Effect of controlled feeding on growth, efficiency and carcass composition of grower pigs from a selected breeding line

By

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Declaration

I, the undersigned, declare that the thesis, which I hereby submit for the degree MSc (Agric) Animal Science: Production Physiology at the University of Pretoria, is my own work and has not previously been submitted by me or another individual for a degree at this or any other tertiary institution.

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H. Mulder
February 2015

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Abstract

Commercial pig production makes use of pigs produced by breeding companies through deliberate breeding plans and selection strategies. This leads to ongoing improvement in growth performance and efficiency of pigs. In order to take full advantage of these genetic improvements the environmental management and nutrition should meet the requirements of the improved pig genotypes. The objective of this study was to determine the growth performances and carcass characteristics of entire male grower – finisher pigs from a specific boar subjected to different feed level allocations and housing systems under South African circumstances. The terminal sire used to produce this male offspring was bred by Topigs Norsvin South Africa and exhibited superior growth performance. This boar achieved an average test gain of 1.740 kg per day. The pigs were randomly allocated to a feeding treatment from an age of 15 weeks. They were either fed on an *ad libitum* basis or a daily controlled amount. This controlled amount of feed was calculated to match their growth potential to produce optimal growth. Furthermore the animals were randomly allocated to one of the two housing systems. The feeding treatments were tested under individual and group housing systems. Controlled feeding led to significantly lower growth rates. This can be seen in the significantly ($P< 0.01$) higher average daily gains (ADG) and 21 week empty bodyweights. The difference in growth rates was due to the difference in nutrient intakes. A strong linear relationship was found between the available lysine and metabolisable energy intake and the ADG achieved. The efficiency with which growth took place was significantly ($P< 0.01$) higher under the controlled feeding treatment in the individual housing system. The feeding treatment applied had no significant effect on the feed efficiency in the group housing system. The difference in efficiency between the two feeding treatments was ascribed to the difference in adipose tissue deposition. A significantly ($P< 0.01$) lower P2 backfat thickness was recorded under the controlled feeding treatment. Carcass parameters were significantly affected by the feeding treatments. Control fed pigs produced carcasses with significantly ($P< 0.01$) higher lean meat percentage and significantly ($P< 0.01$) lower fat percentage, warm carcass mass, cold carcass mass and carcass compactness. The housing system in which pigs were kept, significantly affected their feed intakes when *ad libitum* feeding was applied. The lower ($P< 0.01$) feed intakes achieved in the group housing system led to the difference between the feeding treatments being smaller than that of the individual housing system. This explains why the difference in performance between feeding treatments in the group housing system was smaller than in the individual housing system. Growth rates and empty bodyweights were only affected when the pigs were fed *ad libitum*. This is demonstrated in the higher ($P< 0.01$) ADGs and empty body weights achieved in the individual housing system. Individual housing led to significantly higher P2 backfat thickness levels ($P< 0.01$) throughout the experiment when data from the two feeding treatments were pooled. Pigs exposed to the group housing system produced lighter carcasses than those kept in the individual housing system. In conclusion the offspring exhibited a higher growth rate and higher slaughter weight when fed on an *ad libitum* basis. *Ad libitum* feeding led to heavier and leaner carcasses and a higher income in the individual housing system. Although *ad libitum* feeding led to a higher growth rate and heavier carcasses in group housing no significant difference was found in the net income. When the offspring was tested in the individual housing system, controlled feeding led to a slower but more efficient growth than achieved with an *ad libitum* feeding regime. Feeding regime had no effect on the efficiency of growth of pigs in the group housing system. The level of feed allowance in commercial situations should match the growth potential of the pigs being used. Furthermore the best feed allowance should be calculated by taking into account effects on growth rate, feed efficiency and carcass composition. Based on these the best economical level should be determined and accurately applied.

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CHAPTER 1
LITERATURE REVIEW

1.1 Introduction and motivation

The goal of maximizing income in pig production is achieved by efficiently producing lean carcasses as close to the market demand as possible. Feed costs are the biggest expense in modern pig production and may account for up 70% of the total costs. Thus by saving on feed costs, pig production's profitability will be increased. By using controlled feeding to provide as close as possible the correct amount of nutrients required for optimal growth, feed costs may be reduced and feed efficiency improved. If controlled feeding is proved to be an effective way of improving the efficiency of growth in grower pigs without negatively affecting the carcass composition it can be applied under commercial situations and lead to savings on feed costs.

The objective of pig production systems is to produce animals marketable for slaughter. This means piglets born are raised to a specific body weight according to the market requirements. The goal is to meet the market requirements as fast and as efficiently as possible. By doing this the income per animal can be maximised. This means a high growth rate and efficient growth is what pig producers strive for. Further income can be maximised by meeting the market requirements as body composition at slaughter determines the commercial value of the animal (Quiniou *et al*., 1996)

High feed prices and low profit margins make any improvement in growth and feed efficiency appealing in pig production. To optimise production several aspects should be controlled, these aspects are all equally important and affect each other. In other words the interplay between genetics, nutrition, physiology and management should be actively managed and investigated for possible improvements. The progress made through selection and breeding programs is immense and has led to improved production per animal and pig production systems. However, the improvement in the animal's genotype and potential for high levels of production must be met by advances made in both nutrition and management. Therefore it is of interest to characterise the relationship between protein deposition and lipid deposition and nutrient supplies in order to adapt feeding strategies to the intrinsic characteristics of each type of pig according to the objectives of the production system (Quiniou *et al*., 1996). Only by ensuring these aspects meets the requirements of the modern pig can we take advantage of its superior genotype.

The trend in pig production is that breeding and selection is done by private breeding companies, breeding and producing improved genotypes commercially available for production purposes. This means there is a constant improvement in the genotypes of the animals used in production systems. These breeding companies further supply the commercial sector with nutrient requirements that need to be met to optimise production from their products. These requirements need to be adapted frequently to match the improvements made by selection. To achieve this, breeding companies test their animals to accurately determine their requirements. However, these requirements are normally determined by using animals in individual housing to ensure accurate measurements and control. This is different from commercial conditions where animals are mostly kept in group housing. From research it becomes clear that growth performance is normally higher when animals are penned individually (de Haer & de Vries, 1993a; Hacker *et al*., 1994). Further to determine nutrient requirements for optimum growth factors influencing growth should be taken into account. Several factors play a role in growth or rate of protein deposition such as age, live weight, genotype, sex, nutrition and the environment (de Greef, 1992). Because of disparities such as these between the testing environment and commercial conditions it is important to verify the accuracy of the requirements determined by the breeding companies to make necessary adjustments.

The objective of this experiment was to determine the best feeding regime to elicit optimum growth performance, for grower pigs originating from a sire bred for a high growth performance. Further the effects of the feeding regime on carcass composition was determined. The experimental results can be used for validation of requirements determined by the breeding company. The experimental treatments were tested in both individual and group housing under South African weather conditions.

The aim of the experiment was to test the following hypotheses.

H_0:

- No difference in growth rate (ADG) and feed efficiency (FCR) will occur between controlled feeding and *ad libitum* fed grower pigs.
- Controlled feeding will not lead to an improvement in carcass composition.

H_A:

- Controlled feeding leads to a higher growth rate (ADG) and better efficiency (lower FCR) than *ad libitum* feeding of grower pigs.
- Controlled feeding leads to an improvement in carcass composition of grower pigs

1.2 Growth

Growth can be defined as the increase in body size, body weight and change in body dimensions. The overall growth of an animal follows a sigmoidal pattern as can be seen in Figure 1.1, this pattern is seen for any measure used to determine growth such as height or body weight. This sigmoidal curve can be divided into two phases according to the rate of growth taking place. Early growth takes place at a fast and increasing rate, this is known as the self-accelerating phase. The rate increases up to its maximum value, known as the inflexion point. From this point onwards growth rate decreases. The last phase is known as the self retarding phase, in this phase growth rate decreases at an increasing rate as the animal ages. The reason for decrease in the growth rate is due to several processes. Growth reaches a plateau at which slow or very little growth takes place. The period during which rapid growth takes place is known as the exponential growth period.

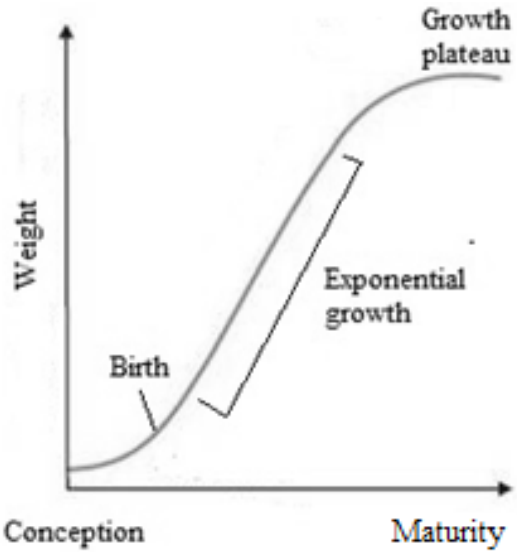

Figure 1.1 Sigmoidal growth curve (Hammond, 1955)

Whilst all tissues in the body follow this sigmoidal growth pattern they are not necessarily in the same growth phase. This means that body tissues start their growth process at different maturities. In Figure 1.2 the order of growth of the different tissues can be seen. Because of this difference in stage of growth between tissues, changes can be seen in the overall body composition and confirmation. This is important in animal production. From this it can be determined when it is the most economical to market an animal for meat production. For meat production the goal is to produce an animal with a high proportion muscle and a low proportion of bones and adipose tissue. In the early work done by D'Arcy (1917) in which he investigated the changes in body shape by using Cartesian transformations the changes in body shape becomes apparent due to this different rates of growth. This difference in growth rates is known as allometry, the study of relative growth, of changes in proportion with increase in size.

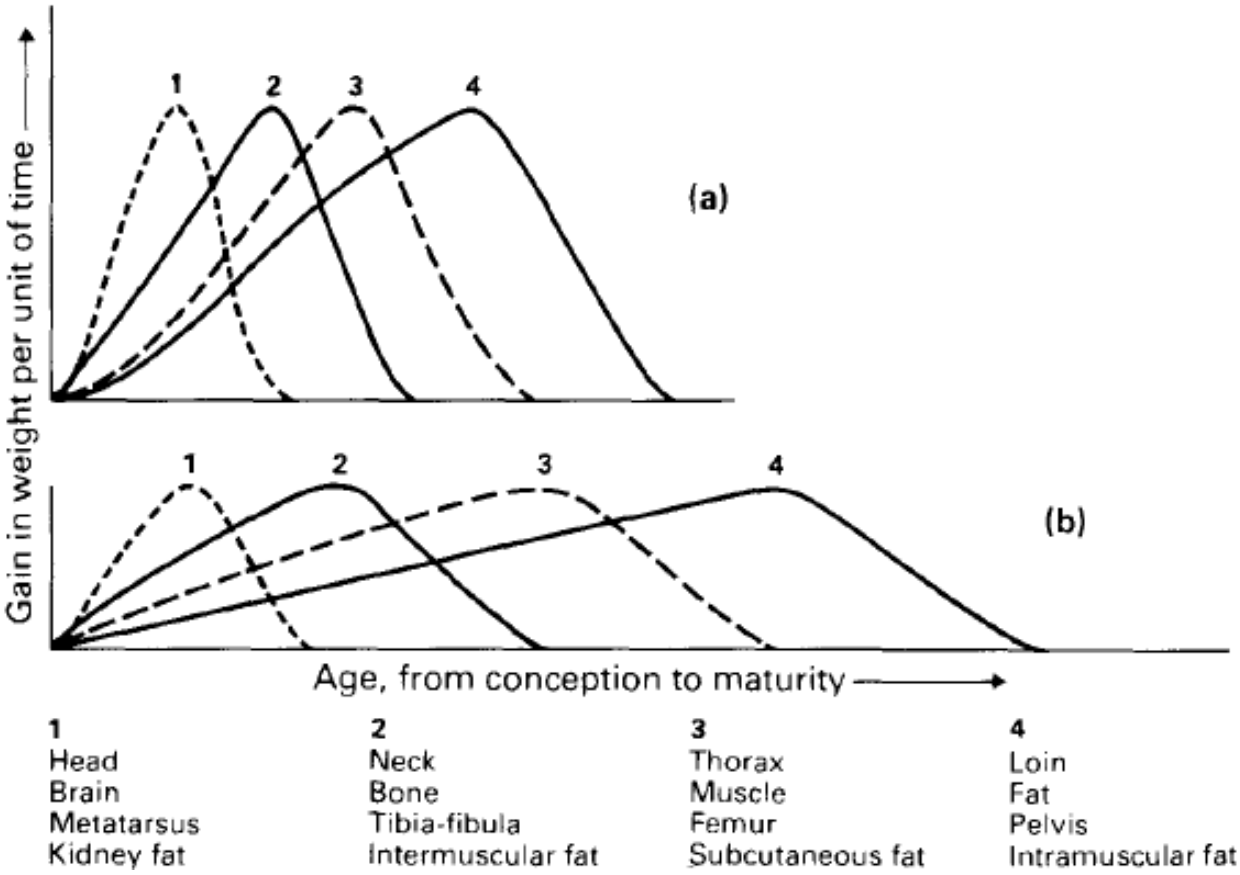

Figure 1.2 Growth rates of body regions and tissues during development from conception to maturity. (Hammond, 1955)

1.3 Growth performance differences between sexes

Gilts and boars are used in commercial grower production. To ensure that optimum growth performance is achieved the different sexes should be fed according to their specific requirements. To be able to do this the growth performance of the different sexes should be understood to determine their requirements for optimum lean growth and maximum efficiency. The difference in performance can be seen in the results of Garitano *et al.* (2013) who tested the effect of gender on growth performance of pigs slaughtered for ham production. They found that barrows had a significantly higher ADG and average daily feed intake (ADFI) than gilts. However, no significant difference was found in feed conversion efficiency (FCE). This higher growth rate and feed intake is in agreement with the results of Latorre *et al.* (2003) who found a 0.15 kg/day difference in feed intake and 38 g/day difference in growth rate in the growth period from 45 to 117 kg. Results on feed conversion contradicts those of Garitano *et al.* (2013), as the barrows tended to have a poorer feed conversion ratio. Several studies found a higher growth rate, feed intake and lower feed efficiency in barrows than in gilts (Friesen *et al*., 1994; Leach *et al*., 1996; Weatherup *et al*., 1998 Lebret *et al*., 2001; Latorre *et al*., 2003, 2004; Serrano *et al*. 2012). This higher growth rate of barrows can be explained by their higher feed intake. Furthermore, the difference in feed efficiency is due to the higher adipose tissue levels seen in barrows, as shown in the results of Friesen *et al.* (1994) who found a 0.32 cm backfat thickness and a 0.62 cm 10^{th} rib fat depth difference between gilts and boars. A similar difference was found in the work done by Latorre *et al*. (2003 & 2004); Garitano *et al.* (2013) and Serrano *et al*. (2012). The decrease in efficiency is explained by the energy intensive process of adipose tissue synthesis in comparison to lean tissue synthesis. Differences in growth performance and feed efficiency

occurs between barrows and intact boars. This difference is apparent from the work of Squires *et al*. (1993) who found that boars grew with conversion ratio of 2.46 whilst barrows grew less efficiently with a value of 2.74. Furthermore it was found that the boars had a lower ADG (941g) in comparison with the barrows (975g). This is in agreement with the results of Xue *et al*. (1995) who found boars had a feed efficiency of 2.48 whilst barrows only achieved 2.62. A similar faster growth rate was found in barrows (799g) compared to the boars who achieved an ADG of 731g. The slower growth rate in boars in comparison to barrows contradicts findings made by Wood & Riley (1982) who found that the intact male had an ADG of 920g whilst the barrows had an ADG of 601g.

1.4.1 Restricted Feeding

Restricted feeding of grower pigs has been used as a method to control the carcass composition. By restricting feed intake to allow maximum protein deposition whilst minimizing the fat deposition in attempt to maximise the carcass grading. Leymaster & Mersmann (1991) tested the effect of feed intake on the subcutaneous adipose tissue layers and carcass composition. This was done by limiting the pig's intakes to 92.5 and 85% of their *ad libitum* intake. The feed restriction led to a significant reduction in adipose tissue, reducing it to a level of 90 and 82% of the level of *ad libitum* fed pigs. There was no significant difference found in water, protein and ash contents between the treatments. Leymaster & Mersmann (1991) continues to say that these changes mean that the expression of chemical components as percentage of carcass soft-tissue weight indicated significantly increases percentages in water, protein and ash as feed intake decreased from *ad libitum* levels. Furthermore the percentage of adipose tissue decreased as the feed intake decreased. These changes in chemical composition between the treatments can be seen in the change in the rate of protein and lipid deposition. The group restricted to 92.5 % of *ad libitum* intake had a 97% and 86% protein and ether lipid composition relative to the *ad libitum* fed animals. Whilst the group restricted to a level of 85% had 94% and 75% deposition ratios. No significant difference was found in the feed conversion to protein, however, they did find that the 92.5 and 75% groups required 5 and 10% less feed per unit of protein deposition. The restrictive feeding led to changes in the backfat thickness, Leymaster & Mersmann (1991) found that the biggest changes occurred in the middle layer, this can be seen in an 86% and 75% change in this layer for the 92.5% and 85% feed intake groups respectively. The difference in changes between the fat layers can be explained by the fact that the middle layer has higher lipogenic activities than the outer layer in mature pigs, as found in several studies (Anderson *et al*., 1972; Anderson & Kauffman, 1973; Hood & Allen, 1977; Sturm *et al*., 1982). The middle layer seem to be in a more dynamic metabolic state than the other two layers. This can be seen in earlier research done by Mersmann (1982b) and Mersmann & Leymaster (1983) who found that in early development the increase in backfat occurs predominantly in the middle layer. Furthermore they found selection based on backfat thickness seems to have the biggest effect on the middle layer of backfat. It was also shown that severe energy intake restriction led to a decrease in backfat thickness which is in agreement with findings made by Hilditch & Pedelty (1940). Leymaster & Mersmann (1991) concluded that restricting pigs to 85 and 92.5% level of their *ad libitum* intake of a 15% crude protein diet resulted in a reduction in daily gains of live weight and adipose tissue but in a nonsignificant decrease in daily deposition of protein. Wenk & Van Es (1976) and Verstegen *et al*. (1982) found that differences in energy metabolism may be related to differences in voluntary feed intake and in the case of restricted feed, related to the level of restriction from *ad libitum* intake. Feed restriction can be used as a method to decrease backfat thickness as shown by the work of Affentrenger *et al*. (1996); Ellis *et al*. (1996); Wood *et al*. (1996) and Candek-Potokar *et al.* (1998) who all found significantly lower backfat tissue when pigs are fed restrictively in comparison with *ad libitum* feeding. Ellis *et al*. (1996) also showed that the rate of adipose tissue deposition increased with weight and it can be expected that differences due to treatment effects will increase with increasing body weight.

The effect of feed restriction from several studies indicated that it leads to a lower growth rate and lower backfat thickness as seen in the work of Meat and Livestock Commission (1989); Affentranger *et al*. (1996); Ellis *et al*. (1996); Wood *et al*. (1996) and Boddicker *et al.* (2011). Ellis *et al.* (1996) found that the *ad libitum* fed pigs grew 165g/day faster than those restricted to 82% of their *ad libitum* feed intake. This is in agreement with the results of Lebret *et al*. (2001) who tested more severe restriction of 75% and found a decrease in growth

rate of 229 g/day. This decrease in growth rate was also observed when only the energy intake is restricted (Quiniou *et al.* 1995 and Weis *et al*., 2004). A restriction of crude protein or lysine intake done by Rao & McCracken (1990) led to similar reductions in ADGs. A study done by Cisneros *et al*. (1994) indicated this decrease in growth rate under restrictive feeding, however, a smaller difference was seen between restricted feeding and *ad libitum* feeding. Most of these studies tested the effect of feed restrictions in combination with higher slaughter weights. These studies showed that by increasing the slaughter weight the overall growth rate is decreased (Ellis *et al*., 1996; Wood *et al*. 1996; Lebret 2001). This decrease in overall growth rate is due to a decrease in growth rate as the animal's body weight increases, in these experiments specifically when body weight exceeded 100 kg. Ellis *et al.* (1996) found the decrease in growth rate to be more severe under restrictive feeding. No difference in growth rate was recorded during the last two weeks, before reaching the 95 kg slaughter weight, between the restricted and *ad libitum* fed animals by Wood *et al.* (1996). The restriction of energy and/or protein was tested by Rao & McCracken (1992a and 1992b) and they found significant decreases in growth rates under all of the restrictive treatments. When energy intake was restricted significant decrease in backfat thickness was observed.

Residual feed intake is defined as the difference between the observed feed intake and the predicted intake by Foster *et al*. (1983). Factors that affect the residual feed intake include the digestibility, absorption and utilization of energy and nutrients after they have been absorbed (De Haer *et al*., 1993b). A possible negative relationship between meal size and lean percentage through the effects on amino acid utilization was reported by De Haer *et al.* (1993b). This can be explained by research done by Bahr & Katiyar (1989) who found that at a low eating frequency the utilization of essential amino acids can disappear rapidly from the body when they are not utilised. The utilization of energy after it has been absorbed is affected by the activity level of the pig. This can be seen in the results of Halter *et al*. (1970) who found that activity levels, of *ad libitum* fed piglets, increased their total heat production to 10-17% and maintenance requirements by 18-25%. De Haer *et al*. (1993b) made the following conclusion from their research: because of the per definition zero correlation between predicted feed intake an residual feed intake, pigs with a combination of a short daily eating time, a low eating frequency and a large feed intake per visit to the feeder would be desired. These results should be taken into account when feed restrictions is tested under different housing conditions as it can explain some of the variation seen in growth performance.

The efficiency with which growth takes place or FCR at different feeding levels is discussed by Whittemore (1993). As the animal ages the efficiency with which growth takes place decreases. This is due to an increase in maintenance cost and adipose tissue deposition. Whittemore (1993) states that decreasing feed intake will not always lead to an improvement in FCR this usually only occurs when high rates of adipose deposition is halted due to the feed restriction. Furthermore Whittemore (1993) states that for a wide range of feed intake little or no change in FCR will occur this is best explained by Figure 1.3. At low levels of feed intake the majority of available nutrients is used for maintenance cost and any growth taking place is highly inefficient. On the other end of the graph very high levels of feed intake leading to an oversupply of nutrients above what is needed for the maximum lean deposition rate the FCR increases due to increasing adipose tissue being deposited. The graph illustrates that relatively wide range of feed intakes that will lead to little or no change in FCR. Within this range increases in feed intake will lead to increases in lean growth. Whittemore (1993) concludes that changes in feed conversion ratio tend to be more evident at extreme levels of feed intake than in the middle of the range. This is in agreement with findings made by Affentranger *et al*. (1996) who restricted pigs to 2.5 kg of feed per day from a body weight of 65 kg and found no significant difference in feed efficiency between the restricted animals and those fed *ad libitum*. No change in efficiency was found by Rao & McCracken (1992a and 1992b) when an energy and/or protein restriction was applied. Boddicker *et al*. (2011) showed that effect of feed restriction depended on the level of restriction, as no change in efficiency was recorded at 75% of *ad libitum* feed intake, however, at 55% restriction a lower feed efficiency was found. An 8 % increase in feed efficiency was found in a study done by Candek-Potokar *et al*. (1998) in which feed intake was restricted to 70 % of the *ad libitum* feed intake up to a 100kg body weight . This is possibly due to the higher amount of fat deposition taking place in *ad libitum* fed pigs which had a 4.4 mm higher backfat thickness at the end of the trial. When the same treatments were applied up to 130 kg body weight the restricted animals

grew 14% more efficient than the ad libitum fed animals and a bigger difference in backfat thickness occured (6 mm). The effect of energy intake restriction on the efficiency with which growth takes place was shown to be non-significant in the work done by Quiniou *et al*. (1995).

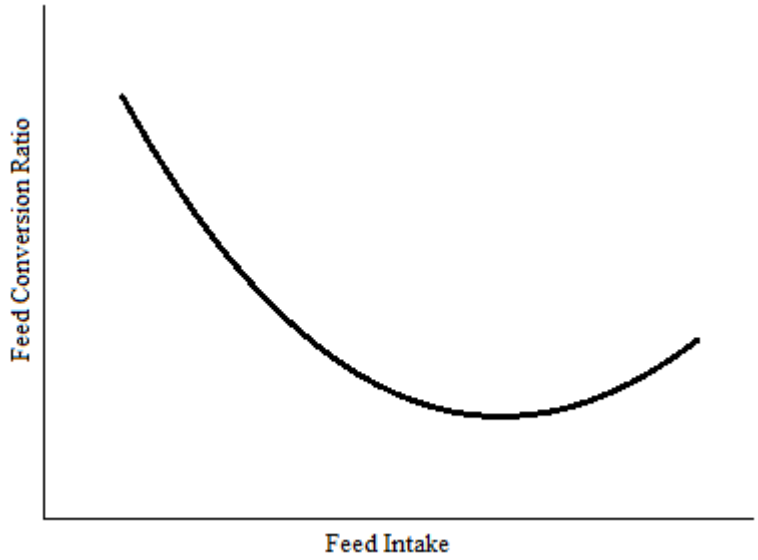

Figure 1.3 Changes in FCR with changes in feed intake level (Whittemore, 1993)

Contradicting results on the effect of restrictive feeding on carcass composition are found in literature. Restrictive feeding led to lower backfat thicknesses in the carcass in studies done by Čandek-Potokar *et al*. (1996), Wood *et al*. (1996); Lebret *et al*. (2001) and Boddicker *et al.* (2011). The carcass weight of pigs fed restrictively was found to be similar to those fed on *ad libitum* basis by Wood *et al.* (1996) and Lebret *et al.* (2001). However, a lower carcass weight under restrictive feeding was found by Čandek-Potokar *et al*. (1996). Affentranger *et al.* (1996) observed a significantly higher lean meat percentage in the carcass when restriction was applied from 65 to 103 kg when Swiss Large White and Duroc was used as the terminal sire. No significant difference was found when Pietran (representing a lean genotype) was used as a terminal sire. In the work done by Lebret *et al.* (2001) restrictive feeding led to significantly higher lean meat percentage when feed intake was restricted to 75 % of *ad libitum* feed intake. This is in agreement with recent findings of Boddicker *et al*. (2011) who found increased water and protein content and lower fat levels under restrictive feeding. Quiniou *et al.* (1995) showed that energy intake restriction leads to increases in the lean proportion and decreases in fat content. Carcass length was found to be unaffected by energy and/or protein restriction by Rao & McCracken (1992a; 1992b).

1.4.2 Compensatory Growth

Compensatory growth (or catch-up) growth may be defined as a physiological process whereby an organism accelerates its growth after a period of restricted development, usually due to reduced feed intake, in order to reach the weight of animals whose growth was never reduced (Hornick *et al*., 2000). The concept of compensatory growth was researched for many years as it was shown by McMeekan (1940) that compensatory growth may occur after a period of feed restriction in pigs. The whole concept of compensatory growth can be summed up by looking at the results of work done by Chiba (1994) who tested the effects of a protein restriction during the grower period (20-50 kg) on the overall growth and growth performance. During the restrictive period animals exposed to the low protein diet grew at a lower rate (18%) and less efficient (23-24%) than those exposed to the high protein diet. Further during the finisher phase (50-100 kg) the previously restricted animals grew faster and utilised feed, energy and lysine more efficiently than their unrestricted peers. This compensatory growth after a period of feed intake restriction can be seen in the results of work done by Prince *et al*. (1983)

who found that pigs exhibited an increase in average daily gain in the period of *ad libitum* feeding after a period of restrictive feeding. The following conclusion was made from the results that: previously restricted pigs are significantly more efficient than non-restricted pigs (Prince *et al*., 1983). This increase in growth rate and efficiency is in agreement with findings made by (Chiba *et al*. (1999); Fabian *et al*. (2002; 2004). These results however, contradicts findings made by Chiba *et al*. (2001) who found no increase in the average daily gain after a period of restrictive feeding. This contradiction in results in restrictive feeding trials can be ascribed to several reasons. Several factors affect the ability of a pig that underwent restrictive feeding to exhibit compensatory growth such as: genotype (Hogberg & Zimmerman, 1978; Fabian *et al*., 2002), severity of restriction (Wahlstrom & Libal, 1983), length of restriction (Prince *et al*., 1983), age (Chiba, 1995), and feed intake during the realimentation period (Bikker *et al*., 1996). To apply compensatory growth successfully as a method to improve overall efficiency the effects of all these factors should be taken into account and controlled. These factors should also be kept in mind when comparing results from different experiments.

Pigs that were exposed to selection for specific traits such as growth and growth performance have undergone physiological and metabolic alterations and may therefore respond differently to dietary manipulations (Fabian *et al*., 2002). This physiological and metabolical changes can affect the animals ability to express compensatory growth. This difference in response can be seen in the work done by Hogberg & Zimmerman (1978) who tested the compensatory growth response on pigs selected from different strains. They found that the lean strain pigs exhibited a compensatory growth response while the fat stain did not. This difference in the ability to express compensatory growth due to selection can be because of several changes that occur due to the selection process. These changes can include: activity of some lipogenic enzymes (Steel & Frobish, 1976); hormonal changes (Buonomo & Klindt, 1993; Ramsay *et al*., 1998 and Cameron *et al*., 2000); metabolism of adipose tissues (Standal *et al*., 1973 and Steele & Frobish, 1976); metabolically active organs (Koong *et al*., 1983 and Pond *et al*. 1988); feed intake (Woltmann *et al*., 1992) and concentration of metabolites (Pond *et al*., 1981, 1988).

The severity of the restriction that is applied to exhibit compensatory growth plays an important role. This can be seen in the results of Wahlstrom & Libal (1983) who tested diets containing three levels (12, 14 and 16%) of protein. They found that even though both the 12 and 14% protein restricted pigs exhibited a compensatory growth response after the four week restriction, only those exposed to the 14% restriction were able to fully recover from the restriction through compensatory growth. The effect of severity of restriction was also shown by Prince *et al*. (1983) who found that by the pigs that were restricted to an 85% level of ad libitum intake had a higher ADG for the total test period than those restricted to a 75% level if intake. This was however, not a significant difference in the ADG in the post restriction phase alone.

The importance of the length of the restriction applied can be seen in the results of Prince *et al*. (1983) who found that during the post restriction phase pigs exposed to a four week restriction grew more efficient than those exposed to a two week restriction. When taking the whole test period into account there was no significant difference in the ADG between the two periods of restriction but the pigs that were restricted for four weeks grew more efficiently.

Age may be a factor determining if, or the extent to which, a compensatory growth response can take place after a nutritional restriction. Chiba (1995) tested the effect of nutritional history on subsequent growth performance. This was done by comparing the growth performance of animals that were either exposed to a simple or complex starter ration. By comparing their growth responses in the grower phase no difference can be seen meaning no compensatory growth occurred in the animals exposed to the simple starter diet. This inability can possibly due to an inadequate number of muscle fibres developing in the restricted animals as explained by Handel & Stickland (1988). The early nutritional restriction may limit the hyperplastic growth of the muscle tissues (Lodge *et al*., 1977; Campbell & Dunkin, 1983). Animals exposed to the restriction will only be able to undergo compensatory growth in their limited amount of muscle fibres and may explain the difference in response to restriction at later stages. In the same trial when a restrictive diet was fed during the grower phase a compensatory growth response occurred in the finisher phase. This was seen in a higher growth rate and growth efficiency than their unrestricted peers. This difference in response is explained by Chiba (1995) as follows: the

extent of compensatory response is possibly dependent on the age of pigs and the degree and duration of dietary energy and (or) amino acid restrictions.

Bikker *et al*. (1996) tested the effect of feed intake in the realimentation period on the compensatory response by allowing previously energy restricted pigs different levels of intake. These energy restricted animals exhibited a compensatory growth response as can be seen from the increase in growth rate and efficiency with which this growth takes place. As the feed allowance increased in the realimentation period the ADG increased. Thus it is important to take the change in feed intake after a restriction into account when comparing compensatory growth responses. An increase in feed intake was seen in the realimentation period of several studies (Nielsen, 1964; Owen *et al*., 1971; Donker *et al*., 1986). Recording the feed efficiency in the realimentation period can be used to determine if compensatory growth occurs even tough an increase in feed intake takes place.

1.4.3 Mechanisms of compensatory growth after a period of restricted feeding

Compensatory growth is the high growth rate and improvement in the efficiency of growth that takes place after a period of restriction. This high rate of growth is possible due to several mechanisms. Firstly animals that were exposed to a restriction have a lower basal metabolism. Ryan *et al*. (1993) found that restricted sheep or cattle had a lower basal metabolism than aged-matched controls and the sparing mechanisms are maintained beyond the restricted growth phase for several weeks. This lowered metabolic rate increases the amount of energy and protein that can be used for growth purposes. At the beginning of the compensatory growth phase the growth that takes place is mostly muscle and protein and the carcass composition is similar to that of the restrictive phase (Wright & Russel, 1991). After this period fat deposition takes over and the final body composition depends on the refeeding duration (Hornick *et al*., 2000). Wright & Russel (1991) found that steers exhibiting compensatory growth grew 37 g/day faster than control animals and further that the restricted animals had a 33% lower adipose tissue level than those their unrestricted peers. This difference in adipose tissue level between the treatments stayed the constant as the steers grew from 350 to 400 kg, only at 450 kg did the adipose tissue level reach the same level between treatments.

In the period of compensatory growth there is a marked increase in the synthesis relative to degradation of protein firstly in the viscera and thereafter in the muscles as can be seen in improved protein accretion and decreased nitrogen excretion as found by Jones *et al*. (1990) and Van Eenaeme *et al*. (1998). Van Eenaeme *et al*. (1998) showed that after a short period of restriction (4 months) an increase was found in both protein synthesis and degradation, although the increase was higher in the protein synthesis than the degradation. Similar results were found after a longer restriction period, however, to a lower extent and took place for a longer period. And when the longest restriction was applied (14 months) the compensatory growth response was mainly due to the increase in protein synthesis. The improvement in nitrogen balance can be explained by the enhanced intracellular and interorgan recycling of amino acids as shown in the work of Van Eenaeme *et al*. (1998). Further Carreira *et al*. (1996) showed that there is a decrease in amino acid oxidation during the realimentation period. Howarth & Baldwin (1971) showed that the deoxyribonucleic acid content increases in muscle, because of the enhanced mitosis of satellite cells.

1.4.4 Mechanism of reduced growth during feed restriction

The level of the compensation that takes place after n period of restriction appears to be proportional to the intensity of the restriction that took place according to earlier work done by Coleman & Evans (1986) and Horton & Holmes (1978). The large variation in this response can probably be explained by the fact that restricted growth can result from several processes, such as various diseases or energy and protein restrictions whose degree may vary considerably (Hornick *et al*., 2000). The reduction in growth rate during a period of restriction leads to a decrease in tissue turnover. According to the work done by Hornick *et al*. (2000) tissues aren't affected on the same level, this can be seen in the fact that the tissues is affected in the following order: viscera > adipose tissue > muscle. This response can be seen in the decrease of the empty visceral fraction during a restriction as shown in the work of Wester *et al*. (1995) who found that liver mass in restricted lambs were 60% of the liver mass of those lambs that were not exposed to an energy or protein restriction. This is in

agreement with findings made by Carstens *et al*. (1991) who found that the extent of change in tissue composition during compensatory growth is greater for non-carcass tissues, which includes the viscera.

During the restrictive period weight loss is caused firstly by the mobilization of a very labile protein compartment (Paqauy *et al*., 1972), protein that has been recently synthesized. This takes place at the same time as a decrease in basal metabolism. Thereafter fat is mobilized if the restriction is severe enough whilst the protein pool is reserved as much as possible (Hornick *et al*., 2000). Lean animals have limited adipose tissue resources and thus muscle is the main source of energy during a restrictive period, as seen in the work of Fattet *et al*. (1984) who showed that animals exposed to an energy restrictive diet can still be in a positive nitrogen balance by utilizing body fat reserves.

The change in body composition seen during the restrictive period is due to metabolic and endocrine changes that occur. The reduction seen in basal metabolism is due to both the decrease in the size and the metabolic activity of the viscera (Ortrigues & Durand, 1995; Yambayamba *et al*., 1996). This reduction can be seen in the results of Otrigues & Durand (1995) who showed a 34 and 38% decrease in the oxygen consumption rates of the portal drained viscera and liver respectively on ewes fed 50% of their maintenance requirements. The liver and adipose tissue release higher amounts of ketone bodies and free fatty acids, respectively, which are utilised as energy sources by muscle and other extra hepatic tissues (Jarret *et al*., 1976; Bossart *et al*., 1985). Furthermore the muscles release lactate, branched chain keto acids (BCKA) and also alanine, glutamine and branched-chain amino acids (BCAA) (Hornick *et al*., 2000). Furthermore 3.5.3'-triiodothyronine (T3) and thyroxine (T4) levels decrease partly due to the decreased responsiveness of the thyroid to thyroid stimulating hormones. T3 and T4 controls metabolism and these lower levels lead to an energy sparing effect by decreasing basal metabolism. An increase in GH is seen during the restriction and this can be explained due to the following reasons. Firstly the lower feed intake reduces the amount of nutrients taken in and in turn reduces the release of somatostatin by the hypothalamus and thus reduces the negative effects on the synthesis and release of growth hormone (Thomas *et al*., 1990). Secondly due to the lower plasma levels of insulin, T3 and T4 the synthesis of GH receptors and plasma levels of GH binding proteins are decreased (Maes *et al*., 1983). The liver is the main producer of IGF-I and needs to bind GH on its receptors to start the production of IGF-I a decrease in receptors and GH binding proteins leads to a decrease in IGF-I production.

IGF-I is transported around the body in the blood by binding with binding proteins (IGFBPs). Several types of IGFBPs exist and they are affected in different ways by restriction. Renaville *et al*. (2000) found that IGFBP-3, which is responsible for most of the binding of IGF-I during normal feeding, concentration decreases during a restrictive period. From their work this decrease seen in IGFBP-3 was however, only statistically significant under severe growth restriction. Hornick *et al*. (2000) however, states that IGFBP-2's concentration increases during periods of restriction and because of its low molecular weight the binding protein is capable of exiting capillaries allowing the interaction of IGF-I with target tissues and possibly reduce excessive catabolism. This increase in IGFBP-2 during restrictive periods can be seen in the work of Renaville *et al.* (2000) who found that bulls exposed to feed restriction had higher levels of circulating IGFBP-2 as feed restriction severity increases. The importance of IGF-I in growth is well known and it would be expected to see a rise in IGF-I levels during a period of faster growth such as compensatory growth. This however, was not the case in work done by Ritacco *et al*. (1997) who measured IGF-I and the expression of IGF-I mRNA in runt piglets after birth undergoing compensatory growth. Runt piglets grew faster and more efficiently than control piglets. Only on the first day after birth was there a significant difference in IGF-I levels but the hepatic IGF-I mRNA and circulating IGFBP were similar between controls and runts. This difference in concentration lasted one day and no difference was recorded up to 14 days of age. Furthermore no difference in plasma concentrations of thyroid hormones was detected between the controls and runts. Dauncy & Geers (1990) however, reported that there is a difference in the number of thyroid hormone receptors on the skeletal muscles of runt pigs meaning that thyroid hormones can still play an important role in the compensatory growth process. Ritacco *et al.* (1997) made the following conclusion on these results: Even though runts are born with reduced circulating IGF-I levels, IGF-I does not seem to be regulating compensatory growth because gene expression and circulating concentrations were not different between controls and runts during this time. The mechanism of compensatory growth that

occur after a period of feed restriction seems to be different from which occurs in runt piglets, even though the growth is similar.

During the restrictive period the mobilization of adipose tissues serves as an energy source. High levels of GH in the plasma allows enhanced mobilization and this is partially achieved due to a high rate of growth hormone binding to receptors limiting the binding and the effect of insulin on adipose tissues (Baumann & Currie, 1980).

1.5 General effects of nutrition on pig growth

To achieve an optimum production level is a common goal for all pig producers and it is therefore important to meet the animal's nutritional needs. By meeting the animals nutritional needs the animal can grow at its optimum rate. The diet fed should supply sufficient amounts of required components such as energy, protein, vitamins and minerals in the correct ratio. These components should be supplied in a digestible form in the diet and without having negative effects on the animal's health. The diet needs to supply sufficient amounts for maintenance as well as growth.

Energy is a vital component of any diet. Energy is needed for both maintenance and growth purposes. The efficiency with which feed is used for maintenance and growth will be negatively affected if energy is either under or over supplied. An under supply of energy will lead to the mobilization of fat reserves and possibly the oxidation of amino acids to release energy needed for maintenance and/or growth. Whilst an oversupply of energy will lead to excess energy being deposited as fat reserves. Due to the market demand for lean meat excess fat is unwanted and will lead to a lower efficiency of growth. To accurately supply the animal's energy needs feed ingredients and ration energy density needs to be quantified. The energy level of ingredients and diets are normally measured and stated as digestible energy. Whilst this is a useful system it is not the most accurate measure of energy content. Digestible energy (DE) does not take into account the energy that is lost in feaces, urine or gas form. This discrepancy can be seen in the work of Noblet & Perez (1993) who found that the amount of energy lost in urine represented 2 to 6 % of dietary digestible energy content and that the metabolisable energy to digestible energy ratio (ME:DE) varied with the crude protein or the amount of digestible crude protein in the diet. Further by using digestible energy content no account is taken of the difference in the efficiency with which the digested sugars, amino acids and volatile fatty acids are used for energy production. The nature of the feed ingredient has important effects on the heat produced during the digestion by using only digestible energy this variance between feedstuffs is ignored. At different physiological stages of animal development different ratios of maintenance to growth occurs. The age of an animal affects the digestibility of nutrients this is due to changes occurring in the digestive tract as the animal ages. And lastly the level of fibre present in the diet affects the digestibility of the diet and thus the amount of energy available for digestion. Due to these reasons metabolisable energy or net energy is preferred for accurate determination of energy density of feedstuffs. It is however, not possible to calculate net energy value based on digestible energy values by using fixed or semi fixed conversion factors.

Pigs do not have an innate requirement for protein as such but rather for specific amino acids and sufficient amount of nitrogen for synthesis of non-essential amino acids (Whittemore, 1993). From this the ideal protein concept was developed where a protein containing the perfect balance of essential amino acids and a sufficient amount of nitrogen to produce the non-essential amino acids This ideal protein is based on the exact amino acid requirement of the animal. It is not only crucial to supply the right amino acids according to requirement but also to supply them in the correct ratio. Even though the amount required of each amino acid is different all the amino acids are of the same importance. By under supplying one amino acid the use of other amino acids is affected. This is best explained by the Liebig or broken barrel concept which depicts the dependency of amino acids supply on each other. The amino acid that is the most deficient in animal requirements is known as the first limiting amino acid. Any amino acids supplied in excess of the required ratio to the first limiting amino acid will not be used for protein tissue accretion but rather be oxidized as an energy source. The oxidation of amino acids for energy decreases the animal's efficiency as the deamination of the amino acids is an energy intensive process. By supplying the animal with the ideal protein the efficiency with which protein tissue is produced is maximised. The exact amino acid requirement for different forms of protein

tissue varies. In the case of grower pigs the diet have to supply to both maintenance and growth requirements. Further it is important to take into account the digestibility of the amino acids used in the diet.

Patience *et al.* (2002) state that the challenge of the feeding program is to achieve the best possible carcass in the shortest available time at an affordable cost under a specific set of genetic, health and environmental conditions.

In commercial production, the main goal of diet formulation and feeding strategy is to maximise profits, which does not necessarily imply maximal animal performance (Chiba, 2000). In order to produce lean marketable pigs the feed should supply the correct balance of nutrients in the correct format. Therefore the requirement for lean growth and maintenance should be accurately met so that the optimum rate of growth can occur and efficiency with which the feed is used for growth can be maximised. The two major nutrients included in diets are energy and protein. Both of these nutrients are needed for lean tissue growth and need to be supplied in the correct ratio. The importance of the ratio of these two nutrients becomes apparent through the fact that dietary energy can have large impacts on feed intake (NRC, 1987). If the protein to energy ratio is too low lean tissue accretion will not take place at the optimum rate, this can be seen in the work of Chiba (1994) who measured growth performance of pigs between 20 and 50 kg live weight in response to two different protein levels. The one group received a ration containing 0.765 g lysine/MJ whilst the other received 0.423 g lysine/MJ. The animals that received the high amino acid diet grew 18% faster and were 23-24% more efficient in utilization of feed and energy. These findings are in agreement with those made by others (Zimmerman & Khajaren, 1973; Campbell *et al*., 1983 and Prince, 1983). A further result of the low amino acid diet was a carcass with a higher level of fat. From this it can be concluded that energy was in oversupply to the protein level. This is in agreement with (Zimmermann & Khajaren, 1973; Campbell *et al*., 1983). Chiba (1994) continued the experiment from 50 to 100 kg live weight by supplying these animals either 0.423g lysine/ MJ or 0.612g lysine/MJ. Animals fed the low protein diet in the grower phase grew faster and utilised feed, energy and lysine more efficiently. Pigs on the high protein diet during the finisher period utilised feed and energy more efficiently but consumed more lysine per kg gain than those receiving the low protein level. The improvement during the finisher period of the animals that received diets low in protein during the grower phase meant there was no significant difference between the two grower groups at 100 kg live weight. Meaning that the advantages of feeding the high protein diet during the grower phase were lost, this is in accordance with earlier studies (Thaler *et al*., 1986). From this Chiba (1994) made the following conclusion: the design of diets to maximise growth of pigs between 20 and 50 kg may have little importance in terms of overall productivity and efficiency. Smith *et al*. (1999) tested the effect of both dietary energy density and lysine: calorie ratio on growth performance by testing different levels of choice white grease as a source of energy in the diets and made the following conclusion: The level of choice white grease or lysine: calorie ratio fed during the growing phase did not affect ADG, average daily feed intake (ADFI), and gain to feed ratio (G: F) during late finishing phase. The results from these studies indicate that the ratio between energy and protein levels during the early grower phase does not affect the overall growth achieved during late finisher phase.

1.6.1 Genetics

In pig production systems the object is to produce a saleable product as efficiently as possible to maximise income. This efficiency is mostly determined by the costs associated with the breeding and growth of the pig as well as the time associated with this process. Genetics is one of the tools used to improve this efficiency and thus the overall profitability of pig production. The private breeding companies in modern pig production are responsible for the majority of the genetic improvement that is achieved. This genetic improvement is achieved through the use of seed-stock populations that undergo performance testing and selection. From the early work done by Hazel (1943) illustrates the approach to multi trait selection being the development of a linear index of phenotypic measurements with respective weightings that maximises its correlation with the selection index being used. This selection objective is defined by Clutter (2011) as a linear combination of breeding values for traits considered of economic importance, and phenotypic measurements are chosen as criteria with which to most effectively estimate genetic merit for the selection objective. To achieve the objective to produce high quality lean pork the selection objectives normally include genetic merit for traits such as leanness, feed

efficiency and growth rate. Clutter (2011) further states that phenotypical traits used included: post weaning growth, live animal backfat thickness at slaughter weight, loin muscle dimensions and live animal backfat at the end of testing period. The success of the use of a selection index depends on the accuracy of the genetic correlation between the traits included.

1.6.2 Genotype x Environment interaction

The environment in which the selection takes place can affect the accuracy of the selection taking place. This means that the correlation between the performances for a specific trait in the nucleus herd with the same trait in commercial production should be taken into account. This possible discrepancy in the performance for a specific trait during performance testing and commercial production can be explained by the general breeding structure used in pig production systems. The majority of selection takes place in the breeding company's nucleus herds. The animals produced from breeding in the nucleus herd are sent to the multiplier herds to increase the number of animals available. Some selection takes place on this level as well. Only the offspring produced and selected from the multiplier herd is used in commercial production. Because the goal is to improve performance in commercial production the breeding and selection in the nucleus should be in accordance to the production goals of the commercial sector. Testing methods in the nucleus populations are designed to provide unbiased estimates of genetic potential, and generally result in relatively uniform performance and greater heritability (Clutter, 2011). However, the difference in the environment within which selection takes place and that of commercial sector can be quite significant. Reasons for this include very strict biosecurity, feeding regimes, testing diets, sex and housing system, pen size, floor space and health status. The G X E interaction due to the interaction between genotype and feeding regime occurs because pigs are normally housed individually and fed on a semi ad libitum basis in nucleus herds, whilst in commercial conditions pigs are housed in groups and fed on an *ad libitum* basis (Nguyen *et al*. 2004). Nguyen *et al*. (2004) continues to state that the animal identified as the best genotype in the testing environment may not be the best in the commercial production environment. A further G X E interaction that should be taken into account is the interaction between genotype and the diet used during selection. This interaction occurs due to the fact that pigs with superior genetic potential for lean growth require a high plane of nutrients in their diet to express their superior genetic potential. This interaction can be seen in the results of Stern *et al*. (1994) who found that selection for lean tissue growth rate were more efficient when selection took place on a high protein diet (18.1% CP) than on a low protein diet (15.8% CP) diet. Stern *et al.* (1994) found a favourable genetic correlation (0.25) between the growth rate and lean percentage in the high protein fed animals whilst an unfavourable genetic correlation (-0.67) were found in the low protein line. Correlations between the performance for a specific trait in the selection environment and the production environment are used to take this Genotype x Environment (G x E) interaction into account. In the work of Mulder & Bijma (2005) who studied the effect of this G x E interaction on the genetic gain achieved by breeding companies they showed that the decrease seen in genetic gain because of the G x E interaction is mostly because of a decrease in the accuracy of selection. From their results it can be seen that by including half-sib performance data the loss in genetic gain can be limited to 10% and the recording of progeny they can limit the loss to 4 %. Clutter (2011) continues to state that the variation in testing environments can change the effective selection objective for a given set of measurements. This is explained by the selecting for rate of gain in animals fed on an *ad libitum* basis. This selection will lead to an increase in feed intake and possibly increased fat deposition rather than an increase efficiency with which feed is used for lean tissue deposition.

1.6.3 Growth Models for selection purposes

Whittemore (1986) developed a growth model explaining the growth rates of different tissues according to genetic potential. This model is best explained by Figures 1.4.1 and 1.4.2.

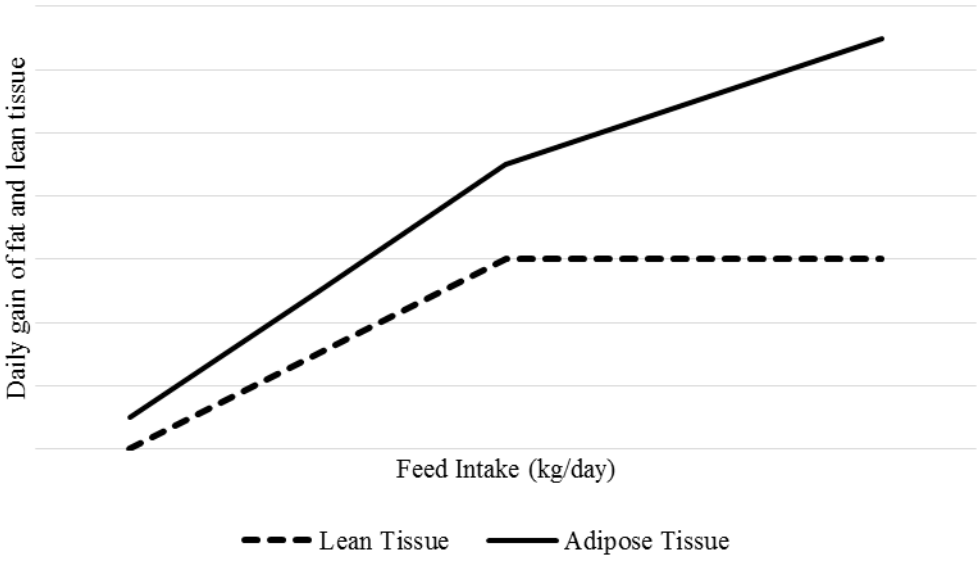

Figure 1.4.1 Genetic potential for lean and adipose tissue deposition. (Whittemore, 1986)

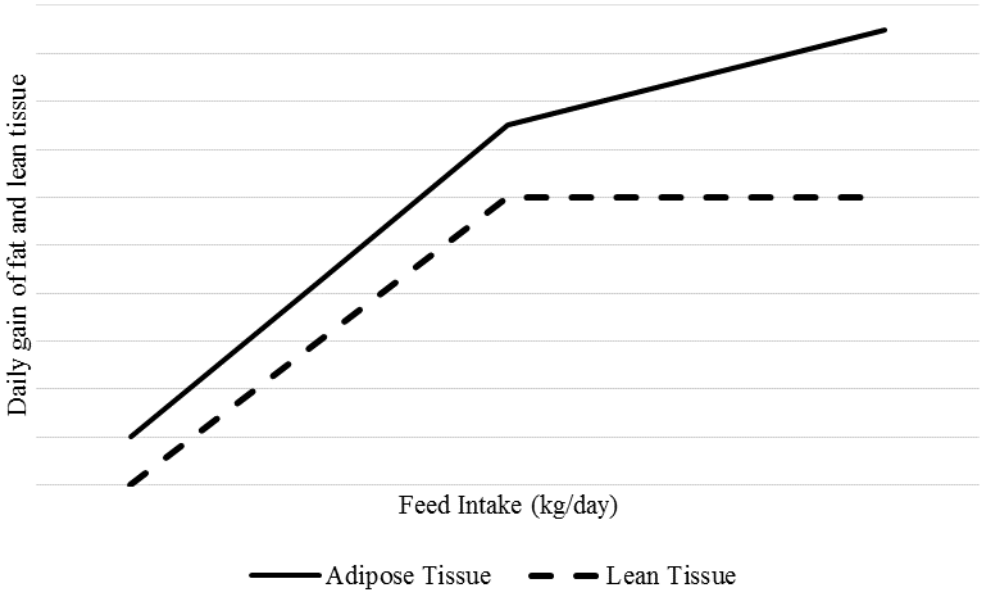

Figure 1.4.2 Genetic potential for lean and adipose tissue deposition. (Whittemore, 1986)

The model explained by Whittemore (1993) is based on four principles. Firstly as the feed intake increases the growth of lean and adipose tissue increases. Secondly at low feeding levels a small increase in feed intake will lead to a high increase in lean and adipose tissue growth. This is growth response is highly efficient because the fat to lean deposition stays more or less constant and gain consists mostly of lean tissue. As the feed intake increases the lean tissue growth increases in a linear fashion up to a certain level after which it stays constant. Thirdly the growth response due to increasing feed intake becomes broken at a certain level and the gradient of the growth response decreases with increasing feed levels. Fourthly genetics determines when this break in growth response occurs. This plateau level is the maximum lean growth potential for the specific animal. During the period of linear growth response fat deposition will take place at a low rate. This is explained by Whittemore (1986) as that under conditions of normal growth, the animal prefers to target for lean while maintaining some

minimal, physiologically normal level of fat in the gains. Only after the genetic potential for lean gain is achieved will there be an increase in the fat deposition. From this we can expect a relatively constant body composition over a wide variety of body weights only changing when the plateau level is reached. After the plateau is reached extra nutrients are converted to fatty tissue and the overall growth rate decrease and a decrease in feed conversion ratio is seen. This can be seen in the work of Dunkin *et* al. (1986); Campbell (1988) and Quiniou *et al.* (1995) indicating that at high dietary nutrient intakes within the constraints of appetite at least some genotypes of pigs have the ability to reach the limit to daily protein deposition and deposit the excess dietary protein and non-protein energy as lipid tissue. The plateau level can be enhanced through selection as seen in Figure 1.4.2. The period before which lean tissue growth stops increasing can be seen as the nutritionally limited phase and during this phase nutrients will be used mostly for lean tissue gain while gaining a physiologically normal level of adipose tissue and the period thereafter as the nutritionally unlimited phase in which most of the energy consumed beyond the need for maximum lean gain is deposited in the form of fat (Clutter, 2011). From this model Whittemore (1986) makes the following conclusion: animals with a higher lean tissue growth potentials can consume greater amounts of food with consequentially improved feed efficiency and no increase in fatness.

Instead of using selection indexes based on a linear function of breeding values of the economic important traits Fowler *et al*. (1976) proposed selection indexes to be based on a more biological objective by using physiological factors related to the market value of the pig. Due to the demand for lean pork production the most important factors in efficient production is related to time and feed used. Fowler *et al*. (1976) suggested lean tissue growth rate (LTGR) and lean tissue feed conversion (LTFC). To apply selection using LTGR estimated lean content would be needed for the beginning and end of the test period whilst LTFC will need require data on the individual feed intakes.

1.6.4 Effect of genetic selection for growth and efficiency in pigs

Genetic improvement of grower pigs through selection has been tested and applied for several years. Selection based on a single trait has proved to be an effective way of changing the animal's performance in that specific trait, this can be seen in the results of Kuhlers & Jungst (1990) who selected for weight at a 70 day age and found an increase of 0.65kg ± 0.29 kg per generation. Interestingly the improvement seen in the 70 day weight was mostly due to an improvement in the post weaning growth. These results was confirmed by later studies also done by Kuhlers & Jungst (1991b) in which they selected for 200 day age weights in a similar fashion and recorded a 4.2 ± 1.3 kg increase per generation. This increase in post weaning growth can also be achieved through selection based on post weaning ADG as seen in the work of Woltmann *et al*. (1995) who tested the effect of this selection on front-end soundness of market weight pigs. Through the selection that took place a differential for total divergence of was 0.47 kg/day was achieved. These results are in agreement with several other studies (Clutter *et al*., 1992; Woltmann *et al*., 1992). The improvement in post weaning growth can however, be due to an increase in daily feed intake if selection takes place on animals that are fed on an *ad libitum* basis. As shown by the results of Clutter *et al*. (1995) who found a difference in average daily intake of 0.52 kg between the fast and slow lines after four generations of selection based on postweaning ADG. During selection for post weaning growth improvements in growth performance should be analyzed whilst keeping possible changes in related traits in mind.

Selection for a single growth trait can lead to changes in carcass composition. This can be seen in the work done by Clutter *et al.* (1995) and Woltmann *et al*. (1995) who found an increase in backfat levels of those animals selected for a higher ADG. Selection for an increase in 200 day weight in Duroc pigs by Kuhlers & Jungst (1991a) resulted in an increase of 0.7 cm backfat at 200 days this however, contradicts results found on Landrace pigs where selection for increased 200 day weight led to a decrease in backfat (Kuhlers & Jungst 1991b). Clutter (2011) explained this in following way: the change in body composition from selection for growth may also depend on the genetic potential for feed intake relative to lean growth in the base populations in which selection is applied. When direct selection is applied to backfat level it can be successfully decreased as shown by Hetzer & Harvey (1976) who selected pigs for high and low backfat levels and after 10 generations of selection in Duroc pigs a difference of 2.6 cm was measured. This is in accordance with results after 8

generations of similar selection on Yorkshire pigs led to a 1.4 cm difference. From further work done on these selected lines of pigs Hetzer & Miller (1972) found that for Duroc pigs there is a negative genetic correlation between both pre- and post-weaning growth with backfat thickness. This however, was not the case for the Yorkshire animals as selection for an increase or decrease in backfat led to a decrease in growth rate. To account for the effects of correlations between growth rate and change in fat levels selection can be based on either LTGR or LTFC. The effect of this was tested by Leymaster *et al*. (1979a; 1979b) who found that selection based on either LTGR or LTFC led to significant results. However, only when selection is based on LTGR was a decrease seen in carcass fatness and an improvement in ADG. When LTFC was used the decrease in carcass fatness and ADG occurred. Cleveland *et al*. (1983) tested the effect of a selection index for an increased daily gain, decrease backfat level and the effect of a feed restriction on the rate and composition of growth. Both the selected and unselected animals were exposed to *ad libitum* or two levels of restrictive feeding. Their results showed a higher rate of protein growth and lower amount of feed required per unit of edible lean meat. Cleveland *et al*. (1983) found that during restrictive feeding both the selected and control lines had a decreased adipose deposition. Further the differences in protein and water gain between the two lines were more apparent when the pigs were exposed to *ad libitum* or 90% of *ad libitum* feed intake. This was explained by Cleveland *et al*. (1983) due to the fact that the selected line had a higher protein requirement that would have not been met under the more severe feed restriction level of 80% ad libitum intake. Further the animals would also be exposed to an energy deficit that could lead to the catabolism of dietary proteins.

Genetic progress can be made through either direct selection or indirect selection of traits. To improve the overall performance of grower pigs all traits should be recorded and taken into account in the selection process. Further genetic and phenotypic correlations between traits should be taken into account. This can be seen in the fact that selection for improvement in the lean feed conversion efficiency under *ad libitum* feeding results in a decline in voluntary feed intake and fat accretion (McPhee, 1981). By applying this selection under restricted feeding an improvement in both the rate and efficiency with which lean growth takes place can be achieved (McPhee, 1981; Cameron & Curran, 1995). By applying selection for lean growth under restrictive feeding conditions selection does not favour those individuals with a higher voluntary feed intake but instead animals that use lower amounts of energy per unit of growth. This is explained by Nguyen *et al*. (2004) as follows: this arises through the choice of animals that waste less energy for maintenance and retain more for growth and which make more efficient use of the retained energy by favouring its partitioning toward lean and away from fat tissue deposition, the energy cost of lean deposition being less than that of the same weight of fat.

1.6.5 Interaction between genetic selection and feeding regime

The current trend in pig production is that the breeding and selection is done by the breeding companies based on performance testing. Possible differences in the feeding regimes used in the testing and commercial environment may lead to a G x E interaction as discussed earlier. This is illustrated by Fowler & Ensminger (1960) who stated that when pigs were reared on *ad libitum* feeding, the growth rates of pigs selected on this feeding regime were lower than those of pigs selected on restricted feeding. This interaction between feeding regimes and genotypes was tested by Cameron & Curran (1995) this was done by testing pigs selected for either of the following traits: lean growth rate on *ad libitum* feeding (LGA), lean growth on restricted feeding (LGS), lean food conversion ratio (LFC) or daily food intake (DFI). The animal's growth performance were tested under *ad libitum* feeding or restricted feeding. They found that animals selected for high performance in LGS grew faster than pigs selected for improvement in LGA and LFC when fed *ad libitum*. This however, was not the case for feed conversion ratios and backfat depths as these remained similar between the lines. When a similar comparison was made under a restricted feeding regime the rankings of the different lines remained broadly similar for growth rate, food conversion ratio and mid-back fat depth. Cameron & Curran (1995) made the following conclusion: The higher growth rate and similar backfat depths of pigs selected for lean growth on a restricted feeding regime compared with pigs selected on an *ad libitum* or restricted feeding, suggested that a restricted feeding regime should be used for evaluating animals, given selection for lean growth rate. Further from their results it becomes clear that selection for high lean growth on a restricted feeding regime was preferable to selection for either high lean growth or high lean food conversion ratio. The benefits of selection

being based on lean growth under restrictive feeding was only confined to growth rate because the interaction between feeding regime and genotype is only valid for growth rate and not backfat depth. Several other studies have shown this interaction between growth traits and feeding regime (Bereskin *et al*., 1990: Kanis, 1990; Woltmann *et al*. 1991). Kanis (1990) studied the effect of the pigs feed intake capacity on the interaction between genotype and feeding regime. From his work it became clear that only traits with a relatively high genetic correlation with feed intake is affected by this interaction. This can be seen in the interaction of average daily gain and related traits such as FCR; LTGR; FTGR and LTFC with feeding regime, whilst no interaction was seen in traits related to body composition such as backfat; lean tissue percentage and fat percentage. This difference between traits is explained by the difference in correlations to feed intake. In earlier work done by Kanis (1988) he found a genetic correlation of 0.8 between feed intake and average daily gain, whilst the correlation between feed intake and body composition was only 0.3. Kanis (1990) found no significant interaction with feeding regime when pigs were restricted to a certain level according to their littermates' *ad libitum* feed intake and from this he hypothesized that variation in the degree of feed restriction (DFR) was the cause of the feeding regime interactions. Similar results were seen when different sexes were tested under a restricted feeding regime. When the feed intake was adjusted to the same level of DFR to take into account the difference in feed intake by the two sexes there were no longer an interaction between sex and feeding regime. Similar conclusions were made by Donker *et al.* (1986).

The effect of a controlled diet on the growth performance, feed efficiency and carcass composition of a modern pig genotype is not specifically known. The purpose of this study is to determine whether controlled feeding will lead to a better performing grower pig in terms of growth rate, the efficiency of growth and the composition of the carcass. Furthermore the feasibility of using controlled feeding in group housing will be tested.

CHAPTER 2
MATERIALS AND METHOD

2.1 Trial Design

The experiment was performed using a 2 x 2 factorial design, consisting of 2 feeding regimes (controlled and *ad libitum* feeding) and 2 housing systems (individual and group housing) as shown in Table 2.1. A total of 56 pigs were kept in the individual housing system of which. The group housing system consisted of two pens, one pen per feeding treatment, containing 21 pigs each.

Table 2.1 Trial design and animal numbers

	Individual Housing (n)	Group Housing (n)
Ad libitum feeding	28	21
Controlled feeding	28	21

The pigs were fed *ad libitum* up to an age of 15 weeks before the trial period started. During this adaption period weekly feed intakes were recorded to determine what the *ad libitum* feed intake was in the different housing systems. This data was used to determine what levels of feeding was used for the controlled feeding. Based on the feed intakes and growth recorded in the adaption period it was decided to add a third Cawi feeder to each of the group pens to ensure that feeder space was not a limiting factor for any of the feeding treatments. Pigs were randomly allocated to feeding treatments and housing systems based on 15 week empty body weights, stratified from low to high. This was done to ensure that the different feeding treatments start the experimental period on the same average body weight. The pigs in the two pens in the group housing were not mixed at the start of the trail period to prevent aggression associated with the establishment of a pecking order. The data indicates (Table 2.2) that there were no differences ($P < 0.05$) in the 15 week starting body weight between the feeding treatments. The pigs in the individual housing achieved a higher growth rate during the adaption period from 10.5 weeks to 15 weeks before the trial period started. Pigs in the individual housing were significantly heavier at the start of the trial indicating a housing effect. Furthermore when comparing the effects of housing system within the *ad libitum* treatment group, the pigs in the individual housing were significantly heavier. Because of this differences seen at the beginning of the trial, empty body weight at 15 weeks was included as a covariant in the statistical analyses to ensure an unbiased comparison between the housing systems.

Table 2.2 Initial (week 15) empty body weights per feeding treatment and housing system

	Ad libitum Feeding	Controlled Feeding	Housing LSM
Individual Housing	$60.64 \pm 0.858_3$	60.45 ± 0.858	$60.45 \pm 0.606_1$
Group Housing	$57.71 \pm 0.990_4$	58.25 ± 0.990	$57.98 \pm 0.700_2$
Treatment LSM	59.18 ± 0.655	59.35 ± 0.655	

$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)
$_{34}$Column means with the different subscripts differ significantly ($P < 0.05$)

2.2 Animals

The pigs originated from Walt Landgoed farm outside Settlers in the Limpopo province of South Africa. The animals were obtained through insemination of TOPIGS-40 sows with the semen from a specific Topigs Norsvin Tempo boar. The offspring were born and cross fostered between sows as per normal farm practices. The piglets were weaned at three weeks of age after which they were moved to an environmentally controlled weaner house. They stayed in the weaner house up to an age of 10.5 weeks in split sex housing. At 10.5 weeks all the male offspring were weighed and selected for the trial based on body weight. A total of 98 intact males were selected to be in the body weight range of 27-36 kg range. The animals were transported to the

Experimental farm of the University of Pretoria the next day using a truck designed for the safe transport of pigs. Upon arrival at the Experimental farm animals were randomly allocated to housing system and pens.

2.3 Health Management

The pigs originated from a farm with high health conditions and has specific pathogen free (SPF) housing conditions. No prophylactic treatment against disease was applied during the trial period. The trial took place in high health housing conditions and bio-security rules and regulations were strictly applied. Throughout the trial the general health of the animals was in a good condition. One pig arrived on the experimental farm with an inguinal hernia, this had no influence on its growth performance and no treatment was applied. One pig started coughing and was successfully treated with Terralon LA® as advised by a veterinarian.

2.4 Ethics approval

This trial conformed to the requirements of the Animal Use and Care Committee of the University of Pretoria, reference number EC107-13.

2.5 Housing and environmental management

The animals were housed in a closed building equipped with extractor fans for ventilation purposes. Before the trial started the ventilation system was thoroughly tested and the house checked for draughts and repaired where necessary. Natural light was supplement with electric lighting during the day for 12 hours. Maximum and minimum temperatures were measured daily using thermometers placed in the middle of the individual and group housing systems respectively at a height of 1.2 meters above the floor. These temperature readings were recorded daily at 06:00 am and the thermometers reset. The animals were allocated to individual pens or group housing pens. The pen dimensions and pen specifications are indicated in Table 2.3. A total of 56 individual pens was used, 28 pens per feeding treatment. In the group housing the 42 pigs used in the trial was divided into two pens, one pen per feeding treatment, containing 21 pigs each.

Table 2.3 Housing dimensions and specifications

Specification	Individual Pens	Group Housing
Size	117 x 290 cm	500 x 348 cm
Feeder/s	1 Individual Feeder	3 Group Feeders
Drinker/s	1 Nipple drinker	2 Nipple Drinkers
Flooring	Partially Slatted	Partially Slatted
Number of pigs	1	21
Stocking Density $m^2/W^{0.67}$	0.15 $m^2/W^{0.67}$	0.037 $m^2/W^{0.67}$

2.6 Feed Rations

A total of 5 different rations were used during the trial (Grower 1-5). The diets were formulated using Format International (London, UK) according to the requirements as stated in the TOPIGS 2012 manual. The nutrient composition of the five diets can be seen in Tables 2.4; 2.5; 2.6; 2.7 and 2.8. The abbreviations used in the nutrient composition tables is listed with their definitions below:

- SID: standard ileal digestibility
- NE: net energy
- Lys: lysine
- M: methionine
- C: cysteine
- Thr: threonine
- Trp: tryptophan
- Val: valine
- Ile: isoleucine

- His: histidine
- dEB: dietary electrolyte balance

Table 2.4 Nutrient Composition of Grower 1

Nutrient	Units	Total	Available
ME	MJ/kg	13.40	
SID Lys:NE		0.10	
SID M+C:Lys		0.60	
SID Thr:Lys		0.66	
SID Trp:Lys		0.20	
SID Val:Lys		0.74	
SID Ile:Lys		0.64	
SID His:Lys		0.42	
Lysine	%	1.16	1.03
Methionine	%	0.39	0.36
Cystein	%	0.31	0.25
Met + Cys	%	0.71	0.62
Threonine	%	0.78	0.67
Thryptophan	%	0.24	0.21
Valine	%	0.89	0.76
Crude protein	%	17.24	14.71
Crude Fibre	%	3.48	
Crude Fat	%	3.81	3.26
Ca:P		1.19	
Calcium	%	0.68	
Phosphorous	%	0.57	0.29
Sodium	%	0.22	
dEB	Meq/kg	171.72	
Chloride	%	0.44	

Table 2.5 Nutrient Composition of Grower 2

Nutrient	Units	Total	Available
ME	MJ/kg	13.34	
SID Lys:NE		0.10	
SID M+C:Lys		0.62	
SID Thr:Lys		0.67	
SID Trp:Lys		0.20	
SID Val:Lys		0.76	
SID Ile:Lys		0.64	
SID His:Lys		0.43	
Lysine	%	1.08	0.96
Methionine	%	0.38	0.35
Cystein	%	0.30	0.25
Met + Cys	%	0.68	0.60
Threonine	%	0.75	0.65
Thryptophan	%	0.22	0.19
Valine	%	0.86	0.73
Crude protein	%	16.45	14.05
Crude Fibre	%	3.44	
Crude Fat	%	3.62	3.11
Ca:P		1.19	
Calcium	%	0.66	
Phosphorous	%	0.56	0.29
Sodium	%	0.22	
dEB	Meq/kg	164.77	
Chloride	%	0.44	

Table 2.6 Nutrient Composition of Grower 3

Nutrient	Units	Total	Available
ME	MJ/kg	13.18	
SID Lys:NE		0.94	
SID M+C:Lys		0.62	
SID Thr:Lys		0.68	
SID Trp:Lys		0.20	
SID Val:Lys		0.74	
Lysine	%	1.04	0.92
Met + Cys	%	0.66	0.57
Threonine	%	0.73	0.63
Tryptophan	%	0.21	0.18
Valine	%	0.80	0.68
Crude protein	%	15.42	13.09
Crude Fibre	%	3.61	
Crude Fat	%	3.71	3.19
Ca:P		1.17	
Calcium	%	0.64	
Phosphorous	%	0.54	0.29
Sodium	%	0.22	
Chloride	%	0.44	

Table 2.7 Nutrient Composition of Grower 4

Nutrient	Units	Total	Available
ME	MJ/kg	13.15	
SID Lys:NE		0.90	
SID M+C:Lys		0.64	
SID Thr:Lys		0.70	
SID Trp:Lys		0.20	
SID Val:Lys		0.75	
Lysine	%	0.99	0.88
Met + Cys	%	0.64	0.57
Threonine	%	0.71	0.62
Thryptophan	%	0.20	0.17
Valine	%	0.78	0.66
Crude protein	%	14.95	12.70
Crude Fibre	%	3.58	
Crude Fat	%	3.58	3.09
Ca:P		1.18	
Calcium	%	0.62	
Phosphorous	%	0.53	0.28
Sodium	%	0.22	
Chloride	%	0.44	

Table 2.8 Nutrient Composition of Grower 5

Nutrient	Units	Total	Available
ME	MJ/kg	13.13	
SID Lys:NE		0.87	
SID M+C:Lys		0.64	
SID Thr:Lys		0.70	
SID Trp:Lys		0.19	
SID Val:Lys		0.76	
Lysine	%	0.95	0.85
Met + Cys	%	0.62	0.55
Threonine	%	0.69	0.60
Thryptophan	%	0.19	0.16
Valine	%	0.75	0.65
Crude protein	%	14.50	12.36
Crude Fibre	%	3.51	
Crude Fat	%	3.36	2.91
Ca:P		1.19	
Calcium	%	0.61	
Phosphorous	%	0.51	0.27
Sodium	%	0.21	
Chloride	%	0.44	

The ingredient composition of the diets used can be seen in Table 2.9. The rations were fed for different periods of time. These periods used can be seen in Table 2.10.

Table 2.9 Ingredient composition of Rations

Ration:	Grower 1	Grower 2	Grower 3	Grower 4	Grower 5
Ingredient	Inclusion Level %	Inclusion Level (%)	Inclusion Level (%)	Inclusion Level (%)	Inclusion Level (%)
Maize 7.5 %	64.5	66.5	66.7	68.0	69.8
Soya Oilcake 46	20	19	15.5	15	15
Wheat Bran 15%	8	8.5	12	12.2	12
Soyabean full fat 36%	4	2.5	2.5	1.5	
Limestone 36	1.25	1.25	1.25	1.25	1.25
Monocaclciumphosphate 21	0.55	0.5	0.4	0.35	0.3
Salt (fine)	0.5	0.5	0.5	0.5	0.5
MG T5 Supa Grower	0.3	0.3	0.3	0.3	0.3
Ahrhoff Clex Vit	0.3	0.3	0.2	0.2	0.2
L-Lysine HCl	0.36	0.34	0.385	0.37	0.365
L-Threonine	0.14	0.14	0.165	0.17	0.165
DL-Methionine	0.105	0.1	0.1	0.1	0.09
L-Tryptophan	0.0375	0.035	0.035	0.032	0.03

Table 2.10 Ration feeding time and duration of feeding

Ration	Start feeding	End feeding	Feeding period (days)
Grower 1	19 Nov	3 Dec	15
Grower 2	4 Dec	15 Dec	12
Grower 3	16 Dec	4 Jan	20
Grower 4	5 Jan	20 Jan	16
Grower 5	21 Jan	28 Jan	8

The animals allocated to the controlled feeding regime treatment were fed according to age. Their feed allowance was calculated and fed per day as can be seen in Table 2.10.

Table 2.11 Controlled feed allocation per day

	Controlled feed allocation (kg/day)					
Day	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21
1	2.18	2.30	2.39	2.51	2.58	2.66
2	2.19	2.31	2.41	2.52	2.58	2.66
3	2.20	2.32	2.42	2.52	2.59	2.67
4	2.21	2.33	2.43	2.53	2.60	2.67
5	2.23	2.34	2.46	2.53	2.60	2.68
6	2.25	2.35	2.46	2.54	2.61	2.68
7	2.28	2.38	2.47	2.54	2.63	2.69

2.7 Proximate analysis of feed samples

Representative samples of all five the rations used in the trial were collected before feeding. These samples were stored and analysed after the trial at the Department of Animal and Wildlife Sciences, Nutrilab, University of Pretoria. Chemical components were determined using the following methods:

- Dry Matter and moisture content: using the Prolab PL001 oven at a temperature of 105 degrees Celsius AOAC (2000)

- Crude protein: using the LECO Trumac® N machine to calculate nitrogen content. Multiply with 6.25 to determine crude protein content AOAC (2000).
- Crude fibre: using the FOSS Fibretec® 2010 Hot Extractor machine AOAC (2000).
- Crude fat (ether extract): using the FOSS Soxtec® 2043 machine AOAC (2000).
- Phosphorous: using the Spekol 1300 apparatus using the spectrophotometric method AOAC (2000).
- Calcium was determined using the method described by Giron (1973) using the Perkin Elmer Atomic Spectrophotometer-2380.

Results from the proximate analysis of feed samples are presented in Table 2.12 on an as fed basis and in Table 2.13 on a dry matter (DM) basis.

Table 2.12 Proximate analysis results on an as fed basis

Feed Ration	Crude Protein (g/100g)	Crude Fibre (g/100g)	Crude Fat (g/100g)	Calcium (g/100g)	Phosphorous (g/100g)	Ca:P ratio
Grower 1	16.00	3.29	3.53	0.54	0.49	1.10:1
Grower 2	16.68	3.45	3.75	0.52	0.51	1.03:1
Grower 3	16.29	3.44	3.08	0.40	0.40	0.99:1
Grower 4	15.30	3.68	3.10	0.67	0.42	1.59:1
Grower 5	15.47	3.95	3.08	0.42	0.44	0.94:1

Table 2.13 Proximate analysis results on a DM basis

Feed Ration	Crude Protein (g/100g)	Crude Fibre (g/100g)	Crude Fat (g/100g)	Calcium (g/100g)	Phosphorous (g/100g)	Ca:P ratio
Grower 1	18.07	3.72	3.98	0.61	0.55	1.10:1
Grower 2	18.83	3.89	4.23	0.59	0.57	1.03:1
Grower 3	18.40	3.89	3.47	0.45	0.46	0.99:1
Grower 4	17.27	4.15	3.50	0.76	0.48	1.59:1
Grower 5	17.41	4.45	3.46	0.47	0.50	0.94:1

An assay of the amino acid levels in the feed was done by the South African Grain Laboratory using the High Performance Liquid Chromatography (HPLC) method. The following method was used to determine the levels of free amino acids: The samples are analysed by the Pico-Tag method using a Waters Breeze HPLC with Empower software (Waters, Millipore Corp., Milford, MA). Samples (500 mg) are extracted with 70 % ethanol, and then derivatized with phenylisothiocyanate (PITC) to produce phenyltiocarbamyl (PTC) amino acids. These derivatized amino acids are analysed by reverse phase HPLC (Cohen *et al.*, 1989). In the case of protein bound amino acids the following method was used: The samples are analysed in duplicate by the Pico-Tag method using a Waters Breeze HPLC with Empower software (Waters, Millipore Corp., Milford, MA). Samples (400 mg) are hydrolysed with 6 N HCl for 24 hours and then derivatized with phenylisothiocyanate (PITC) to produce phenyltiocarbamyl (PTC) amino acids. These amino acids are then analysed by reverse phase HPLC (Cohen *et al.*, 1989).The results of the amino acid assay are presented in Table 2.14.

Table 2.14 Proximate analysis results of amino acid assay on an as fed basis

Amino Acid	Units	Grower 1	Grower 2	Grower 3	Grower 4	Grower 5
Tryptophan	g/100g	0.19	0.205	0.20	0.205	0.235
Methionine	g/100g	0.35	0.33	0.30	0.33	0.365
Cystine	g/100g	0.365	0.375	0.365	0.345	0.35
Aspartic Acid	g/100g	1.475	1.525	1.425	1.41	1.305
Glutamic Acid	g/100g	3.105	3.22	3.105	2.955	2.875
Serine	g/100g	0.895	0.915	0.865	0.84	0.805
Glycine	g/100g	0.72	0.75	0.73	0.69	0.685
Histidine	g/100g	0.545	0.55	0.555	0.56	0.55
Arginine	g/100g	1.105	1.105	1.06	1.01	1.00
Threonine	g/100g	0.84	0.82	0.825	0.79	0.81
Alanine	g/100g	0.875	0.945	0.89	0.885	0.88
Proline	g/100g	1.095	1.125	1.145	1.115	1.09
Tyrosine	g/100g	0.505	0.495	0.50	0.46	0.415
Valine	g/100g	0.89	0.945	0.915	0.815	0.81
Isoleucine	g/100g	0.665	0.69	0.645	0.65	0.605
Leucine	g/100g	1.45	1.45	1.425	1.47	1.375
Phenylalanine	g/100g	0.81	0.82	0.78	0.78	0.73
Lysine	g/100g	1.055	1.125	0.99	1.06	1.12

2.8 Parameters measured

Average Daily Gain (ADG):

ADG was calculated based on weekly weightings. Animals were weighed at the same time and on the same day every week. To achieve empty body weight recording feed was taken away twelve hours before every weighing. This parameter was broken down further into partial and cumulative average daily gains.

- Partial Average Daily Gain:
  This parameter was used to express the rate of empty bodyweight within a specific week during the trial period. This was calculated by determining the weight gain for a specific week by subtracting the initial empty bodyweight from the end empty bodyweight and dividing it by the number of days. For example:
  Partial ADG week 16 = (empty bodyweight end of week 16 – empty bodyweight start of week 16) ÷ 7 days
- Cumulative Average Daily Gain:
  This parameter was used to express the rate of bodyweight gain over achieved since the start of the trial period. This was calculated by determining the weight gain from the beginning of the trail period up to a specific point and dividing the value by the number of days that has passed since the start of the trial period. For example:
  Cumulative ADG week 16 = (empty bodyweight end of week 16 – empty bodyweight beginning week 15) ÷ 14 days

Feed Intake (FI):

- Feed intake was determined on a weekly basis. This was achieved by recording the amount of feed supplied during the week and subtracting the amount of feed residues recorded at the end of the week.

Backfat measurements:

- P2 Backfat thickness was measured ultrasonically every week. This was done during the weekly weighing session. A Renco Lean Meater probe was used. The measurement was taken 50 mm from the midline at the last rib.

Feed conversion ratio (FCR):

FCR was used to express the feed efficiency of the animals. This was calculated by using the weekly feed intakes and the weekly gain in empty bodyweight. This parameter was further broken down into partial and cumulative FCR.

- Partial Feed Conversion Ratio:
  This was used to express the efficiency with which growth took place in a specific week of the trial. This was calculated by dividing the total feed intake for the week by the total empty bodyweight gain. For example:
  Partial FCR week 16 = total feed intake week 16 ÷ (empty bodyweight end of week 16 – empty bodyweight start of week 16)
- Cumulative Feed Conversion Ratio:
  This parameter expresses the efficiency with which feed was used for empty bodyweight gain from the start of the trail period up to a specific point. This was calculated by dividing the total feed intake from the start of the trial by the empty bodyweight gain from the start of the trial. For example:
  Cumulative FCR week 16 = (feed intake week 15 + feed intake week 16) ÷ (empty bodyweight end of week 16 – empty bodyweight start of week 15)

Carcass characteristics:

- At 21 weeks of age the trial was completed and the animals were slaughtered at Eskort Abattoir in Heidelberg, South Africa. The following characteristics were recorded or calculated: hot carcass mass, cold carcass mass, dressing percentage, lean meat percentage, carcass length and carcass compactness.

Lean meat percentage:

- Lean meat percentage was calculated by using the backfat thickness and eye muscle thickness values measured using the Hennessy Grading probe. This measurements was taken between the 2nd and 3rd last ribs, 45 mm from the mid – backline of the hanging carcass. The following formula was used: Hennessy%Lean = 72.5114 - (0.4618 x fat thickness) + (0.057 x eye muscle thickness).

Carcass Compactness:

- Carcass compactness was used to evaluate carcass conformation. This was calculated by dividing the cold carcass weight (kg) by the carcass length (cm). This formula is a modification of the formula used by Bruwer (1984). Carcass length was measured using a flexible measuring tape to determine the distance from first to the last vertebra following the spinal cord.

2.9 Statistical Analysis

Average daily gain (ADG), feed conversion ratio (FCR) and P2 backfat measurements were measured weekly during the trial. Data were analysed statistically as a 2 x 2 factorial design with the GLM model (Statistical Analysis System, 2013) for differences between treatment and housing system. Repeated Measure Analysis of Variance with GLM model was used for repeated measures e.g. Means and standard errors were calculated and the significance of difference ($P < 0.05$ and $P < 0.01$) between means was determined by the Fischers test (Samuels, 1989).

CHAPTER 3
RESULTS AND DISCUSSION

The following parameters were recorded and tested in the individual and group housing systems: feed intake, empty body weight, ADG (partial), ADG (cumulative), FCR (partial), FCR (cumulative), P2 backfat thickness, carcass lean meat percentage, carcass fat, warm carcass mass, cold carcass mass, carcass length, carcass compactness, total feed cost, carcass income and net income. Since individual feed intakes of pigs in group housing was not recorded, the FCR for group housing was calculated per pen by using the total body weight gain and total feed intake per pen. Further available lysine and energy intake were calculated for the pigs in individual housing system based on their individual feed intakes.

3.1 Environmental conditions during the trial

Minimum and maximum temperatures for the two housing systems were recorded throughout the trial and are illustrated in Figure 3.1. Although individual housing had higher average maximum and lower average minimum temperatures, the variation in minimum and maximum temperatures between housing systems was negligible (<1.5°C) and probably did not affect the performance of pigs in different housing systems.

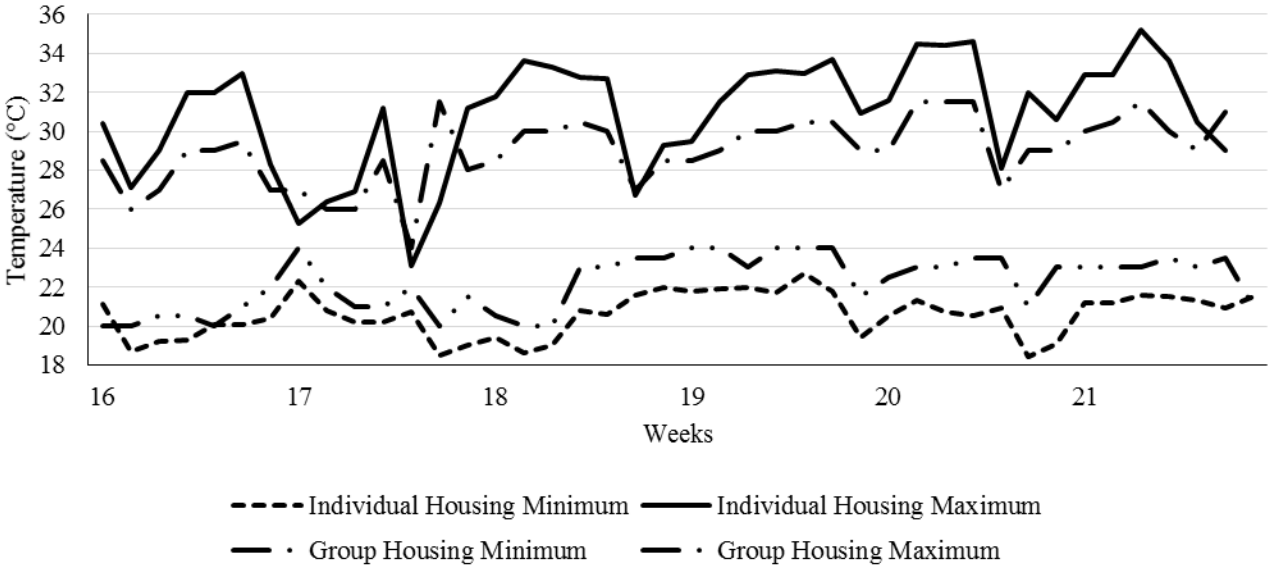

Figure 3.1 Minimum and maximum temperatures for individual and group housing systems

3.2 Feeding Treatments

The aim of the feeding treatments was to accurately supply the predetermined amount of feed to those animals under the controlled feeding regime, whilst allowing the *ad libitum* fed animals access to as much feed as they would consume. The main effects of the feeding treatments and housing systems on the feed intakes are presented in Table 3.1. Overall the feeding treatments led to higher intakes ($P < 0.01$) in the animals fed *ad libitum* compared to those exposed to controlled feeding. Similar differences were noted for feed intakes between housing systems. This indicates that feeding treatments were successfully applied. When comparing the overall effect of the housing systems it can be seen that *ad libitum* fed pigs in the individual housing had a significantly higher feed intake than those in the group housing ($P < 0.01$). No difference is expected within the controlled feeding as they received the same feed daily. This overall housing system effect is due to the significantly higher feed intake in the individual housing when fed *ad libitum*.

Table 3.1 Main effects of feeding treatments and housing systems on total feed intakes

	Ad libitum Feeding (Feed intake, kg)	Controlled Feeding (Feed intake, kg)	Housing LSM (Feed intake, kg)
Individual Housing	$134.09 \pm 2.152^{A}{}_{1}$	102.96 ± 2.152^{B}	$118.52 \pm 1.522_{1}$
Group Housing	$117.41 \pm 2.485^{A}{}_{2}$	102.96 ± 2.485^{B}	$110.18 \pm 1.757_{2}$
Treatment LSM	125.75 ± 1.643^{A}	102.96 ± 1.643^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)
$_{34}$Column means with the different subscripts differ significantly ($P < 0.05$)

Feed intakes were calculated on a weekly basis. The feed intakes were compared between feeding treatments for the two housing systems (Table 3.2) and within the different housing systems (Table 3.3 and 3.4). In both the pooled and between housing system comparisons, the *ad libitum* fed pigs had a significantly higher feed intake than the controlled fed animals throughout the entire experimental period. A similar trend occurred within the group housing system, however, during week 18 no significant difference was seen in feed intake between the two treatments. This is probably due to the blockage of two of the *ad libitum* group's feeders during week 17 that led to lower feed flow levels. The blockage was due to a feed bag containing pieces of cottonseed oilcake, and after this occurrence the specific bag was no longer used and other bags checked for sunflower oilcake contamination. The effect of this blockage can be seen in the drop in feed intake from 18.77 kg in week 16 to 17.59 during week 17 (Table 3.4). The feed intake resumed expected levels from week 19 onwards. This event was taken into account with the analysis of the response in the different parameters during week 17 and 18.

Table 3.2 Weekly feed intakes for feeding treatments (individual and group housing systems pooled).

Week	*Ad libitum* feeding (Feed intake, kg/week)	Controlled feeding (Feed intake, kg/week)
16	18.52 ± 0.119^{A}	15.52 ± 0.121^{B}
17	19.48 ± 0.155^{A}	16.31 ± 0.116^{B}
18	20.12 ± 0.159^{A}	17.08 ± 0.160^{B}
19	23.00 ± 0.154^{A}	17.76 ± 0.155^{B}
20	23.63 ± 0.229^{A}	18.30 ± 0.231^{B}
21	23.05 ± 0.229^{A}	18.86 ± 0.231^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Table 3.3 Weekly feed intakes for feeding treatments in the individual housing system

Week	*Ad libitum* feeding (Feed intake, kg/week)	Controlled feeding (Feed intake, kg/week)	Difference (Feed intake, kg/week)
16	18.28 ± 0.201^{A}	14.74 ± 0.190^{B}	3.54
17	21.36 ± 0.194^{A}	15.87 ± 0.183^{B}	5.49
18	22.31 ± 0.268^{A}	16.37 ± 0.253^{B}	5.94
19	23.63 ± 0.259^{A}	17.01 ± 0.245^{B}	6.62
20	23.81 ± 0.386^{A}	17.21 ± 0.365^{B}	6.6
21	23.66 ± 0.385^{A}	17.91 ± 0.364^{B}	5.76

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Table 3.4 Weekly feed intakes for feeding treatments in group housing system

Week	*Ad libitum* feeding (Feed intake, kg/week)	Controlled feeding (Feed intake, kg/week)	Difference (Feed intake, kg/week)
16	18.77 ± 0.232^{A}	16.30 ± 0.241^{B}	2.47
17	17.59 ± 0.223^{A}	16.75 ± 0.232^{B}	0.84
18	17.93 ± 0.308	17.80 ± 0.320	0.13
19	22.37 ± 0.298^{A}	18.50 ± 0.310^{B}	3.87
20	23.45 ± 0.444^{A}	19.40 ± 0.461^{B}	4.05
21	22.45 ± 0.444^{A}	19.82 ± 0.461^{B}	2.63

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

There was a significant difference between the two feeding treatments in the group housing for most of the experiment. However, the difference between the two feeding treatments was smaller than the difference seen in the individual housing. This should be taken into account when the differences in parameters are compared under group housing conditions.

The effects of housing systems on feed intake are compared in Table 3.5. The controlled fed animals received the same amount of feed per week in the group and individual housing. Therefore only the feed intake of the *ad libitum* fed groups are compared. In this comparison a significantly higher feed intake occurs in the individual housing during week 17 to 19. The feeder blockage during week 17 explains the difference seen during week 17. This significant difference in feed intake between the housing systems matches the results when comparing differences between treatments within the housing systems. A trend can be seen that the *ad libitum* feed intake is higher under individual housing conditions. The feed intakes for individual pigs in the group housing is based on the assumption that all of the pen mates consumed the same amount of feed. This should be kept in mind when comparing results between the two housing systems.

Table 3.5 Weekly feed intakes for *ad libitum* fed pigs in the different housing systems

Week	Individual housing (Feed intake, kg/week)	Group housing (Feed intake, kg/week)
16	18.28 ± 0.201	18.77 ± 0.232
17	21.36 ± 0.194^{A}	17.59 ± 0.223^{B}
18	22.31 ± 0.268^{A}	17.93 ± 0.308^{B}
19	23.63 ± 0.259^{A}	22.37 ± 0.298^{B}
20	23.81 ± 0.386	23.45 ± 0.444
21	23.66 ± 0385	22.45 ± 0.444

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Overall the application of the different feeding treatments was successfully applied. The effect of housing system on feed intake could be due to several factors such as differences in temperatures, number of animals per pen, stocking density, health status and activity levels. Throughout the experiment no observable disease conditions occurred and it can be assumed that this was not the cause of the housing effect seen. The number of pigs per pen plays a role in their feed intake. Several studies indicate that increasing the number of pigs from one to five leads to a significant drop in feed intake. Feed intake decreases by 8 to 10 percent as shown by the work of Gonyou *et al*. (1992); Gonyou & Stricklin (1998); Chapple (1993). When the number of pigs per pen was increased further no significant effect on feed intake was recorded. This is in agreement with the result of similar studies done by Nielsen & Lawrence (1993), Schmolke & Gonyou (2000), Turner *et al*. (2000) and Wolter *et al*. (2001) who found no significant effect of increasing pig number above 5 on their feed intakes. These results indicate that the number of pigs in the group housing might have led to a lower feed intake than that was seen in the individual housing. The stocking density in the group housing was 0.037 $m^2/W^{0.67}$ (Table 2.3) and can be excluded from the housing effect observed. A review done by Black (2009) on stocking density in groups of five pigs or more found that feed intake decreases when less than 0.035 $m^2/W^{0.67}$ floor space is available. This was not the case in the group housing (Table 2.3) and it can therefore be assumed that the housing effect on feed intake was not due to the stocking density used. The temperature at which pigs are kept can affect their feed

intake. If the ambient temperature drops below their lower critical temperature, feed intake is increased to supply energy for heat production. When the ambient temperature exceeds the evaporative critical temperature, feed intake drops. These responses to changes in temperature can be seen in the work done by Black *et al.* (1999). Housing temperatures followed the same pattern for the two housing systems. However, the individual housing had slightly higher maximum and lower minimums than the group housing. If this difference had a significant effect on feed intake it would have led to a lower feed intake in the individual housing and therefore does not explain the housing effect seen on feed intake. The activity levels of pigs in the different housing systems might affect the level of feed intake. In a study done by Gonyou *et al.* (1992) the activity and feed intake levels were compared between pigs housed in groups of five and pigs housed in individual pens. Individually penned pigs had a significantly higher feed intake than those in the group housing. Furthermore group penned pigs spent 20% more time standing than individually penned pigs. This difference in activity level however, did not have a significant effect on the time spent eating. This indicates that individually housed pigs consumed a higher quantity of feed in the same time as those housed in groups. Higher levels of activity in group housing might lead to a decrease in feed intake, this decrease however, is not due to the feeding time being limited.

3.3 Growth Performance

The main effects of the treatments on empty body weight gains during the trial period, from week 15 to 21, are compared in Table 3.6. This comparison shows that *ad libitum* feeding led to significantly higher body weight gain than controlled feeding in both housing systems. This significantly higher body weight gain due to *ad libitum* feeding is also seen when comparing treatments in the different housing systems. When comparing the effect of the housing system used, it can be seen that animals in the individual housing grew to a significantly higher body weight in the experimental period under both feeding treatments. This same pattern occurs under *ad libitum* feeding where the individually housed pigs grew to a significantly higher body weight. However, housing system did not have a significant effect on the empty bodyweight gains achieved when pigs were fed controlled levels.

Table 3.6 Main effects of feeding treatment and housing system on empty body weight gain from 15 to 21 weeks

	Ad libitum feeding (kg)	Controlled feeding (kg)	Housing LSM (kg)
Individual Housing	$54.60 \pm 0.794^{A}{}_{1}$	43.33 ± 0.779^{B}	$48.96 \pm 0.556_{1}$
Group Housing	$46.57 \pm 0.900^{A}{}_{2}$	41.85 ± 0.900^{B}	$44.21 \pm 0.636_{2}$
Treatment LSM	50.59 ± 0.600^{A}	42.59 ± 0.595^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)

The main effects of feeding treatment and housing system on the average daily gains can be seen in Table 3.7. The *ad libitum* feeding treatment led to a significantly higher ADG (individual and group housing pooled). *Ad libitum* feeding had the same effect in the individual and group housing systems. The overall effect of the housing systems can be seen in the fact that individually housed pigs had a significantly higher growth rate than those housed in groups. A similar effect of housing system is seen in *ad libitum* fed pigs. However, when the pigs are fed controlled levels, housing had no significant effect on their growth rates. This similar body weights and growth rates achieved under controlled feeding indicates that the differences between the housing systems under *ad libitum* feeding is due to the level of feed intake.

Table 3.7 Main effects of feeding treatment and housing system on average daily gain

	Ad libitum feeding (kg/d)	Controlled feeding (kg/d)	Housing LSM (kg/d)
Individual Housing	$1.25 \pm 0.031^{A}{}_{1}$	1.03 ± 0.031^{B}	$1.14 \pm 0.022_{1}$
Group Housing	$1.11 \pm 0.036^{a}{}_{2}$	1.00 ± 0.036^{b}	$1.05 \pm 0.025_{2}$
Treatment LSM	1.18 ± 0.024^{A}	1.01 ± 0.024^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)

A comparison of the weekly empty body weights per feeding treatment in both housing systems can be seen in Table 3.8. At the end of the first week of feeding according to treatment, the *ad libitum* fed pigs had a significantly higher body weight than the controlled fed pigs. This significant difference between the two treatments exists throughout the experimental period. The level of significance for this difference increases from 95% during the first week to 99% during the following weeks.

Table 3.8 Weekly empty body weights of pigs in different feeding treatments (individual and group housing systems pooled)

Week	*Ad libitum* feeding (kg)	Controlled feeding (kg)
16	67.6 ± 0.25^{a}	66.7 ± 0.25^{b}
17	75.7 ± 0.29^{A}	73.9 ± 0.29^{B}
18	84.5 ± 0.40^{A}	80.6 ± 0.40^{B}
19	93.3 ± 0.45^{A}	88.1 ± 0.45^{B}
20	102.6 ± 0.50^{A}	95.0 ± 0.50^{B}
21	110.11 ± 0.59^{A}	102.1 ± 0.58^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

When comparing empty body weights in the individual housing system the *ad libitum* fed pigs had a significantly higher empty body weight than those controlled fed. This however, is not the case in the group housing system (Table 3.9). Only from week 18 onwards is a significantly higher body weight seen for the *ad libitum* fed animals.

Table 3.9 Empty body weights for feeding treatments in the group housing system

Week	*Ad libitum* feeding (kg)	Controlled feeding (kg)
16	66.7 ± 0.38	66.5 ± 0.38
17	73.8 ± 0.44	74.3 ± 0.44
18	82.2 ± 0.61^{a}	80.5 ± 0.61^{b}
19	90.6 ± 0.69^{A}	87.1 ± 0.68^{B}
20	99.2 ± 0.77^{A}	93.9 ± 0.76^{B}
21	106.4 ± 0.89^{A}	101.6 ± 0.01^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

The significant difference in empty body weights between the two feeding treatments is in line with the partial or weekly average daily gain results shown on Table 3.10. The *ad libitum* fed pigs had a significantly higher average daily gain from week 16 to week 20. In week 21 of the experiment there was no significant difference found between the two feeding treatments for partial ADG. This is due to the ADG gain of the *ad libitum* fed pigs decreasing from previous weeks. The reason for this might be that these animals have reached their maximum lean tissue growth potential. These results indicate that the level of feeding significantly affected the growth rate during the experimental period.

Table 3.10 Weekly partial average daily gains per feeding treatment (individual and group housing system pooled)

Week	*Ad libitum* Feeding (kg/d)	Controlled Feeding (kg/d)
16	1.16 ± 0.036^{A}	1.03 ± 0.036^{B}
17	1.15 ± 0.029^{A}	1.02 ± 0.029^{B}
18	1.26 ± 0.034^{A}	0.96 ± 0.033^{B}
19	1.25 ± 0.032^{A}	1.07 ± 0.032^{B}
20	1.33 ± 0.030^{A}	0.98 ± 0.030^{B}
21	1.07 ± 0.031	1.01 ± 0.031

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

When growth rates are compared in the different housing systems, a similar trend can be seen in the individual housing. This can be seen in Table 3.11 showing the partial ADG values. Throughout the experimental period the *ad libitum* fed pigs grew significantly faster than those whose intake was controlled.

Table 3.11 Weekly partial average daily gains per feeding treatment in the individual housing system

Week	*Ad libitum* Feeding (kg/d)	Controlled Feeding (kg/d)
16	1.28 ± 0.048^{A}	1.05 ± 0.047^{B}
17	1.31 ± 0.039^{A}	0.95 ± 0.038^{B}
18	1.34 ± 0.045^{A}	1.07 ± 0.044^{B}
19	1.31 ± 0.043^{a}	1.18 ± 0.042^{a}
20	1.45 ± 0.040^{A}	1.02 ± 0.039^{B}
21	1.11 ± 0.041^{A}	0.93 ± 0.040^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

When comparing the growth rates of the two treatments in the group housing (Table 3.12) different results are found. The *ad libitum* fed only grew significantly faster than the controlled fed pigs during week 18 to 20. During week 21 the *ad libitum* fed pig's growth rate decreased similar to that which was seen in the individual housing. In the group housing there seems to be a delay in the period between when the feeding treatment starts, and a divergence in growth response can be seen. Only from week 18 onwards did a significantly higher partial average daily gain only occur.

Table 3.12 Weekly partial average daily gains per feeding treatment in the group housing system

Week	*Ad libitum* Feeding (kg/d)	Controlled Feeding (kg/d)
16	1.04 ± 0.054	1.01 ± 0.054
17	1.00 ± 0.043	1.11 ± 0.043
18	1.18 ± 0.050^{A}	0.86 ± 0.050^{B}
19	1.19 ± 0.048^{A}	0.96 ± 0.048^{B}
20	1.21 ± 0.046^{A}	0.95 ± 0.046^{B}
21	1.04 ± 0.047	1.10 ± 0.047

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Figure 3.2 illustrates the difference in empty body weights for the entire experimental period. This figure clearly indicates the significant difference seen throughout the trial between the two feeding treatments in the individual housing. The delayed divergence in empty body weights for group housed pigs can be seen on the graph. This is in agreement with Figure 3.3 and 3.4 which illustrates the partial and cumulative average daily gains achieved respectively. Once again the significantly higher growth rate of *ad libitum* animals in the

individual housing is clear. When comparing the group housed pigs the feeding treatments only diverge from week 18 onwards. Further whilst no significant difference between the groups for partial ADG was recorded during week 21, a significant difference occurs in cumulative ADG. Even though the *ad libitum* fed group housed pig's growth rate decreases during the last week cumulatively, they still grow significantly faster than their controlled fed peers.

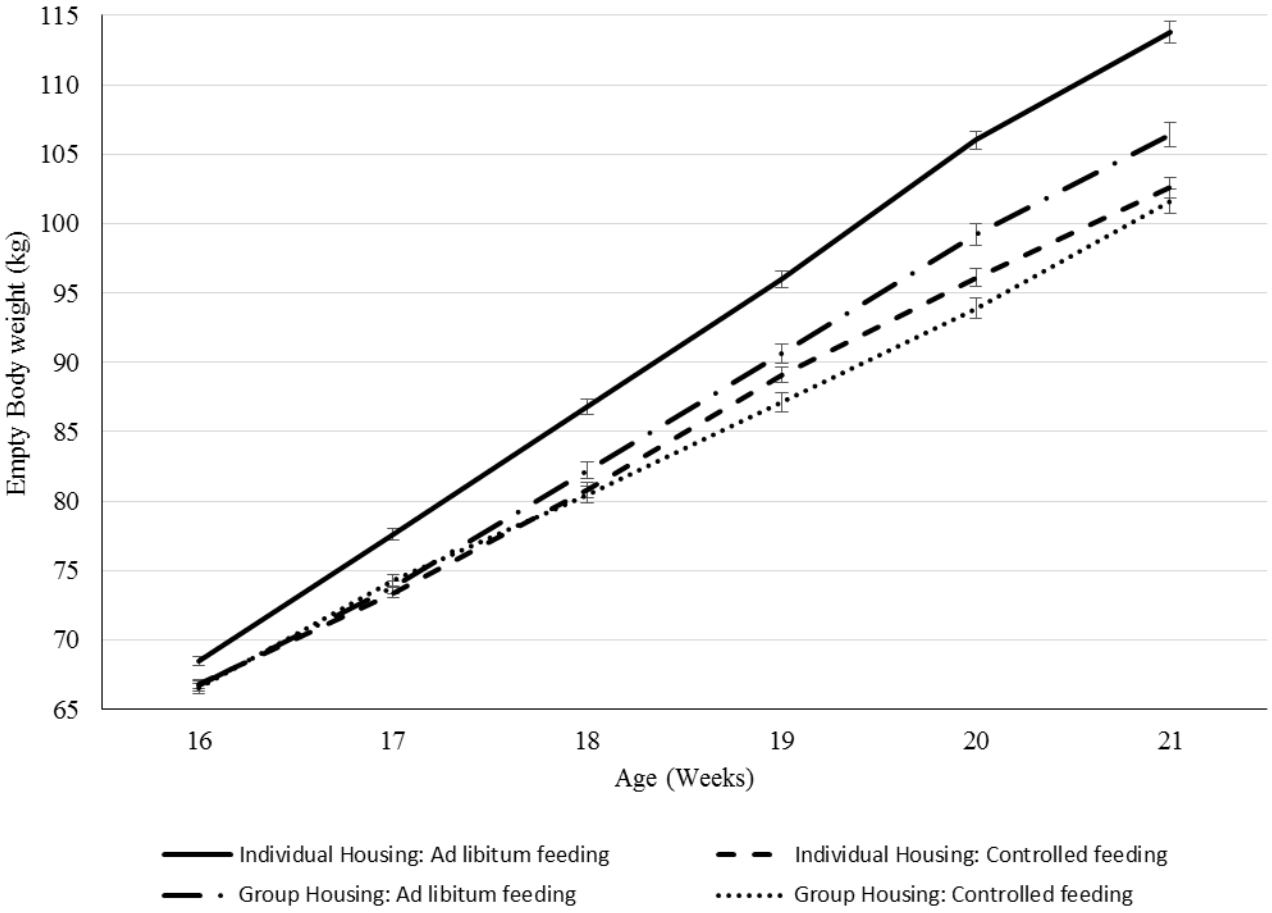

Figure 3.2 Weekly empty body weight means and standard deviations for feeding treatment and housing system combinations.

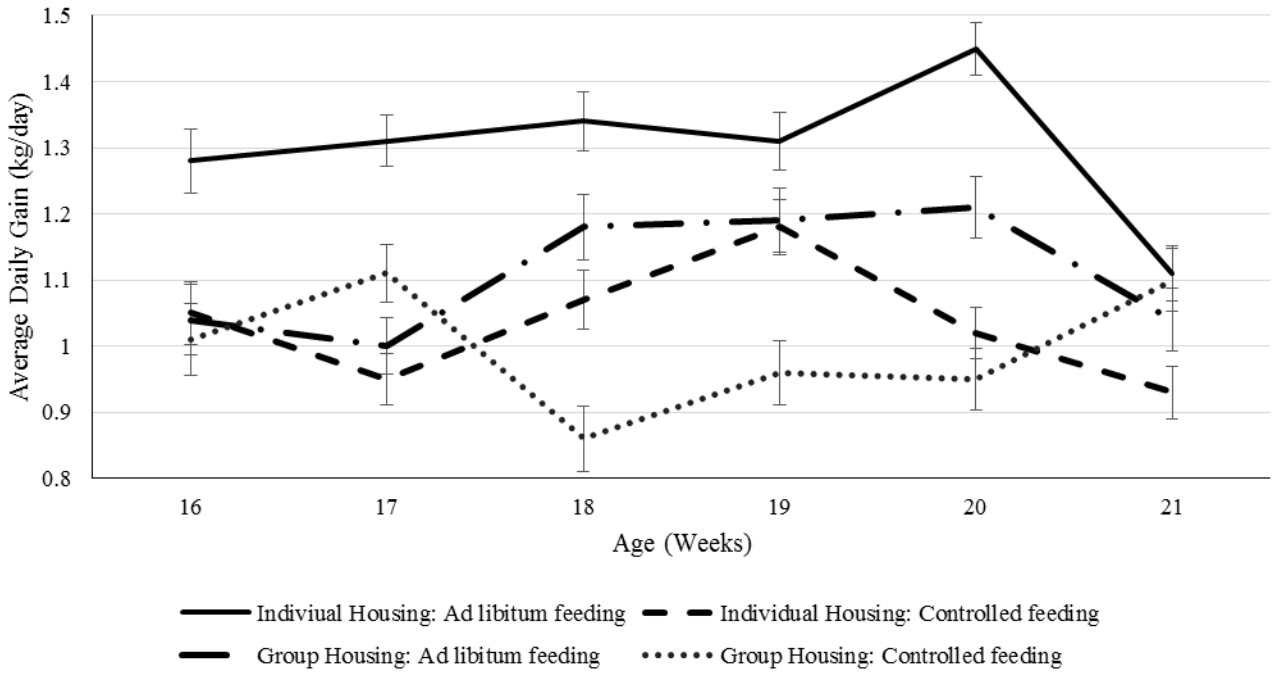

Figure 3.3 Weekly partial average daily gain means and standard deviations for feeding treatments and housing system combinations

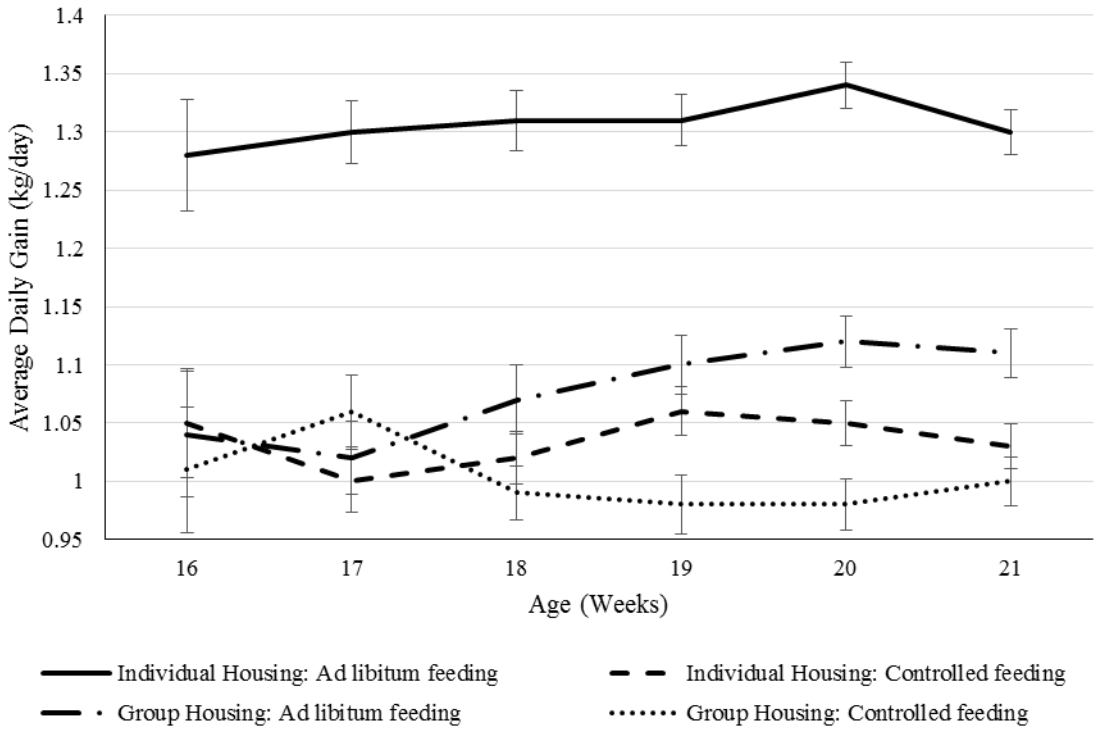

Figure 3.4 Weekly cumulative average daily gain means and standard deviations for feeding treatment and housing system combinations

When comparing feeding treatment effects overall, it is clear that *ad libitum* feeding led to significantly higher empty body weights and ADGs. This significant feeding treatment effect is visible throughtout the trail for individual housing, however, in the group housing the significant difference start only from 18 weeks onwards. This delay in differential growth performance can be attributed to the feed intakes achieved by the *ad libitum* fed group. During week 17 they had a low intake due to the feeder blockage and week 18 there was no significant difference in feed intake between the two groups. The significance in growth therefore is only visible when the *ad libitum* fed group achieves a significantly higher feed intake than their controlled fed peers. The difference in growth performance between the feeding treatments showed a similar pattern that was seen in feed intake. The differences between the treatments were larger in the individual housing system in comparison to those seen in the group housing system. This indicates the relationship between feed intake and growth performance. During week 21 no significant difference in partial ADG was detected in the group housing whilst the individually housed *ad libitum* fed pigs grew faster than their controlled fed peers. However, in both housing systems a decrease in growth rate was seen and it was found that the partial ADG for week 21 was lower ($P > 0.01$) than that achieved during week 20 (individual and group housing pooled). The bigger differences in growth rates in individual housing ensured that the growth rates were still significant in week 21 after this decrease took place. The reason for this decrease in growth rate seen in all of the feeding treatments and housing systems is due to the fact that the animals have reached their maximum lean tissue growth potential.

The higher performance in growth rate and empty body weights achieved under *ad libitum* feeding, is in agreement with the results of Leymaster & Mersmann (1991), who compared the growth of pigs under restrictive feeding by restricting pigs to 85 and 92.5% level of their *ad libitum* intake of a 15% crude protein diet. This resulted in a reduction in daily gains and live weights achieved. This is in agreement with findings made by Meat and Livestock Commission (1989); Cisneros *et al*. (1994); Quiniou *et al.* (1995); Affentranger *et al.* (1996); Ellis *et al.* (1996); Wood *et al.* (1996). This increase in growth rate as the feed intake increases, matches the predictions of the linear plateu concept, the model developed by Whittemore (1986). This model states that an increase in feed intake will lead to a linear increase in lean and adipose doposition in the period before the maximum lean depositon rate is reached. De Greef (1992) verified this model and showed that this principle matches the data he collected. This model further predicts that when the maximum lean protein deposition level is reached, the amount of lean depositon decreases and adipose tissue deposition increases. This change in fat : lean deposition ratio is seen in during week 21 when growth rates decrease in both feedings.

The housing effects on the empty body weights achieved is compared in Table 3.13. Pigs housed in individual housing had significantly higher empty body weights throughout the experimental period when fed on an *ad libitum* basis. This was only the case during week 19 and 20 when controlled feeding was applied (Table 3.14).

Table 3.13 Weekly empty body weights for *ad libitum* fed pigs in the different housing systems

Week	Individual housing (kg)	Group housing (kg)
16	68.5 ± 0.34^{A}	66.7 ± 0.38^{B}
17	77.6 ± 0.39^{A}	73.8 ± 0.44^{B}
18	86.8 ± 0.54^{A}	82.2 ± 0.61^{B}
19	96.0 ± 0.60^{A}	90.6 ± 0.69^{B}
20	106.0 ± 0.67^{A}	99.2 ± 0.77^{B}
21	113.8 ± 0.78^{A}	106.4 ± 0.89^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Table 3.14 Weekly empty body weights for controlled fed pigs for the different housing systems

Week	Individual Housing (kg)	Group Housing (kg)
16	66.8 ± 0.33	66.5 ± 0.38
17	73.4 ± 0.38	74.3 ± 0.44
18	80.8 ± 0.52	80.5 ± 0.61
19	89.1 ± 0.59[a]	87.1 ± 0.68[b]
20	96.1 ± 0.66[a]	93.9 ± 0.76[b]
21	102.6 ± 0.76	101.6 ± 0.88

[AB] Row means with different superscripts differ highly significantly ($P < 0.01$)
[ab] Row means with different superscripts differ significantly ($P < 0.05$)

A similar trend in housing effect is seen in the growth rates achieved in the different feeding treatments. When comparing cumulative ADG in the *ad libitum* feeding (Table 3.15), it is clear that under *ad libitum* feeding individual housing led to a significantly higher growth rate throughout the trial. This difference in growth performance due to housing can be explained by the different levels of feed intake achieved according to housing system. Figure 3.4 illustrates the feed intakes within the *ad libitum* treatment. From this it is clear that the individually housed pigs had a significantly higher feed intake during weeks 17 to 19.

Table 3.15 Cumulative average daily gains per week for *ad libitum* fed pigs for the different housing systems

Week	Individual Housing (kg/d)	Group Housing (kg/d)
16	1.28 ± 0.048[A]	1.04 ± 0.054[B]
17	1.30 ± 0.027[A]	1.02 ± 0.031[B]
18	1.31 ± 0.026[A]	1.07 ± 0.030[B]
19	1.31 ± 0.022[A]	1.10 ± 0.025[B]
20	1.34 ± 0.020[A]	1.12 ± 0.022[B]
21	1.30 ± 0.019[A]	1.11 ± 0.021[B]

[AB] Row means with different superscripts differ highly significantly ($P < 0.01$)

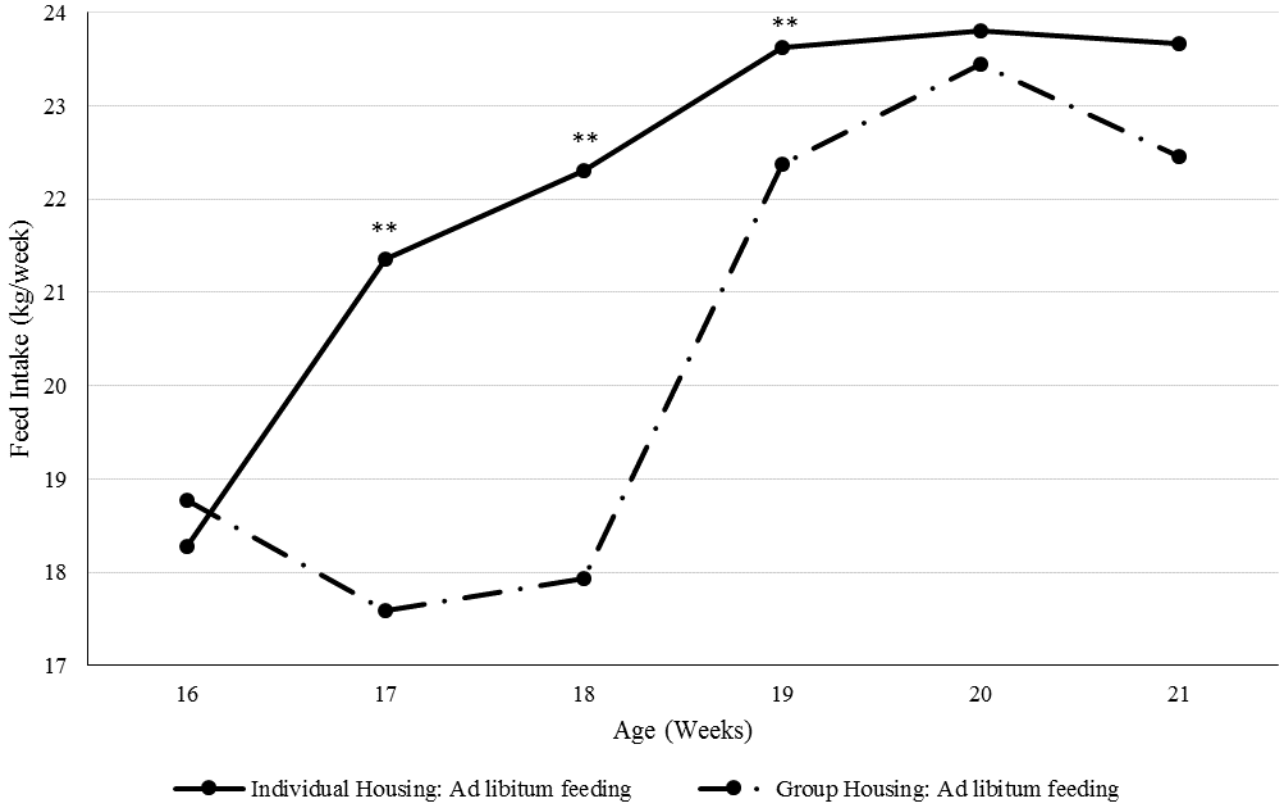

Figure 3.5 Weekly *ad libitum* feed intakes per housing system
** Weekly means with the two asterisks differ significantly ($P < 0.01$)

When a comparison was done of the growth rates achieved within the controlled feeding treatment (Table 3.16), housing only had a significant effect during week 19 and 20.

Table 3.16 Cumulative average daily gains for controlled fed pigs for the different housing systems

Week	Individual Housing (kg/d)	Group Housing (kg/d)
16	1.05 ± 0.047	1.01 ± 0.054
17	1.00 ± 0.027	1.06 ± 0.031
18	1.02 ± 0.023	0.99 ± 0.023
19	1.06 ± 0.021^{A}	0.98 ± 0.025^{B}
20	1.05 ± 0.019^{A}	0.98 ± 0.022^{B}
21	1.03 ± 0.019	1.00 ± 0.021

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

In the controlled feeding treatment the growth rates and empty body weights overall show no significant housing effect taking place. However, during week 19 and 20 the individually housed pigs grew significantly faster than those in the group housing. The exact reason for this is still unknown.

3.4 Feed Efficiency

To study the effects of feeding treatment and housing system on the efficiency with which feed was utilised for growth feed conversion ratio is compared. The overall effects of housing system and feeding treatment on FCR are compared in Table 3.17. From this table it can be concluded that controlled fed animals were significantly more efficient when data from housing systems are pooled together. This higher level of efficiency under controlled feeding is seen in the individual housing as well. In the group housing however, no significant difference in efficiency was observed. The housing system in which the animals were kept had no significant effect on their efficiency.

Table 3.17 Main effects of feeding treatment and housing system on feed conversion ratios

	Ad libitum Feeding	Controlled Feeding	Housing LSM
Individual Housing	2.52 ± 0.036^{A}	2.38 ± 0.035^{B}	2.45 ± 0.025
Group Housing	2.54 ± 0.041	2.49 ± 0.041	2.51 ± 0.029
Treatment LSM	2.53 ± 0.027^{A}	2.43 ± 0.027^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

When comparing the feeding treatment effects across housing systems per week (Table 3.18), it can be seen that controlled fed pigs were more efficient than *ad libitum* fed pigs during the last three weeks of the experiment. In addition to this during week 17 the same difference in efficiency occurred.

Table 3.18 Weekly cumulative feed conversion ratios of pigs (individual and group housing systems pooled)

Week	*Ad libitum* Feeding	Controlled Feeding
16	2.38 ± 0.087	2.20 ± 0.086
17	2.37 ± 0.033^{A}	2.21 ± 0.033^{B}
18	2.33 ± 0.025	2.31 ± 0.024
19	2.40 ± 0.020^{A}	2.32 ± 0.020^{B}
20	2.43 ± 0.016^{A}	2.38 ± 0.0158^{B}
21	2.52 ± 0.015^{A}	2.41 ± 0.015^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

The effect of the feeding treatments in the individual housing can be seen in Table 3.19 and Figure 3.5. This comparison shows that the feeding treatment applied only had a significant effect on efficiency during weeks 19 and 21. During these two weeks the controlled fed animals were more efficient than their peers.

Table 3.19 Cumulative feed conversion ratio in the individual housing system

Week	*Ad libitum* Feeding	Controlled Feeding
16	2.30 ± 0.115	2.23 ± 0.112
17	2.28 ± 0.044	2.29 ± 0.044
18	2.33 ± 0.033	2.28 ± 0.032
19	2.41 ± 0.026^{B}	2.24 ± 0.026^{B}
20	2.41 ± 0.021	2.30 ± 0.021
21	2.52 ± 0.020^{B}	2.38 ± 0.020^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

A comparison of the feeding treatment effects in the group housing system is shown in Table 3.20 and Figure 3.6. A significant feeding treatment effect was only found during week 17 that lead to a significantly higher efficiency in the controlled fed pigs.

Table 3.20 Cumulative feed conversion ratio in the group housing system

Week	*Ad libitum* Feeding	Controlled Feeding
16	2.46 ± 0.130	2.18 ± 0.130
17	2.46 ± 0.050^{A}	2.13 ± 0.050^{B}
18	2.32 ± 0.037	2.33 ± 0.037
19	2.39 ± 0.030	2.41 ± 0.030
20	2.44 ± 0.024	2.47 ± 0.024
21	2.52 ± 0.023	2.44 ± 0.023

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

In all of the comparisons made it can be seen that the feed conversion ratio increased weekly. This trend is clearly illustrated in Figure 3.6 and 3.7. There are two reasons for this. Firstly as the animals grow, their maintenance requirements increase relative to body mass. This means that a larger proportion of the available nutrients is used for maintenance and a smaller proportion for growth as the animals grow. Secondly the adipose to lean deposition ratio increases as the animal matures. Due to the higher energy cost of adipose deposition in comparison to lean deposition the FCR decreases. This relationship between adipose deposition and FCR is illustrated in Figure 3.8. The significant difference in efficiency seen in week 21 between the feeding treatments in the individual housing is probably due to the high rate of adipose deposition taking place in the *ad libitum* fed pigs. A significant difference was only seen during week 17 in the group housing system. The feeder blockage that occurred may explain in these differences. The feeding treatment did not influence the pigs during the first few weeks of the experiment in the individual housing system and had no effect on pigs in the group housing system.

In the individual housing system the controlled feeding treatment led to a higher feed efficiency during the last part of the experiment. This difference in efficiency only occurred when large differences in backfat thickness occurred between the feeding treatments. In the group housing the feed conversion ratios were not significantly affected by the feeding treatment. This similarity in efficiency is due to the significant but smaller differences in backfat thickness between the feeding treatments. These results are in agreement with that of Whittemore (1993) who showed that feed intake only affects feed efficiency when it halts the deposition of high quantity of adipose tissue, or when the intake is so low that the majority of the nutrients are used for maintenance purposes. This relationship was previously explained by Figure 1.3. These results are in agreement with that of Čandek-Potokar *et al.* (1996) who reported a higher level of efficiency under restrictive feeding conditions. However, Quiniou *et al*. (1995) and Afftentranger *et al.* (1996) reported a relatively constant feed conversion ratio between feeding treatments. The smaller difference in the feed intakes between the two feeding treatments in the group housing system compared to that of the individual housing may further explain why no significant difference occurred in in feed efficiency within the group housing system. A significant difference in feed efficiency in group housing can be expected if the feeding treatments produce larger differences in feed intake.

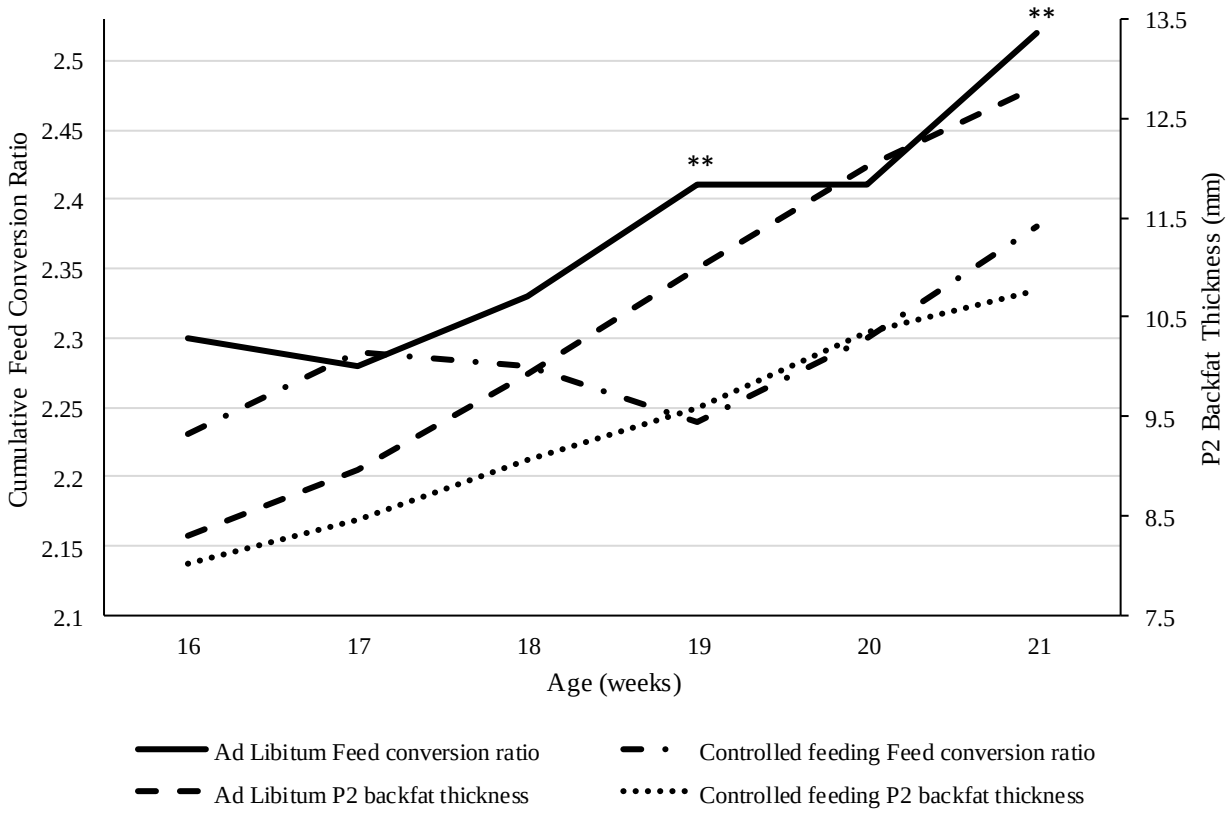

Figure 3.6 Cumulative feed conversion ratios and P2 backfat thicknesses per feeding treatment in the individual housing system
**Weekly cumulative feed conversion ratios with two asterisks differs significantly ($P < 0.01$)

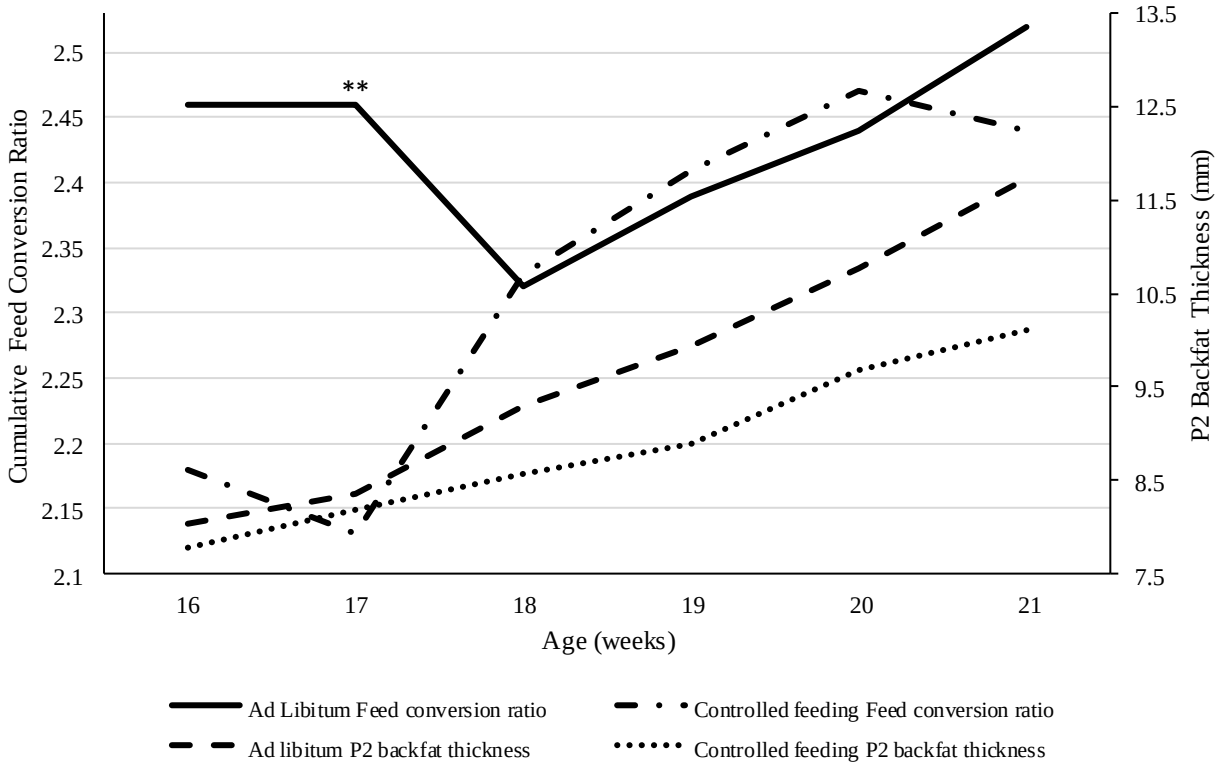

Figure 3.7 Cumulative feed conversion ratios and P2 backfat thicknesses per feeding treatment in the group housing system

**Weekly cumulative feed conversion ratios with two asterisks differs significantly ($P < 0.01$)

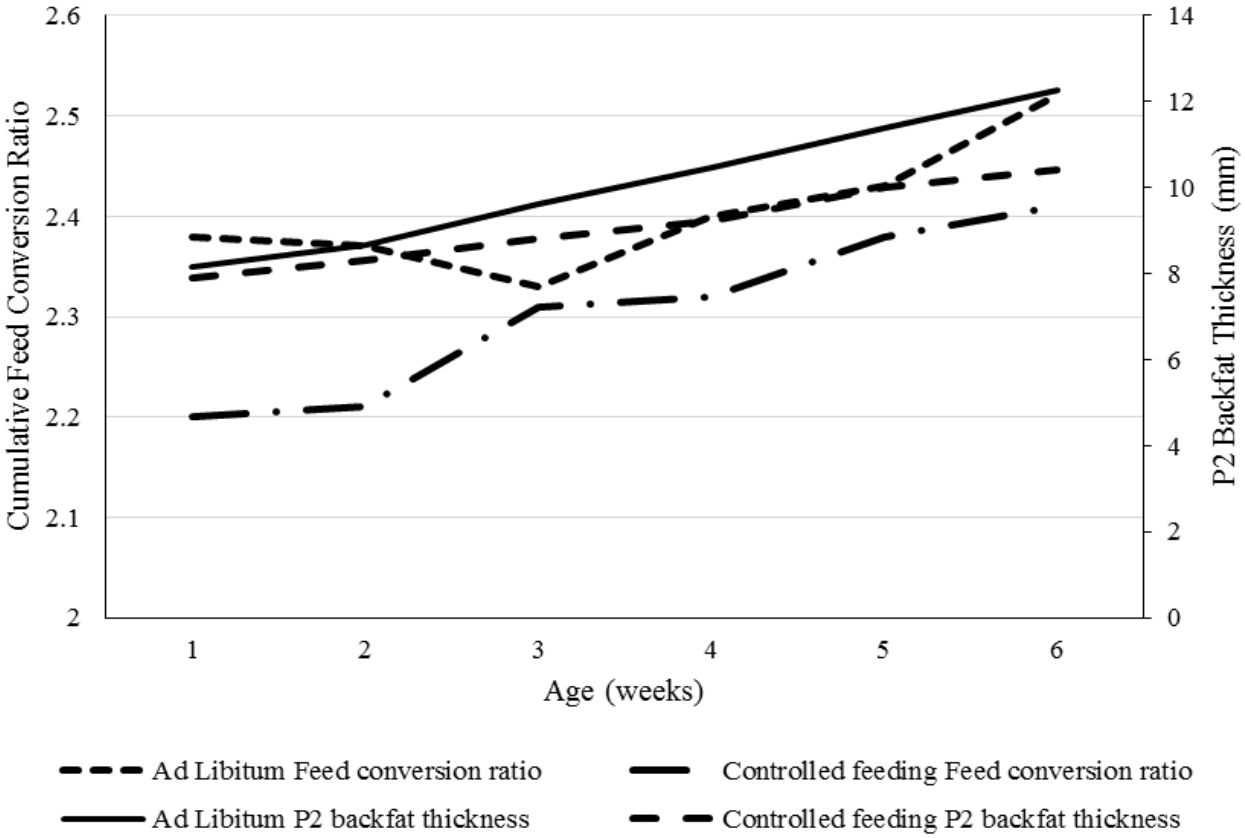

Figure 3.8 Comparison of P2 backfat thicknesses and cumulative feed conversion ratios per feeding treatment (individual and group housing system pooled)

When the effect of housing system on feed conversion ratios was analyzed, no significant effect was found throughout the trial for the pigs fed *ad libitum*. Pigs housed individually within the controlled feeding system were significantly more efficient than those in group housing during week 19 and 20 (see Table 3.21). This might be due to a difference in activity levels between the housing systems. Pigs in the group housing had more space for physical activity and would have expended more energy on this. The pigs in the individual housing would have had more energy available for growth than those housed in in groups. Activity levels were not specifically measured in this trial and the exact amount of energy expended on physical activity can only be speculated.

Table 3.21 Cumulative FCR for controlled fed pigs across housing system

Week	Individual Housing	Group Housing
16	2.23 ± 0.112	2.18 ± 0.130
17	2.29 ± 0.044	2.13 ± 0.050
18	2.28 ± 0.032	2.33 ± 0.037
19	2.24 ± 0.026^{A}	2.41 ± 0.030^{B}
20	2.30 ± 0.021^{A}	2.47 ± 0.024^{B}
21	2.38 ± 0.020	2.44 ± 0.023

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

3.5 P2 Backfat Thickness

The main feeding treatment and housing effects on the P2 backfat measurements are compared in Table 3.22. *Ad libitum* feeding led to a significantly higher backfat thickness when housing systems were combined

and in the different housing systems. The housing in which the pigs were kept had no significant effect on the overall P2 backfat thickness measured.

Table 3.22 Main effects of feeding treatment and housing system on the total change over the trial period in P2 backfat thickness

	Ad libitum Feeding (mm)	Controlled Feeding (mm)	Housing LSM (mm)
Individual Housing	4.45 ± 0.313^{A}	2.84 ± 0.313^{B}	3.64 ± 0.221
Group Housing	3.79 ± 0.361^{A}	2.17 ± 0.361^{B}	2.98 ± 0.255
Treatment LSM	4.12 ± 0.239^{A}	2.50 ± 0.239^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

The effect of *ad libitum* feeding treatment on P2 backfat thickness was clearly visible throughout the experimental period when data from the housing systems are pooled (Table 3.23). The level of significance of these differences increased from 95% to 99% from week 18 onwards.

Table 3.23 Weekly P2 backfat thickness (individual and group housing system pooled)

Week	*Ad libitum* Feeding (mm)	Controlled Feeding (mm)
16	8.17 ± 0.091^{a}	7.89 ± 0.091^{b}
17	8.67 ± 0.104^{a}	8.32 ± 0.103^{b}
18	9.61 ± 0.105^{A}	8.82 ± 0.105^{B}
19	10.46 ± 0.127^{A}	9.24 ± 0.126^{B}
20	11.39 ± 0.147^{A}	10.01 ± 0.146^{B}
21	12.27 ± 0.159^{A}	10.43 ± 0.158^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

The same trend of higher backfat thicknesses under *ad libitum* feeding can be seen in the feeding treatment comparison for the individual housing Table 3.24. Pigs fed *ad libitum* had a significantly higher backfat thickness from week 17 onwards.

Table 3.24 Weekly P2 backfat thickness in the individual housing system

Week	*Ad libitum* Feeding (mm)	Controlled Feeding (mm)
16	8.30 ± 0.122	8.01 ± 0.119
17	8.97 ± 0.138^{A}	8.45 ± 0.135^{B}
18	9.92 ± 0.140^{A}	9.07 ± 0.136^{B}
19	10.99 ± 0.169^{A}	9.59 ± 0.165^{B}
20	12.02 ± 0.196^{A}	10.34 ± 0.191^{B}
21	12.82 ± 0.212^{A}	10.77 ± 0.206^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Table 3.25 compares the effects of feeding treatment effects in the group housing. From week 18 onwards the *ad libitum* fed pigs had a significantly higher backfat thickness ($P < 0.01$) than the controlled feeding group.

Table 3.25 Weekly P2 backfat thickness in the group housing system

Week	*Ad libitum* Feeding (mm)	Controlled Feeding (mm)
16	8.04 ± 0.137	7.78 ± 0.139
17	8.36 ± 0.156	8.19 ± 0.157
18	9.30 ± 0.158^{A}	8.57 ± 0.159^{B}
19	9.94 ± 0.190^{A}	8.89 ± 0.192^{B}
20	10.77 ± 0.220^{A}	9.68 ± 0.223^{B}
21	11.72 ± 0.238^{A}	10.10 ± 0.241^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

It is clear that *ad libitum* feeding treatment led to a higher backfat thickness than controlled feeding. Ellis *et al.* (1996) made similar findings when restricting feed intake to 82% of *ad libitum* feed intake. The restricted animals had a significantly lower backfat thickness, and the difference between the restricted and *ad libitum* fed animals increased with body weight. Lower level of backfat thickness under controlled or restricted feeding was reported in several studies (Quiniou *et al*., 1995; Affentranger *et al*., 1996; Wood *et al*., 1996; Quiniou *et al*. 1996; Čandek-Potokar *et al*., 1998; Lebret *et al*., 2001). The divergence between the two treatments can be seen in both housing systems in Figure 3.7. However, there is a difference in the week at which this divergence starts. With the individual housing the divergence starts a week earlier than that of the group housing. This delay in the divergence among the treatments within the group housing can be explained by the low feed intakes achieved under *ad libitum* feeding. If this was not the case the increase in fat deposition would be expected to follow a similar pattern to the *ad libitum* fed pigs in the individual housing. From Figure 3.7 it is clear that fat deposition under controlled feeding followed a similar pattern across housing system. This indicates the relationship between feed intake and backfat deposition.

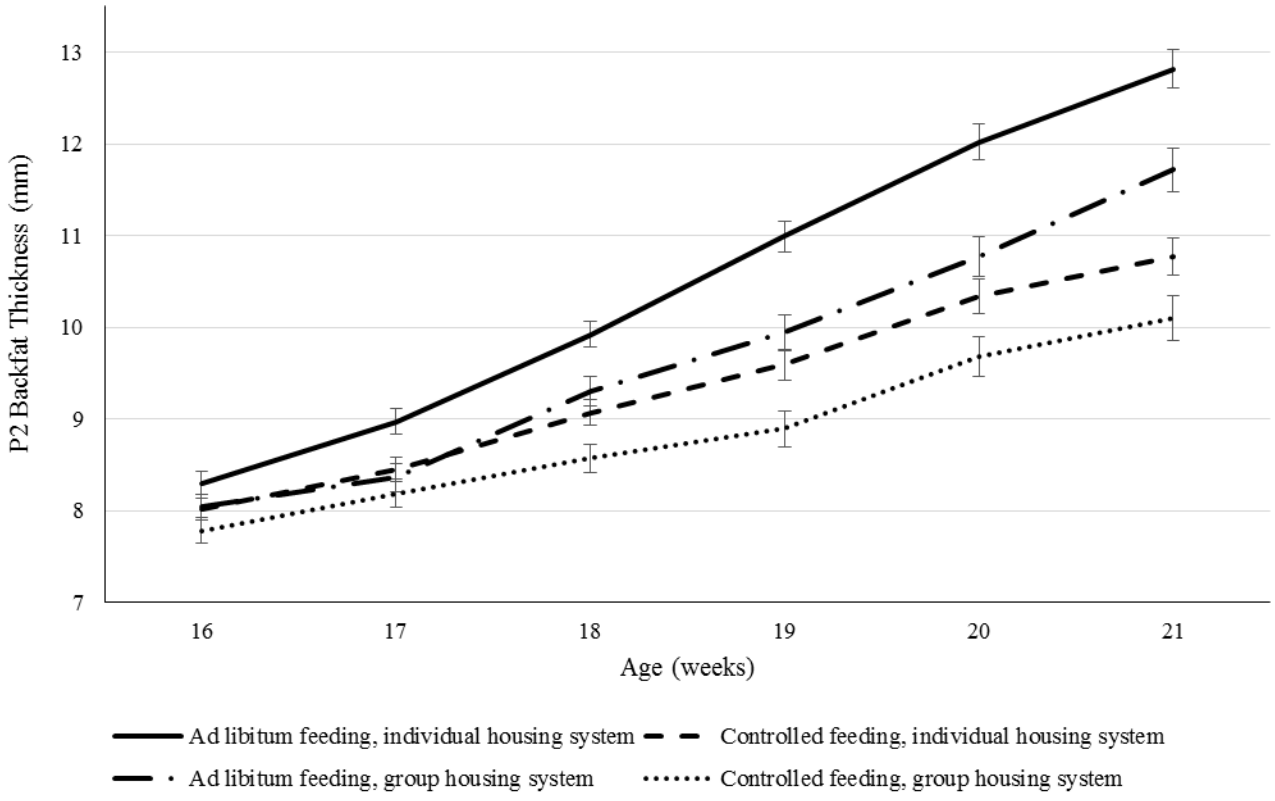

Figure 3.9 The P2 backfat thicknesses means and standard deviations of pigs in different feeding treatment and housing system combinations

The effects of the housing system on P2 backfat thickness can be seen in the comparison in Table 3.26. This shows that throughout the experiment the pigs in the individual housing had a significantly higher backfat thickness ($P < 0.05$) than those kept in the group housing. Further the level of significance of this difference between the housing systems increase from 95 % to 99 % from week 18 onwards.

Table 3.26 Effect of housing system on P2 backfat thickness of pigs (individual and group housing system pooled)

Week	Individual Housing (mm)	Group Housing (mm)
16	8.15 ± 0.085^{a}	7.91 ± 0.098^{b}
17	8.71 ± 0.097^{a}	8.27 ± 0.111^{b}
18	9.49 ± 0.098^{A}	8.94 ± 0.112^{B}
19	10.29 ± 0.118^{A}	9.42 ± 0.136^{B}
20	11.18 ± 0.137^{A}	10.22 ± 0.157^{B}
21	11.80 ± 0.148^{A}	10.91 ± 0.170^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

When comparing backfat thickness results in the *ad libitum* feeding treatment (Table 3.27) the individually housed pigs also had a significantly higher backfat thickness ($P < 0.01$) than the group housed pigs. This difference started at week 17.

Table 3.27 Effect of housing system on P2 Backfat thickness of *ad libitum* fed pigs

Week	Individual Housing (mm)	Group Housing (mm)
16	8.30 ± 0.122	8.04 ± 0.137
17	8.97 ± 0.138^{A}	8.36 ± 0.156^{B}
18	9.92 ± 0.140^{A}	9.30 ± 0.158^{B}
19	10.99 ± 0.169^{A}	9.94 ± 0.190^{B}
20	12.02 ± 0.196^{A}	10.77 ± 0.220^{B}
21	12.82 ± 0.212^{A}	11.72 ± 0.238^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

When a similar comparison is done in the controlled feeding treatment (Table 3.28) it can be seen that housing system only led to a significant difference from week 18 onwards. This delay in the onset of difference between housing systems is similar to those seen for the different treatment types. This is possibly due to the fact that as the animal grows and body weight increase fat deposition increases. This increase in lipid deposition with stage of growth is in agreement with the results of Quiniou *et al*. (1996) Only at a certain body weight is there a significant increase in fat deposition and only after this has been reached is the variance in backfat thickness according to housing system and treatment apparent. In Figure 3.9 it is shown that this increase in rate of adipose deposition occurs between week 17 and 18. Furthermore higher activity levels in the group housing may have led to a higher energy expenditure and lower levels of adipose tissue deposition.

Table 3.28 Effect of housing system on P2 backfat thickness for controlled fed pigs

Week	Individual Housing (mm)	Group Housing (mm)
16	8.01 ± 0.119	7.78 ± 0.139
17	8.45 ± 0.135	8.19 ± 0.157
18	9.07 ± 0.136^{A}	8.57 ± 0.159^{B}
19	9.59 ± 0.165^{A}	8.89 ± 0.192^{B}
20	10.34 ± 0.191^{A}	9.68 ± 0.223^{B}
21	10.77 ± 0.206^{A}	10.10 ± 0.241^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

3.6 Carcass Composition

The following carcass traits were statistically compared: lean meat percentage, fat percentage, warm carcass mass, cold carcass mass, carcass length and carcass compactness. The effects of feeding treatments on these traits were compared by pooling data from both housing systems together in Table 3.29. This comparison shows that the feeding treatments had a significant effect on all of the carcass traits except carcass length. *Ad libitum* feeding led to a significantly lower lean meat percentage than controlled feeding. This is also apparent in the fact that *ad libitum* feeding led to a significantly higher fat percentage. When comparing carcass mass achieved it was found that *ad libitum* feeding led to significantly heavier carcasses than controlled feeding. This was the case for both warm and cold carcass mass. Finally *ad libitum* fed pigs had a significantly higher carcass compactness which means more carcass mass units per carcass length unit.

Table 3.29 Feeding treatment effect on carcass compositions traits (individual and group housing system pooled)

Carcass Traits	Units	*Ad libitum* Feeding	Controlled Feeding
Lean Meat Percentage	%	66.68 ± 0.183^{A}	67.56 ± 0.182^{B}
Fat Percentage	%	18.61 ± 0.376^{A}	16.25 ± 0.373^{B}
Warm Carcass Mass	kg	87.80 ± 0.884^{A}	81.06 ± 0.877^{B}
Cold Carcass Mass	kg	85.29 ± 0.879^{A}	78.61 ± 0.872^{B}
Carcass Length	cm	101.01 ± 0.559	99.98 ± 0.554
Carcass Compactness	kg/cm	0.84 ± 0.008^{A}	0.79 ± 0.008^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

When comparing the feeding treatment effects in the individual housing system (Table 3.30) the same trend was seen. With *ad libitum* feeding having lower lean meat percentages and higher fat percentages than the controlled fed pigs. Further *ad libitum* feeding led to a higher carcass mass and carcass compactness.

Table 3.30 Feeding treatment effects on carcass composition traits in the individual housing system

Carcass Traits	Units	*Ad libitum* Feeding	Controlled Feeding
Lean Meat Percentage	%	65.91 ± 0.242^{A}	67.30 ± 0.238^{B}
Fat Percentage	%	20.21 ± 0.498^{A}	16.76 ± 0.489^{B}
Warm Carcass Mass	Kg	92.59 ± 1.170^{A}	82.91 ± 1.149^{B}
Cold Carcass Mass	Kg	90.07 ± 1.162^{A}	80.41 ± 1.141^{B}
Carcass Length	Cm	102.75 ± 0.738	101.01 ± 0.725
Carcass Compactness	kg/cm	0.84 ± 0.008^{A}	0.80 ± 0.011^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

In the group housing system (Table 3.31) feeding treatments had no significant effect on carcass composition. Lean meat percentage and fat percentage were not significantly different between the feeding treatments. This contradicts the significant difference found between the treatments for P2 backfat thickness at

21 weeks of age. Even though a difference was found before slaughter this difference is only 1.6 mm and is only an indication of the overall fat percentage. Further *ad libitum* fed pigs had a significantly higher carcass compactness than those that were controlled fed.

Table 3.31 Feeding treatment effects on carcass composition traits in the group housing system

Carcass Traits	Units	*Ad libitum* Feeding	Controlled Feeding
Lean Meat Percentage	%	67.44 ± 0.275	67.82 ± 0.275
Fat Percentage	%	17.01 ± 0.564	15.75 ± 0.564
Warm Carcass Mass	kg	83.01 ± 1.326^{A}	79.22 ± 1.326^{B}
Cold Carcass Mass	kg	80.51 ± 1.318^{A}	76.81 ± 1.318^{B}
Carcass Length	cm	99.27 ± 0.837	98.95 ± 0.837
Carcass Compactness	kg/cm	0.81 ± 0.012^{A}	0.78 ± 0.012^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Feeding treatment significantly affected the lean meat percentage of the carcasses. Controlled feeding led to a significantly higher lean meat percentage when housing system data is combined and in the individual housing alone. This higher lean meat content under controlled feeding is in agreement with the results on carcass fat percentage. Here controlled feeding led to significantly lower carcass fat across and in the individual housing. No feeding treatment effects were found in the group housing. This decrease in lean meat percentage and increase in carcass fat when *ad libitum* feeding is compared to restrictive or controlled feeding is in agreement with the results of Quiniou *et al*. (1995) and Affentranger *et al.* (1996). This finding made by Affentranger *et al.* (1996) was only the case for pigs originating from a cross between Swiss Landrace and either Large White or Duroc, when similar comparisons were made for Pietran crosses no differences in carcass fat and lean meat percentage were found. This indicates that genotype plays a role in the effect of the feeding treatment on carcass composition. Further Ellis *et al.* (1996); Wood *et al.* (1996) and Čandek-Potokar *et al.* (1998) found a significantly higher carcass fatness under *ad libitum* feeding regimes. The effect of feeding treatment on the carcass fatness is in agreement with the effects seen on P2 backfat thickness when pooled data for housing systems is compared and in the individual housing. In the group housing a 1.62 mm higher ($P < 0.01$) P2 backfat was recorded for the *ad libitum* feeding. This difference however, did not lead to a significant difference in carcass fatness.

Warm carcass mass and cold carcass mass was affected ($P < 0.01$) by the feeding treatments. *Ad libitum* feeding led to a significantly heavier hot and cold carcass mass when comparing pooled data and data per housing system. This agrees with findings that *ad libitum* feeding led to significantly higher body weights at 21 weeks of age. Similar increases in carcass weight were found in the study of Čandek-Potokar *et al*. (1998). This however, contradicts the results of Quiniou *et al*. (1995) and Wood *et al.* (1996). The reason for this contradiction is the fact that in these two studies, pigs were slaughtered upon reaching a predetermined body weight, thus removing the variation in body weight at slaughter due to the different treatments. This leads to the similar carcass weights for the different treatments.

Carcass length was not significantly affected by the feeding treatment used. However, a trend can be seen for slightly longer carcass under *ad libitum* feeding. This absence of treatment effect on carcass length is similar to findings made by Rao & McCracken (1992b) and Čandek-Potokar *et al*. (1998) who tested feed intake restrictions and found no differences in carcass lengths.

Carcass compactness was significantly affected by the feeding treatment applied. This can be seen in the fact that the *ad libitum* fed pigs had a significantly higher compactness across in the different housing systems and when the data is pooled together. Carcass compactness is used as a method to assess the conformation of carcasses and as a predictor of leanness or lean to bone ratio (Webb, 1992).This means that more lean meat per unit carcass size was produced under *ad libitum* feeding no matter what housing system was used. Webb (1992) found that nutritional factors coupled with slaughter mass are the most important factors that affect the conformation of sheep carcasses. Furthermore high energy diets were found to lead to improvements in both the hind leg compactness and carcass compactness.

The housing system in which the pigs were kept influenced carcass traits. These effects can be seen when the carcass traits between the housing systems are compared for *ad libitum* fed pigs (Table 3.32). This shows that pigs housed individually had significantly fatter carcasses with a lower lean meat percentage than those in group housing. Individually housed pigs had heavier warm and cold carcass masses. The individually housed pigs had higher carcass compactness and grew to a longer body length than those housed in groups.

Table 3.32 Housing system effects on carcass composition traits of *ad libitum* fed pigs

Carcass Traits	Units	Individual Housing	Group Housing
Lean Meat Percentage	%	65.91 ± 0.242^{A}	67.44 ± 0.275^{B}
Fat Percentage	%	20.21 ± 0.498^{A}	17.01 ± 0.564^{B}
Warm Carcass Mass	kg	92.59 ± 1.170^{A}	83.01 ± 1.326^{B}
Cold Carcass Mass	kg	90.07 ± 1.162^{A}	80.51 ± 1.318^{B}
Carcass Length	cm	102.75 ± 0.738^{A}	99.27 ± 0.837^{B}
Carcass Compactness	kg/cm	0.88 ± 0.011^{A}	0.81 ± 0.012^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

When a similar comparison of carcass traits is done in the controlled feeding treatment (Table 3.33) different results were found. The only significant housing effect was on carcass mass. The pigs housed individually had a significantly higher warm and cold carcass mass. The significance of the latter difference was of a lower level of significance ($P > 0.05$) than the differences found in the *ad libitum* feeding group ($P > 0.01$).

Table 3.33 Housing system effects on carcass composition traits of controlled fed pigs

Carcass Traits	Units	Individual Housing	Group Housing
Lean Meat Percentage	%	67.30 ± 0.238	67.82 ± 0.275
Fat Percentage	%	16.76 ± 0.489	15.75 ± 0.564
Warm Carcass Mass	kg	82.91 ± 1.149^{a}	79.22 ± 1.326^{b}
Cold Carcass Mass	kg	80.41 ± 1.141^{a}	76.81 ± 1.318^{b}
Carcass Length	cm	101.01 ± 0.725	98.95 ± 0.837
Carcass Compactness	kg/cm	0.80 ± 0.011	0.78 ± 0.012

^{ab} Row means with different superscripts differ significantly ($P < 0.05$)

This difference in carcass composition between the housing systems can be ascribed to the differences seen in feed intake. When comparing the housing systems when feed intakes are controlled, carcass composition of pigs were similar. The higher carcass weights found in the individual housing in the feeding treatments and when the data is pooled is in agreement with results on empty body weight which indicates significantly higher body weights in the individual housing within the *ad libitum* treatment throughout the trial. A significant difference in empty bodyweights between the two housing systems was only recorded for two weeks.

3.7 Nutrient Intakes

The available lysine and metabolisable energy intakes were determined by accurately measuring the feed intake of the pigs kept in individual housing and the feed's nutrient composition. Because feed intake was not determined per animal in group housing the nutrient intakes were only compared between the feeding treatments in the individual housing system. Table 3.34 shows the main feeding treatment effects on the nutrient intakes. It is clear that significantly higher levels of available lysine and ME was taken in by the pigs fed on *ad libitum* basis.

Table 3.34 Main effects of feeding treatments on the available lysine and metabolisable energy intakes

	Units	*Ad libitum* Feeding	Controlled Feeding
Available Lysine Intake	g	1195.06 ± 25.178^{A}	916.95 ± 25.178^{B}
Metabolisable Energy Intake	MJ	1764.45 ± 37.625^{A}	1354.79 ± 37.625^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

This significant differences in nutrient intakes is apparent throughout the entire experimental period as can be seen in Table 3.35 and Table 3.36 indicating the available lysine and ME intakes per feeding treatment respectively.

Table 3.35 Weekly feeding treatment effects on available lysine intakes in the individual housing system

Week	*Ad libitum* Feeding g/d	Controlled Feeding g/d
16	18.28 ± 0.201^{A}	14.74 ± 0.190^{B}
17	21.36 ± 0.194^{A}	15.87 ± 0.183^{B}
18	22.31 ± 0.268^{A}	16.37 ± 0.253^{B}
19	23.63 ± 0.259^{A}	17.01 ± 0.245^{B}
20	23.81 ± 0.386^{A}	17.21 ± 0.365^{B}
21	23.66 ± 0.385^{A}	17.91 ± 0.364^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

Table 3.36 Weekly feeding treatment effects on metabolisable energy intakes in the individual housing system

Week	*Ad libitum* Feeding MJ/d	Controlled Feeding MJ/d
16	18.28 ± 0.201^{A}	14.74 ± 0.190^{B}
17	21.36 ± 0.194^{A}	15.87 ± 0.183^{B}
18	22.31 ± 0.268^{A}	16.37 ± 0.253^{B}
19	23.63 ± 0.259^{A}	17.01 ± 0.245^{B}
20	23.81 ± 0.386^{A}	17.21 ± 0.365^{B}
21	23.66 ± 0.385^{A}	17.91 ± 0.364^{B}

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)

The relationship between metabolisable energy and available lysine with growth performance is noticeable when the respective intakes are compared with the animal's ADG. Figure 3.10 depicts the relationship between available lysine intake and the cumulative average daily gain for both the feeding treatments. This indicates that the level of lysine intake has a relationship with the growth rate that occurs irrespective of the feeding treatment applied. Figure 3.11 indicates the relationship between ME intake and the cumulative ADG. Both these figures illustrate a relationship between the nutrient intake and growth rate that is achieved. However, the level of available lysine seems to be more closely related to the growth rate than ME.

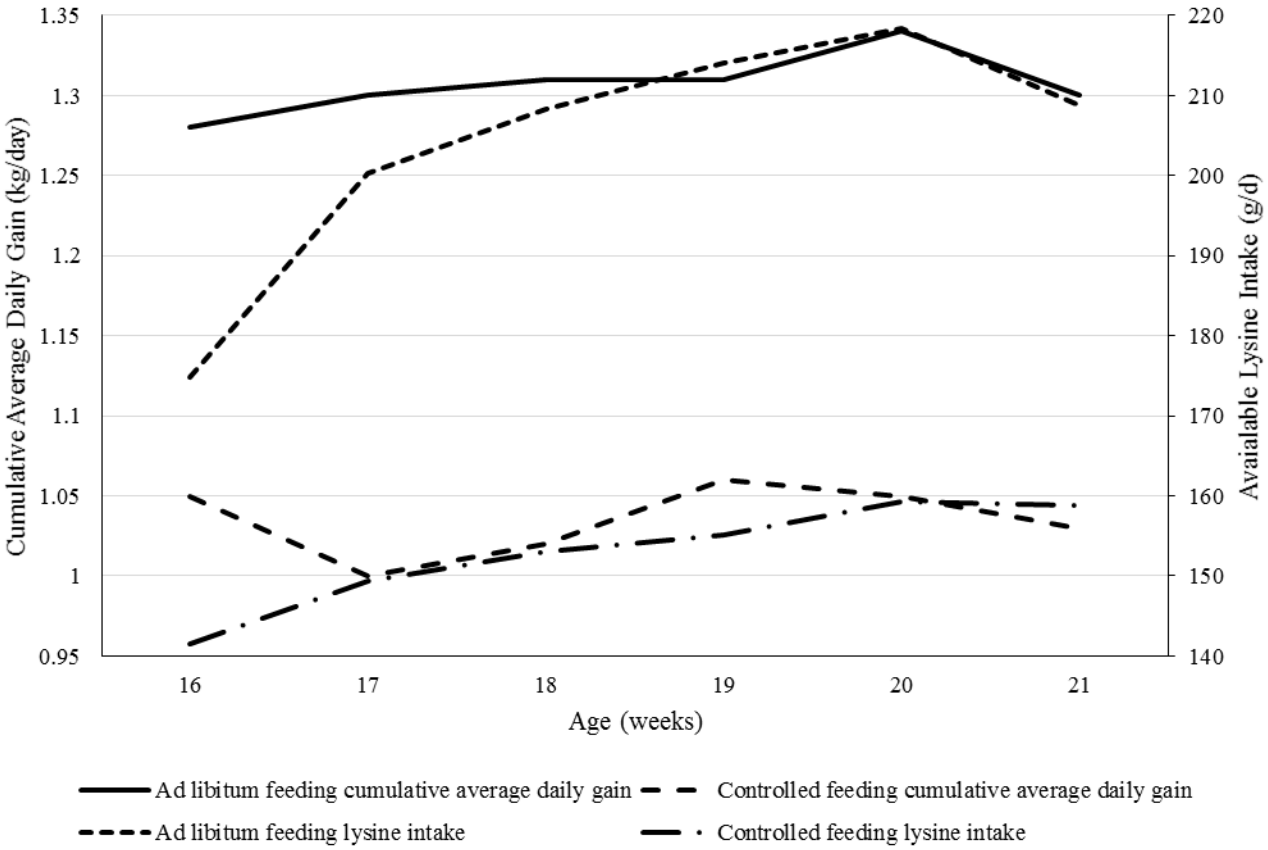

Figure 3.10 Cumulative average daily gains and available lysine intakes per feeding treatment in the individual housing system

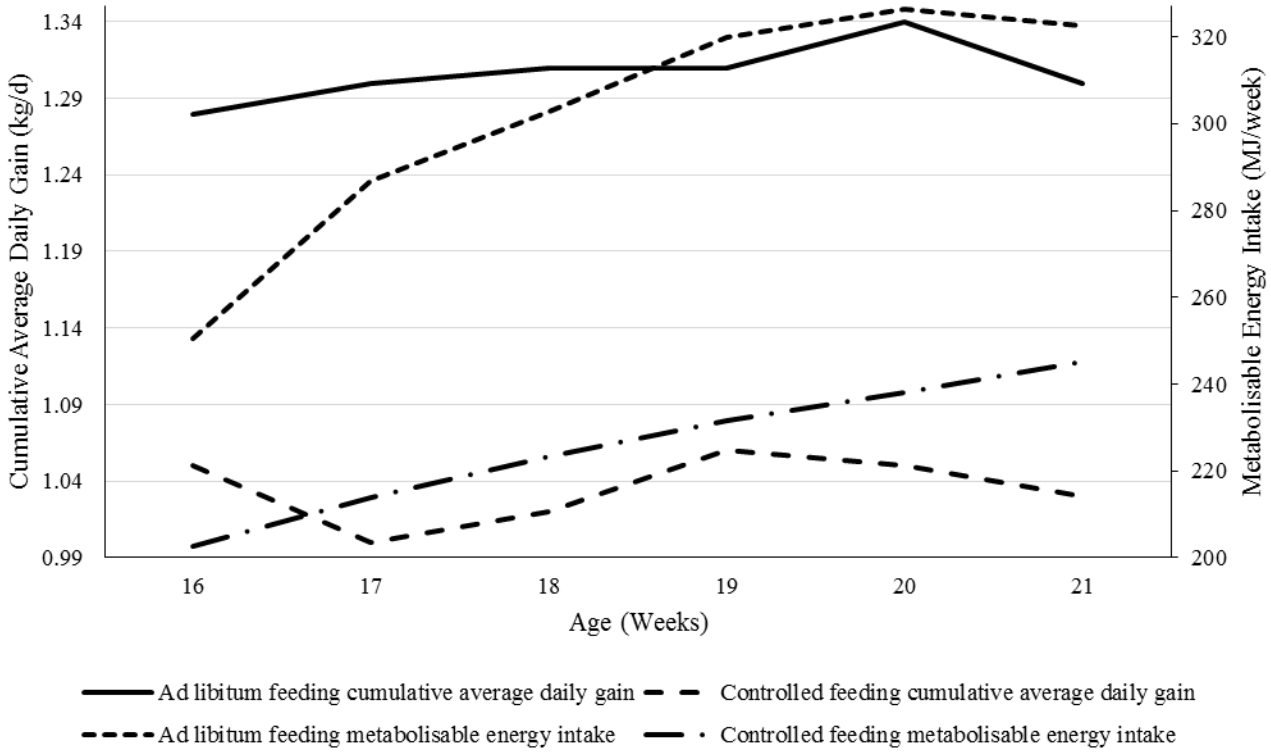

Figure 3.11 Cumulative average daily gains and metabolisable energy intakes per feeding treatment in the individual housing system

A regression analysis was done on the growth performance of the *ad libitum* fed animals and their lysine and energy intakes respectively. A strong linear relationship was found for both total available lysine and metabolisable energy intake with the ADG achieved during the trial period. This is illustrated in Figure 3.12 and 3.13, which shows that growth rate increase as the nutrient intake (feed intake) increased. This is in agreement with the differences in growth rates recorded between the two feed treatments.

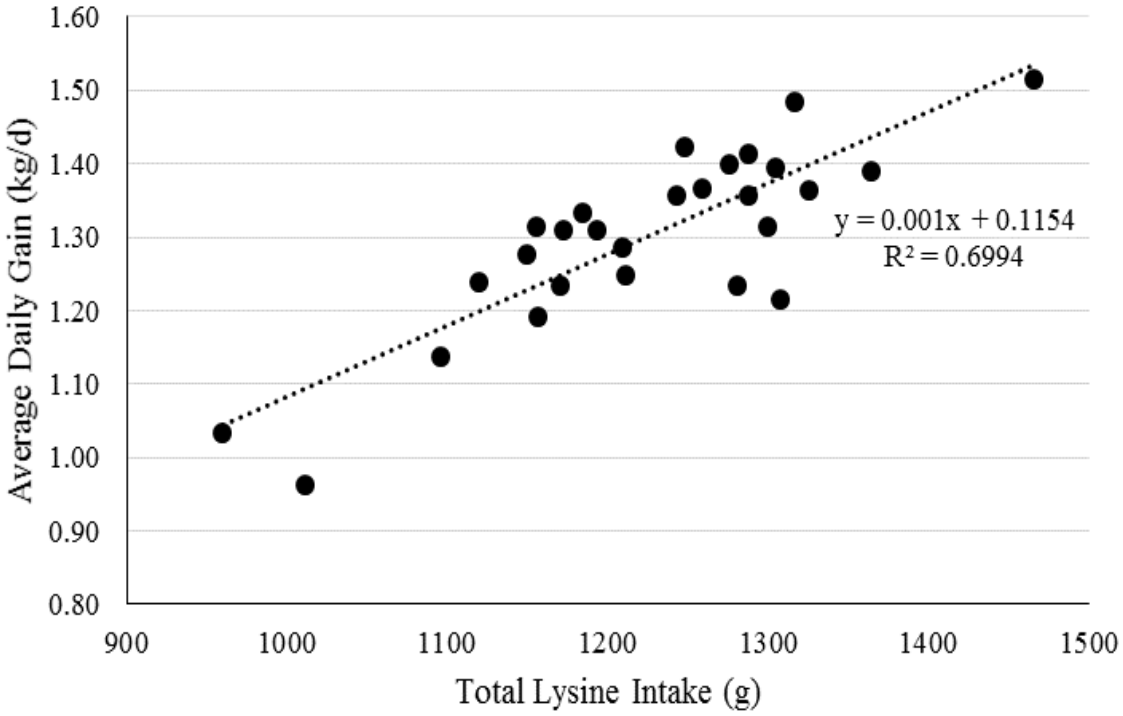

Figure 3.12 Regression analysis of average daily gains on available lysine intakes for *ad libitum* fed individually housed pigs expressed over the entire trial period

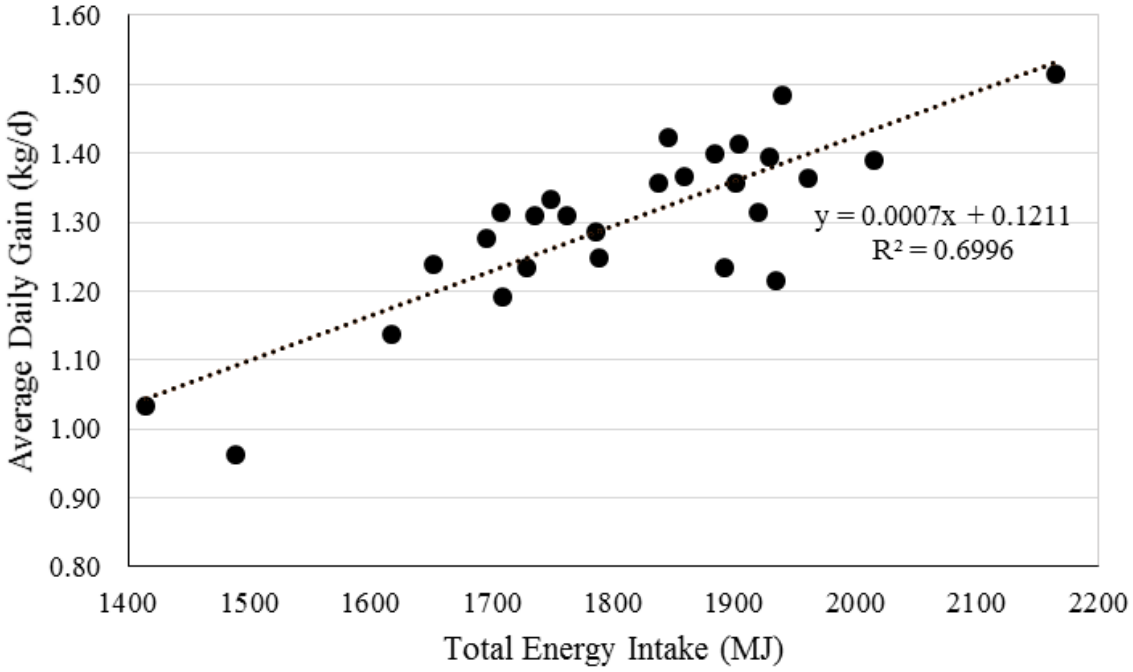

Figure 3.13 Regression analysis of average daily gains on metabolisable energy intakes for *ad libitum* fed individually housed pigs expressed over the entire trial period

3.8 Monetary effects

To compare the effects that the feeding treatments and housing systems had on the economics of the systems, total feed cost, carcass income and net income were compared. Table 3.37 compares the different effects on the total feed costs. The *ad libitum* fed animals had a significantly higher total feed cost when pooled data from the two housing systems are compared. This trend can be seen in the housing systems as well, where in both cases *ad libitum* feeding had a significantly higher total feed cost. This was expected due to the higher intakes under *ad libitum* feeding. Housing system also had a significant effect on total feed cost when data of the different feeding treatments are pooled. Individual housing had a significantly higher feed cost for both controlled and *ad libitum* feeding. These results agree with the results of feed intake indicating a higher feed intake in the individual housing when pigs are fed *ad libitum*. Since the controlled fed pigs received the same amount of feed irrespective of housing system no significant difference in total feed cost was expected between the housing systems

Table 3.37 Main effects of feeding treatment and housing system on total feed costs

	Ad libitum Feeding (ZAR)	Controlled Feeding (ZAR)	Housing LSM (ZAR)
Individual Housing	$557.25 \pm 5.423^{A}{}_{1}$	443.15 ± 5.326^{B}	$500.20 \pm 3.801_{1}$
Group Housing	$477.56 \pm 6.150^{A}{}_{2}$	432.86 ± 6.150^{B}	$455.21 \pm 4.348_{2}$
Treatment LSM	517.41 ± 4.100^{A}	438.00 ± 4.068^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)

Table 3.38 compares the carcass incomes achieved for the different feeding treatment and housing system combinations. Overall a significantly higher carcass income was achieved when *ad libitum* feeding was applied. In the two housing systems the *ad libitum* fed pigs also had a significantly higher carcass income. This difference between the two treatments had a lower level of significance (95%) in the group housing. The housing system in which the pigs where kept had a significant effect on carcass income, in that the individually housed pigs had a significantly higher carcass income when feeding treatment data is pooled. In the *ad libitum* feeding the same difference occurred between the housing systems. In the controlled feeding the individually housed pigs had a higher carcass income than the controlled fed pigs. This difference had a lower level of significance (95%).

Table 3.38 Main effects of feeding treatment and housing system on carcass income

	Ad libitum Feeding (ZAR)	Controlled Feeding (ZAR)	Housing LSM (ZAR)
Individual Housing	$1846.52 \pm 23.830^{A}{}_{1}$	$1648.35 \pm 23.400^{B}{}_{3}$	$1747.43 \pm 16.699_{1}$
Group Housing	$1650.45 \pm 27.020^{a}{}_{2}$	$1574.69 \pm 27.020^{b}{}_{4}$	$1612.57 \pm 19.106_{2}$
Treatment LSM	1748.48 ± 18.014^{A}	1611.52 ± 17.872^{B}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)
$_{34}$Column means with the different subscripts differ significantly ($P < 0.05$)

Table 3.39 Main effects of feeding treatment and housing system on the net income

	Ad libitum Feeding (ZAR)	Controlled Feeding (ZAR)	Housing LSM (ZAR)
Individual Housing	$1289.26 \pm 21.585^{A}{}_{1}$	1205.20 ± 21.196^{B}	$1247.23 \pm 15.126_{1}$
Group Housing	$1172.89 \pm 24.475_{2}$	1141.83 ± 24.475	$1157.36 \pm 17.307_{2}$
Treatment LSM	1231.08 ± 16.317^{a}	1173.52 ± 16.189^{b}	

^{AB} Row means with different superscripts differ highly significantly ($P < 0.01$)
^{ab} Row means with different superscripts differ significantly ($P < 0.05$)
$_{12}$Column means with the different subscripts differ highly significantly ($P < 0.01$)

The housing system and feeding treatment effects on the net carcass income are compared in Table 3.39. *Ad libitum* feeding led to a higher net income than controlled feeding (individual and group housing data pooled). When comparing the net income in the individual housing, the higher income for *ad libitum* feeding was highly significant (99%). However, in the group housing the feeding treatment had no significant effect on the net income. Pigs housed individually achieved a significantly higher net income than those housed in groups. This superiority of individual housing can be seen within the *ad libitum* treatment leading to a significantly higher net income. Housing however, did not significantly affect the net carcass income achieved under controlled feeding.

These results indicate that *ad libitum* feeding leads to higher feed costs and higher carcasss incomes. This increase in carcass income is only high enough to offset the increase in feed costs when applied in individual housing, as indicated by the significantly higher net income. In comparison to *ad libitum* feeding controlled feeding led to lower total feed costs and carcass incomes. This however, only had a significant effect on the net income when individual housing was used. The net income in group housing was unaffected by the feeding treatment applied.

Housing system had a significant effect on the net incomes achieved. Individual housing led to significantly higher incomes when pigs were fed *ad libitum*. However, when controlled feeding was applied, housing system did not affect the net income.

CHAPTER 4
CONCLUSION

4.1 Effect of feeding treatments

Ad libitum fed pigs had significantly higher feed intakes than controlled fed pigs throughout the experiment. Pigs that were allocated to the controlled feeding treatment achieved lower empty body weights than those in the *ad libitum* feeding treatment. Feeding treatment influenced growth performance with lower growth rates achieved under controlled feeding. The difference in growth performance was significant throughout the trial when a significant difference in feed intake occurred between the two feeding treatments. Due to the feeder blockage that occurred within the *ad libitum* fed group pen their feed intake was restricted in an unplanned way. This led to the delay in the growth rate differences between the feeding treatments. This slower growth is assumed to have had a negligible effect on the overall growth performance, and that the pigs resumed their optimal growth potential under their assigned feeding treatment and environmental conditions. A decrease in growth rate was found during the last week (21) of the experiment for all the pigs except the controlled fed group housed animals. This trend indicates that the pigs have reached their maximum lean protein deposition level at around 20 to 21 weeks of age. The difference in growth rate between the feeding treatments is due to the difference in nutrient intakes. A strong linear relationship was found between the available lysine and metabolisable energy intake respectively.

Feed conversion ratios increased as the animals aged and can be ascribed to a higher maintenance requirement and an increase in the adipose to lean deposition ratio. Overall, controlled feeding led to an improvement in feed efficiency when comparing data from both housing systems combined. A similar improvement in overall efficiency was found in the individual housing system under controlled feeding. The more efficient growth occurred in the last few weeks of the experiment. This is due to the fact that controlled feeding prevented the high rate of adipose deposition that occurred under *ad libitum* feeding. Even though a significant difference in P2 backfat thickness was recorded between the different feeding treatments in the group housing this difference was not large enough to significantly affect the feed conversion ratio. A bigger difference in feed intake between the feeding treatments would have led to an increase in the difference in P2 backfat thickness and may have led to differences in feed efficiency between the feeding treatments, similar to those found in the individual housing.

The slower growth rates under controlled feeding leads to the rejection of the hypothesis that controlled feeding leads to a higher growth rate. Controlled feeding led to an improved efficiency in the individual system, however, no significant difference was found in the group housing. The hypothesis that controlled feeding leads to an improvement in efficiency is rejected for the group housing, however, it was the case in the individual housing.

By controlling feed intakes of pigs a significantly lower P2 backfat thickness was achieved in comparison with those that were fed *ad libitum*. The rate of increase in P2 backfat thickness increased with time. The divergence between the feeding treatments occurred at different times during the trial. The week delay in significant difference in P2 backfat thickness can be explained by the smaller difference in feed intakes between treatments within the group housing system.

The carcasses were significantly affected by the feeding treatments applied. *Ad libitum* feeding led to significantly heavier carcasses in the different housing systems and when the data from the housing systems were pooled. Overall controlled fed animals produced carcasses with significantly higher lean meat percentages and lower fat content. This difference however, was not found between the feeding treatments in the group housing. The length of the carcass was unaffected by the feeding treatments. Controlled feeding produced carcasses with a significantly lower compactness in the different housing systems and when housing systems are pooled. Controlled feeding led to a lighter carcass with a higher lean meat content. The success of using controlled feeding to improve carcass composition depends on the carcass classification used to determine carcass income.

Due to the difference in feed intakes between the feeding treatments the *ad libitum* fed pigs had a significantly higher total feed cost. Controlled feeding led to significantly lower carcass incomes in the different

housing systems and when the housing types are pooled. When comparing the net incomes of the feeding treatments, no significant difference between the feeding treatments was found when applied in the group housing system. A significantly higher net income was achieved when pigs were fed *ad libitum* in the individual housing. When comparing these monetary effects it should be kept in mind that only feed cost and carcass income was included in the calculations and several other fixed and variable costs should be taken into account under commercial conditions. Controlled feeding in the individual housing system led to a lighter carcass with a higher lean meat content and a lower fat percentage. This improvement in carcass composition was not found in the group housing system. The hypothesis that controlled feeding leads to an improvement in carcass composition can be confirmed for individually housed pigs. For group housed pigs it is however rejected for the specific levels of controlled feeding tested in this trial.

4.2 Effect of housing systems

An overall housing system effect seen throughout the experiment was the lower feed intakes achieved in the group housing system. This led to a smaller difference between the two feeding treatments in the group housing and one can expect the difference in performance due to the feeding treatment effect to be smaller. Housing system had a significant effect on the empty body weights and growth rates achieved under the *ad libitum* feeding only. Housing system had no overall significant effect on the empty body weights and growth rate achieved under the controlled feeding treatment. The reason for the differences seen during week 19 and 20 within the controlled feeding treatment is still unexplained. The difference seen between the housing systems in the *ad libitum* treatment was due to the difference in feed intake.

Housing system had no significant overall effect on the efficiency of growth achieved in the trail.

Individual housing led to significantly higher P2 backfat thickness levels throughout the experiment when data from the two feeding treatments were pooled.

Pigs exposed to the group housing system produced lighter carcasses than those kept in the individual housing. This is in agreement with the findings on empty body weight. No other differences in the carcasses was caused by the housing system used.

Individual housing had a significantly higher feed cost than that of group housing when *ad libitum* feeding is applied. The carcass incomes was significantly higher for pigs kept under individual housing. This was the case for both feeding treatments and when the data is pooled. There was no housing system effect on the net income for pigs under controlled feeding. However, when fed *ad libitum*, a significantly higher net income is achieved when pigs are kept in individual housing.

4.3 Summary

The pigs exhibited a higher growth rate and achieved a higher slaughter weight when fed on an *ad libitum* basis. *Ad libitum* feeding led to a heavier carcasses with a higher level of fat and a higher income in the individual housing system. Even though *ad libitum* feeding led to a higher growth rate and heavier carcasses in group housing no significant difference was found in the net income. When the pigs were tested in an individual housing system controlled feeding led to a slower but more efficient growth than achieved under an *ad libitum* feeding regime. Feeding regime had no effect on the efficiency of growth taking place in the group housing system.

Based on these results it seems that there was little advantage of applying *ad libitum* feeding in the group housing conditions. However, when the trends in growth performance and the results of individual housing are kept in mind it seems that a higher feed intake under group housing would have led to a similar difference between feeding treatments as seen in the individual housing. Further research needs to be done to ensure that pigs in group housing achieve their true *ad libitum* feed intakes.

The results of this study confirms that the superior growth potential of the specific Tempo boar is in part, at least, transmitted to its offspring.

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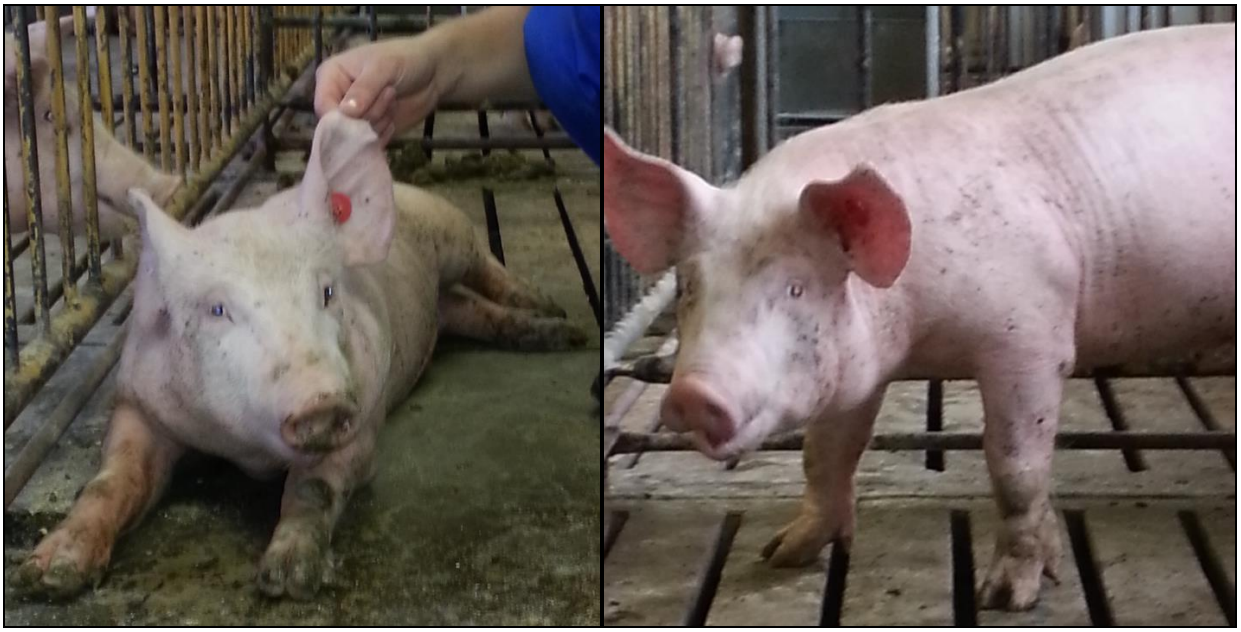
APPENDIX I
TRIAL PHOTOS

Individual housing system pens

Tagging at an age of 1 day, for identification purposes at Walt Landgoed, Bela Bela



Pigs in individual housing at 11 weeks

Sunflower oilcake causing the feeder blockage in week 17 in the group housing system


Left: Weekly weighing and P2 Backfat measurements. Right: Renco Backfat Probe used for P2 backfat measurements

Pigs in the group housing system at 21 weeks of age

The highest empty body weight was achieved in the individual housing system under the *ad libitum* feeding treatment. "Billybob" weighed 133.40 kg at an age of 21 weeks.

Off-loading pigs for slaughter at Eskort Abattoir, Heidelberg, South Africa

Pigs cooled down after with water spray and fans after off-loading in the lairages

Left: Carcasses after slaughter. Right: Carla Rittinori assisting with carcass length measurements.