman, 1983). The lowest FCE was on T5 (313.63 g gain/kg food) and the highest FCE on T1 (580.87 g gain/kg food). Therefore the content of the first limiting nutrient in the diet, in this case lysine, will have a significant effect on the rate of growth irrespective of the environmental temperature. As this content increases so less food is required for maximum growth, so increasing the FCE. An improved FCE was achieved with the addition of supplemental lysine in T6. Environmental temperature had a significant effect ($P < 0.05$) on the response in FCE. The lowest FCE was at 18°C (417.83 g gain/kg food) presumably due to poorer growth rates and elevated maintenance needs at this temperature. More energy is partitioned into cold thermogenesis at this temperature and as a result there is less net energy available for tissue deposition. The highest FCE was at 22°C (491.25 g gain/kg food) slightly higher than that at 26°C (474.33 g gain/kg food). There

was no significant dietary lysine x temperature interaction indicating that the response to dietary lysine concentration was independent of environmental temperature.

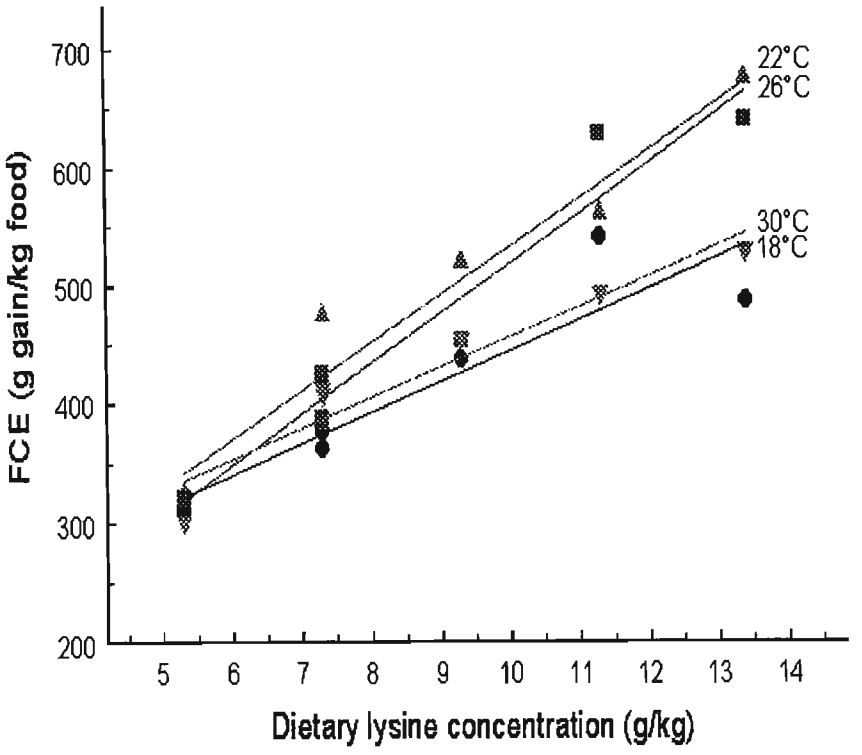

Figure 3.5 The effect of dietary lysine concentration on the feed conversion efficiency of growing pigs from 12 kg to 25 kg live weight at four different temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

At lower dietary lysine concentrations there appears to be no dietary treatment x temperature interaction affecting the response in FCE (g gain/kg food). However, as the dietary lysine concentration increases there becomes a clear distinction between the response at 18°C and 30°C, when compared to the response at 22°C and 26°C. This response is very similar to that in the previous experiment where at the low and high environmental temperatures the FCE was lower than that at 22°C and the comfort temperature 26°C. The FCE at lower temperatures may be due to more energy being partitioned into cold thermogenesis, resulting in less net energy available for tissue growth, therefore lowering the efficiency of feed conversion.. Over the same dietary lysine concentrations the pigs at 30°C maintained a slightly higher FCE than at 18°C.

However, this was lower than at 22°C and 26°C. At high environmental temperatures the pigs exhibited poorer growth rates resulting in a poorer FCE.

3.3.2 *Body composition*

The protein, fat, moisture and ash contents of the pigs at 25 kg live weight are shown in Table 3.6.

There were significant differences ($P < 0.001$) in the protein content of the empty body weight of the pigs at 25 kg live weight over the range of dietary lysine concentrations. There appeared to be a linear decrease in protein content with decreasing dietary lysine concentration to T5. An increase in the protein content of the empty body weight of the pigs at 25 kg on T6 from T5 is indicative of a positive growth response with the addition of supplemental lysine to a lysine limiting diet. There was an 19.9% reduction in body protein between pigs fed on T1 (3.715 kg) as opposed to those fed on T5 (2.976 kg). Similar responses were obtained in the previous experiment in response to dietary threonine concentration. The results in the present experiment confirm those reported previously for growing pigs (Yen *et al.*, 1986; Henry, Colleaux and Seve, 1992).

There was no statistically significant effect of environmental temperature on protein contents of the empty body over the four different temperatures. However, there was a decrease in protein content of the empty carcass with increasing environmental temperature. The lowest protein content was at 30°C (3.298 kg) and is most likely a result of lowered feed intakes (decreased DE intakes) and poorer growth rates at this temperature. The highest protein content was at 18°C (3.442 kg), and represents an increase from 14.2% protein content of the empty carcass at 30°C to 14.8% at 18°C. Similar results were obtained by Campbell and Taverner (1988) who found that protein content increased with decreasing environmental temperature from 17.1% at 14°C to 16.3% at 32°C. There was no significant dietary treatment x temperature interaction indicating that the response to dietary lysine level is independent of environmental temperature.

There was a significant effect ($P < 0.001$) of dietary lysine concentration on the lipid content of the empty body weight. Lipid content increased linearly from T1 (2.103 kg) to T5 (4.926 kg).

This represents an increase of 134% increase in the fat content of the empty carcass with decreasing lysine concentration from T1 to T5 (Figure 3.6). The fat content of the empty carcass decreased with the addition of supplemental lysine to T6 from T5. There was no significant effect of environmental temperature on the lipid content of the empty carcass, nor was there a significant dietary treatment x temperature interaction.

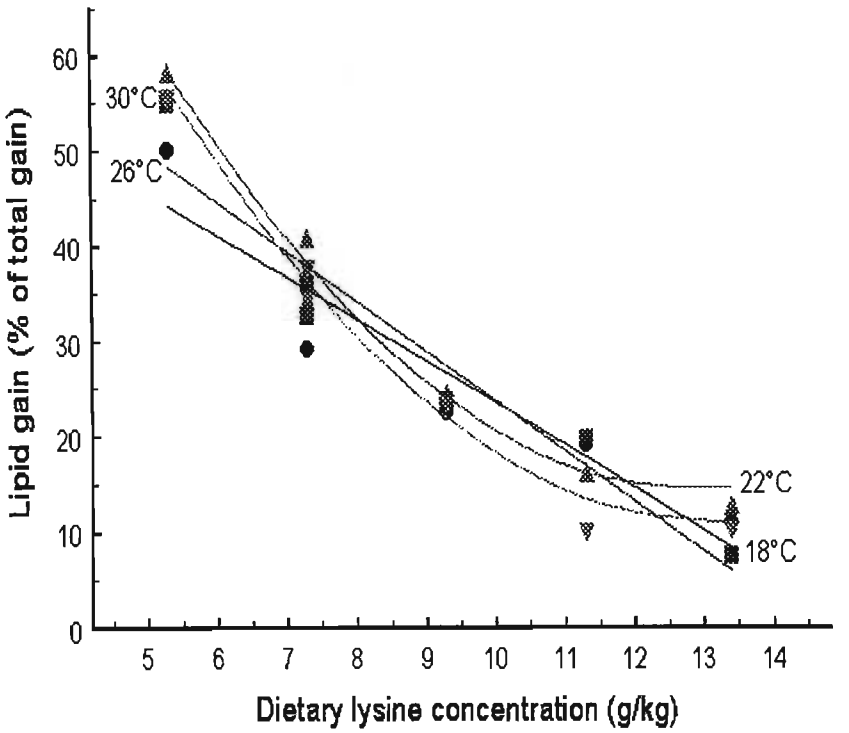

Figure 3.6 The effect of dietary lysine concentration on the lipid content (gains) of the total gains of growing pigs from 12 kg to 25 kg live weight at four different temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

From Figure 3.6 there appears to be no temperature x dietary treatment interaction affecting the response in lipid gains. At all the temperatures lipid gains appeared to follow the same trend over the range of dietary lysine concentrations and as result there was no discernible difference in lipid gains (as a % of total gains) between the temperatures.

Table 3.6 Table showing the protein weight, lipid weight, moisture weight and ash weight of the empty body weight of pigs at 25 kg live weight when fed diets with different lysine concentrations at four different environmental temperatures.

Temperature	Dietary Treatment	Protein (kg)	Lipid (kg)	Moisture (kg)	Ash (kg)
18°C	T1	3.875	2.200	16.300	0.770
	T2	3.515	2.730	15.405	0.640
	T3	3.380	3.090	15.300	0.645
	T4	3.370	3.555	14.650	0.710
	T5	3.130	4.905	14.275	0.705
	T6	3.380	4.100	14.620	0.770
22°C	T1	3.625	2.280	15.880	0.740
	T2	3.630	2.640	15.695	0.730
	T3	3.455	3.320	15.550	0.745
	T4	3.360	3.925	14.710	0.760
	T5	2.975	5.100	13.495	0.715
	T6	3.265	4.095	14.370	0.680
26°C	T1	3.700	1.810	16.710	0.695
	T2	3.485	2.700	15.825	0.730
	T3	3.470	3.330	16.140	0.745
	T4	3.295	4.100	14.810	0.710
	T5	2.975	4.960	13.565	0.715
	T6	3.290	3.845	15.035	0.765
30°C	T1	3.660	2.120	16.655	0.700
	T2	3.630	2.110	16.540	0.765
	T3	3.280	3.110	15.095	0.715
	T4	3.225	3.870	14.725	0.725
	T5	2.825	4.740	13.665	0.680
	T6	3.170	4.230	14.645	0.665
SEM		0.090	0.207	0.334	0.038
Main Effects and SEM of:					
Temperature					
18°C		3.442	3.430	15.092	0.707
22°C		3.385	3.560	14.950	0.728
26°C		3.369	3.458	15.347	0.727
30°C		3.298	3.633	15.221	0.708
SEM		0.037	0.084	0.136	0.015
Dietary Treatment:					
T1		3.715	2.103	16.386	0.726
T2		3.565	2.545	15.866	0.716
T3		3.396	3.213	15.521	0.713
T4		3.313	3.863	14.724	0.726
T5		2.976	4.926	13.750	0.704
T6		3.276	4.068	14.667	0.720
SEM		0.045	0.103	0.167	0.019
Significance of:					
Temperature (Temp)		NS	NS	NS	NS
Dietary Treatment (T)		***	***	***	NS
Temp X T		NS	NS	NS	NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

There were significant differences ($P < 0.001$) in the moisture content of the empty carcass over the range of dietary lysine concentrations. Moisture content decreased linearly from T1 to T5 as lysine became more limiting. Temperature had no significant effect on body moisture content.

3.3.3 *Protein and lipid retention*

The effects of dietary lysine concentration and environmental temperature on protein and fat deposition are shown in Table 3.7. There was a highly significant effect ($P < 0.001$) of dietary lysine content on protein growth rates. Protein retention (PR) decreased linearly with a decrease in the dietary concentration of lysine. As the dietary lysine intake decreased from T1 to T5 protein growth rates decreased by 57.9% over the same range (Figure 3.7). This is a significant reduction in daily protein retention indicating that the animals are unable to grow at their inherent potential due to the deficiency of lysine in T2 to T5. A positive protein growth response was observed on T6 from T5 with the addition of supplemental lysine to T5.

The main effect of temperature had a significant effect ($P < 0.001$) on protein growth rates, with the highest PR occurring at 18°C (77.08 g/day). The lowest PR was at 30°C (56.66 g/day). PR decreased linearly with an increase in environmental temperature. The differences in PR between 18°C, 22°C and 26°C were not as high as the difference in PR between these temperatures and 30°C. These differences are also seen with LR, MR and AR where at 18°C, 22°C and 26°C the differences observed are not as high as between the same temperatures and 30°C. This suggests that at low temperatures pigs fed *ad libitum* will have a voluntary energy intake sufficient to maintain a constant energy retention (PR and LR), indicating that both PR and LR are independent of environmental temperature (Rinaldo and Le Dividich, 1991; Ferguson, 1996). There is a considerable reduction in PR at 30°C . There was a 16.9% decline in PR with pigs grown at 30°C (56.66 g/day) as compared with that at 26°C (68.28 g/day). Similar results were shown by Campbell and Taverner (1988) between 14°C and 32°C, and Rinaldo and Le Dividich (1991) between 25°C and 31.5°C. The reduction in PR at high temperatures may be a consequence of depressed feed intake and a reduction in the net energy available for tissue deposition.

There was a highly significant effect ($P < 0.001$) of temperature on lipid retention (LR). This may be attributed to the high lipid growth rate at 22°C. There was a 27.1% decline in LR between 22°C (111.02 g/day) and 30°C (80.95 g/day). At cool temperatures the pigs overconsumed on energy due to increased feed intakes resulting in increased fat deposition. At 22°C less energy would be partitioned into cold thermogenesis than at 18°C, resulting in the higher LR at 22°C (111.02 g/day) than at 18°C (105.95 g/day).

Table 3.7 Table showing the protein (PR), lipid (LR), moisture (MR) and ash (AR) deposition of the empty body of pigs grown between 12 kg and 25 kg live weight when fed feeds with different lysine concentrations at different environmental temperatures.

Temperature	Dietary Treatment	PR (g/d)	LR (g/d)	MR (g/d)	AR (g/d)
18°C	T1	96.3	53.1	375.0	16.0
	T2	99.1	99.4	411.8	11.7
	T3	80.9	101.8	362.7	11.5
	T4	66.2	102.3	273.5	12.1
	T5	51.8	149.0	235.7	10.7
	T6	68.2	130.1	276.2	14.9
22°C	T1	99.1	66.8	415.1	17.1
	T2	89.7	76.3	368.5	15.1
	T3	80.4	110.7	360.1	15.4
	T4	62.5	115.4	261.9	13.3
	T5	43.0	143.9	194.0	10.4
	T6	70.2	153.0	292.8	12.1
26°C	T1	93.5	37.8	419.1	13.5
	T2	88.6	88.4	399.2	15.5
	T3	72.5	101.6	344.5	13.6
	T4	59.9	121.5	266.3	11.6
	T5	31.0	98.9	141.7	7.6
	T6	64.2	121.3	293.6	14.4
30°C	T1	78.5	45.5	356.4	11.5
	T2	69.3	39.9	314.9	12.4
	T3	63.7	87.0	296.7	12.6
	T4	50.6	100.5	231.9	10.6
	T5	28.8	105.1	153.7	7.2
	T6	49.0	107.8	230.7	8.8
SEM		4.57	11.98	20.92	1.58
Main Effects and SEM of:					
Temperature					
18°C		77.1	106.0	322.5	12.8
22°C		74.2	111.0	315.4	13.9
26°C		68.3	94.9	310.7	12.7
30°C		56.7	81.0	264.1	10.5
SEM		1.87	4.89	8.54	0.64
Dietary Treatment:					
T1		91.9	50.8	391.4	14.5
T2		86.7	76.0	373.6	13.7
T3		74.4	100.3	341.0	13.3
T4		59.8	109.9	258.4	11.9
T5		38.7	124.2	181.3	9.0
T6		62.9	128.1	273.3	12.6
SEM		2.29	5.99	10.46	0.79
Significance of:					
Temperature (Temp)		***	***	***	**
Dietary Treatment (T)		***	***	***	***
Temp X T		NS	NS	NS	NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

There was a significant increase ($P < 0.001$) in LR as the dietary concentration of lysine decreased from T1 to T5. Once again this was expected on the poorer quality diets due to increased feed intakes and the animals overconsuming energy which is deposited as lipid. There was a significant decrease ($P < 0.001$) in water retention with decreasing dietary lysine concentration to T5.

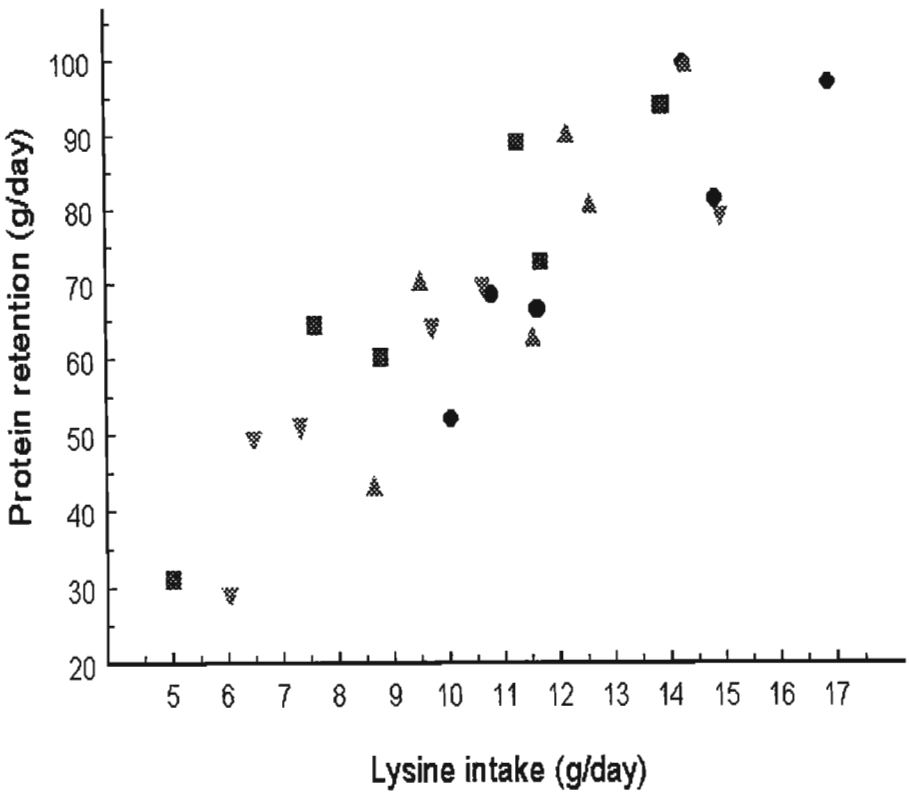

Figure 3.7 The effect of lysine intake on the protein growth rate of growing pigs from 12 kg to 25 kg live weight at four different environmental temperatures, (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C.

From Figure 3.8 it is evident that at low dietary lysine concentrations protein retention decreased with increasing temperature. Feed intake at low dietary lysine contents was highest at 18°C and lowest at the comfort temperature 26°C. It appears that at low environmental temperatures the pigs are able to compensate better for a deficiency in the amino acid through increased feed intakes and improved protein growth rates (at 18°C and 22°C). Over the range of dietary lysine concentrations the highest PR was at 18°C and the lowest at 30°C. At higher environmental

temperatures it has been shown that voluntary feed intakes are depressed and this may have resulted in lower protein growth rates at this temperature. There appears to have been a dietary treatment x temperature interaction affecting the response in protein accretion rate.

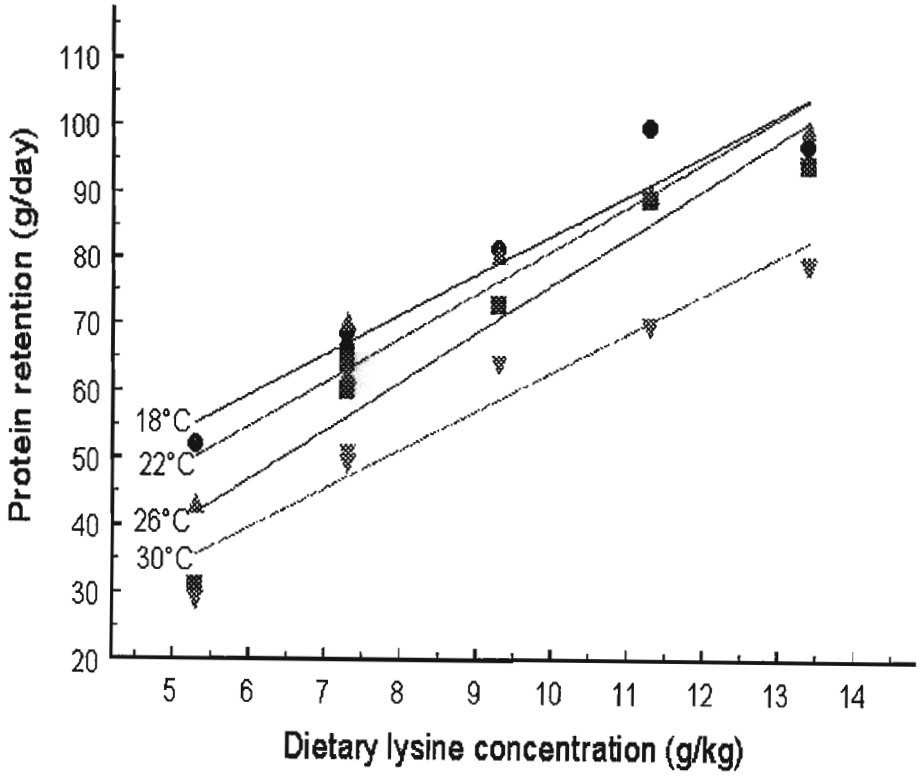

Figure 3.8 The response in daily protein retention in growing pigs from 12 kg to 25 kg live weight to dietary lysine concentration at (●) 18°C, (▲) 22°C, (■) 26°C and (▼) 30°C.

3.3.4 *Heat loss*

Total heat loss was calculated using the equations outlined in the previous experiment (2.3.1.4). The results for Total Heat Loss (THL) are shown in Table 3.8.

There were significant differences ($P < 0.05$) in THL between the temperature treatments. There were no significant differences in THL between the dietary lysine treatments. Maximum THL occurred on T5 (12.091 MJ/d). The temperature treatment with the highest THL (18°C) also had the highest feed intake. Maximum heat output was observed in animals fed T5 at 18°C, T5 at 22°C, T4 at 26°C and T5 at 30°C.

Although some of the additional heat produced at 18°C was as a result of cold thermogenesis, the potential exists for animals to lose more heat when fed a diet with a high heat increment of feeding, such as T5, than those kept at higher temperatures. Pigs kept at 18°C in this experiment lost the greatest amount of heat on T5 (14.267 MJ/d) whereas those at 30°C on T5 lost only 12.569 MJ/d, the highest amount of heat lost at this temperature (30°C). At higher temperatures the animals are unable to lose sufficient heat to the environment, and are thus prevented from achieving the desired intake of the lysine deficient diet (Schenck *et al.*, 1992). As in the previous experiment these results once again show that the pigs attempt to increase their intakes of a feed in order to meet their requirement for the limiting nutrient.

Table 3.8 Table showing the Total Heat Loss (MJ/d) for pigs between 12 kg and 25 kg live weight when fed diets differing in lysine concentration at four different environmental temperatures.

Temperature	Dietary Treatment	Total Heat Loss (MJ/d)
18°C	T1	12.20
	T2	11.67
	T3	14.11
	T4	11.09
	T5	14.27
	T6	13.72
22°C	T1	9.05
	T2	10.11
	T3	10.71
	T4	10.57
	T5	11.68
	T6	10.35
26°C	T1	9.93
	T2	8.80
	T3	12.93
	T4	13.62
	T5	9.85
	T6	11.27
30°C	T1	11.01
	T2	10.29
	T3	10.52
	T4	11.35
	T5	12.57
	T6	9.50
SEM		1.45
Main Effects and SEM of:		
Temperature		
18°C		12.84
22°C		10.41
26°C		11.07
30°C		10.88
SEM		0.59
Dietary Treatment:		
T1		10.55
T2		10.22
T3		12.07
T4		11.66
T5		12.09
T6		11.21
SEM		0.72
Significance of:		
Temperature (Temp)		*
Dietary Treatment (T)		NS
Temp X T		NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

3.3.5 *Efficiency of protein utilization*

As in the previous experiment the efficiency of protein utilization can be determined from the equation as defined by Kyriazakis and Emmans (1992a), *viz*:

$$DIPI = FI \times CP \times v \times d_{cp} \qquad (g/d) \qquad (3.1)$$

where FI = Food intake (g/d)
CP = Crude protein (N X 6.25) content of the food (g/g)
d_{cp} = digestibility of CP (0.80)

In this experiment the protein value (v) was calculated for all diets as:

$$v = (LC/CP)/70 \qquad (3.2)$$

where LC = Lysine content of the dietary treatment (g/kg)
CP = Crude protein content of the diet (g/g)
70 = 70 g lysine/kg ideal protein

Figure 3.9 illustrates the relationship between protein retention (PR) and digestible ideal protein intake (DIPI). The regression equation fitted to these data was:

$$PR = 12.7 + 0.451 \times DIPI \qquad (g/d) \qquad (3.3)$$

The slope of the fitted line (0.451) provides an estimate of the apparent efficiency of ideal protein utilization on diets limiting in lysine. The regression equation was obtained using all 48 data points. When the mean values of two pigs on each treatment were used, i.e. 24 data points, the regression equation fitted to this data was:

$$PR = 7.77 + 0.491 \times DIPI \qquad (g/d) \qquad (3.4)$$

This provides a slightly higher estimate (0.491) of the apparent efficiency of ideal protein utilization on diets differing in lysine concentration. Figure 3.9 illustrates the relationship between protein retention and digestible ideal protein intake.

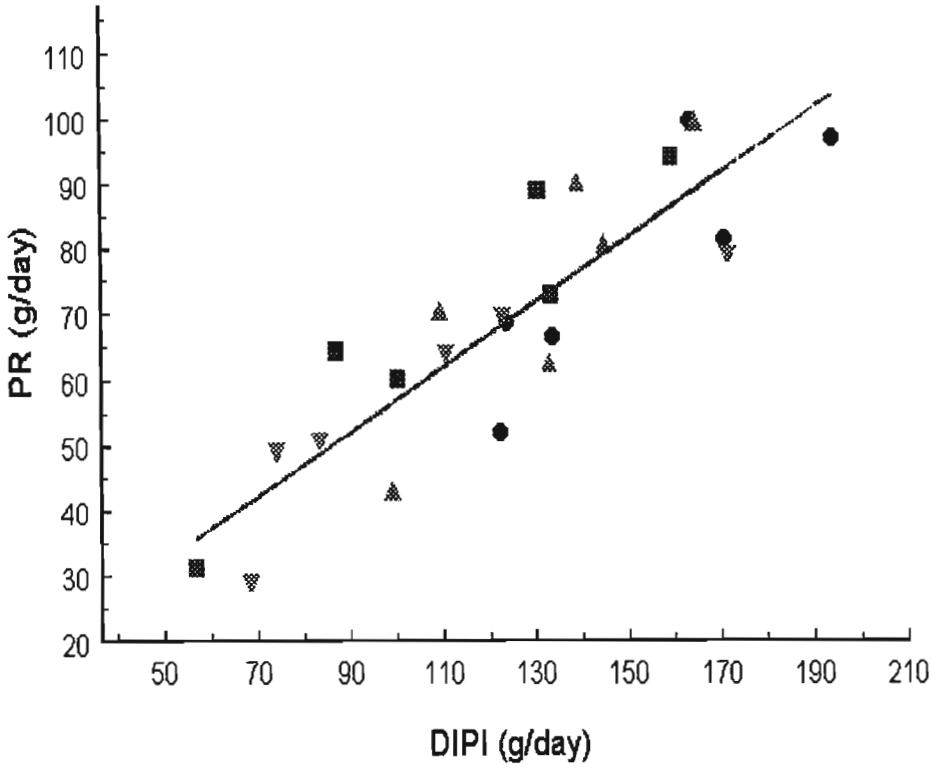

Figure 3.9 The daily rates of protein retention in pigs grown from 12 kg to 25 kg live weight against digestible ideal protein intake on diets differing in lysine concentration and housed at four different ambient temperatures; (●) 18°C, (▲) 22°C, (■) 26°C, (▼) 30°C. Solid line (-) represents fitting of regression equation (3.4).

The net efficiency of ideal protein utilization (e_p) above maintenance was calculated using the equation 2.10 in the previous chapter. The e_p values calculated for the six dietary lysine treatments and four environmental temperatures are shown in Table 3.9.

There were significant differences ($P < 0.001$) in efficiencies of protein utilization as the dietary lysine concentration decreased from T1 to T5 (and crude protein contents decreased from T1 to T5). As feed intakes decreased from T5 to T1 and digestible ideal protein intakes increased, there was a significant increase ($P < 0.001$) in protein retention. There appeared to be a trend for increasing e_p over the same treatments (T5 to T1) with the lowest$_p$e on T5 (0.543) and the highest on T2 (0.701). However, there was a large decrease in e_p on T1. It is likely that the maximum protein growth was achieved on this food, with some wastage of lysine. The e_p on T6 increased significantly from T5 with the addition of supplemental lysine to T6. As in the previous experiment this once again indicates that where an amino acid is the limiting nutrient the

supplementation of poor diets with the limiting amino acid may improve the efficiency with which the pigs utilize the dietary protein content.

There was a significant increase ($P < 0.01$) in e_p with increasing ambient temperature up to 26°C. There was a decrease in e_p at 30°C. At lower environmental temperatures there is an increased demand for energy and a subsequent increase in feed intakes. This results in the overconsumption of protein and a reduction in the efficiency of protein utilization. The e_p was highest at the comfort temperature of 26°c (0.711) and was lowest at 18°C (0.568). At 30°C there are depressed feed intakes and hence lower digestible ideal protein intakes as well as reduced protein growth rates. This results in a lower e_p at this temperature when compared to that at 26°C. The results seem to indicate that at environmental temperatures outside the thermoneutral zone the e_p will be reduced. Similar results were obtained by Ferguson (1996) using the same environmental temperatures. However, his results indicated no reduction in e_p at 30°C.

Table 3.9 The efficiencies of protein utilization (e_p) of growing pigs between 12 kg and 25 kg live weight at six dietary lysine concentrations and four environmental temperatures.

Temperature	Dietary Treatment	e_p
18°C	T1	0.539
	T2	0.669
	T3	0.552
	T4	0.550
	T5	0.475
	T6	0.622
22°C	T1	0.663
	T2	0.721
	T3	0.615
	T4	0.524
	T5	0.501
	T6	0.734
26°C	T1	0.647
	T2	0.773
	T3	0.607
	T4	0.685
	T5	0.686
	T6	0.870
30°C	T1	0.500
	T2	0.641
	T3	0.658
	T4	0.719
	T5	0.513
	T6	0.800
SEM		0.060
Main Effects and SEM of:		
Temperature		
18°C		0.568
22°C		0.626
26°C		0.711
30°C		0.638
SEM		0.024
Dietary Treatment:		
T1		0.587
T2		0.701
T3		0.608
T4		0.619
T5		0.543
T6		0.756
SEM		0.030
Significance of:		
Temperature (Temp)		**
Dietary Treatment (T)		***
Temp X T		NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

3.3.6 *Efficiency of lysine utilization*

In order to predict the efficiency of lysine utilization it is necessary to determine lysine retention in the carcass protein of the growing pigs. In this experiment an estimate of the lysine concentration (g/kg crude protein) of the whole body of pigs was used. Kyriazakis, Emmans and McDaniel (1993) estimated this concentration to be 70.5 g lysine/kg body protein. The protein retention data obtained in the present experiment were used to determine the lysine retention at each dietary lysine concentration and at each environmental temperature. Hence, the lysine retention data for each lysine intake were used to determine the efficiency of lysine utilization. Regression analysis was conducted to determine the relationship between deposition rates and intakes.

The daily rates of lysine deposition and intake are shown in Table 3.10. There were significant differences ($P < 0.001$) in lysine intakes between the dietary treatments. Lysine intakes decreased with decreasing dietary lysine concentration. There was an increase in lysine intake on T6 compared with T5. There were significant differences ($P < 0.001$) between the lysine deposition rates at different dietary threonine contents. These showed a linear response with increasing lysine retention as the dietary lysine content increased. This once again shows that the deposition of a limiting amino acid in carcass protein is linearly related to amino acid intake in pig feeds (Batterham *et al.*, 1990; Beech *et al.*,1991). Lysine deposition was a linear function of daily lysine intake. A linear regression of daily carcass lysine deposition on daily lysine intake (Figure 3.10) indicated that the efficiency of lysine utilization for carcass lysine deposition in pigs raised from 12 kg to 25 kg live weight was 0.45 ($r^2 = 0.77$). A linear regression using the mean values of all pigs on T3 to T6 for all temperatures was performed (assuming that lysine was not limiting in T1 and T2), as was performed and explained in the previous experiment with threonine. This provides an estimate of the efficiency of lysine utilization for carcass lysine deposition when a diet is deficient in this amino acid is fed to young growing pigs from 12 kg to 25 kg live weight. The regression equation fitted to these data is:

$$LYSR = -0.13 + 0.451 \times LYSI \qquad (g/d) \qquad (3.5)$$

where LYSR = Lysine retention (g/d) and LYSI = Lysine intake (g/d)

Table 3.10 The daily rates of lysine intake and lysine retention of growing pigs between 12 kg and 25 kg live weight at six dietary lysine contents and four different environmental temperatures.

Temperature	Dietary Treatment	Lysine Intakes (g/d)	Lysine Retention (g/d)
18°C	T1	16.89	6.79
	T2	14.30	6.99
	T3	14.85	5.70
	T4	11.62	4.67
	T5	10.05	3.65
	T6	10.77	4.81
22°C	T1	14.32	6.99
	T2	12.16	6.33
	T3	12.58	5.67
	T4	11.53	4.41
	T5	8.64	3.03
	T6	9.49	4.95
26°C	T1	13.90	6.59
	T2	11.29	6.24
	T3	11.71	5.11
	T4	8.78	4.22
	T5	5.02	2.19
	T6	7.60	4.53
30°C	T1	14.94	5.54
	T2	10.61	4.89
	T3	9.70	4.49
	T4	7.32	3.57
	T5	6.04	2.04
	T6	6.47	3.46
SEM		0.90	0.32
Main Effects and SEM of:			
Temperature			
18°C		13.08	5.43
22°C		11.45	5.23
26°C		9.71	4.81
30°C		9.18	3.99
SEM		0.37	0.13
Dietary Treatment:			
T1		15.01	6.48
T2		12.09	6.11
T3		12.21	5.24
T4		9.81	4.22
T5		7.43	2.73
T6		8.58	4.43
SEM		0.45	0.16
Significance of:			
Temperature (Temp)		***	***
Dietary Treatment (T)		***	***
Temp X T		NS	NS

SEM standard error of means; NS not significant; * P < 0.05; ** P < 0.01; *** P < 0.001

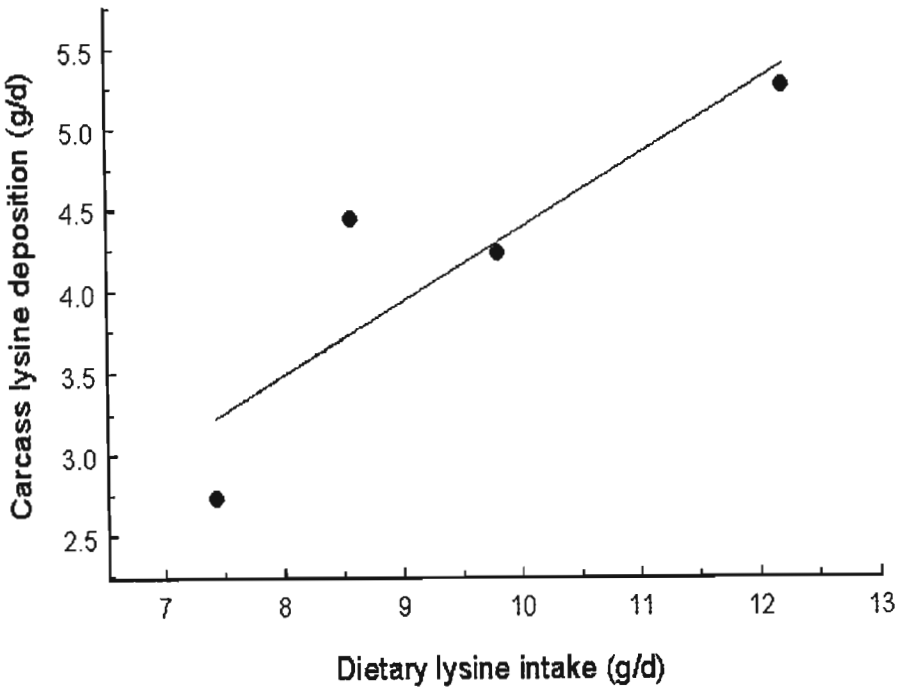

Figure 3.10 Relationship between lysine deposition rate in the carcass and daily dietary lysine intake of pigs fed on diets containing graded levels of lysine from 12 kg to 25 kg live weight. Straight line (-) represents fitting of regression equation.

The estimate of the efficiency of lysine utilization presented above was found to be significantly lower than in the literature. Adeola (1995) found the efficiency of lysine utilization in growing pigs from 10 kg to 20 kg live weight to be 0.72. Batterham *et al.* (1990) estimated the efficiency of lysine utilization over the live weight range 20 kg to 45 kg to be 0.86. However, this efficiency (0.86) was expressed on an ileal digestible lysine basis; but when expressed on total dietary lysine basis (using 85% ileal lysine digestibility) the efficiency was 73% (Adeola, 1995). The estimate in the present study is therefore rather low, even though it is an improved estimate through using only the mean values for all pigs on T3 to T6 for all temperatures to obtain the regression equation. The result was a regression of carcass lysine on dietary lysine intake using only four data points, i.e. only two degrees of freedom. When all the data points for all pigs on T1 to T6 at 18, 22, 26 and 30°C were used to obtain the regression equation, a much lower estimate of the efficiency of lysine utilization (0.37) was obtained (Figure 3.11). This estimate shows that in the present study with pigs from 12 kg to 25 kg live weight, dietary lysine was utilized for carcass lysine deposition with an efficiency of only half that found in the other studies mentioned above. However, it is noteworthy that in the experiment by Batterham *et al.* (1990), pigs within the live

weight range 20 kg to 45 kg were used versus 12 kg to 25 kg. In the present study an estimate of the proportion of lysine in the body protein of pigs was used whereas in the other studies chemical analysis of carcass tissue was performed, this being a more appropriate option. The efficiency of lysine utilization in the current experiment could possibly be different if more animals had been used. This would provide for more data points and may improve the estimate for efficiency of lysine utilization. The regression equation determined from the 48 data points ($r^2 = 0.68$) was:

$$LYSR = 0.846 + 0.370 \times LYSI \qquad (g/d) \qquad (3.6)$$

Because more data points were used to obtain the regression equation one would assume that the best fit estimate of efficiency of lysine utilization here would be more reliable. However, both estimates presented here are significantly lower than those found in the literature. In Figure 3.11, 95% confidence limits have been included and although the best fit estimate of efficiency of lysine utilization has been plotted, this efficiency, determined by the slope of the regression line, may vary within the bounds of the confidence limits shown.

To assess the effect of temperature on the efficiency of lysine utilization a linear regression of daily carcass lysine deposition on daily lysine intake at each temperature was performed. The regression equations were determined from 12 data points at each temperature and dietary treatment. The relationship between carcass lysine deposition and dietary lysine intake at each temperature is shown in Figure 3.12. The regression equations are;

18°C: $$LYSR = 1.470 + 0.303 \times LYSI \qquad (g/d) \qquad (3.7)$$
$r^2 = 0.49$

22°C: $$LYSR = -1.067 + 0.550 \times LYSI \qquad (g/d) \qquad (3.8)$$
$r^2 = 0.69$

26°C: $$LYSR = 0.470 + 0.447 \times LYSI \qquad (g/d) \qquad (3.9)$$
$r^2 = 0.79$

30°C: $$LYSR = 0.949 + 0.332 \times LYSI \qquad (g/d) \qquad (3.10)$$
$r^2 = 0.80$

where LYSR = Carcass lysine retention (g/d); LYSI = Dietary lysine intake (g/d)

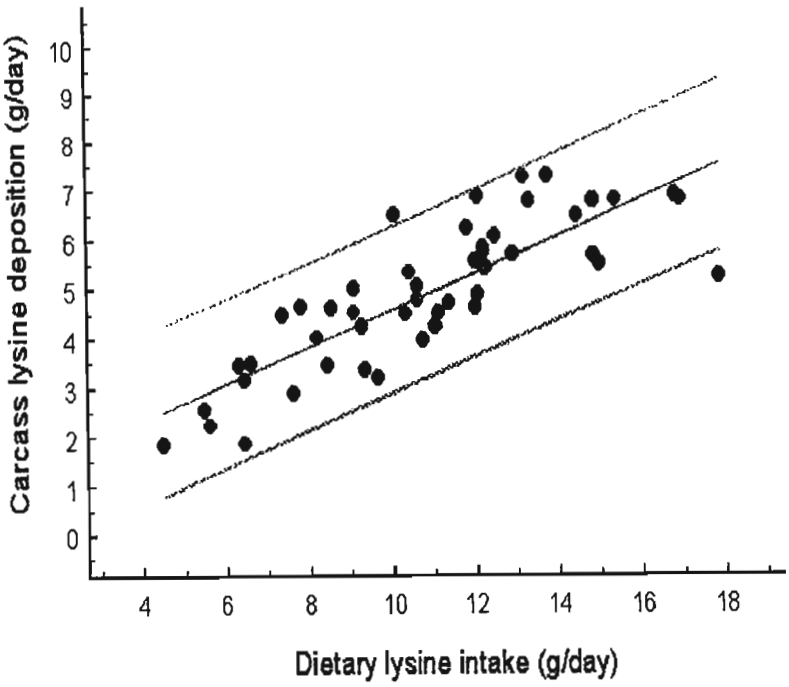

Figure 3.11 The relationship between carcass lysine deposition and dietary lysine intake in growing pigs between 12 kg and 25 kg live weight when fed six dietary lysine treatments at four different environmental temperatures.

Figure 3.12 illustrates the relationship between dietary lysine intake and carcass lysine deposition at four different environmental temperatures. The slopes of the regression lines provide an estimate of the efficiency of lysine utilization. In the current experiment the temperature treatment with the lowest efficiency of lysine utilization appeared to be 18°C with an estimate of 0.30 and the highest 22°C with an estimate of 0.55. At lower environmental temperatures the animals increase feed intakes to produce heat. This results in higher dietary lysine intakes at these temperatures. A possible reason for the poor efficiency of lysine utilization at 18°C is that at this temperature the animals had very high feed intakes and on the dietary treatments with higher dietary lysine concentrations the animals may have overconsumed lysine resulting in a decrease in the efficiency with which the pigs can utilize this amino acid for carcass lysine deposition. At this temperature at high dietary lysine intakes (T1) a decrease in carcass lysine deposition is noticed (Table 3.9). At high environmental temperatures (30°C) the pigs exhibited poor protein growth rates and decreased feed intakes. At this temperature the pigs had a significantly lower estimate for the efficiency of lysine utilization (0.33) than at 22°C or at 26°C. Over a range of dietary lysine intakes at 26°C (within the comfort zone), the pigs showed increased carcass lysine deposition over the other environmental temperatures.

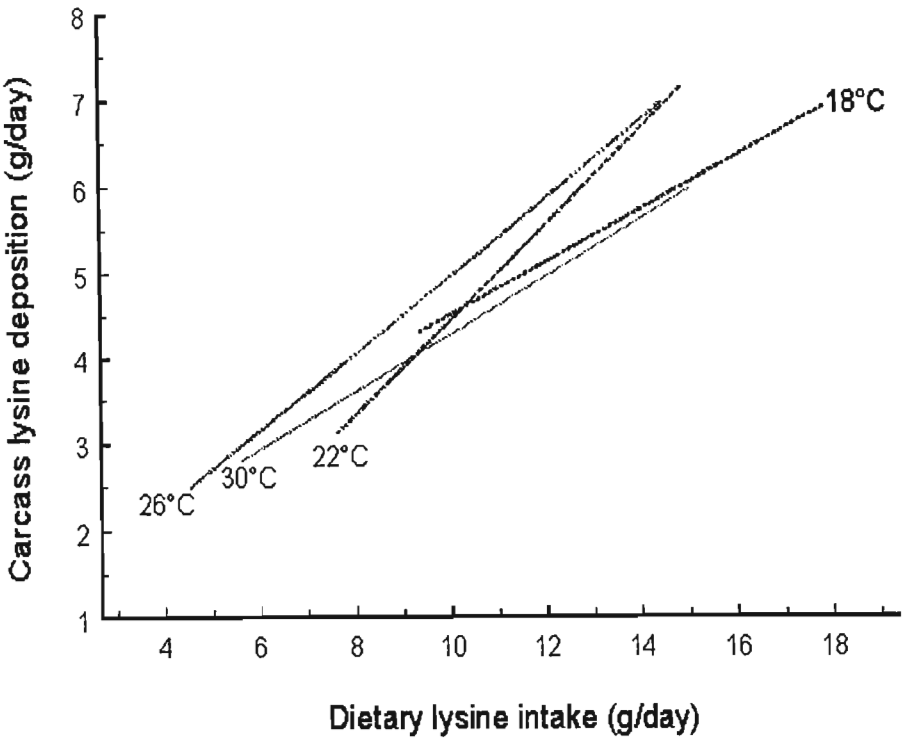

Figure 3.12 The relationship between dietary lysine intake and carcass lysine deposition of pigs grown at 18°C, 22°C, 26°C and 30°C on diets with graded levels of lysine from 12 kg to 25 kg live weight.

At 22°C as dietary lysine intakes increased the animals deposited significantly more carcass lysine than at lower dietary lysine intakes. With higher feed intakes at this temperature the environment is sufficiently cool to allow the extra heat increment of feeding to be dissipated, therefore allowing the animals to utilise dietary lysine more efficiently for carcass lysine deposition as the dietary lysine intakes increased.

3.4 Conclusion

Diets deficient in lysine had a significant effect on daily growth rates, food intakes and the body composition of the gain. The extent of the response depended on the dietary concentration of the amino acid. Pigs attempted to maintain a constant lysine intake by increasing their feed intake on diets deficient in this amino acid. Once again it was demonstrated that the extent to which the animals can compensate for the deficiency in the amino acid will depend on the amount of heat the animal can lose. Hence, environmental temperature is an important factor determining the response in growing pigs to diets deficient in an amino acid. This was clearly illustrated in the above discussion (3.3.2.1). As environmental temperature decreased the pigs were able to increase feed intakes (and improve growth rates) and thereby increase intakes of the limiting amino acid, in this case, lysine. It was shown with the heat loss data that the lower the environmental temperature the more heat the animal can lose. It can be concluded that at lower environmental temperatures pigs are able to compensate better for a deficiency in an amino acid in a diet. The optimum balance of amino acids to energy (depending on the criterion chosen) depends on the potential growth rate of the animal as well as the environmental temperature, with the lysine:DE ratio for maximum growth being lower as the temperature decreases.

GENERAL DISCUSSION

In order to determine the optimum dietary intakes (and hence concentrations) of amino acids at different stages of the growing period, the response of pigs to a range of dietary amino acid concentrations or intakes of each of the essential amino acids must be known. The two experiments conducted in this thesis investigated the response of young growing pigs to a range of dietary lysine and dietary threonine concentrations at different environmental temperatures. The dietary treatments provided the animals with graded levels of each of the amino acids tested. Various response criteria were used to evaluate the response of the pigs to diets deficient in threonine in the first experiment and lysine in the second experiment.

The results indicated that the pigs, when fed a diet deficient in an amino acid, increase feed intakes (and hence nutrient intakes) in an attempt to consume sufficient of the limiting nutrient to satisfy their requirements for this nutrient. Where increasing feed intakes could not compensate for the deficiency in the amino acid, daily growth rates and body tissue gains were constrained to different extents depending on the deficiency. On poor quality diets with low dietary concentrations of the test amino acid the pigs increased feed intakes, but the extent to which this could take place was constrained by environmental temperature.

The response in feed intake followed the same trends as the response in total heat loss. At lower environmental temperatures on diets deficient in an amino acid the animals were able to increase feed intakes beyond those levels attained by animals at higher environmental temperatures. Hence, the ability of the animals to compensate for a deficiency depended on the maximum amount of heat the animals could lose; heat being generated by increased feed intakes and, hence increased digestive and metabolic processes.

It was found that the lowest dietary amino acid concentration on which a pig can maintain its maximum daily growth rates will depend on the ambient temperature. The lower the temperature the more heat the pig can dissipate and therefore, the more the pig can compensate for an amino acid deficiency through increased feed intakes.

This thesis investigated responses in young growing pigs to dietary lysine and dietary threonine as affected by environmental temperature. The results indicate that a diet deficient in a nutrient, specifically an amino acid, will adversely affect pig production through decreased growth rates and increased feed intakes. However, it is shown that environmental temperature plays an important role in determining how the animal responds to a deficiency in an essential amino acid in a diet, and to what extent the animal can compensate for this deficiency in an attempt to attain its maximum inherent growth potential.

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APPENDIX 1

Summary of some of the results for pigs kept at 18°C in the experiment reported in Chapter 2.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Threonine Intake (g/d)	Threonine Retention (g/d)
T1	14.56	23.41	25.16	0.57	0.99	576	3.87	1.55	16.56	0.79	83.68	16.50	331.80	14.17	12.078	0.656	8.02	3.20
	12.38	22.96	25.56	0.53	0.86	616	3.70	2.60	15.50	0.73	82.21	66.36	318.12	13.50	8.228	0.751	6.97	3.14
T2	12.86	22.95	24.88	0.55	1.34	410	3.62	2.36	15.71	0.72	82.93	59.42	342.46	13.61	15.232	0.623	8.31	3.17
	12.02	23.01	24.84	0.53	1.25	424	3.74	1.82	16.14	0.79	85.95	34.93	354.28	16.28	14.798	0.701	7.75	3.28
T3	12.16	22.44	24.58	0.55	1.26	437	3.74	3.79	14.99	0.66	81.65	111.88	290.51	10.51	12.605	0.794	6.55	3.12
	14.36	23.50	25.98	0.57	1.32	432	3.40	3.23	14.59	0.75	77.54	114.19	303.56	15.51	13.526	0.707	6.86	2.96
T4	13.62	22.22	24.94	0.44	1.09	404	3.50	3.63	14.83	0.80	57.35	89.81	220.51	12.43	10.970	0.810	4.69	2.19
	13.28	23.34	25.80	0.47	1.88	250	3.08	4.36	13.56	0.70	49.12	130.91	204.57	10.46	21.054	0.367	8.08	1.88
T5	11.06	22.69	24.68	0.33	1.63	202	2.98	5.22	12.54	0.66	38.82	116.63	148.94	8.03	18.271	0.446	5.54	1.48
	12.86	21.77	23.24	0.34	2.07	164	3.08	5.17	13.32	0.68	36.73	117.75	146.90	7.44	24.713	0.324	7.04	1.40
T6	12.50	24.55	25.96	0.51	1.90	268	3.58	5.31	14.92	0.84	65.65	153.39	248.98	15.40	20.175	0.560	8.17	2.51
	12.42	25.03	26.72	0.54	1.22	443	3.45	5.02	14.72	0.75	68.59	160.13	272.79	13.64	9.875	0.971	5.25	2.62

Summary of some of the results for pigs kept at 22°C in the experiment reported in Chapter 2.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Threonine Intake (g/d)	Threonine Retention (g/d)
T1	12.98	23.78	25.96	0.76	1.16	655	3.79	2.57	16.13	0.83	116.60	89.14	463.72	23.63	10.947	0.764	9.40	4.45
	13.36	23.03	24.84	0.55	0.99	556	3.75	1.92	15.92	0.84	89.86	39.55	353.81	18.86	11.001	0.701	8.02	3.43
T2	11.90	24.00	25.66	0.64	1.20	533	3.68	2.75	16.11	0.75	92.01	80.95	388.36	16.07	12.105	0.784	7.44	3.51
	12.46	23.53	25.48	0.62	1.21	512	3.67	2.81	15.67	0.73	91.95	85.66	368.83	15.30	12.053	0.776	7.50	3.51
T3	13.18	22.52	24.80	0.59	1.32	447	3.34	3.28	14.58	0.67	79.05	116.23	326.36	12.15	13.423	0.719	6.86	3.02
	12.56	22.65	24.64	0.37	1.09	339	3.52	3.20	14.66	0.7	53.61	65.88	202.4	8.63	12.531	0.611	5.67	2.05
T4	13.12	23.32	25.02	0.46	1.25	368	3.80	4.12	15.15	0.74	70.52	108.90	243.16	10.95	12.217	0.859	5.38	2.69
	14.10	24.32	25.98	0.44	1.16	379	3.53	4.14	14.32	0.77	62.57	119.79	214.3	12.33	10.660	0.821	4.99	2.39
T5	13.82	22.86	24.64	0.39	1.04	375	3.12	4.32	13.61	0.66	42.84	113.93	179.28	7.30	9.668	0.845	3.54	1.64
	13.74	23.28	25.22	0.41	1.31	313	3.20	4.65	13.94	0.72	45.95	126.19	185.83	9.38	13.070	0.688	4.45	1.76
T6	11.84	24.00	26.10	0.57	1.19	479	3.10	5.06	14.33	0.71	58.05	163.66	272.05	12.67	9.540	0.830	5.12	2.22
	13.98	23.17	24.90	0.52	1.44	361	3.09	4.48	14.24	0.73	54.55	159.10	254.69	12.94	13.467	0.625	6.19	2.08

Summary of some of the results for pigs kept at 26°C in the experiment reported in Chapter 2.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Threonine Intake (g/d)	Threonine Retention (g/d)
T1	14.08	24.03	26.20	0.58	1.08	537	3.99	2.10	16.60	0.83	96.75	45.31	364.48	17.61	11.975	0.690	8.75	3.70
	13.92	23.52	25.78	0.57	0.83	687	4.08	1.89	16.37	0.74	101.73	36.03	358.14	13.32	8.493	0.981	6.72	3.89
T2	11.92	23.87	25.72	0.58	1.22	475	3.77	2.63	16.35	0.72	87.96	68.89	365.36	13.50	12.060	0.701	8.05	3.36
	13.96	22.91	25.48	0.54	1.00	540	3.70	2.15	15.72	0.81	60.69	34.79	236.16	12.23	11.003	0.604	6.60	2.32
T3	13.48	23.58	25.34	0.41	0.92	446	3.67	3.14	15.48	0.79	61.77	70.31	238.31	12.08	8.606	0.819	5.06	2.36
	10.32	24.13	26.44	0.51	1.14	447	3.57	3.42	15.83	0.75	66.55	80.55	289.73	12.94	11.124	0.684	6.27	2.54
T4	11.56	24.18	25.86	0.41	1.07	383	3.55	4.02	15.38	0.71	55.36	88.06	229.35	9.49	9.719	0.649	5.56	2.11
	13.64	24.37	26.08	0.43	1.16	371	3.69	3.86	15.52	0.85	61.60	94.83	236.13	13.73	10.496	0.662	6.03	2.35
T5	12.82	22.80	25.32	0.34	1.01	337	3.28	4.51	13.8	0.71	40.48	93.53	152.79	6.91	9.454	0.745	3.84	1.55
	12.9	22.45	24.32	0.33	1.00	330	2.97	5.05	13.31	0.67	33.45	114.3	146.06	6.91	8.689	0.609	3.80	1.28
T6	13.58	24.32	25.66	0.38	0.90	422	3.76	4.10	15.32	0.74	58.50	93.46	209.10	9.26	7.662	1.031	4.32	2.23
	13.92	23.19	24.96	0.46	1.10	418	3.44	3.58	14.99	0.67	62.41	101.88	256.07	8.81	10.116	0.844	4.80	2.38

Summary of some of the results for pigs kept at 30°C in the experiment reported in Chapter 2.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Threonine Intake (g/d)	Threonine Retention (g/d)
T1	11.98	22.15	25.08	0.44	0.90	489	3.61	1.62	15.72	0.66	64.76	21.59	270.21	8.88	10.970	0.560	7.29	2.47
	13.98	24.14	25.86	0.57	1.02	559	4.09	2.08	16.66	0.74	101.98	44.88	370.09	13.36	10.963	0.778	8.26	3.90
T2	13.66	23.10	25.32	0.49	1.03	476	3.74	2.86	15.28	0.72	76.70	72.88	274.87	11.15	9.533	0.740	6.80	2.93
	12.00	24.21	26.10	0.47	1.31	359	3.84	2.41	16.68	0.72	72.18	47.73	301.58	10.90	14.518	0.532	8.65	2.76
T3	13.16	24.32	26.06	0.46	1.15	400	3.77	3.51	15.79	0.72	69.09	87.15	265.27	10.18	10.979	0.708	6.33	2.64
	13.14	24.06	25.84	0.41	1.05	390	3.87	3.38	15.60	0.74	65.85	74.36	233.79	9.96	10.168	0.754	5.78	2.52
T4	12.68	21.69	24.24	0.39	1.12	348	3.12	3.66	13.73	0.68	45.15	87.44	189.04	8.59	10.675	0.477	5.82	1.72
	13.44	23.91	25.82	0.35	0.91	385	3.74	3.49	15.34	0.76	53.31	68.33	194.06	9.02	8.388	0.740	4.73	2.04
T5	11.82	23.68	25.64	0.35	1.11	315	3.28	5.11	14.02	0.72	41.93	106.23	166.72	8.49	10.356	0.687	4.22	1.60
	12.52	23.32	25.28	0.26	1.07	243	3.30	5.15	13.79	0.71	31.73	84.29	119.08	6.08	10.905	0.544	4.07	1.21
T6	13.02	23.23	25.34	0.41	1.01	406	3.42	3.98	14.68	0.62	53.38	97.42	213.41	6.47	9.249	1.037	4.85	2.04
	12.54	25.20	26.74	0.53	1.35	393	3.80	4.79	15.20	0.74	76.03	139.72	267.83	12.01	11.830	1.058	6.48	2.90

APPENDIX 2

A summary of the regression equations used to plot the response curves (at each temperature) to dietary threonine concentration in Chapter2.

Average daily gains (ADG):

18°C: $ADG = -0.468 + 0.317 \times THR - 0.0242 \times THR^2$

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.4680	0.1676	-2.79	0.021
THR	0.31735	0.06161	5.15	0.000
THR^2	-0.024191	0.005374	-4.50	0.000

s = 0.03399 $r^2 = 0.87$

22°C: $ADG = 0.208 + 0.0583 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.20790	0.09325	2.23	0.050
THR	0.05831	0.01650	3.53	0.005

s = 0.08201 $r^2 = 0.56$

26°C: $ADG = 0.176 + 0.0537 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.17638	0.05677	3.11	0.011
THR	0.05371	0.01004	5.35	0.000

s = 0.04993 $r^2 = 0.74$

30°C: $ADG = 0.206 + 0.0405 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.20602	0.07125	2.89	0.016
THR	0.04052	0.01261	3.21	0.009

s = 0.06267 $r^2 = 0.51$

Feed intake (FI):

18°C: $FI = 2.44 - 0.190 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	2.4407	0.3069	7.95	0.000
THR	-0.19022	0.05430	-3.50	0.006

s = 0.2699 $r^2 = 0.55$

22°C: $FI = 1.35 - 0.0275 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	1.3470	0.1406	9.58	0.000
THR	-0.02750	0.02488	-1.10	0.295

s = 0.1237 $r^2 = 0.11$

26°C: $FI = 1.07 - 0.0061 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	1.0689	0.1364	7.83	0.000
THR	-0.00606	0.02414	-0.25	0.807

s = 0.1200 $r^2 = 0.06$

30°C: $FI = 1.18 - 0.0175 \times THR$

Predcitor	Coef	Stdev	t-ratio	P
Constant	1.1816	0.1602	7.38	0.000
THR	-0.01751	0.02835	-0.62	0.551

s = 0.1409 $r^2 = 0.4$

Feed conversion efficiency (FCE):

18°C: $FCE = -62.0 + 81.9 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	-61.97	79.50	-0.78	0.454
THR	81.86	14.07	5.82	0.000

s = 72.64 $r^2 = 0.78$

22°C: $FCE = 113 + 60.3 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	113.32	62.95	1.80	0.102
THR	60.34	11.14	5.42	0.000

s = 55.36 $r^2 = 0.75$

26°C: $FCE = 110 + 62.1 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	109.97	46.77	2.35	0.041
THR	62.096	8.276	7.50	0.000

s = 41.13 $r^2 = 0.85$

30°C: $FCE = 142 + 46.7 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	141.51	52.67	2.69	0.023
THR	46.712	9.318	5.01	0.000

s =46.32 $r^2 = 0.72$

Lipid gain (LIPG):

18°C: $LIPG = 101 - 12.4 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	100.675	8.053	12.50	0.000
THR	-12.435	1.425	-8.73	0.000

$s = 7.083$ $r^2 = 0.88$

22°C: $LIPG = 86.5 - 9.96 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	86.465	5.954	14.52	0.000
THR	-9.957	1.054	-9.45	0.000

$s = 5.237$ $r^2 = 0.90$

26°C: $LIPG = 154 - 37.3 \times THR + 2.41 \times THR^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	153.78	20.09	7.65	0.000
THR	-37.347	7.389	-5.05	0.000
THR^2	2.4142	0.6445	3.75	0.005

$s = 4.077$ $r^2 = 0.95$

30°C: $LIPG = 80.8 - 9.64 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	80.842	5.162	15.66	0.000
THR	-9.6425	0.9133	-10.65	0.000

$s = 4.539$ $r^2 = 0.92$

Protein retention (PR):

18°C: $PR = -105 + 53.6 \times THR - 3.78 \times THR^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	-104.66	27.32	-3.83	0.004
THR	53.60	10.04	5.34	0.000
THR^2	-3.7837	0.8762	-4.32	0.002

s = 5.542 $r^2 = 0.92$

22°C: $PR = -3.5 + 13.7 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	-3.49	11.17	-0.31	0.761
THR	13.711	1.977	6.94	0.000

s = 9.825 $r^2 = 0.83$

26°C: $PR = -3.43 + 12.6 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	-3.433	9.655	-0.36	0.730
THR	12.629	1.708	7.39	0.000

s = 8.492 $r^2 = 0.85$

30°C: $PR = 7.7 + 10.1 \times THR$

Predictor	Coef	Stdev	t-ratio	P
Constant	7.73	13.64	0.57	0.583
THR	10.051	2.414	4.16	0.002

s = 12.00 $r^2 = 0.63$

where THR = Dietary threonine concentration (g/kg)

APPENDIX 3

Summary of some of the results for pigs kept at 18°C in the experiment reported in Chapter 3.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Lysine Intake (g/d)	Lysine Retention (g/d)
T1	12.86	23.72	25.50	0.57	1.21	471	3.92	2.31	16.33	0.76	96.86	57.27	370.62	15.40	11.962	0.545	16.82	6.83
	13.06	23.40	25.84	0.61	1.22	500	3.83	2.09	16.27	0.78	95.75	48.92	379.42	16.54	12.439	0.533	16.96	6.75
T2	13.90	23.12	25.46	0.67	1.20	558	3.57	3.10	15.35	0.63	102.38	122.97	407.07	10.80	9.286	0.748	13.20	7.22
	13.18	22.62	25.50	0.73	1.40	521	3.46	2.36	15.46	0.65	95.78	75.86	416.60	12.68	14.054	0.589	15.40	6.75
T3	12.76	23.21	25.38	0.65	1.17	556	3.45	3.10	15.44	0.69	88.00	108.67	385.91	13.99	9.565	0.720	11.82	6.20
	12.10	22.75	24.98	0.56	1.77	316	3.31	3.08	15.16	0.60	73.82	94.99	339.48	9.05	18.645	0.384	17.88	5.20
T4	12.32	22.80	24.92	0.50	1.39	360	3.44	3.17	15.01	0.71	68.80	86.72	287.19	12.07	12.334	0.547	12.09	4.85
	12.26	22.73	24.72	0.50	1.28	391	3.30	3.94	14.29	0.71	63.58	117.79	259.77	12.17	9.847	0.552	11.14	4.48
T5	12.98	23.11	25.12	0.45	1.46	308	3.09	4.54	14.00	0.75	47.53	128.83	212.74	11.8	13.655	0.502	9.34	3.35
	12.72	24.30	25.82	0.52	1.68	310	3.17	5.27	14.55	0.66	56.05	169.15	258.59	9.63	14.880	0.448	10.75	3.95
T6	12.76	23.74	25.16	0.54	1.68	321	3.53	4.07	14.94	0.82	76.38	131.56	296.77	17.38	16.321	0.602	12.26	5.38
	12.84	22.92	24.96	0.51	1.27	402	3.23	4.13	14.30	0.72	60.05	128.63	255.53	12.41	11.120	0.641	9.27	4.23

Summary of some of the results for pigs kept at 22°C in the experiment reported in Chapter 3.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Lysine Intake (g/d)	Lysine Retention (g/d)
T1	13.56	23.10	25.86	0.72	1.07	673	3.51	2.09	16.00	0.79	95.50	58.04	434.33	20.42	10.034	0.609	14.87	6.73
	13.58	23.11	25.66	0.67	0.99	677	3.74	2.47	15.76	0.69	102.65	75.56	395.88	13.68	8.062	0.717	13.76	7.24
T2	12.38	23.75	26.10	0.62	1.11	559	3.54	2.82	15.96	0.74	82.44	82.23	367.94	14.89	10.142	0.656	12.21	5.81
	12.08	22.96	25.18	0.62	1.10	564	3.72	2.46	15.43	0.72	97.05	70.45	369.04	15.32	10.082	0.785	12.10	6.84
T3	13.00	23.88	26.38	0.71	1.28	555	3.34	3.23	15.89	0.73	80.29	114.37	401.47	15.66	11.059	0.593	12.93	5.66
	12.90	23.36	25.90	0.59	1.21	488	3.57	3.41	15.21	0.76	80.53	107.02	318.70	15.15	10.357	0.637	12.22	5.68
T4	12.44	23.06	25.22	0.53	1.27	417	3.17	4.00	14.48	0.70	59.86	124.41	273.99	12.00	9.579	0.522	11.05	4.22
	13.28	23.66	25.40	0.49	1.38	355	3.55	3.85	14.94	0.82	65.20	106.36	249.78	14.57	11.551	0.525	12.01	4.60
T5	13.40	23.36	25.52	0.40	1.19	336	3.09	4.90	13.87	0.74	40.86	127.07	178.50	9.78	10.219	0.546	7.62	2.88
	11.74	22.53	24.78	0.48	1.51	318	2.86	5.30	13.12	0.69	45.17	160.75	209.48	11.08	13.141	0.455	9.66	3.18
T6	12.58	23.39	25.48	0.56	1.17	479	3.25	4.09	14.45	0.65	65.05	133.32	280.47	10.27	9.452	0.763	8.54	4.59
	14.32	23.23	25.64	0.67	1.43	469	3.28	4.10	14.29	0.71	75.30	172.65	305.03	13.94	11.245	0.704	10.44	5.31

Summary of some of the results for pigs kept at 26°C in the experiment reported in Chapter 3.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Lysine Intake (g/d)	Lysine Retention (g/d)
T1	12.90	23.79	26.22	0.67	0.96	698	3.71	1.78	17.05	0.68	95.58	36.66	442.37	12.89	9.363	0.690	13.34	6.74
	12.06	23.19	25.14	0.60	1.04	577	3.69	1.84	16.37	0.71	91.39	38.87	395.81	14.09	10.496	0.604	14.46	6.44
T2	13.08	23.09	25.14	0.67	0.96	698	3.47	2.75	15.65	0.69	91.70	93.28	407.52	14.28	6.978	0.892	10.08	6.46
	14.10	23.45	26.06	0.66	1.19	555	3.50	2.65	16.00	0.77	85.40	83.41	390.92	16.81	10.619	0.654	12.50	6.02
T3	12.66	24.73	26.74	0.64	1.35	474	3.49	3.84	16.05	0.73	78.51	127.78	363.94	14.11	12.237	0.639	12.02	5.53
	14.28	23.88	26.44	0.55	1.28	430	3.45	2.82	16.23	0.76	66.56	75.42	325.04	13.17	13.627	0.574	11.39	4.69
T4	12.84	24.12	26.24	0.61	1.40	436	3.35	4.06	15.31	0.76	70.84	137.01	324.95	15.23	13.477	0.783	9.10	4.99
	13.04	23.46	25.68	0.44	1.30	338	3.24	4.14	14.31	0.66	48.98	106.07	207.70	8.04	13.757	0.587	8.45	3.45
T5	12.92	23.42	25.54	0.36	1.06	340	3.06	4.72	14.13	0.72	35.98	104.71	168.96	8.30	10.919	0.716	5.51	2.54
	12.34	22.38	24.02	0.26	0.87	299	2.89	5.2	13.00	0.71	26.03	93.17	114.53	6.80	8.776	0.655	4.52	1.84
T6	12.82	23.70	25.52	0.53	1.27	417	3.30	3.81	15.13	0.78	63.03	115.09	290.65	14.69	11.059	0.886	7.37	4.44
	13.24	23.43	26.00	0.58	1.35	430	3.28	3.88	14.94	0.75	65.37	127.44	296.47	14.20	11.488	0.854	7.83	4.61

Summary of some of the results for pigs kept at 30°C in the experiment reported in Chapter 3.

Dietary Treatment	Starting Weight (kg)	EBW (kg)	End Weight (kg)	ADG (kg/d)	Food Intake (kg/d)	FCE	Body Protein (kg)	Body Lipid (kg)	Body Moisture (kg)	Body Ash (kg)	Protein Deposition (g/d)	Lipid Deposition (g/d)	Moisture Deposition (g/d)	Ash Deposition (g/d)	Total Heat Loss (MJ/d)	ep	Lysine Intake (g/d)	Lysine Retention (g/d)
T1	13.84	24.16	26.60	0.58	1.07	542	3.68	2.32	16.75	0.75	79.77	54.11	361.34	13.16	10.573	0.511	14.87	5.62
	12.22	23.29	25.96	0.55	1.08	509	3.64	1.92	16.56	0.65	77.31	36.81	351.54	9.82	11.454	0.489	15.01	5.45
T2	14.38	24.23	26.46	0.50	1.01	495	3.71	2.16	16.87	0.78	71.16	41.09	322.18	12.68	10.206	0.660	10.61	5.02
	13.88	23.21	25.54	0.49	1.01	485	3.55	2.06	16.21	0.75	67.36	38.61	307.67	12.18	10.381	0.621	10.61	4.75
T3	11.66	21.99	24.10	0.44	1.16	379	3.15	3.37	14.20	0.63	63.46	100.66	282.87	10.14	10.963	0.604	10.32	4.47
	13.44	23.56	26.26	0.53	1.02	520	3.41	2.85	15.99	0.80	63.89	73.25	310.46	15.05	10.082	0.712	9.08	4.50
T4	12.98	22.62	25.22	0.44	0.99	444	3.06	3.84	14.28	0.68	44.55	99.29	215.31	9.08	9.570	0.728	6.44	3.14
	12.92	24.06	26.20	0.47	1.26	373	3.39	3.90	15.17	0.77	56.72	101.71	248.45	12.16	13.137	0.710	8.19	4.00
T5	12.74	22.52	25.04	0.35	1.08	324	2.88	4.60	13.76	0.63	31.46	101.74	161.67	6.13	11.434	0.603	5.62	2.22
	13.32	22.73	25.22	0.34	1.24	274	2.77	4.88	13.57	0.73	26.20	108.50	145.78	8.29	13.705	0.422	6.45	1.85
T6	12.30	23.72	25.70	0.43	1.14	377	3.24	4.36	14.36	0.67	49.23	108.26	211.15	8.56	9.811	0.785	6.61	3.47
	12.08	23.42	26.56	0.47	1.09	431	3.10	4.10	14.93	0.66	48.82	107.42	250.19	9.12	9.182	0.814	6.32	3.44

APPENDIX 4

A summary of the regression equations used to plot the response curves (at each temperature) to dietary lysine concentration in Chapter3.

Average daily gains (ADG):

18°C: $ADG = 0.383 + 0.0205 \times LYS$

Predictor	Coef	Stdev	t-ratio	p
Constant	0.38314	0.06119	6.26	0.000
LYS	0.020522	0.006520	3.15	0.010

s = 0.06131 $r^2 = 0.50$

22°C: $ADG = 0.345 + 0.0271 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.34503	0.06598	5.23	0.000
LYS	0.027084	0.007031	3.85	0.003

s = 0.06611 $r^2 = 0.60$

26°C: $ADG = 0.228 + 0.0356 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.22771	0.08734	2.61	0.026
LYS	0.035598	0.009307	3.83	0.003

s = 0.08751 $r^2 = 0.60$

30°C: $ADG = 0.262 + 0.0227 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	0.26231	0.03530	7.43	0.000
LYS	0.022656	0.003761	6.02	0.000

s = 0.03537 $r^2 = 0.78$

Feed intake (FI):

18°C: $FI = 1.73 - 0.0378 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	1.7334	0.1903	9.11	0.000
LYS	-0.03777	0.02028	-1.86	0.092

s = 0.1907 $r^2 = 0.26$

22°C: $FI = 1.61 - 0.0427 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	1.6095	0.1016	15.84	0.000
LYS	-0.04270	0.01083	-3.94	0.003

s = 0.1018 $r^2 = 0.61$

26°C: $FI = -0.507 + 0.410 \times LYS - 0.0227 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	-0.5066	0.4718	-1.07	0.311
LYS	0.4097	0.1076	3.81	0.004
LYS^2	-0.022724	0.005707	-3.98	0.003

s = 0.1172 $r^2 = 0.66$

30°C: $FI = 1.22 - 0.0138 \times LYS$

Predcitor	Coef	Stdev	t-ratio	P
Constant	1.21987	0.08340	14.63	0.000
LYS	-0.013808	0.008887	-1.55	0.151

s = 0.08357 $r^2 = 0.19$

Feed conversion efficiency (FCE):

18°C: FCE = 183 + 26.1 x LYS

Predictor	Coef	Stdev	t-ratio	P
Constant	183.45	68.07	2.698	0.023
LYS	26.091	7.254	3.60	0.005

s = 68.21 r^2 = 0.56

22°C: FCE = 127 + 40.5 x LYS

Predictor	Coef	Stdev	t-ratio	P
Constant	127.34	38.70	3.29	0.008
LYS	40.510	4.124	9.82	0.000

s = 38.78 r^2 = 0.91

26°C: FCE = 94.5+ 42.3 x LYS

Predictor	Coef	Stdev	t-ratio	P
Constant	94.55	59.16	1.60	0.141
LYS	42.277	6.304	6.71	0.000

s = 59.27 r^2 = 0.82

30°C: FCE = 200 + 25.5 x LYS

Predictor	Coef	Stdev	t-ratio	P
Constant	199.91	45.57	4.39	0.001
LYS	25.548	4.856	5.26	0.000

s =45.66 r^2 =0.74

Lipid gain (LIPG):

18°C: $LIPG = 67.5 - 4.41 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	67.525	7.004	9.640	0.001
LYS	-4.4072	0.7463	-5.91	0.004

s = 4.962 $r^2 = 0.90$

22°C: $LIPG = 142 - 19.9 \times THR + 0.775 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	141.86	15.48	9.172	0.003
LYS	-19.947	3.352	-5.65	0.011
LYS^2	0.7750	0.1872	4.14	0.026

s = 2.720 $r^2 = 0.99$

26°C: $LIPG = 76.1 - 5.24 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	76.083	7.017	10.84	0.000
LYS	-5.2356	0.7477	-7.00	0.002

s = 4.971 $r^2 = 0.93$

30°C: $LIPG = 139 - 19.5 \times LYS + 0.742 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	138.50	14.75	9.396	0.003
LYS	-19.541	3.3653	-5.815	0.010
LYS^2	0.7422	0.1784	4.16	0.025

s = 2.592 $r^2 = 0.99$

Protein retention (PR):

18°C: $PR = 23.5 + 5.96 \times LYS$

Predictor	Coef	Stdev	t-ratio	P
Constant	23.538	7.569	3.11	0.011
LYS	5.9603	0.8066	7.39	0.000

s = 7.584 $r^2 = 0.85$

22°C: $PR = -38.7 + 19.2 \times LYS - 0.676 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	-38.74	22.50	-1.72	0.119
LYS	19.208	5.134	3.74	0.005
LYS^2	-0.6762	0.2722	-2.48	0.035

s = 5.591 $r^2 = 0.93$

26°C: $PR = -74.3 + 25.4 \times LYS - 0.974 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	-74.31	30.00	-2.48	0.035
LYS	25.438	6.845	3.72	0.005
LYS^2	-0.9740	0.3629	-2.68	0.025

s = 7.455 $r^2 = 0.91$

30°C: $PR = -46.9 + 17.9 \times LYS - 0.650 \times LYS^2$

Predictor	Coef	Stdev	t-ratio	P
Constant	-46.95	14.88	-3.16	0.012
LYS	17.921	3.395	5.28	0.000
LYS^2	-0.6504	0.1800	-3.61	0.006

s = 3.697 $r^2 = 0.96$

where LYS = Dietary lysine concentration (g/kg)