

**OPTIMIZING GENETIC SELECTION FOR SOW PRODUCTIVITY,
GROWTH AND CARCASS TRAITS IN SOUTH AFRICAN LARGE
WHITE PIGS**

BEKEZELA DUBE

Thesis submitted for the Degree Doctor of Philosophy in Animal Science at the
Mafikeng Campus of the North West University



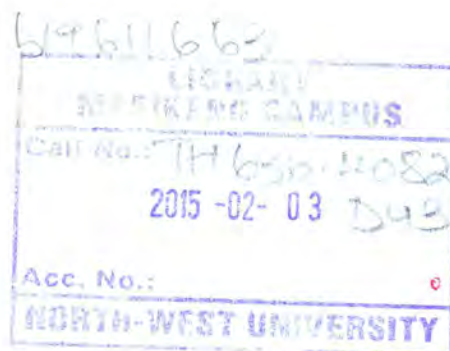
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Preface

The study in this thesis has been conducted to suggest means of efficient genetic selection in the South African pig industry by incorporating economic parameters into genetic selection programs. Six studies were conducted to come up with recommendations for the pig industry in South Africa thus, the thesis consists of nine chapters. The first chapter is the general introduction outlining the broad objectives of the pig industry and how those objectives can be attained. In this first chapter, the current situation in the South African pig industry is also provided. Chapter 2 reviews the literature on all the aspects covered by the entire study. Non-genetic effects on sow productivity are determined and presented in Chapter 3, while those on growth and carcass traits are discussed in Chapter 4. These non-genetic effects facilitated the generation of genetic parameter estimates. Chapters 5 and 6 are dedicated for the result discussion on genetic parameters for sow productivity traits, and growth and carcass traits, respectively. Derivation of economic values using production and economic information for the traits was done in Chapter 7. Genetic parameter estimates and economic values were combined to develop selection indices, which are presented and discussed in Chapter 8. Based on research results obtained in the current study, some general conclusions and recommendations for the South African pig industry are outlined in Chapter 9.

Declaration

I, **Bekezela Dube**, declare herewith that the thesis entitled, **Optimizing Genetic Selection for Growth, Carcass and Sow Productivity Traits in South African Large White Pigs**, which I herewith submit to the North-West University as completion of the requirements set for the **Doctor of Philosophy** degree in **Animal Science**, is my own work and has not already been submitted to any other university. I understand and accept that the copies that are submitted for examination are the property of the University.

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Abstract

The objective of this study was to develop an approach for efficient genetic selection in pig breeding programs. This approach will optimize genetic selection for sow productivity, growth and carcass traits by integrating genetic and economic parameters. Non-genetic effects on sow productivity, growth and carcass traits were identified so that they could be adjusted during the genetic analyses of these traits. Genetic analyses for sow productivity traits were done on 29719 records for 7983 sows from 29 herds, using a repeated records model. Twenty thousand and seventy nine animals from 29 herds, which were performance-tested between 1990 and 2008, were included in the analyses for growth traits. Analyses for carcass traits were done on 5406 animals from 20 herds, which were carcass-evaluated between 1993 and 2007. Growth and carcass traits were analyzed using a maternal effects model. The sow productivity traits analyzed were: number born alive (NBA), litter birth weight (LBWT), 21-day litter size (D21LS), 21-day litter weight (D21LWT) and inter-farrowing period (IFP). For growth and carcass traits, the traits analyzed were ultrasonic backfat thickness (BFAT), test period gain (TPG), lifetime gain (LTG), feed conversion ratio (FCR), age at slaughter (AGES), lean percentage (LEAN), drip-free lean percentage (DLEAN), drip loss percentage (DRIP), dressing percentage (DRESS), carcass length (CRLTH), eye muscle area (AREA) and carcass fat (CFAT). These traits were analyzed using Residual Maximum Likelihood (REML) procedures in ASREML.

Estimates of heritability for sow productivity traits ranged from 0.01 ± 0.010 for IFP to 0.10 ± 0.011 for LBWT, while those for growth and carcass traits ranged from 0.13 ± 0.062 for

DRIP to 0.63 ± 0.104 for AREA. Permanent environmental effects were significant for NBA, LBWT, D21LS and D21LWT. Significant maternal genetic effects were observed in TPG, LTG, AGES, LEAN, DLEAN, DRIP and DRESS. In sow productivity traits, genetic correlations ranged from -0.01 ± 0.164 between IFP and D21LS to 0.68 ± 0.038 between D21LS and D21LWT. Genetic correlations among growth and carcass traits ranged from -0.02 ± 0.262 between DRESS and TPG to -0.99 ± 0.012 between LTG and AGES. Low genetic variations were observed in all sow productivity traits, whereas substantial genetic variation exists in growth and carcass traits. Genetic correlations among sow productivity traits suggest that improvement of litter size may be done by selecting for litter weight or vice versa. Selecting for growth rate may improve feed conversion ratio and reduce age at slaughter, which may be improved without significantly compromising on carcass traits. Improving carcass leanness may be associated with improved carcass yield. The genetic trends for various traits show that there has been no consistent improvement in these traits, suggesting that farmers might have not used breeding values all the time during selection. Genetic parameters can be utilized efficiently when economic parameters are incorporated into breeding programs. Thus, economic values can play a pivotal role in improving the efficiency of pig breeding programs.

Simulation models based on a 100-sow herd were used in the derivation of economic values for sow productivity, growth and carcass traits. Traits included in the study were NBA, D21LS, D21LWT, average daily (lifetime) gain (ADG), FCR, AGES, DRESS, LEAN and BFAT. Economic values for NBA, D21LS, D21LWT, ADG, FCR, AGES and DRESS were derived using the partial budgeting approach. Partial differentiation of the profit function was used to derive economic values for LEAN and BFAT. An economic value was defined as change in

profit per unit genetic change in a trait. The respective economic values (ZAR) for sow productivity traits were 61.26, 38.02 and 210.15. For growth and carcass traits, the economic values (ZAR) were 33.34, -21.81, -68.18, 5.78, 4.69 and -1.48, respectively. These economic values indicate the direction and emphasis of selection and were sensitive to changes in feed prices and marketing prices of carcasses and maiden gilts. The economic values were used with genetic parameters to develop possible breeding objectives and indices. Genetic responses to selection and economic return for each index and its corresponding breeding objective were computed. The best index for sow productivity consisted of NBA and D21LWT. For growth and carcass traits, the best index consisted of AGES, DRESS and BFAT, where AGES and BFAT were included as indicator traits for ADG and LEAN, respectively. Genetic progress and economic return were sensitive to changes in economic values. In order to benefit from changes in economic values, the economic values should be updated so that appropriate weights are placed on the index traits. Producers and consumers may benefit from index selection as it results in optimum improvement in all breeding objective traits and assist in relating selection programs to profit.

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Chapter 1

General Introduction

The goal of any pig industry is to benefit the producer and the consumer, where the former is interested in making profit and the latter wants value for money. Thus, the pig enterprise needs to make profit, sustain production, and be competitive by satisfying the consumer. In a capitalist society, profitability seems a logical unit of expression for that final evaluation (MacNeil *et al.*, 1997). Modern agriculture has therefore shifted from production to productivity and sustainability (Olesen *et al.*, 2000). While meat yield is important from the producer and consumer viewpoints, consumers also demand lean meat and need to be satisfied (Webb *et al.*, 2006). Improvement of these carcass attributes can be achieved by taking into consideration the production inputs and outputs.

The genotype is one of the main inputs of livestock enterprises and characterizes each enterprise by emphasizing specific traits, driven by, *inter alia*, market demands. Animal and/or product improvement are pivotal to productivity and sustainability, and can be achieved through genetic selection. Selection is the major tool for genetic improvement (Strandberg & Malmfors, 2006). While selection should be done on each of the traits, these traits differ in genetic variability and economic importance (Hazel, 1943). Also, returns resulting from selection are not the same for all traits. Selection should, therefore, take into account these differences among the traits. This problem of multi-trait selection almost invariably involves evaluating animals on more than one trait and making compromises among traits to arrive at a final evaluation of each candidate for selection (MacNeil *et al.*, 1997).

Meat quality has increasingly become important for processors and consumers; thus pig breeding programs select for rapid lean meat production to satisfy consumer needs (Lo *et al.*, 1992; Brocks *et al.*, 1999; Chen *et al.*, 2003b; Webb *et al.*, 2006). This has a positive impact on enterprise profit as lean tissue is deposited more efficiently than fat (Chen *et al.*, 2003b). Most selection experiments for lean growth rate have been based on a classical linear selection index that combines ultrasonic measures of backfat thickness and average daily gain (McKay, 1992; Cameron, 1994; Cameron & Curran, 1994). Lean percentage has been found to be negatively correlated to carcass fat and backfat thickness (Nguyen & McPhee, 2005). There is, therefore, a possibility of improving lean percentage by selecting against backfat thickness.

Although lean meat is the desired ultimate product, the quantity of the product and cost of producing that product should also be considered in genetic improvement programs. This entails including such traits as, growth and reproductive (sow productivity) traits when defining the breeding goal of a pig enterprise. Growth rate is directly related to the amount of feed consumed before marketing, hence the cost of producing the product. Thus, it has a direct relationship with enterprise profit. This is because feed costs account for more than two thirds of production costs in pig industries (Hoque *et al.*, 2009). Feed efficiency in swine may be improved indirectly by selecting for growth rate and against backfat thickness (Cleveland *et al.*, 1983). Selection programs have improved the growth rate of the pig (Imboonta *et al.*, 2007); while lean growth rate is an important trait for genetic improvement programs (Chen *et al.*, 2003b). Fowler *et al.* (1976) proposed that developing a biological index combining growth rate and lean percentage would improve lean tissue growth.

Sow productivity is recognized as a key factor influencing the efficiency and economic viability of the pig industry and is a leading concern of commercial producers and breeders (Kim, 2001). Improvement of litter size is an important breeding goal in pigs (Ollivier *et al.*, 1990), but has an unfavourable relationship with the number of still-born pigs (Johnson *et al.*, 1999a; Tribout *et al.*, 2003). A correlation between production traits and decreased reproductive performance has been reported (Zhang *et al.*, 2000; Holm *et al.*, 2004). In contrast, Imboonta *et al.* (2007) observed that selection for growth rate will increase the number of piglets born per litter. Therefore, genetic improvement of both production and sow productivity traits should be targeted for in selection programs.

The first step in designing a breeding program is the development of a breeding objective, which is part of a decision-making process (Goddard, 1998). Henriksen (2003) viewed a breeding objective as a combination of prophecy and science, since it predicts which kind of pig is desired in 5-10 years and makes sure it is ready on time. Simultaneous improvement of traits involves employing one of the following techniques, tandem selection, independent culling or index selection. Of these selection methods; the selection index is the most efficient (Young, 1961; Finney, 1962) in that it takes into account the genetic and economic components into consideration (Hazel & Lush, 1942; Hazel, 1943). Use of the selection index involves identifying traits that directly affect enterprise profit. The traits affecting profit constitute a breeding objective and these traits are termed “economically relevant traits”. However, some of the traits in the breeding objective may not be directly measurable. The selection criteria are the traits that are measured on the animals or products, which are indicators of traits in the breeding

objective. To improve the traits in the breeding objective, selection criteria are chosen with the aim of improving enterprise profit or reducing risk.

If selection is to be most efficient to producers, the definition of the value of a pig product should be based on a combination of both biological (breeding values) and economic values. It, therefore, compels developing a comprehensive and systematic way of relating changes in performance levels at the animal level to changes in profitability at the enterprise or production system level (MacNeil *et al.*, 1997). Relative economic values for traits used in the selection index are the changes in enterprise profit at optimum levels of production, which result from a unit change in each trait (McArthur, 1987). These reflect change in profit for a unit change in the trait, when all other traits in the list are held constant. Therefore, to construct a selection index, the economic values of each of the traits should be derived. Only economically relevant traits should be included in the selection objective to be improved (MacNeil *et al.*, 1997).

Several methods can be used to calculate economic values (Smith *et al.*, 1986; Ponzoni, 1988; Groen, 1989). The simplest way to derive economic values is to calculate the difference between costs and revenues (Ponzoni, 1988). Bio-economic models have been used over the years as a method of calculating economic values for traits included in the breeding objective for livestock selection programs (Skorupski *et al.*, 1995; Amer *et al.*, 1997; Conington *et al.*, 2000). Such models aim to effectively describe complex livestock production systems, taking into account genetic, nutritional, management, and economic factors (Jones *et al.*, 2004). The genetic parameters are then combined with the economic value to determine a numeric weighting for

each trait. For each animal, the performance in each trait is multiplied by the numeric weighting factor and summed to determine the index value.

In South African pigs, the emphasis has been for too long, on input efficiency (growth rate, feed conversion efficiency and backfat thickness), and too short on output efficiency (carcass and meat quality traits) (Visser, 2004). Yet efficiency of feed utilization and optimal utilization of capital invested is the chief decider of profitability (Pieterse, 2006). It is, therefore, necessary to place equal emphasis on both input and output efficiency to produce desirable carcasses at least cost. Genetic parameters have been estimated for some carcass and growth traits (Visser, 2004). However, economic values for carcass and growth traits have not been estimated before in South African Large White pigs. The South African producers are rewarded for the quality and quantity of their products using the South African Pork Producers Organization (SAPPO) pricing system. The pricing system is guided by the PORCUS classification system, which takes into account carcass leanness and live weight.

The level of production and sophistication in South African pig production systems calls for simultaneous genetic evaluation and improvement of all traits that affect profit. Not only that there are no economic values derived for economically relevant traits, the breeding objectives for the Southern African pig industries has not been clearly defined. Selection indices, which have been recommended as a tool for simultaneous selection and genetic improvement of traits, have not been well-developed for the South African pig industry. Genetic parameters and economic values are needed to relate changes occurring at genetic level to changes in profit. The broad objective of this study was to optimize genetic improvement for carcass yield and quality and

sow productivity by developing selection indices for the South African Large White population.

The specific objectives were to:

- i. Identify important environmental factors affecting sow productivity, growth and carcass traits;
- ii. Generate genetic parameters for sow productivity, growth and carcass traits;
- iii. Derive economic values for sow productivity, growth and carcass traits; and
- iv. Develop selection indices for sow productivity traits and for growth and carcass traits.

Chapter 2

Review of Literature

2.1. Non-genetic effects on sow productivity

2.1.1. Introduction

In pig production systems, the primary source of market animals is the conception and farrowing of live piglets by the sow. Enterprise income depends on the number of animals marketed, thus the efficiency of sow productivity is a very important component of pig production systems. Therefore, to improve the efficiency of pig enterprises, sow productivity should be maximized. To achieve this, all factors affecting sow productivity should be identified. Non-genetic factors are an integral part of pig production systems, and should be identified and evaluated.

2.1.2. Effect of herd of origin on sow productivity traits

Many different factors affect the performance of sows in a herd, and the way the producer manipulates these factors, determines the performance of a sow. Management is therefore a characteristic of every herd and it affects sow performance (Lawlor & Lynch, 2007). Some of the management factors that constitute herd of origin are: feeding practices (Aherne, 2002; Kongsted, 2005), proportion of gilts (Dewey *et al.*, 1995; Aherne, 2002) and lactation length (Clark & Leman, 1987; Koketsu & Dial, 1998). The collective effects of several factors constitute the herd effect, therefore the effect herd of origin has on sow productivity should be investigated.

2.1.3. Effect of year of farrowing on sow productivity traits

The environment in which sows are kept determines how the sows will respond to certain practices applied on them. These environmental factors affect several physiological processes in the sow's body to determine its ultimate performance. Climatic conditions vary from one to year to another, such that, the performance of sows also varies from year to year. Peltoniemi *et al.* (1999) observed the effect of year on rebreeding rate in Finnish sows. In addition, producers always practice genetic selection to improve herd performance. Despite being lowly heritable, sow productivity has been shown to be responsive to selection (Neal & Johnson, 1986; Southwood & Kennedy; 1991; Haley & Lee, 1992). An investigation should be done in order to determine if year of farrowing affects sow productivity.

2.1.4. Effect of season of farrowing on sow productivity traits

The physiological processes occurring in the body of a sow are affected by the prevailing conditions. These conditions vary during the year, resulting in corresponding variations in the physiological processes. Changes in physiological conditions in pigs due to season have been reported (Mauget, 1982; Stone, 1982; Claus & Weiler, 1985; Prunier *et al.*, 1996). Ambient temperature and photoperiod have been identified as factors affecting the performance of sows, as these vary with season (Love *et al.*, 1993; Prunier *et al.*, 1997; Boma & Bilkei, 2006). Previous studies reported the effect of season on sow reproductive performance (Dominguez *et al.*, 1996; Mungate *et al.*, 1999; Peltoniemi *et al.*, 1999). The effect of season of farrowing on sow productivity should be ascertained.

2.1.5. Effect of age at service on sow productivity traits

Success of conception depends on the preparedness of the sow's uterine environment. The sow's physiological conditions, which depend on age, determine how ready it is for conception. Clark *et al.* (1988) reported the effect of age at conception on sow's reproductive performance of North American pigs. The effect of age is generally manifested in parity as reported in some studies (Mungate *et al.*, 1999; Milligan *et al.*, 2002; Damgaard *et al.*, 2003). Differences among parities of different US breeds were observed, where superior performance was in parities three to six (Yen *et al.* (1987). Milligan *et al.* (2002) also reported that birth weights in parities less three were higher than those in later parities. Therefore, the effect of the sow's age at service on sow productivity should be investigated.

2.1.6. Interaction effects on sow productivity traits

Although there are several factors affecting different traits, interactions among factors may exist in affecting some traits. In some studies, an interaction between management and season has been reported (Love *et al.*, 1995; Peltoniemi *et al.*, 1999). The interactions may suggest inconsistent performance in seasons from one to another. Therefore, interactions between different factors affecting sow productivity traits in SA Large White pigs should be tested.

2.1.7. Conclusions

Non-genetic factors have been shown to have an effect on sow productivity in several studies. Such research has not been done on the SA Large White pigs. Since different non-genetic factors were shown to be present in different herds, the non-genetic factors affecting sow productivity traits in SA Large White pigs should be identified. The fact that the products that

reach the consumer result from postweaning growth performance of pigs, necessitates the need to also identify non-genetic factors affecting growth and carcass traits

2.2. Non-genetic effects on growth and carcass traits

2.2.1. Introduction

Terminal production systems play a pivotal role in the pig industry by raising pigs for the market. The value of a pig is realized when inputs of rearing are weighed against revenue obtained at marketing; hence postweaning growth performance is of paramount importance. Success of terminal production systems therefore depends on a myriad of factors affecting growth performance of and carcasses produced by the pigs. Non-genetic factors may modify the genetic potential of pigs to perform during the postweaning period and the carcass they produce. It is therefore important to identify the non-genetic factors that affect growth and carcass traits.

2.2.2. Effect of herd of origin on growth and carcass traits

Herd of origin has been identified as a factor affecting growth performance and carcass characteristics. Differences in management practices among herd constitute the herd of origin effect. Some of the management factors that constitute herd of origin are: feeding practices (Aherne, 2002; Kongsted, 2005). The effect of pre-test environment on growth and carcass attributes has been reported previously (Beattie *et al.*, 2000; Gentry *et al.*, 2002; 2004; Hansen *et al.*, 2006). The collective effects of several factors constitute the herd effect and determine the ultimate performance of pigs in a particular herd. Therefore, the herd effect on growth and carcass traits should be done.

2.2.3. Effect of year of testing on growth and carcass traits

Pigs are brought for testing into total confinement after a pre-test period, such that the testing conditions are uniform over the years. This suggests that any differences may be attributed to conditions outside the testing environment. Differences in growth performance and carcass characteristics may be due to carry-over effects from the pre-test environment. Birth and rearing environment have been reported to affect growth and carcass traits (Nilzen *et al.*, 2001; Gentry *et al.*; 2004). Furthermore, response to genetic selection may cause differences between years. These traits have been shown to be of moderate heritability (Johnson *et al.*, 1999b; Nguyen & McPhee, 2005; Oh *et al.*, 2005; Chimonyo & Dzama, 2007). Determination of whether year of testing affects growth and carcass traits should be done.

2.2.4. Effect of season of testing on growth and carcass traits

Growth performance and carcass characteristics are an outcome of the nutrients ingested and assimilated by the animal. The amount of nutrients ingested and the efficiency with which these nutrients are utilized determine the growth of the pig and the carcass it will produce. Prevailing conditions are the primary determinant of physiological processes, which affect nutrient intake and utilization. Previous studies reported the effects of ambient temperature on growth and carcass traits (Close, 1987; Le Dividich *et al.*, 1987; Bee, 2004). Trezona *et al.* (2004) observed that pigs were fattest and leanest during spring and autumn, respectively. The effect of season of testing on growth and carcass traits should be investigated.

2.2.5. Effect of sex on growth and carcass traits

Since performance testing of pigs is done before puberty, both males and females are performance-tested. Male pigs have been reported to have lower growth rates than their female counterparts (Latorre *et al.*, 2003). Nieuwhof *et al.* (1991), Friesen *et al.* (1994) and Latorre *et al.* (2003) observed poorer feed conversion ratios in males than in females. Differences in carcass characteristics due to sex have been observed (Serrano *et al.*, 2008). However, Mayoral *et al.* (1999) and Lattore *et al.* (2003) found no differences in carcass characteristics attributable to sex. The disparities among the different studies underline the need to investigate the effects of sex on growth and carcass traits.

2.2.6. Effect of testing environment on growth traits

Two testing environments are available in the pig industry, and these are central testing stations and farms. Use of central testing stations allows for the testing of certain traits, such as carcass traits, which would be otherwise impossible under farm conditions. Testing of animals under these two environments may result in differences in the performance of test-pigs and in the carcasses they produce. Rearing environment has been reported to influence subsequent growth performance (Beattie *et al.*, 2000; Gentry *et al.*, 2004). Therefore, it should be determined if there are any differences in growth performance of animals tested in the two different environments.

2.2.7. Effect of test period feed intake on growth and carcass traits

Nutrients from the feed are the tissue building blocks and therefore, growth performance is directly related to the nutrients ingested. Thus, Garcia-Valverde *et al.* (2008) observed increasing growth rate with increasing feed intake. Two forms of feed intake exist and have been reported carcass traits differently. Decreasing carcass yield and quality with increasing *ad libitum* feed intake have been reported previously (Affentranger *et al.*, 1996; Akdag *et al.*, 2008). Contrary to this, Ramaekers *et al.* (1996) observed contrasting results showing increased lean content with increasing feed content when daily feed intake was restricted. These studies used average daily feed intake to evaluate the effect of feed intake. The effect of total feed consumed by the pig during the test period on growth and carcass traits should also be investigated.

2.2.8. Effect of age at start of test on growth and carcass traits

Pigs are brought to testing stations after weaning and variations of age at the start of the test may exist. Daza *et al.* (2007) reported higher growth rates in pigs that started the test at an older age compared to those which started at a younger age. Higher average daily gain and carcass weight, as a consequence of older age at the beginning of the free-range fattening period has been reported previously (Daza *et al.*, 2007). Variations in carcass characteristics due to age have also been reported (Mayoral *et al.*, 1999; Daza *et al.*, 2005; Daza *et al.*, 2007). Age at the beginning of the test period seems to be important in the growth of test-pigs and the carcasses they produce. Therefore, differences in growth performance and carcass characteristics due to age at the start of the test need to be investigated.

2.2.9. Interaction effects on growth and carcass traits

Interactions among factors in affecting some traits have been in some studies previously. A herd $\times$ year of testing effect on growth and carcass has been observed (Cassady *et al.*, 2004). Wallenbeck *et al.* (2009) observed a herd-year-season interaction when they investigated the genotype $\times$ environment interaction in Hampshire boars. In the SA Large White pigs, interactions among factors affecting growth and carcass traits should be studied.

2.2.10. Conclusions

Several studies have shown the presence of different factors affecting growth performance and carcass characteristics in different populations. In addition, interactions between some of the factors were also observed. However, the non-genetic factors affecting growth and carcass traits in SA Large White pigs have not been identified. Identification of non-genetic effects in pig production systems will help in the estimation of genetic parameters, which are used in genetic selection programs. Therefore, a review of genetic parameters in pig production systems should be provided.

2.3. Genetic parameters for sow productivity traits

2.3.1. Introduction

Sustainability is pivotal to the success of a pig enterprise and is enhanced by genetic improvement of the sow. Improvement of the sow ensures translates to more pigs born and surviving to weaning and marketing. To genetically improve sows, genetic parameters for sow productivity should be estimated. These genetic parameters give an indication of how traits will

respond to selection when genetic selection is applied on them or other traits. A review of the genetic parameters for sow productivity traits in literature is given.

2.3.2. Heritability estimates for sow productivity traits

Very few studies have been conducted on heritability estimates for birth and 21-day weights (individual or litter weight). The literature estimates for weights at birth and 21 days range from very low to moderate (Bereskin, 1984; Chen *et al.*, 2003a; Hoque *et al.*, 2009). Litter size has been recognized as the most important economic component of sow productivity (Estany *et al.*, 2002). Litter size is a complex physiological trait affected by several component traits expressed sequentially, e.g. ovulation, fertilization, embryo survival and foetal survival (Leymaster *et al.*, 1986). Heritability estimates for litter size at birth and 21 days have been reported in literature are generally very low (Southwood & Kennedy, 1991; Roehe & Kennedy, 1995; Chen *et al.*, 2003a; Imboonta *et al.*, 2007). Generally, reproductive traits are of low heritability suggesting that response to genetic selection might be low.

2.3.3. Permanent environmental effects on sow productivity

Permanent environmental effects indicate the maternal ability of the sow and reflect the extent to which each record can be repeated over the production period of a sow. Mothering ability, measured by 21-day litter weight, was considered as a composite trait combining litter size and average piglet weight at 21 days (Fernandez *et al.*, 2008). Gilt and sow records should be considered as separate reproductive traits because the physiological development of reproductive organs differs with parity (Oh *et al.*, 2006). Milk production in gilts may be 20% lower than in multiparous sows, as a consequence of lower feed intake and additional requirements of energy

for tissue growth (Walker & Young, 1993). Therefore, the significance of permanent environmental effects should be investigated to facilitate genetic selection.

2.3.4. Genetic correlations among sow productivity traits

Piglet birth weight has been shown to have negative genetic correlations with number of piglets born, and birth to weaning survival (Roehe, 1999; Rosendo *et al.*, 2007). Number born alive had positive genetic correlations with litter birth weight (0.58 ± 0.18) and 21-day litter weight (0.91 ± 0.30), but negative genetic correlations with average 21-day weight (-0.88 ± 0.78) (Irvin & Swiger, 1984). Irvin & Swiger (1984) reported positive genetic correlations for litter birth weight with litter size at birth (0.76 ± 0.17), litter size at 21 days (0.64 ± 0.16) and litter weight at 21 days (0.88 ± 0.21). The genetic correlations between number born alive and number weaned were 0.870 ± 0.058 and 0.718 ± 0.059 in Yorkshire and Landrace, respectively (Su *et al.*, 2007). Chimonyo *et al.* (2006) observed a genetic correlation of 0.263 ± 0.033 between number born alive and litter weight at birth in Mukota pigs. In Yorkshire pigs, the genetic correlations for number born alive with number weaned and litter weight at 21 days was 0.19 and 0.14, respectively (Chen *et al.*, 2003a). These estimates suggest that genetic correlations exist and vary between populations, thus estimation of the genetic correlations among sow productivity traits in this population is necessary. In addition, genetic correlations for inter-farrowing period with other sow productivity traits have not been investigated.

2.3.5. Genetic and phenotypic trends for sow productivity traits

Genetic and phenotypic trends for reproductive traits in pigs have been reported in literature. Neal & Johnson (1986) and Haley & Lee (1992) observed an increase in litter size after selecting for its components. Johnson *et al.* (1999a) observed increasing genetic trends for number born alive, litter birth weight, number weaned and litter weaning weight. Improvements in genetic and phenotypic trends were observed for number born alive, litter size and weight at 21 days (Kaplon *et al.*, 1991). Positive trends in number born alive and number weaned were reported by Southwood & Kennedy (1991) in Canadian pigs. In a separate study, Chen *et al.* (2003c) observed increasing genetic trends for number born alive, number weaned and litter weight at 21 days for U.S. breeds. Although studies have been done on genetic and phenotypic trends, no study has been conducted on the South African (SA) Large White population.

2.3.6. Conclusions

Sow productivity traits have been shown to be of low heritability, suggesting that their response to genetic selection might be slow. Despite this, over time, these traits show improvements following genetic selection. Studies on genetic parameters for sow productivity in SA Large White pigs are lacking. This underscores the need to estimate the genetic parameters for this population. For improvements in the pig industry to be complete, genetic parameters for growth and carcass traits should also be estimated. Therefore, to learn about genetic parameters for these traits, a review should also be done.

2.4. Genetic parameters for growth and carcass traits

2.4.1. Introduction

Following weaning, pigs are raised independent of the sow, and their growth ability takes center stage. Improvement of growth performance is therefore an aspect of pig breeding programs that should be emphasized. The characteristics of the carcasses produced from these pigs at marketing should also be considered to satisfy the consumer. Since these traits are important to the pig industry, they should be improved through genetic selection programs. Genetic parameters for growth and carcass traits are therefore needed to properly implement genetic selection for these traits. To obtain the general magnitude of the genetic parameters for growth and carcass traits in literature, a review of previous studies is performed.

2.4.2. Heritability estimates for growth and carcass traits

Estimates for backfat thickness reported in literature range from moderate (Johnson *et al.*, 1999b; Nguyen & McPhee, 2005) to high (Suzuki *et al.*, 2005; Imboonta *et al.*, 2007). A low heritability estimate for average daily gain of 0.18 ± 0.04 was reported by Nguyen & McPhee (2005), while most estimates were moderate (Lo *et al.*, 1992; Johnson *et al.*, 1999b; Suzuki *et al.*, 2005). Contrasting estimates for age at slaughter (0.04 and 0.43 ± 0.08) were obtained by Schwab & Baas (2008) and Lo *et al.* (1992), respectively. Low to moderate heritability estimates for feed conversion ratio were observed in previous studies (Hermesch *et al.*, 2000; Nguyen & McPhee, 2005; Suzuki *et al.*, 2005).

Heritabilities for carcass traits have been reported in literature for different pig breeds. Lean percentage and dressing percentage generally have moderate to high heritability estimates, while drip loss is lowly heritable (Newcom *et al.*, 2002; Suzuki *et al.*, 2005; van Wijk *et al.*, 2005; Gilbert *et al.*, 2007). Heritability estimates for eye muscle area ranged from moderate to very high (Lo *et al.*, 1992; Newcom *et al.*, 2002; Oh *et al.*, 2005). Despite moderate estimates obtained by some authors for carcass length (Lo *et al.*, 1992; Gilbert *et al.*, 2007), a very low heritability estimate (0.09 ± 0.02) was reported (Suzuki *et al.*, 2005). The disparities among different studies suggest that heritability estimates in SA Large White pigs should also be estimated to facilitate genetic selection.

2.4.3. Maternal genetic effects on growth and carcass traits

There are very few studies on the contributions of maternal genetic effects to phenotypic variations of growth and carcass traits. Maternal heritabilities estimates for backfat thickness and average daily gain obtained by Ferraz & Johnson (1993) in U.S. pig breeds were less than 0.05. A moderate maternal heritability (0.20 ± 0.005) for preweaning growth rate was reported by Chimonyo & Dzama (2007) in Mukota pigs. Average daily gain for different stages of growth was analyzed and the contributions of maternal genetic effects to phenotypic variance ranged from 0.04 to 0.16 (Cassady *et al.*, 2002). These authors obtained an estimate of 0.06 for backfat thickness. Chimonyo & Dzama (2007) reported estimates of 0.11 ± 0.001 and 0.03 ± 0.002 for carcass length and cold dressed mass, respectively. Since maternal genetic effects have not been estimated in SA Large White pigs, a study should be done to estimate the maternal contribution to phenotypic variance of growth and carcass traits in this population.

Correlations between direct and maternal genetic effects reported in literature have mostly been negative. Ferraz & Johnson (1993) reported correlations between direct and maternal genetic effects for average daily gain and backfat thickness of -0.34 and -0.26, respectively. Negative correlations ranging from -0.28 to -0.50 were reported by Chimonyo & Dzama (2007) for average daily gain, backfat thickness, cold dressed mass and carcass length. Average estimates of correlations obtained by Chen *et al.* (2002) were -0.43, -0.44, -0.48 and -0.32 for average daily gain, backfat thickness, days to 113.5 kg and loin eye area, respectively. No studies have estimated correlations between direct and maternal genetic effects for growth and carcass traits for the SA Large White pigs.

2.4.4. Genetic correlations among growth and carcass traits

Genetic correlations indicate how related the traits are, and have implications in genetic selection processes. Backfat thickness had an unfavourable genetic correlation with average daily gain, where the estimates were 0.28 ± 0.18 , 0.37 and 0.34 ± 0.04 (Lo *et al.*, 1992; Johnson *et al.*, 1999b; Suzuki *et al.*, 2005, respectively). The genetic relationship between backfat thickness and feed conversion ratio has been favourable as shown by some literature estimates, which were 0.65 ± 0.07 (Suzuki *et al.*, 2005) and 0.43 ± 0.13 (Nguyen & McPhee, 2005). Estimates of the genetic correlation between average daily gain and feed conversion ratio observed by Johnson *et al.* (1999b), Nguyen & McPhee (2005) and Suzuki *et al.* (2005) were -0.32, -0.99 and -0.09 ± 0.07 , respectively. Age at slaughter had genetic correlations of -0.83 ± 0.08 and -0.13 ± 0.12 with average daily gain and backfat thickness, respectively (Johnson *et al.*, 1999b).

Lean percentage had a negative genetic correlation of -0.57 ± 0.08 with carcass fat (Nguyen & McPhee, 2005). Knapp *et al.* (1997) observed an unfavourable genetic correlation between lean percentage and drip loss of 0.33. Dressing percentage had positive genetic correlations (0.36 ± 0.07 and 0.55) with eye muscle area (Hicks *et al.*, 1998; Oh *et al.*, 2005, respectively). Carcass dressed mass had a genetic correlation of 0.53 ± 0.046 with carcass length in Mukota pigs (Chimonyo & Dzama, 2007).

Correlations between growth and carcass traits provide an opportunity to improve carcass attributes through improvements on live animals. Negative genetic correlations of -0.72 ± 0.19 and -0.45 were observed between backfat thickness and eye muscle area (Lo *et al.*, 1992; Suzuki *et al.*, 2005, respectively). The genetic correlations between lean percentage and backfat thickness were -0.77 , -0.82 ± 0.07 and -0.98 (Sonesson *et al.*, 1998; Nguyen & McPhee, 2005; van Wijk *et al.*, 2005, respectively). Backfat thickness had a positive genetic correlation of 0.81 ± 0.09 with carcass fat (Nguyen & McPhee, 2005); while a favourable positive genetic correlation (0.25 ± 0.06) between backfat thickness and drip loss was reported (Suzuki *et al.*, 2005). Genetic correlations for feed conversion ratio with lean percentage (-0.53 ± 0.12) and eye muscle area (-0.59 ± 0.07) were reported (Suzuki *et al.*, 2005; van Wijk *et al.*, 2005, respectively).

Average daily gain had genetic correlations of -0.18 ± 0.09 and -0.09 ± 0.05 with eye muscle area (Lo *et al.*, 1992; Suzuki *et al.*, 2005, respectively). Suzuki *et al.* (2005) reported a genetic correlation of 0.14 ± 0.11 between average daily gain and drip loss. The genetic correlations for carcass length with pre- and postweaning average daily gain ranged from 0.35 to 0.55 (Chimonyo & Dzama, 2007). Chimonyo & Dzama (2007) also observed an unfavourable

genetic relationship between carcass length and backfat thickness (0.42). To facilitate genetic selection in the SA Large White pigs, genetic correlations among growth and carcass traits should be estimated.

2.4.5. Genetic and phenotypic trends for growth and carcass traits

Genetic improvement of growth and carcass traits is estimated through genetic trends. Phenotypic trends show whether genetic improvement is translated to phenotypic improvement. Chen *et al.* (2002) reported improving genetic trends for backfat thickness and days to 113.5 kg in four different breeds. Kaplon *et al.* (1991) also observed improving genetic and phenotypic trends for backfat thickness, average daily gain and days to 110 kg in Polish Large white. Kennedy *et al.* (1996) pointed out that it would be realistic for industry breeding programs to achieve 1.7 to 2.9 % improvement per year for backfat thickness and 1.5 % per year for days to slaughter. Smith (1984) suggested that improvements of 3 to 5 % and 2.7 % for backfat thickness and growth rate, respectively, are possible. There is a paucity of information on genetic and phenotypic trends for carcass traits in literature. Increasing trends for loin eye area were observed by Chen *et al.* (2002) in four pig breeds. They reported genetic changes in loin eye area and lean growth rate of 0.42 and 0.91 % of their means per year, respectively. The lack of information on genetic and phenotypic trends for SA Large White pigs underscores the need to conduct studies to estimate these trends in this population.

2.4.6. Conclusions

Generally, growth and carcass traits have medium to high heritability and significant maternal genetic effects have been reported. The maternal genetic effects were negatively correlated to

direct genetic effects. Despite the variations in heritabilities of the different traits, evidence shows that the traits were generally responsive to selection. There is lack of information on genetic parameter estimates for growth and carcass traits in the SA pig populations. Efficient development of breeding programs entails developing appropriate breeding goals by integrating genetic parameters with economic parameters.

2.5. Development of breeding goals

2.5.1. Introduction

Although estimation of genetic parameters is necessary in pig breeding programs, by its own genetic parameter estimation is not enough to ensure profitability and sustainability. The aim of pig enterprises is to make profit and pig breeding programs should develop strategies that relate genetic improvements in traits to profit. Strategies that relate genetic changes in a trait to changes in profit are necessary for the SA pig industry. An outline of the discussion of how strategies that relate genetic changes to profit have been developed and implemented is given. A motivation of such strategies in SA, pointing out the deficiencies of the SA pig industry, is also outlined.

2.5.2. The breeding goal

The general aim of genetic improvement of farm animals is to increase the efficiency of production. In this regard, the breeding goal for most enterprises is to increase the level of satisfaction, which is achieved by maximizing profit and managing risk. Harris *et al.* (1984) and Ponzoni & Newman (1989) stressed the importance of a formal definition of the breeding goal as

a relevant step in the development of breeding programmes. The breeding goal is usually to increase the profit of the firm or industry, or society that is investing in a breeding program (Goddard, 1998). The consensus is that the objective should include long-term genetic gain and non-additive genetic changes such as inbreeding depression and possibly a weighting against the variability of outcome (Goddard, 1998).

2.5.3. The breeding objective

After defining the breeding goal, the breeder identifies those traits that will result in the achievement of the breeding goal when improved. These traits of economic importance are aggregated to form the breeding objective (Ponzoni, 1986). The breeding objective is a linear combination of traits in which the coefficient of each is its effect on profit when all other traits are held constant (Hazel, 1943). Hazel (1943) pointed out that the aggregate genotype is a function of individual genetic merit weighted by economic values of traits, i.e. their relative economic importance. The choice of traits to be included in the breeding objective should be based on the relative contribution of each trait to the overall efficiency of production, usually evaluated from an economic perspective (Goddard, 1998). Market demands usually dictate the direction to be taken by production in livestock enterprises; hence, the producer has to identify the traits that affect production. Before the foundation papers of the 1940s, breeding objectives for all livestock were predominantly visual (Harris & Newman, 1994). The expectation was that “form determines function”, with function meaning performance. The process of developing breeding objectives requires the knowledge of performance, the systems of production, available genetic resources among other production and economic information (Ponzoni & Newman, 1989; Hirooka *et al.*, 1998; Urioste *et al.*, 1998).

The breeding objective is described by a profit function that takes genetic values as input and produces profit as output. Improved profit potential is by optimal selection of multiple traits, some cryptically manifested, which requires accurate estimates of parameters describing interrelated biological systems (Blake, 1984). This implies that the breeding objective must be written in terms of traits that apply to an individual and in which genetic change can be predicted (Goddard, 1998). Goddard (1998) pointed out that the same breeding objective must be utilized for three decisions, which are: (i) the choice of individual animals as parents; (ii) choices of breeds or crosses; and (iii) evaluation of investment in the breeding program. The choice of individual animals leads to selection criteria, while the evaluation of investment must be related to predicted genetic changes (Goddard, 1998). However, attainment of a breeding goal of maximum profit is precluded by inadequate knowledge about its constituent traits and their proper weights (Blake, 1984).

2.5.4. Economically important traits

Genetic improvement entails identifying the parent stock of the future generation using traits that affect profit as yardsticks of selection. The assessment of risks and potential returns of breeding objectives is considered the key to the success of any enterprise. Bourdon (1998) concluded that the objective of new trait development has been to provide more complete descriptions of breeding stock. When implemented properly, the breeding objective will enable breeders and producers to use expected phenotypic expressions to predict future profit and risk.

Many traits that are measured on animals do not directly affect profit, as some are only used for management purposes. In cattle, for example, a producer is not paid for how much a piglet

weighs at birth. However, birth weight is recorded to help predict genetic merit for other traits, such as, growth rate and farrowing ease. The traits that breeders are trying to improve are called economically relevant traits (ERTs). These traits directly affect profitability in that they are associated with a specific cost of production or an income stream. On the other hand, indicator traits are traits that are used to indicate the merit an animal has for a particular ERT. Indicator traits mainly add information to the prediction of ERTs. An indicator trait will have no economic value when the ERTs with which it is associated with are included in the list. In the above example, when growth rate and farrowing ease are already being considered, birth weight has no economic value. Estimated breeding values for ERTs are applicable to individual animals and are interpreted in the conventional manner.

Determination of economic values for each trait in the breeding objective is a prerequisite for the development of a breeding objective. Economic values reflect the change in profit for every unit change in a given trait, when all other traits in the list are held constant. Therefore, the ERT's contribution should be considered regardless of the presence or absence of any other traits in the objective. Many ERTs have multiple indicator traits and the following is an outline of ERTs in pig production.

2.5.4.1. *Sow productivity traits*

Sow productivity is recognized as a key factor affecting the efficiency and economy of the pig enterprise for both the seedstock and commercial producer. Sow productivity traits, such as, litter size, litter weight and survival rate at weaning have more economic importance than other swine traits (Yen *et al.*, 1987). From a reproduction and production viewpoint, litter size can be

considered the most economically important trait and, therefore, constitutes a component of several selection objectives. Productivity per farrowing is usually considered the basis for evaluating the genetic merit of pigs in a herd and usually refers to such traits as number of live pigs farrowed and litter size and total litter weight at some standard age, such as, 21 days (Bereskin, 1984). These traits are often combined in the form of an index (Schinckel & Einstein, 1999). However, selection for litter size has an unfavorable effect on number of stillborn piglets (Johnson *et al.*, 1999a; Tribout *et al.*, 2003). Producers are now giving more attention to the improvement of litter size at birth and mothering ability (Yen *et al.*, 1987). Litter weight at 21 d is an indication of a sow's milking ability and litter size, while litter size at 21 d indicates the sow's mothering ability and the pigs' survival ability.

2.5.4.2. *Production traits*

Feed intake constitutes the highest proportion of production costs (Hoque *et al.*, 2007); hence it should be minimized without compromising product yield and/or quality. Therefore, traits such as, growth rate and feed intake should be included in the breeding objective. However, feed intake may be accounted for by including feed conversion ratio in the objective. See *et al.* (1995) identified feed conversion ratio as an important variable in reducing production costs. Some authors have warned against including feed conversion ratio in the breeding objective as they considered it a ratio trait (Gunsett, 1986; Garrick, 2006). Since the mid 1960s, selection emphasis in the South African pig performance testing scheme has been on growth rate, feed conversion ratio and reduced backfat thickness and structural soundness. Reduction of backfat thickness is done with the aim of improving leanness. The importance of feed intake in pig production systems underscores the importance of the length of time an animal spends during

fattening. Age at slaughter, which, in turn depends on growth rate, is directly related to the amount of feed an animal will consume to reach a target slaughter weight.

The fact that evaluation of carcass traits needs an animal to be sacrificed has necessitated the development of mechanisms of estimating carcass characteristics in live animals. These include ultrasound, computer tomography and magnetic resonance imaging (Turner *et al.*, 1990; McClure *et al.*, 2003). Backfat thickness is determined through ultrasound to estimate carcass leanness (Bruwer, 1992). Several studies (e.g., Hermes *et al.*, 2000; Nguyen & McPhee, 2005) show that backfat thickness measured using ultrasound predicts carcass backfat very well, however it does not replace the value of real direct carcass evaluations.

2.5.4.3. *Carcass traits*

Detailed carcass determination and evaluation is labour-intensive, costly, time consuming, and takes time before the information is analyzed, released and assimilated and used by the industry. For the stud breeder and producer, the two most important traits are Hennesy lean percentage and dressing percentage. Leaner and higher carcass weights are associated with better profit margins as the South African Meat Industry Company (SAMIC) payment is based on mass and lean content.

Water holding capacity is also important to the pig industry, although the producer is not directly paid for this trait. Meat with a lot of drip is not desirable to the consumer and some nutrients can be lost through the exudates. The measured trait for water holding capacity is drip loss. Determination of drip loss involves meticulous cutting, weighing and refrigeration before the

actual drip loss percentage can be ascertained. A strong genetic correlation between drip loss and pH has been reported (Hernandez *et al.*, 1998; Le Bihan-Duval *et al.*, 2001; Suzuki *et al.*, 2005). This is evidenced by low and high pH values observed in pale, soft and exudative (PSE) and dark, firm and dry (DFD) meats, respectively. As a result, most commercial abattoirs record pH on carcasses to estimate the quality of carcasses. A model that combines lean percentage and drip loss percentage, through drip-free lean percentage is being utilized by the South African pig industry during the marketing of carcasses.

2.5.5. Selection criteria

Economically important traits should not be left out of the breeding objective simply because they are not measured. If an ERT is not measured, information on other measurable trait(s) correlated to it can be used to predict it. Estimation of a trait's genetic value for an animal requires performance measurement, but measuring performance for all traits is sometimes not possible or expensive to implement (Falconer, 1981). Selection criteria or indicator traits are the observations or measurements utilized in the estimation of an animal's genetic value. The basis for using a measurable character as a criteria lies upon the strength of the relationship between the character and the trait targeted for evaluation. Accuracy of selection is optimized when more characters are included as criteria in the index of a trait because when sources of information are increased the accuracy of estimation is also increased (Pirchner, 1983). Table 2.1 shows the motivation for indirect selection when the trait in the breeding objective is highly correlated to a selection criterion.

Table 2.1 Motivation for indirect selection given high genetic correlation between the traits

Trait 1 (breeding objective)	Trait 2 (measured)
Has low heritability	Has high heritability
Is sex limited	Can be measured in both sexes
Is a carcass trait	Can be measured on live animals
Is expressed late in animal's life	Is expressed early in animal's life
Is expensive to measure	Is cheap to measure

2.5.6. Definition of profit

Since the goal of pig enterprises is to improve profit, the perspective from which profit should be viewed and the objective of improvement should be defined. The following are the questions, which need to be answered.

- a. Should profit be viewed from the perspective of the farmer, the industry or the consumer?
- b. Should profit be expressed per farm, per animal or per unit product?
- c. Should the objective be to
 - i. maximize profit? $(P = R - C)$;
 - ii. maximize return on investment? $(P = R/C)$; or
 - iii. minimize cost per unit product $(P = C/R)$

where, P = profit, R = return, and C = cost

The perspective should depend on who is being asked to invest in the breeding program. Goddard (1998) pointed out that these decisions only affect the relative economic weights if the profit function makes the enterprise appear to be highly profitable or if management variables have not been optimized. If profit is high, then an increase in the scale of enterprise that increases R , C , and the product, proportionately increases $y = R - C$, but not R/C . This scenario increases profit per farm but not per unit of product, while, on the other hand, the farmer benefits and the consumer does not (Goddard, 1998). Groen (1997) suggested that the derivation of economic values should be performed at farm level, where the profit is expressed per animal.

2.5.7. The profit function

To obtain maximum economic gain from selection, an expression of the breeding goal for individual animals is needed. Trait economic values at the commercial level suggest that genetic progress should be accompanied by economic progress (Tess *et al.*, 1983; De Vries, 1989; Faust *et al.*, 1993). In the past, breeding objectives were defined purely in biological terms due to lack of detailed economic assessments (Franklin, 1986). In the biological definition, costs and revenues are expressed in terms of energy and/or protein, while in the economic definition; they are expressed in terms of money (Kosgey *et al.*, 2003). The biological definition is not ideal because not all costs and revenues can be expressed in terms of energy and/or protein (Groen, 1989).

In modern day pig breeding programmes, most workers begin by formulating a profit equation (Ponzoni, 1988; Bekman & Van Arendonk, 1993; Charfeddine & Alenda, 1997). A profit function is a procedure that describes the change in net economic returns as a function of a series

of physical, biological and economic parameters (Gibson, 1992). Profit should therefore be defined as a function of additive genetic values of aggregate genotype traits. The profit function may include variables caused by management decisions but this inclusion is only necessary if the management variables interact with genetic values to determine profit (Goddard, 1998). Therefore, when genotypes affected by such management variables are compared, each should be evaluated with management decisions set to their optimum for that genotype. The profit function may be an explicit nonlinear formula, even to the extent of having an intermediate optimum (Moav & Hill, 1966; Goddard, 1998).

2.5.8. Bio-economic models

Bio-economic models have increasingly been used over recent years to calculate economic values for traits included in the breeding objective for livestock selection programmes (Jones *et al.*, 2004). The approach has been used for pigs (Skorupski *et al.*, 1995), beef cattle (Amer *et al.*, 1997), dairy cattle (Groen, 1989) and sheep (Conington *et al.*, 2000). Such models aim to effectively describe complex livestock production systems, taking into account genetic, nutritional, management and economic factors.

2.5.9. Perspective to consider economic weights

Perspectives from which to consider economic weights are: (i) the individual company selling seedstock; (ii) the industry; and (iii) the consumer. For a vertically integrated firm, where market signals are relayed from consumers to breeders, the profit can be considered from all the three perspectives (Goddard, 1998). However, market signals are not always relayed from consumers to breeders. Such a situation distorts the objectives of seedstock breeders. For the

industry as a whole, the profit function for an integrated firm is the correct basis for assessing economic weights even if market signals are not transmitted up the marketing chain (Goddard, 1998).

2.5.10. Discounting economic values

Traits in the breeding objective are not always expressed at the same time or with the same frequency. Benefits from selection that come earlier may be more valuable than benefits that are realised later. Furthermore, genes relating to the expression of traits like carcass composition will be expressed only once at the end of any one animal's lifetime, whereas genes relating to sow productivity will be expressed in every parity over an animal's entire lifetime. Therefore, when determining the relative importance of traits in the selection objective, the timing and the number of expressions of the traits should be accounted for. This is normally done by discounting the value of genetic change in future years to a net present value (Dekkers & Gibson, 1998).

The discounted gene flow method of McClintock & Cunningham (1974), gene flow (or Markov chain) methodology (Hill, 1974) or diffusion coefficients (McArthur *et al.*, 1990) can be used to achieve this. Alternatively, the feed and cash forecast budgets are calculated on an annual basis to account for the frequency of expression of traits (e.g. Ponzoni & Newman, 1989). The discounted gene flow is normally preferred; as it takes into account both the frequency and time of expression of traits (Ponzoni & Newman, 1989). The annual income and expense budget forecast method can be refined by following the consequences of genetic change for at least the lifetime of an average animal (Holmes *et al.*, 2000).

Goddard (1998) notes that, although discounting is very important to assess the total value of genetic change, it does not seem to substantially alter economic weights. The discounted gene flow method was also observed to have a small effect on economic values for Merino sheep, compared to the income and expense per year approach (Ponzoni, 1986). Ponzoni & Newman (1989) however found that, in beef cattle, discounting increased the importance of traits expressed early in the life of animals. The disparity was attributed to shorter life assumed for the Merino sheep.

2.5.11. The South African situation

Trait improvement and/or improved management are done to maximize profit and are carried out in a sustainable manner. Genetic selection in SA is done using breeding values generated by the Integrated Registration and Genetic Information Systems, managed by the Agricultural Research Council. Selection is solely on breeding values and the national herd is monitored and evaluated through the performance-testing scheme, which includes Phases B and D. Recording, monitoring and evaluation are done in these Phases, each having indices for selection. Performance testing in Phase B is done central testing stations, namely, Irene, Cedara and Elsenburg. Testing in Phase is done in farms, where farmers do not have the capacity to measure traits such as DLEAN. The index for Phase B is shown in Equation 2.1. For Phase D, the same index is used except that DLEAN is not included because carcass evaluation is not done at the farms. Where FCR is not calculated at the farms, FCR is also included in the index. The calculation of the coefficients b_1 to b_5 is not clear; hence the values of these coefficients are not readily available.

$$I = b_1 \text{AGES} + b_2 \text{FCR} + b_3 \text{BFAT} + b_4 \text{ADG} + b_5 \text{DLEAN} \quad [\text{Equation 2.1}]$$

These indices may not be ideal for profit maximization as they are not derived from economic parameters. The derivation of the coefficients of these indices is not clear. Thus, although the selection index theory was developed decades ago, it has not been convincingly practiced in South Africa (Visser, 2004). In addition, the inclusion of backfat thickness and drip-lean percentage in the same index may not be advisable since the former is an indicator of the latter, which is an ERT. Also, average daily gain and age at slaughter may not be recommended to be placed in the same index, as age at slaughter may be considered an indicator of average daily gain. When implemented properly, the Phase B and Phase D selection indices can yield positive outcomes for the SA pig industry. There is no recording of individual birth and 21-day weights because of the additional labour involved. Instead, litter weight at birth and 21 days are recorded.

2.5.12. Conclusions

To implement genetic improvement in a pig enterprise, the improvement should be related to profitability so as to justify the existence of the enterprise. The starting to achieve this is the development of a development of a goal. This is followed by the definition of a breeding objective consisting of traits which when improved will achieve the breeding goal, which are economically relevant traits. Selection criteria should then be identified as traits measurable on animals and related to the breeding goal. The lack of a clearly defined breeding goal in the South African pig industry underlines the need to develop an appropriate breeding goal to

improve the efficiency of genetic selection. Economic values for economically relevant traits aid in genetic selection programs by allowing selection for more than one trait.

2.6. Selecting for more than one trait

2.6.1. Introduction

Several traits are of economic value and they are considered for simultaneous improvement during selection (Hazel, 1943; Falconer & Mackay, 1996). Breeders are not only faced with the decision of which traits to improve, but also of the magnitude to which the chosen traits should be improved. They must decide among numerous traits of economic importance and determine whether to improve performance by a small amount in several traits or make larger amounts of improvement in fewer traits (Stewart *et al.*, 1990). When deciding on which traits to improve, the breeder should consider that returns from selection are not the same for all the traits. Selection intensity is the limiting factor in selection programs, thus the breeder should decide how many traits to improve and how much selection pressure to apply on each trait. One trait may be improved by a large magnitude by applying all the selection intensity to it. On the other hand, several traits may be improved to a lesser degree by spreading the selection pressure among them.

Since returns from selection take time to be realized, selection programs should aim to achieve the breeding goal for the future. This is enhanced by the fact that genetic progress is cumulative and permanent. The main purpose of selection in livestock breeding is to achieve maximum genetic progress toward a stated economic goal (Du Plessis & Roux, 1998, 1999) or to improve

the net merit (Weigel *et al.*, 1995; Wilton *et al.*, 1998), economic efficiency (Dekkers, 1991) or the aggregate breeding value of animals (Kluyts, 2004). The aggregate breeding value represents a fundamental concept, the breeding objective, which is seldom fully implemented in livestock breeding (Harris & Newman, 1994). The most important aspect of this response should be the economic importance of the genetic change. Since there are several traits to improve, the breeder should decide which traits deserve the most improvement. Cognizance must be taken of the fact that as the number of traits chosen for selection increases, the genetic change in each trait decreases (Hazel & Lush, 1942). For a given number of traits selected for, expected response is $\frac{1}{\sqrt{n}}$, where n is the number of traits. It is, therefore, of paramount importance to identify those traits, that when improved, will result in the greatest economic gain for the enterprise.

2.6.2. Selection methods

After deciding on the traits to be measured, the breeder has different selection methods at his disposal to choose from. The disadvantage of tandem selection is that some animals that may be closely aligned to the breeding objective may not be selected because the animal may be inferior to other animals for the current selection criterion (Hazel & Lush, 1942). Furthermore, response is sporadic as greatest response occurs during those generations when the trait is selection criterion. Negative correlations among traits may result in cancellations of genetic progress achieved in some traits. This necessitates the use of a method that attempts improvements on several traits simultaneously. In independent culling levels, any animal not satisfying the minimum standard for any one trait is culled. In this method, varying emphases can be placed on the traits. One major drawback is that an animal that has superior performance in one trait, but only average performance in another may be culled. Although the initial identification of traits

involves economic importance of traits, the actual selection criteria are not integrated with their respective economic values. Young (1961) found that relative efficiency of a selection method depends upon the number of traits selected, relative economic values of the traits, heritabilities, phenotypic and genetic correlations between traits, and selection intensity. Index selection has been described as the best method of selection for multiple traits (Hazel & Lush, 1942).

2.6.3. Index selection

Index selection permits extra merits in one trait to offset deficiencies in other traits (Hazel & Lush, 1942), which is not the case with other methods of selection. Index selection entails the calculation of a type of total score, where the net values of all measured traits are combined into a single index value. The heritabilities of traits, correlations among traits and the respective values for each trait are used in the development of an index. An index value is calculated based on the animal's performance and/or its relatives for each trait. Animals are then selected based on how they rank on the index value. The index value is an estimate of the cumulative value, e.g., the Rand (R) value of the animal's genetic potential of all traits in the objective. In index selection, all traits are improved simultaneously and differential emphasis can be placed on each trait based on heritability and economic value. Selection indexes are well-suited to periodic recalculation providing a logical framework for non-linear relationships between profit and performance or other changes in economic conditions (Hazel *et al.*, 1994). Periodic recalculation of linear indexes will apparently compensate for non-linear relationships of profit and economically important traits with little loss in efficiency of selection (Groen *et al.*, 1994). Therefore, the selection index is the best way to maximize efficiency of selection while utilizing all parameters affecting profitability.

2.6.3.1. The classical approach

The classical method of selection index construction was developed by Hazel (1943). Weightings on selection criteria are determined by setting up and solving the selection index equations. Van Vleck (1993) provided a summary of constructing a classical selection index. If animal i has t traits with linear economic value, then the overall or aggregate economic value can be defined as:

$$T_i = v_1 BV_{i1} + v_2 BV_{i2} + \dots + v_t BV_{it} = \sum_{j=1}^t v_j BV_{ij} = \mathbf{v}' \mathbf{a}_i \quad [\text{Equation 2.2}]$$

where,

BV_{ij} = breeding value of animal i for trait j ;

v_j = economic value per unit of trait j , $j = 1, \dots, t$

$\mathbf{a}_i$ = a vector of breeding values for animal i for traits in T (i.e., $BV_{i1}, \dots, BV_{it}$) and

$\mathbf{v}$ = a vector of economic values for traits in T (i.e., $v_1, \dots, v_t$).

If records are available for m traits measured on the animal i to be evaluated $\{X_{i1}, X_{i2}, \dots, X_{im}\}$, the problem would be to weight each record to estimate T_i with an index of the traits, i.e.

$$\hat{T} = I = \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_m X_{im} = \mathbf{b}' \mathbf{x}_i \quad [\text{Equation 2.3}]$$

where β_k is the weight for measured trait k which will maximize the correlation of I_i with

T_i (r_{TI}) ($k = 1 \dots m$), $\mathbf{b}'$ is a vector of selection index weights (i.e. index coefficients $\beta_1 \dots \beta_m$)

and $\mathbf{x}_i$ is a vector of phenotypic records on animal i (i.e. $X_{i1} \dots X_{im}$), expressed as deviations from

contemporary group means and adjusted for non genetic effects. The following equation provides solutions to the index coefficients.

$$\mathbf{Pb} = \mathbf{Qv} \quad [\text{Equation 2.4}]$$

where,

$\mathbf{P}$ is the $m \times m$ matrix of phenotypic variances and covariances among the measured traits

$\mathbf{Q}$ is the $m \times t$ matrix of genetic covariances between the m measured traits and the t traits in the aggregate genotype

$\mathbf{b}$ and $\mathbf{v}$ are vectors of m index weights and t economic values respectively, as defined previously.

Index weights are obtained by re-arranging the equation [2.4] as follows:

$$\mathbf{b} = \mathbf{P}^{-1}\mathbf{Qv} \quad [\text{Equation 2.5}]$$

This approach has some shortcomings as pointed out by Bourdon (1998). Firstly, it lacks accuracy because it does not contain information on relatives and secondly, it is biased because genetic differences among contemporary groups are not accounted for. Thus, there have been some refinements to this classical approach.

2.6.3.2. *Refinements to index selection*

In most selection programs, traits that are selected for differ in variability, heritability, correlation with others and economic merit (Hazel, 1943). The initial work on index selection was pioneered by Hazel (1943) and his plans were, (i) the purpose of index selection should be to

achieve maximum genetic progress toward a stated economic goal; and (ii) economic return to the livestock enterprise should be of primary importance. Thus, any genetic change that would be achieved should be of some economic value to the enterprise. Gain from change in all individual traits included could be summed into improvement in aggregate genotype as:

$$\Delta H = \sum_{i=1}^n a_i \Delta G_i \quad [\text{Equation 2.6}]$$

where, H is the aggregate breeding value, a_i is the economic weight for trait i , and G_i is the breeding value for trait i .

A restricted selection index was developed by Kempthorne & Nordskog (1959), where some traits can be designed to change while holding the response in other traits constant. The optimum selection index was an extension to the restricted selection index (Tallis, 1962). It was implemented by setting the response in some traits by a fixed amount while maximum genetic progress is achieved in others. An extreme case of Tallis's optimum selection index is to control the relative gains in all traits incorporated in the index. The Smith-Hazel index deals with the aggregate genotype as a single trait and provides no control over its components. On the other hand, a restricted selection index provides a way to manipulate genetic changes in component traits. While most selection indexes are developed before selection begins, the index in retrospect is obtained after the conclusion of selection (Dickerson *et al.* 1954). Williams (1962) proposed the base index, which is the sum of the products of economic weights and phenotypic values for each trait. The disadvantage with this index is that it does not take into account the

inheritance of the trait or the genetic and phenotypic associations. It is for this reason that the base index is not as efficient as the Smith-Hazel index.

2.6.3.3. *Indices based on estimated breeding values*

Henderson (1951) divided the construction of the selection index into two steps, which are given in the following summary. First, estimation of breeding values (EBV) for breeding objective traits is done. However, in practice, observations of many breeding objective traits are not available. This may be attributed to the difficulties of measuring or being too expensive to measure with existing technology. Prediction of the breeding value for a trait can be done in a multi-trait analysis using the measured traits with which it is correlated. Another possibility is the one suggested by Schneeberger *et al.* (1992), where the EBV for an unobserved trait can be calculated as a linear function of EBV for the selection criteria. Estimated breeding values for the measured traits (selection criteria) are combined to calculate EBV for the objective traits, each selection criteria EBV being weighted by coefficients derived as follows (Schneeberger *et al.*, 1992; Gibson, 1995):

$$\mathbf{b} = \mathbf{G}_{11}^{-1} \mathbf{G}_{12} \mathbf{v} \quad [\text{Equation 2.7}]$$

where, $\mathbf{G}_{11}$ is the genetic variance-covariance matrix of the measured traits; $\mathbf{G}_{12}$ is the genetic covariance matrix between the measured traits and the objective traits.

The calculation of the index value (I) is given by Henderson (1963) as:

$$I_i = v_1EBV_{i1} + v_2EBV_{i2} + \dots + v_tEBV_{it} = \mathbf{v}'\hat{\mathbf{a}}_i \quad [\text{Equation 2.8}]$$

where,

I_i = estimated aggregate economic merit of an animal, i , as a parent

EBV_{ij} = EBV of animal i for breeding objective trait j

$\hat{\mathbf{a}}_i$ = vector of EBV for animal i for traits in the objective.

$\mathbf{v}$ = vector of economic values

In other words, genetic predictions can simply be substituted for true breeding values in the breeding objective. In some cases, if an objective trait is not measured, calculation of its EBV may be dispensed with by accounting for the trait when determining the economic values of traits with which it is closely associated. For example, in New Zealand, feed intake is incorporated by accounting for the feed costs associated with higher productivity when the economic value of the milk revenue or beef revenue traits is assessed (Holmes *et al.*, 2000).

Wilton (1982) suggested that, in practice, replacement of genetic predictions from multiple-trait evaluations with corresponding predictions from a series of single-trait evaluations may be an adequate approximation. Thus, calculating selection index weights and applying them to the available BLUP of breeding values may be a starting point from which to implement genetic evaluation for profitability (MacNeil *et al.*, 1997).

2.6.3.4. *Response to selection and economic return*

In any breeding program where genetic selection is applied, genetic progress is expected on traits on which selection is applied and correlated traits. In the original classic approach, response to selection can be estimated as described by Gibson (1995).

$$\mathbf{R} = i \frac{\mathbf{b}'\mathbf{G}}{\sqrt{\mathbf{b}'\mathbf{P}\mathbf{b}}} \quad [\text{Equation 2.9}]$$

$$\mathbf{R} = i \frac{\mathbf{b}'\mathbf{G}}{\sqrt{\mathbf{b}'\mathbf{G}\mathbf{v}}} \quad [\text{Equation 2.10}]$$

where, i is the selection intensity, $\mathbf{b}$ is the vector of index weights; $\mathbf{G}$ is the genetic covariance matrix between breeding objective traits and selection criteria; $\mathbf{P}$ is the phenotypic variance-covariance matrix for selection criteria and $\mathbf{v}$ is the vector of economic values.

Groen (1990) proposed the calculation of response to selection ($\mathbf{R}$) from an index based on EBVs as follows:

$$\mathbf{R} = i \frac{\mathbf{a}'\mathbf{G}}{\sqrt{\mathbf{a}'\mathbf{G}\mathbf{a}}} \quad [\text{Equation 2.11}]$$

where, $\mathbf{G}$ is the variance-covariance matrix for breeding objective traits and $\mathbf{a}$ is the vector of economic weights. This formula works when breeding objective traits and selection criteria are similar.

When breeding goal traits are different from selection criteria, Schneeberger *et al.* (1992) proposed the calculation of genetic progress based on genetic and phenotypic matrices. Genetic responses (**d**) for selection criteria are then computed as:

$$\mathbf{d} = \frac{(\mathbf{Var}(\hat{\mathbf{u}}))\mathbf{b}}{\sqrt{s_I^2}} \quad [\text{Equation 2.12}]$$

where, $\mathbf{Var}(\hat{\mathbf{u}})$ is an approximation of the variance-covariance matrix of the EBVs, **b** are the index weights, s_I^2 is the variance of the index. Genetic responses (**n**) for breeding goal traits are computed as follows:

$$\mathbf{n} = \frac{(\mathbf{G}_{21}\mathbf{G}_{11}^{-1})(\mathbf{Var}(\hat{\mathbf{u}}))\mathbf{b}}{\sqrt{s_I^2}} \quad [\text{Equation 2.13}]$$

where, $\mathbf{G}_{21}$ is the genetic covariance matrix between breeding objective traits and selection criteria, $\mathbf{G}_{11}$ is the genetic variance-covariance matrix for selection criteria,

Economic return is obtained by multiplying genetic responses for breeding goal traits by their respective economic values and summing them (Wolfova *et al.*, 2007b; Banga, 2009). Schneeberger *et al.* (1992) partitioned each one dollar increase in the index into cents contributed by change in each selection criteria by multiplying the change in each index trait by its index weight. They also partitioned each one dollar increase in the objective into cents contributed by change in each of the traits in the breeding objective by multiplying the change in the objective trait by its economic value.

2.6.3.5. *Limitations of index selection*

Selection may decrease or increase genetic variation depending on initial gene frequencies. This suggests that as heritability of the index nears zero, no selection is possible. Restricted selection indices have been criticized for severe potential losses of economic gain (Gibson & Kennedy, 1990). The induction of negative correlations among favorable traits during the application of index selection will reduce genetic progress. One major feature of the unrestricted selection index is that it has no control over the component traits. Thus, a plateau or zero genetic change may occur in index selection when gains in some component traits are balanced by losses in others, thereby leading to zero change in net merit (Lin, 1978).

Response to selection depends on genetic variability within a population, suggesting that selection should reduce the magnitudes of genetic parameters in the long run. The more efficient the selection index, the faster the percent reduction in the genetic variance can be expected in subsequent generations (Lin, 1978). The changes of the genetic parameter estimates due to selection may justify the reconstruction of the index (Lin, 1976). Therefore, the selection index should be a dynamic index and not a static one. Williams (1962) labeled the Smith-Hazel index as an *estimated index* since phenotypic and genetic parameters are never known and thus the index has to be derived by use of sample estimates. Therefore, its efficiency may be compromised.

Economic values may change from time to time or vary from one location to another, suggesting the necessity of reconstructing the index to handle the economic changes. Changes in economic values signify a change in net merit, the selection goal, thereby reducing the overall selection

gains (Lin, 1978). For most cases the idea of weighting factors is reasonable, but sometimes it is unacceptable (Strandberg & Malmfors, 2006). For example, a boar that has problems to stand on its feet should not be selected regardless of how good its index value might be. In this case, the option might be to combine index selection and independent culling levels.

2.6.4. Conclusions

Development of breeding objectives allows the efficient application of selection practices, which are targeted to traits that affect profitability. This is facilitated by the integration of economic parameters and genetic parameters into selection indices, which ensures the application of appropriate selection pressures on economically relevant traits. Despite being highly recommended and utilized in other countries, integration of genetic and economic parameters in breeding programs has not been implemented in the SA pi industry. Thus, derivation of economic values and development of selection indices have not been done properly. To properly develop a breeding program, non-genetic should be identified and evaluated, which will be used in the estimation of genetic parameters. Economic values need to be derived, which will be combined with genetic parameters to develop economic selection indices.

Chapter 3

Non-Genetic Factors Affecting Sow Productivity Traits

3.1. Introduction

Sow productivity is the primary factor affecting a pig production enterprise, as it determines the number and weight of piglets born. Thus, sow productivity influences the number of animals surviving to weaning and ultimately, marketing (Rehfeldt & Kuhn, 2006). In this regard, enterprise productivity depends on the efficiency of reproduction of sows in the herd. Sow productivity therefore affects the efficiency and economic viability of the pig industry and is a leading concern of commercial producers and breeders (Kim, 2001). Several factors affect the performance of sows and these include non-genetic factors, which need to be optimized to maximize production efficiency.

Management, which is specific for a given herd, has been reported as affecting sow productivity in several studies (Ashenhurst, 1983; Koketsu & Dial, 1998; Aherne, 2002; Lawlor & Lynch, 2007). In essence, management is a composite factor consisting of factors that include feeding and breeding practices. The fact that in most pig operations gilts have the highest proportions (Schukken *et al.*, 1994), suggests the importance of their non-productive period in the herd. Thus, the age first service of the gilts is of paramount importance. The productive life of a sow should be ascertained to identify the level of productivity according to parity, which has been shown affect sow productivity (Yen *et al.*, 1987; Mungate *et al.*, 1999). Sow reproductive performance is related to its physiological condition, which in turn, depends on several factors.

Thus, age at service reflects the physiological conditions of the sow at the time of service, hence affects subsequent reproductive performance.

Since animal breeding programs select animals based on their genetic merit, adjustments should be done for non-genetic effects in these programs. In South Africa, information on non-genetic factors affecting sow productivity is lacking, necessitates the need to identify these factors as they play an important role in genetic evaluation of pigs. Therefore, the objective of this study was to identify non-genetic factors affecting sow productivity in South African Large White pigs.

3.2. Materials and Methods

3.2.1. Data

The study was conducted on South African Large White sows from 29 herds across the country, and the distribution of this data across parities is shown in Table 3.1. Data used in the analysis were obtained from the Integrated Registration and Genetic Information System (INTERGIS) of South Africa. Pedigree information was obtained from the Large White breed society. The study was to evaluate sow productivity and the traits were treated as traits of the dam. The original data set comprised of 47578 records on 15359 sows. After removing missing farrowing dates, the data were then edited by removing, (i) records that were greater or less than three standard deviations from the mean, and (ii) contemporary groups with less than five animals and/or with less than two sires to ensure connectedness. Contemporary groups were created by concatenating herd, year and season of farrowing. Two seasons of service considered were,

summer (October to March) and winter (April to September). The final data set comprised of 29719 records on 7983 sows from 29 herds, 1189 sires and 3857 dams, which farrowed between 1990 and 2008. Therefore, 17859 records were deleted during editing.

Table 3.1 Distributions of sows, sires, dams, herds, contemporary groups and litter size across parities

Parity	Sows	Sires	Dams	Herds	HYS	Litter size
1	7983	1189	3857	29	330	9.71
2	6281	1122	3344	28	326	10.41
3	4773	1024	2785	28	316	11.07
4	3542	924	2193	26	294	11.24
5	2549	797	1721	26	269	11.24
6	1792	658	1293	25	243	11.10
7	1204	503	907	24	218	11.00
8	801	394	625	22	190	10.76
9	448	275	366	19	138	10.64
10+	346	153	196	13	103	10.27

HYS – herd, year and season of farrowing contemporary group

3.2.2. Traits

The traits analyzed were number born alive (NBA), litter weight at birth (LBWT), 21-day litter size (D21LS), 21-day litter weight (D21LWT) and inter-farrowing period (IFP). Number born alive is the number of live piglets born and LBWT is the total weight of live piglets at birth.

Twenty-one-day litter size is the number of piglets that reach 21 days of age and the total weight of these piglets is D21LWT. These 21-day traits were adjusted to 21 days of age. The number of days between successive farrowings is the IFP. The summary statistics for these traits are contained in Table 3.2.

Table 3.2 Summary statistics for sow productivity traits and covariates

Trait	Records	Mean	Min	Max	SD
NBA (pigs)	29719	10.46	4.00	16.00	2.42
LBWT (kg)	29719	15.24	6.00	28.00	3.48
D21LS (pigs)	21317	8.50	4.00	13.00	1.70
D21LWT (kg)	21317	47.50	19.00	76.00	11.07
IFP (days)	21518	200.00	123.00	277.00	18.85
AGS (days)	29719	775.37	286.00	1631.00	265.90

NBA – number born alive; LBWT – litter birth weight; D21LS – 21-day litter size; D21LWT – 21-day litter weight; IFP – inter-farrowing period; AGS – age at service

3.2.3. Statistical analyses

The data were checked for normality and the significant effects were determined using the GLM Procedures of SAS (SAS, 2003), to get the final model for each trait. Effects of interactions between independent variables were also determined. The covariate included was age of sow at service (AGS). Equation 3.1 was used in the development of models.

$$y_{ijklm} = \mu + H_i + P_j + Y_k + S_l + \beta_0(AGS)_{ijklm} + \beta_1(AGFS)_{ijklm} + C_x C_y + e_{ijklm} \quad [\text{Equation 3.1}]$$

where, y_{ijklm} is the observed trait, μ is the population mean, H_i is the effect of the i^{th} herd of origin, P_j is the effect of the j^{th} parity, Y_k is the effect of the k^{th} year of service, S_l is the effect of the l^{th} season of service, β_0 and β_1 are the regression coefficients of the observed trait on the respective covariate; $(AGS)_{ijklm}$ is age of sow at service and $(AGFS)_{ijklm}$ is the sow's age at first service. $CxCy$ represents two-way interactions between independent class factors fitted in the model and the e_{ijklm} is the random error term.

3.3. Results and Discussion

3.3.1. Effect of herd of origin

Herd of origin affected ($P < 0.001$) all traits. The summary of the least squares means for the herds are shown in Table 3.3. Different managements and environments may be responsible for the differences observed between herds. Lawlor & Lynch (2007) suggested that one of the factors to consider in management is gilt management and selection. More gilts are served and farrowed than sows of any other parity (Lawlor & Lynch, 2007). Therefore, if gilt litter size is low, the average born alive for the herd will be reduced. In addition, maximizing the litter size in gilts will maximize lifetime performance (Dewey *et al.*, 1995; Aherne, 2002). Sow feeding is another important management factor that affects sow performance (Aherne, 2002; Kongsted, 2005). These authors pointed the importance of different feeding programmes for different production stages, including different gestation stages. In this study, however, information on feeding management of sows was not available. Lactation length also has an effect on the subsequent litter performance (Lawlor & Lynch, 2007). If weaning is done earlier than 28, uterine involution may not be complete, thus reducing the subsequent litter size (Koketsu & Dial,

1998). Each day increase in the farrowing to conception interval (less than 36 days) is responsible for a subsequent increase in number born alive of up to 0.09 pigs (Clark *et al.*, 1988). Aherne (2002) furthermore noted that stress or movement of sows before implantation reduces farrowing rates and lower litter sizes. In this regard, Lawlor & Lynch (2007) suggested that sows should be moved from the service area to their gestation quarters either within the first 72 hours post-breeding or at least 28 days after breeding. Ashenhurst (1983) pointed out that, over- or under-using boars is likely to reduce litter size. Since there are many management factors considered, it is unlikely that all herds across the country adopt similar management strategies. Differences due to herd of origin may thus be attributed to different management practices.

Table 3.3 Summary of the least square means for the different herds of origin

	No of herds	N	Overall mean ($\pm$ s. e.)	n	Min ($\pm$ s. e.)	n	Max ($\pm$ s. e.)
NBA (pigs)	29	29719	10.21 $\pm$ 0.003	963	9.05 $\pm$ 0.291	481	11.07 $\pm$ 0.314
LBWT (kg)	29	29719	14.70 $\pm$ 0.009	131	11.87 $\pm$ 0.511	145	18.46 $\pm$ 0.502
D21LS (pigs)	29	21317	9.07 $\pm$ 0.003	372	8.30 $\pm$ 0.214	824	10.26 $\pm$ 0.201
D21LWT (kg)	29	21317	49.93 $\pm$ 0.043	1484	39.45 $\pm$ 1.350	818	77.12 $\pm$ 1.693
IFP(days)	29	21518	153.94 $\pm$ 0.025	3324	146.01 $\pm$ 1.563	123	160.00 $\pm$ 2.022

N – total number of sows in all herds; n – number of sows in the herd; NBA – number born alive; LBWT – litter birth weight; D21LS – 21-day litter size; D21LWT – 21-day litter weight; IFP – inter farrowing period

3.3.2. Effect of year of farrowing

Year of farrowing affected ($P < 0.001$) all traits and the results are shown in Figures 3.1a to e. There have been improvements in litter traits at birth through years of farrowing. An increase was observed in D21LS from 1991 to 1997, after which the trend was indiscernible. There was an increase in D21LWT until 1993, which was followed by a decrease until 1996, and then there was an increase. Deterioration in IFP was observed from 1991 until 2007. Peltoniemi *et al.* (1999) also observed the effect of year on rebreeding rate in Finnish sows. Climatic variations from year to year may have caused the observed trends. Also, genetic changes due to selection may be responsible for the improvements in most of the traits.

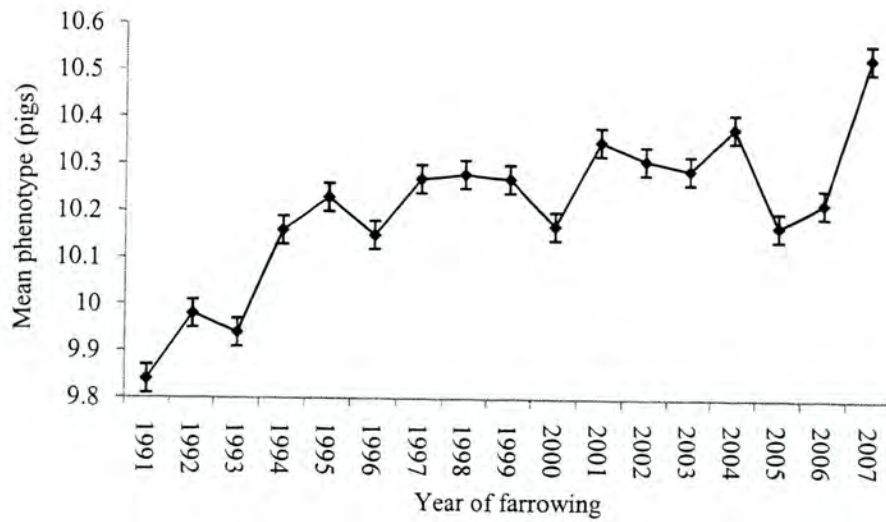


Figure 3.1a Phenotypic trend for number born alive

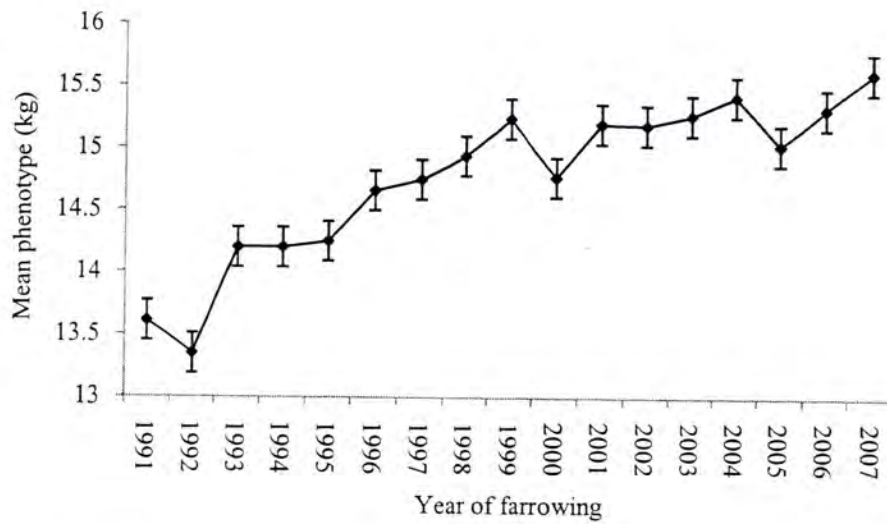


Figure 3.1b Phenotypic trend for litter birth weight

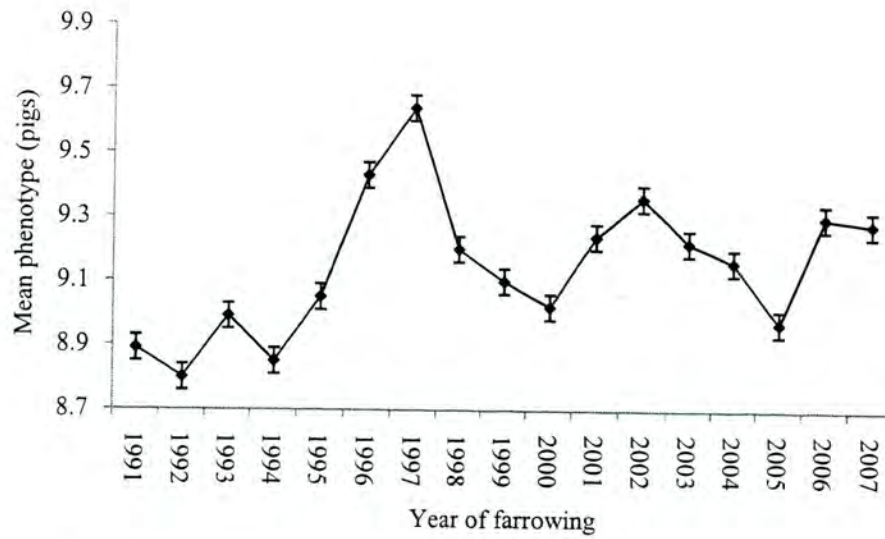


Figure 3.1c Phenotypic trend for 21-day litter size

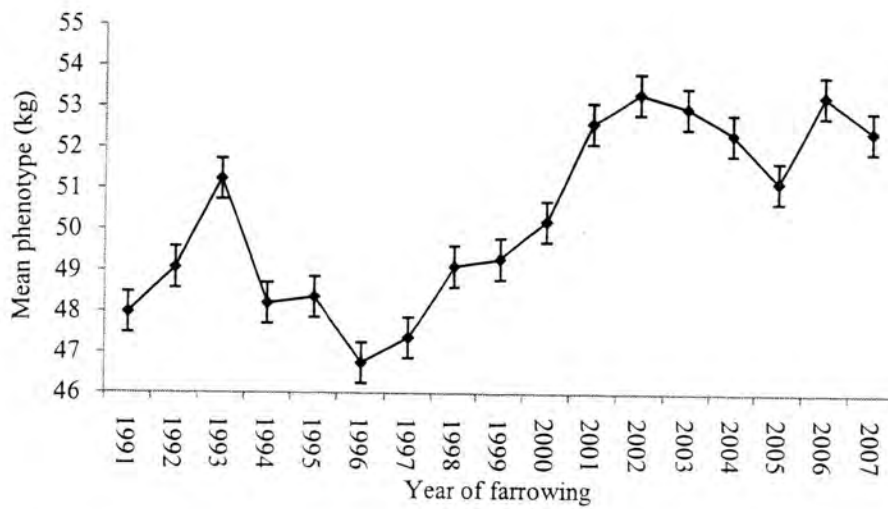


Figure 3.1d Phenotypic trend for 21-day litter weight

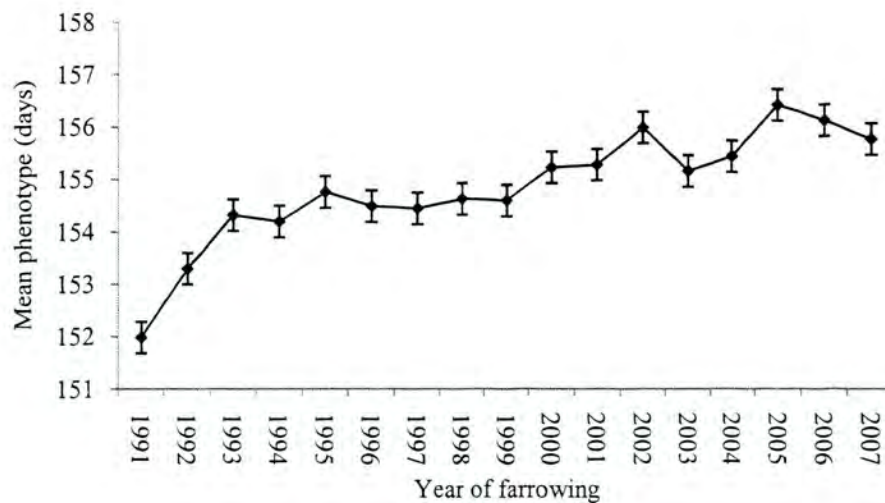


Figure 3.1e Phenotypic trend for inter-farrowing period

3.3.3. Effect of season of farrowing

Table 3.4 shows the effect of season of farrowing on sow productivity. Significant effects ($P < 0.001$) of season on sow productivity were observed. Seasonal infertility in the domestic sow has been recognized as a potential economical loss to the pig industry (Peltoniemi *et al.*, 1999). Sows served in during summer had higher litter sizes and weights at birth and 21 days. No differences ($P > 0.05$) due to season were detected in IFP. Mungate *et al.* (1999) also observed that sow performance was higher during the summer months. The effect of season on litter size and weight is consistent with Dominguez *et al.* (1996), but contradicts some studies (Xue *et al.*, 1994; Love *et al.*, 1995; Peltoniemi *et al.*, 1999). Seasonal effects on 21-day litter weight may be attributed to lower voluntary feed intake of the sow in summer due to high temperatures, which reduces milk production.

Alternatively, this could be caused by seasonal variation in prolactin secretion as has been shown to occur in the wild pig (Mauget, 1982). Farrowing rate, weaning-to-estrus interval and age of

puberty in gilts have been reported to be influenced by season (Love *et al.*, 1993; Prunier *et al.*, 1996). Peltoniemi *et al.* (1999) identified late summer and early autumn as the seasons when these reproductive parameters consistently show the lowest values, indicative of a 'seasonal infertility period' in Europe. Changing photoperiod is thought to provide the primary cue for determining the season when reproductive activity is most appropriate (Love *et al.*, 1993). The role of temperature in seasonal infertility has been reported previously (Love *et al.*, 1993; Prunier *et al.*, 1997; Boma & Bilkei, 2006). From these studies, it seems likely that temperature is second to photoperiod in significance as a causative factor in seasonal infertility. The effect of temperature may be plausible in the current study, where summer is characterized by high temperatures which reduce voluntary feed intake, thereby affecting the fertility of the sow. The effect of season should not be limited to the fertility of the sow. Both photoperiod and temperature have been shown to affect fertility of the boar, where boars had decreased steroid synthesis, sperm counts and libido in summer compared to winter (Stone, 1982; Claus & Weiler, 1985). In this study, to maximize on sow performance, farrowing should be done in winter.

Table 3.4 Least squares means for the effect of season of farrowing

	N	Summer	N	Winter
NBA	14397	10.12 ^a ±0.282	15322	10.30 ^b ±0.823
LBWT	14397	14.41 ^a ±0.398	15322	15.00 ^b ±0.401
D21LS	14397	8.97 ^a ±0.191	15322	9.18 ^b ±0.188
D21LWT	14397	49.16 ^a ±1.323	15322	50.70 ^b ±1.322
IFP	14397	154.18 ^a ±1.564	15322	153.82 ^a ±1.560

Means with different superscripts are significantly different at $P < 0.001$; NBA – number born alive; LBWT – litter birth weight; D21LS – 21-day litter size; D21LWT – 21-day litter weight; IFP – inter farrowing period

3.3.4. Effect of age at service

The effects of age at service on sow productivity are in Table 3.5. Quadratic relationships for AGS with NBA, LBWT and IFP were observed. No effect ($P > 0.05$) AGS was observed on the 21-day traits. As the square of AGS increased by 0.15 days, there was a corresponding increase of one piglet in NBA. A one-kg increase in LBWT was a result of an increase of 0.27 days in the square of AGS. Also, an increase of 1.259 days in the square of AGS was associated with a one day increase in IFP. Clark *et al.* (1988) also reported the effect of age at conception on sow's reproductive performance of North American pigs. Age at service is related to the state of readiness for reception of embryos of the sow's uterus, thus its effect is observed on litter birth traits. Uterine involution after pregnancy also determines how much time will be taken until the uterus is ready for the next litter, thus affecting IFP. Costa *et al.* (2004) and Lawlor & Lynch (2007) attributed the state of uterine involution to lactation length, suggesting uterine involution will not be complete in sows where lactation is short, such as, 21 days. For this reason, sows

weaned at 21 days or less might have a reduction in litter size at the subsequent farrowing (Koketsu & Dial, 1998). Each day increase in the farrowing to conception interval (less than 36 days) is responsible for a subsequent increase in number born alive of up to 0.09 pigs (Clark & Leman, 1987). Koketsu & Dial (1997) observed that as lactation length increased, weaning-to-first-service interval and weaning-to-conception interval decreased, and litter weaning weight increased. In addition, longer lactation length and farrowing-to-conception interval were associated with larger subsequent litter size (Koketsu & Dial, 1997). Increasing the farrowing-to-conception period increases AGS in the next litter, hence IFP is also increased. Despite being associated with improvements in NBA and LBWT, increasing AGS has the effect of deteriorating IFP. Therefore, keeping old sows in the herd may increase the inter-farrowing periods, hence increasing generation intervals and slowing down herd improvement.

Table 3.5 Effects of age at service on sow productivity traits

	AGS	AGS ²
NBA***	0.007±0.0001	0.015±0.0001
LBWT***	0.013±0.0001	0.027±0.0001
D21LS	ns	ns
D21LWT	ns	ns
IFP***	0.630±0.0103	1.259±0.0205

*** P < 0.001; LBWT – litter birth weight; D21LS – 21-day litter size; D21LWT – 21-day litter weight;

IFP – inter farrowing period; AGS – age at service; ns – not significant

3.3.5. Interaction effects

The interactions observed in this study were: (i) herd of origin $\times$ year of farrowing; and (ii) herd of origin $\times$ year of farrowing $\times$ season of farrowing. This was contemporary group effect and shows that management varied from one herd to another over the seasons of years, which is not surprising since the herds originated from all over the country. Optimal management conditions, dictated by the local climate differ from one part of the country to another and from to year. No other interaction was observed in this study. Contrary to this, some studies, (Love *et al.*, 1995; Peltoniemi *et al.*, 1999) reported an interaction between management and season, which showed that certain management practices were peculiar to a particular season. Therefore, management practices seem to vary from herd to herd, as years progress, probably due to changing climatic and economic conditions.

3.4. Conclusions

All sow productivity traits were generally affected by herd of origin, year and season of farrowing. The results indicate that different management practices exist in different herds, which are consistent from season to season, but not from year to year. Superior in sow performance was observed in winter, which may be attributed to photoperiod and ambient temperature. The increasing litter birth weight and size as sows grew older suggests keeping sows for longer in the breeding herd. For genetic evaluation of sow productivity to be a success, these non-genetic factors should be adjusted for during the estimation of genetic parameters for sow productivity.

Chapter 4

Non-Genetic Factors Affecting Growth and Carcass Traits

4.1. Introduction

The value of a meat animal is realized when its product is marketed and expressed relative to the input costs incurred. Growth and its associated traits in pigs reflect to a certain degree the value of the animal; hence live measurements can be used to evaluate an animal. Valuable pigs are the ones which from each unit of food energy, waste least in such processes as, digestion and physical activity and retain most by favouring conversion of metabolizable energy to lean than conversion to fat tissue (Webster, 1977). This has desirable implications on enterprise profit, as feed constitutes a large portion (60 – 70 %) of pig enterprise costs (Hoque *et al.*, 2007). Thus, pig characteristics that are positive for profitability are high growth rate, low food conversion ratio and low carcass fatness (McPhee & MacBeth, 2000). Improvement has been achieved in some breeding programs through selection for lean growth rate (McPhee *et al.*, 1991; Cameron, 1994).

Success of these breeding programs is facilitated by the variation that exists in growth and carcass traits in pigs. This variation can be partitioned into genetic and environmental components. Environmental variance, albeit not transferable from parent to offspring, plays an important part in the performance of livestock and their products. Knowledge of non-genetic factors helps in standardizing management of the breeding animals. Some non-genetic effects, such as, farm, sex and age on growth and carcass traits have been reported in literature for sheep (Cassady *et al.*,

2004), pigs (Serrano *et al.*, 2008), goats (Maghoub *et al.*, 2004) and cattle (Nephawe *et al.*, 2006). It is therefore imperative that non-genetic factors be considered in livestock improvement programs in order to accurately estimate breeding values.

Therefore, proper identification and estimation of non-genetic effects on growth and carcass traits being evaluated is a necessity in pig improvement schemes. In South Africa, there is a paucity of information on non-genetic factors affecting growth performance and carcass characteristics of centrally tested pigs. The purpose of this study was to evaluate the non-genetic effects on growth and carcass traits in South African Large White pigs.

4.2. Materials and Methods

4.2.1. Pig management

The South African Pig Performance Testing Scheme is conducted to extend and improve the national pig herd by means of scientifically founded and proven methods and practices. Performance testing occurred throughout the year on castrates and females, such that at any point in the year there were animals being tested. The animals were tested and slaughtered at three testing centres, namely Irene, Elsenburg and Cedara. Records available from performance testing are for Phases B and D. Phase B testing is the central boar and gilt performance and carcass quality test phase, conducted at the three testing centres. On the other hand, Phase D is the on-farm testing of pigs.

Under the Phase B, every year each member submitted 44 pigs (22 boars and 22 gilts) for testing. These 44 pigs represented a minimum of five herd sires per breed or line, or 50 % of the herd sires per breed or line, whichever was the greatest. On arrival, pigs were treated for internal and external parasites and quarantined under the supervision of the responsible State veterinarian, were individually penned on solid concrete floors and fed until they commenced testing at 27 kg. During the test period, animals were individually housed and fed *ad libitum* using individual self-feeders and water was also available *ad libitum* from nipples. The feed was provided in pellet form and was compiled as shown in Table 4.1.

Total feed intake from the beginning of the test to 86 kg was calculated at the end of the test period. Parameters of growth rate, feed consumption and age at slaughter (86 kg) were measured on these animals. Backfat measurements were taken using a Backfat Scanner A100 probe at 77 kg and at slaughter (86 kg) at the T23 position, which was the position that is 6.5 cm from the midline between the second and third last rib. Weighing during the test period was done weekly without any change in the feeding routine and performance testing was completed at a live weight of 86 kg. The Phase D scheme involves on-farm performance testing of boars and gilts, measuring growth rate, ultrasonic backfat measurements and, where possible, feed intake and feed conversion ratio.

Table 4.1 Composition of the diet

Item	Content
Yellow maize meal (%)	67.00
Wheaten bran (%)	10.44
Fish meal (%)	12.50
Soyabean oil cake meal (%)	5.46
Mono calcium phosphate (%)	0.23
Limestone powder (%)	0.37
Salt (%)	1.00
Molasses (%)	3.00
Vitamins and minerals premix (%)	0.15
Synthetic Lysine (%)	0.15
Chemical composition*	
Protein (g/kg)	18.0
Lysine (g/kg)	1.1
Fibre (g/kg)	6.0
Ca (g/kg)	0.80
P (g/kg)	0.70
Biotin (mg/kg)	0.13
Manganese (mg/kg)	52
Copper (mg/kg)	10
Zinc (mg/kg)	120
Iron (mg/kg)	171
Iodine (mg/kg)	0.2
Energy (DE) MJ/kg	14
Fat (%)	4.0

* figures on air dry basis

4.2.2. Measurements

Pigs were weighed weekly during the test period without any change in the feeding routine and feed consumption was determined by calculating the difference between total feed supplied and the remaining feed in a week. The pigs from the performance testing scheme (Phase B) were randomly selected for carcass evaluation. Age at slaughter (86 kg) was recorded on these pigs. Backfat measurements were taken using a Backfat Scanner A100 probe at slaughter, 6.5 cm from the midline between the second and third last rib (T23 position). At the completion of the test, the animals were electrically stunned with 250V for 7-10 sec before exsanguinations at the various abattoirs and various measurements were taken on the carcasses. Animal ethics approval was obtained from the Agricultural Research Council Animal Ethics Committee.

A state veterinarian or meat inspector performed the necessary inspection of the carcasses after slaughter. Warm weights were recorded soon after slaughter before the carcasses were hung in a cold storage room for 24 hours. The next day, cold carcass weights were taken before each carcass was then split along the midline. Carcass length was then measured from the cranial edge of the pubic symphysis to the cranial edge of the first rib at the angle of curvature. Loin samples, measuring approximately 2 cm thick and 15 cm long, were cut off from each carcass at the T23 position and weighed. Each loin sample was placed into a nelson bag and tied to prevent the loin sample from touching the bottom of the barrier bag or air coming into the barrier bag. The mass of each new empty and clean barrier bag was obtained in grams before placing in the loin sample. This parcel was then stored in a refrigerator between 0 and 5°C for 48 hours, after which the loin sample in the nelson bag was removed. The mass of the barrier bag, which included exudates collected as drip, was recorded in grams. Fat and muscle thicknesses were

measured on the dressed carcass at the T23 position. Eye muscle area was determined using a square grid.

4.2.3. Data

Performance and carcass data used for the study were obtained from the Integrated Registration and Genetic Information System (INTERGIS) of South Africa. Pedigree information was obtained from the Large White breed society. The original growth data contained 81411 records, while the original carcass data comprised of 5492 records. Pigs with missing birth and testing dates, feed intake and feed conversion ratio records were removed, and then the data were edited to remove values that were greater or less than three standard deviations from the mean. The final data analyzed are shown in Table 4.2. The final data contained 20079 pigs from 29 herds that were performance-tested between 1990 and 2008, and 5406 pigs from 20 herds, carcass-evaluated between 1993 and 2007. Carcass fat, CRLTH and eye AREA were evaluated between 1998 and 2007; hence have fewer records. Data for growth traits had 1289 sires, 3216 dams and 340 contemporary groups. Each contemporary group (HYS) was created by concatenating herd, year and season of testing. The two seasons of testing considered were, summer (October to March) and winter (April to September). There were 636 sires, 1289 dams and 178 contemporary groups in the data for carcass traits. To ensure sufficient variation and connectedness in the data, contemporary groups with less than five pigs and/or less than two sires were removed.

Table 4.2 Summary statistics for growth and carcass traits and covariates included in the analyses

	N	Mean	Min	Max	SD
BFAT (mm)	20079	12.27	7.00	24.00	2.84
TPG (g/day)	20079	1019.00	690.50	1327.00	107.33
LTG (g/day)	20079	676.60	524.40	814.20	50.34
FCR (kg/kg)	20079	2.08	1.40	3.10	0.26
AGES (days)	20079	127.70	106.00	164.00	10.15
LEAN (%)	5406	69.20	65.00	72.00	1.42
DLEAN (%)	5406	56.78	52.00	61.00	2.00
DRIP (%)	5406	3.08	0.29	5.46	2.03
DRESS (%)	5406	77.58	69.00	85.00	3.03
CRLTH (cm)	2267	77.23	65.00	85.00	2.13
AREA (cm ²)	2267	40.00	19.26	64.36	5.75
CFAT (mm)	2267	12.00	25.15	38.5	4.38
FEED (kg)	20079	140.1	95.5	185.5	15.0
AGEB (days)	20079	70.7	51.0	92.0	6.2

BFAT – ultrasonic backfat thickness; TPG – test period weight gain; LTG – lifetime weight gain; FCR – test period feed conversion ratio; AGES – age at slaughter; LEAN – lean percentage; DLEAN – drip-free lean percentage; DRIP – drip loss; DRESS – dressing percentage; CRLTH – carcass length; AREA – eye muscle area; CFAT – carcass fat

4.2.4. Traits

Traits measured on live pigs were ultrasonic backfat thickness at slaughter (BFAT), test period weight gain (TPG), lifetime weight gain (LTG), test period feed conversion ratio (FCR) and age at slaughter (AGES). Feed conversion ratio was calculated as kg of feed consumed to gain 1 kg of body weight. The carcass traits studied included traits derived or calculated from other measurements, such as, lean percentage (LEAN), drip-free lean percentage (DLEAN), drip loss percentage (DRIP), dressing percentage (DRESS), carcass fat (CFAT), and traits measured directly which were carcass length (CRLTH) and eye muscle area (AREA). Dressing percentage was cold carcass weight expressed as a percentage of slaughter weight. Carcass fat was the average of the thinnest and thickest carcass fats, measured on the mid section and shoulder, respectively. Lean meat percentage and drip loss were calculated using Equations 4.1 and 4.2, respectively (Bruwer, 1992). Drip-free lean percentage combines lean percentage and drip loss percentage as shown in Equation 4.3.

$$\text{LEAN (\%)} = 72.5114 - (0.4618 \times \text{T23 fat}) + (0.0547 \times \text{T23 muscle}) \quad [\text{Equation 4.1}]$$

$$\text{DRIP (\%)} = \left(\frac{(\text{combined drip} + \text{bag weight (g)}) - \text{bag weight (g)}}{\text{weight of chop (g)}} \right) \times 100 \quad [\text{Equation 4.2}]$$

$$\text{DLEAN (\%)} = 29.37 + (0.56 \times \text{LEAN \%}) - 3.1\sqrt{(\text{T23 fat})} \quad [\text{Equation 4.3}]$$

where, T23 fat and T23 muscle are fat and muscle thicknesses, respectively at T23 position.

4.2.5. Statistical analyses

The data were checked for normality and the significant effects of covariates on each trait were determined using PROC REG of SAS (SAS, 2003) by checking for independency and multicollinearity among covariates. Then, the covariates, which had significant effects on the response variable were taken to the GLM Procedures of SAS (SAS, 2003), where they were combined with class variables, to get the final model for each trait. Preliminary analyses showed no differences between growth or carcass traits due to test centre, suggesting uniformity in testing standards of the three testing stations. Covariates included in the study were test period total feed intake (TFI) and age at the beginning of the test period (AGEB). Effects of interactions between independent variables were also determined. The following model equation (Equation 4.4) was used in the development of the models for all the traits.

$$y_{ijklm} = \mu + H_i + Y_j + S_k + SEX_l + \beta_0(TFI)_{ijklm} + \beta_1(AGEB)_{ijklm} + C_x C_y + e_{ijklm} \quad [\text{Equation 4.4}]$$

where, y_{ijklm} is the observed trait, H_i is the effect of the i^{th} herd of origin, Y_j is the effect of the j^{th} year of testing, S_k is the effect of the k^{th} season of testing, SEX_l is the effect of the l^{th} sex of the animal, β_0 and β_1 are the regression coefficients of the observed trait on the respective covariate; $(TFI)_{ijklm}$ is the test period total feed intake, $(AGEB)_{ijklm}$ is the age at the beginning of the test period, $C_x C_y$ represents two-way interactions between independent class factors fitted in the model and the e_{ijklm} is the random error term.

4.3. Results and Discussion

4.3.1. Effect of herd of origin

Herd of origin affected ($P < 0.001$) all growth and carcass traits. Table 4.3 shows the summary statistics of the least square means for the growth and carcass traits. The standard errors and standard deviations show the magnitude of variations within and between herds, respectively. The standard errors were derived by dividing the standard deviation of the distribution of herd means by the square root of the number of herds. Differences in growth performance and carcass characteristics in pigs were attributable to the birth and rearing environment (Gentry *et al.*, 2004). Herd performance differences may suggest carry-over effects from pre-test performance differences, which are a result of different environmental conditions. Growth performance is determined by muscle fibre characteristics (Larzul *et al.*, 1997), which are programmed during the prenatal period (Foxcroft *et al.*, 2006). Furthermore, muscle fiber type percentages are influenced by environmental factors (Gentry *et al.*, 2004; Petersen *et al.*, 1997). Bee (2004) observed the effect of gestation feeding on carcass quality of progeny. Thus, pre-test environment has an effect on growth and carcass attributes (Beattie *et al.*, 2000; Gentry *et al.*, 2002; 2004; Hansen *et al.*, 2006). These results suggest that differences in growth performance may be due to differences in management practices applied in different farms. Management at different farms should be best to produce pigs that perform well during the growth period and produce desirable carcasses.

Table 4.3 Summary statistics of Least Squares means for growth and carcass traits

	No of Herds	N	Overall Mean ($\pm$ s. e.)	n	Min ($\pm$ s. e.)	n	Max ($\pm$ s. e.)
BFAT (mm)	29	20079	12.9 $\pm$ 0.011	100	10.3 $\pm$ 0.212	521	15.4 $\pm$ 0.091
TPG (g/day)	29	20079	986.5 $\pm$ 0.582	757	893.1 $\pm$ 3.601	5133	1059.1 $\pm$ 1.782
LTG (g/day)	29	20079	650.7 $\pm$ 0.212	757	569.8 $\pm$ 1.581	5133	704.7 $\pm$ 0.783
FCR (kg/kg)	29	20079	2.3 $\pm$ 0.001	100	2.1 $\pm$ 0.002	854	2.4 $\pm$ 0.011
AGES (days)	29	20079	133.1 $\pm$ 0.057	5133	122.3 $\pm$ 0.163	757	150.7 $\pm$ 0.322
LEAN (%)	20	5406	68.7 $\pm$ 0.022	220	67.4 $\pm$ 0.112	345	69.5 $\pm$ 0.090
DLEAN (%)	20	5406	56.1 $\pm$ 0.028	220	54.3 $\pm$ 0.154	345	57.3 $\pm$ 0.122
DRIP (%)	20	5406	3.69 $\pm$ 0.021	8	2.19 $\pm$ 0.663	106	4.81 $\pm$ 0.191
DRESS (%)	20	5406	77.6 $\pm$ 0.030	355	75.5 $\pm$ 0.152	260	79.3 $\pm$ 0.183
CRLTH (cm)	7	2267	77.3 $\pm$ 0.044	220	75.9 $\pm$ 0.452	8	78.7 $\pm$ 0.791
AREA (cm ²)	7	2267	40.3 $\pm$ 0.112	8	35.4 $\pm$ 1.870	345	43.7 $\pm$ 0.482
CFAT (mm)	7	2267	25.34 $\pm$ 0.001	308	23.01 $\pm$ 0.251	13	28.05 $\pm$ 1.182

N – total number of animals in all herds; n – number of animals in the herd; s. e. – standard error, SD – standard deviation, BFAT – backfat thickness, TPG – test period weight gain, LTG – weight gain from birth to slaughter, FCR – feed conversion ratio during test, AGES – age at slaughter, LEAN – lean percentage, DLEAN – drip-free lean, DRIP – drip loss, CRLTH – carcass length, DRESS – dressing percentage, AREA – eye muscle area; CFAT – carcass fat

4.3.2. Effect of year of testing

All growth and carcass traits were affected ($P < 0.001$) by year of testing. The least square means for the effect of year of testing on growth traits are shown in Figures 4.1a to 4.1e, while those for

carcass traits are shown in Figures and 4.2a to 4.2g. The reduction in BFAT and CFAT from 1990 to 2008 is desirable to consumers who prefer lean meat (Webb *et al.*, 2006). There were decreasing trends for AGES that favors farmers, as fewer days to slaughter translate to less feed consumed, which constitutes about 60 – 70 % of pig enterprise costs (Hoque *et al.*, 2006). There were increases in both TPG and LTG from 1990 to 2000 as well as general increases in LEAN and DLEAN from 1993 to 2007. Drip loss decreased from 1993 to 1998, after which there was no discernible trend. A general decline in carcass yield was observed, depicted by the decreasing AREA. The jumps observed in DRIP and DRESS may be attributed to the amount of data collected that were not consistent (not presented) over the years. Since DRIP can only be determined in laboratories, there may have been inconsistent calculation of DRIP in some or all the testing centres. This may also be due to correlated responses to selection on different traits during different periods, when emphasis on traits might have varied. Although these animals were in total confinement, carry over effects from their respective herds may explain the observed differences during the years, as shown by the significant herd effect and its interaction with year of testing on growth and carcass traits (Cassady *et al.*, 2004). Growth traits have been reported to be heritable (Johnson *et al.*, 1999b; Nguyen & McPhee, 2005; Oh *et al.*, 2005; Chimonyo & Dzama, 2007). Prenatal environmental influences may be exerted on growth and carcass characteristics (Foxcroft *et al.*, 2006). Nilzen *et al.* (2001) and Gentry *et al.* (2002; 2004) observed the effect of birth and rearing environment on growth and carcass characteristics. These trends may also suggest response to selection and/or management practices on these or other correlated traits; hence improvement may be expected if the appropriate treatments are applied on them.

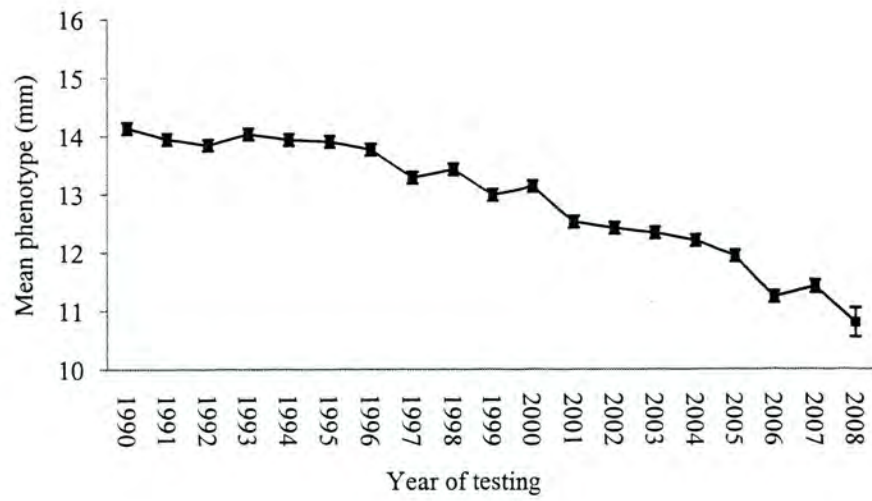


Figure 4.1a Phenotypic trend for backfat thickness

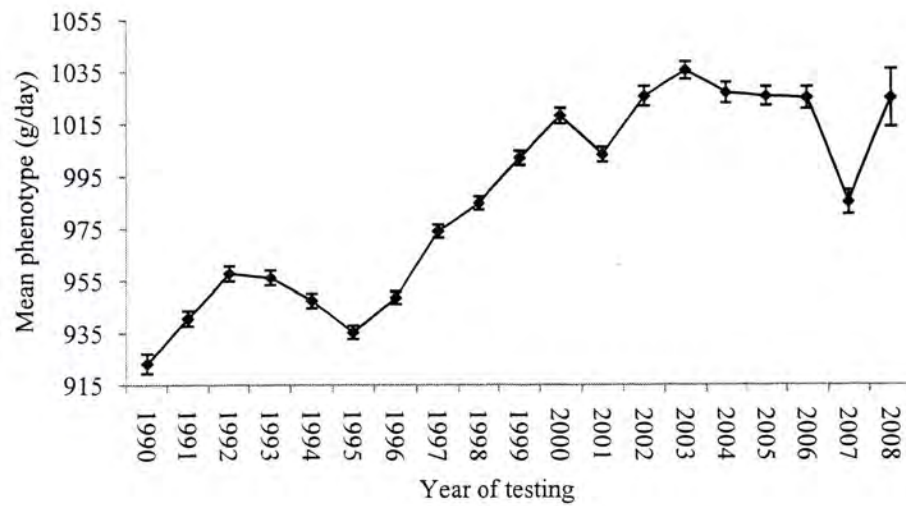


Figure 4.1b Phenotypic trend for test period weight gain

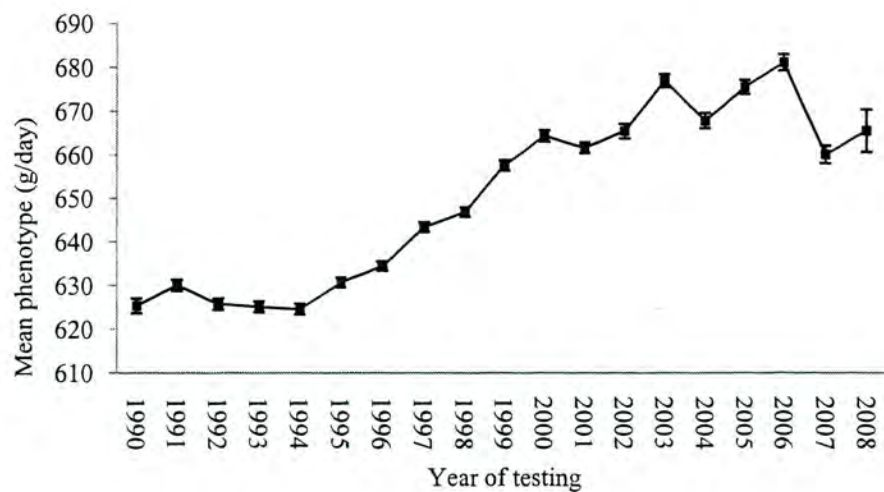


Figure 4.1c Phenotypic trend for lifetime weight gain

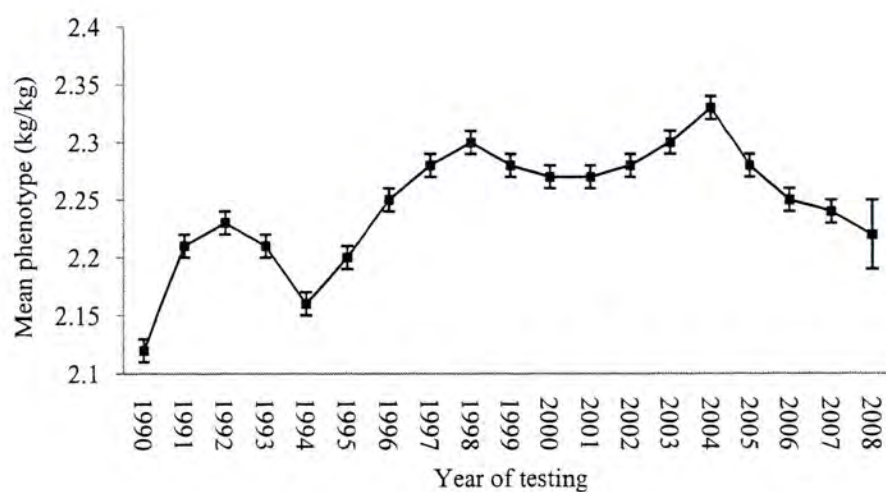


Figure 4.1d Phenotypic trend for feed conversion ratio

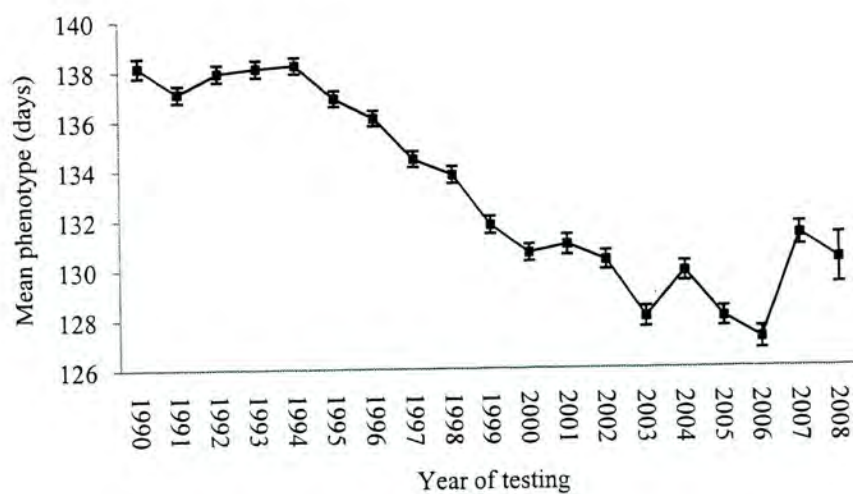


Figure 4.1e Phenotypic trend for age at slaughter

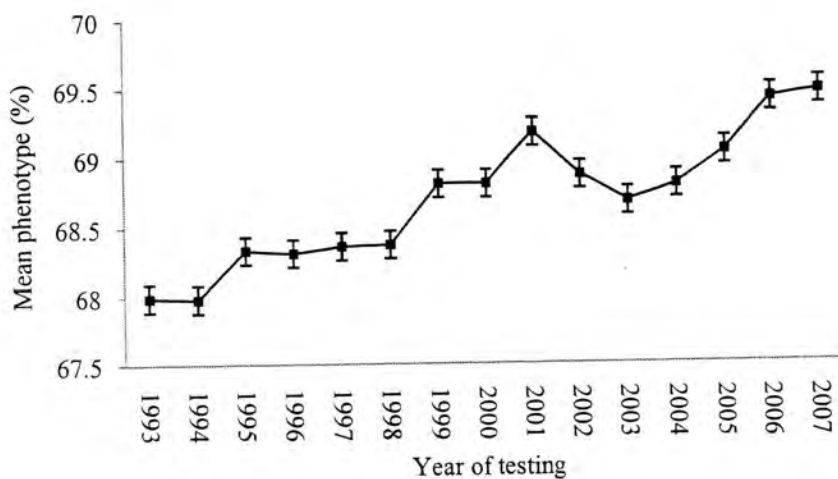


Figure 4.2a Phenotypic trend for lean percentage

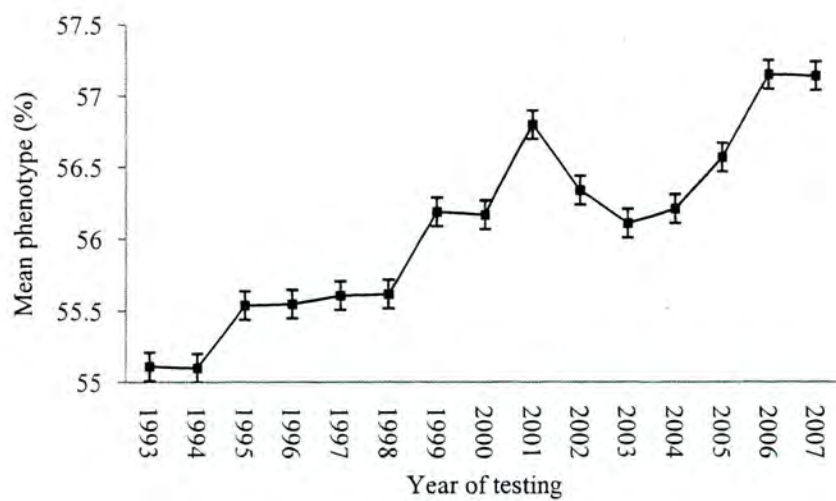


Figure 4.2b Phenotypic trend for drip-free lean percentage

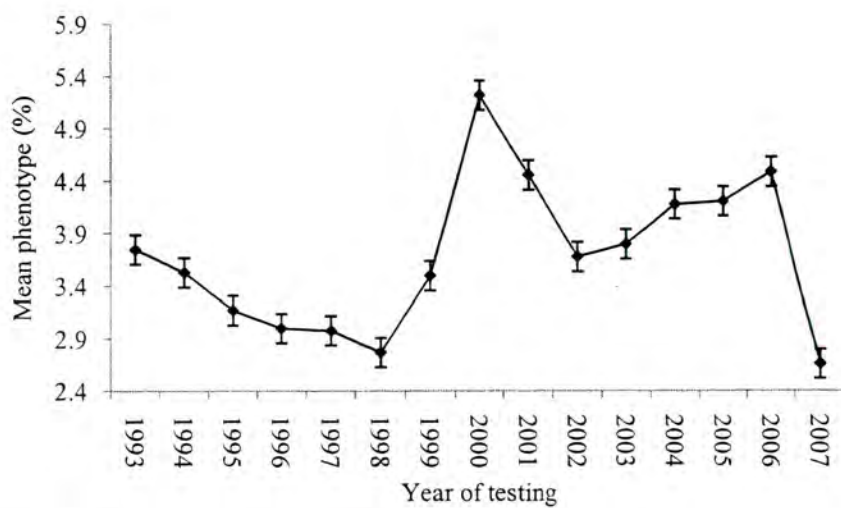


Figure 4.2c Phenotypic trend for drip loss percentage

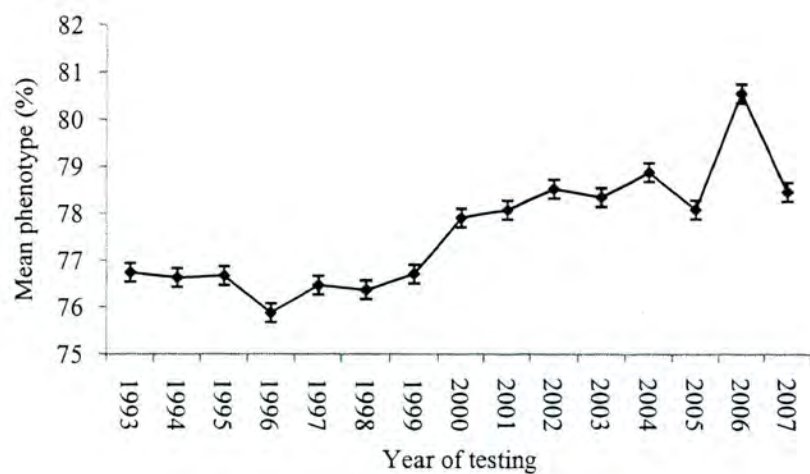


Figure 4.2d Phenotypic trend for dressing percentage

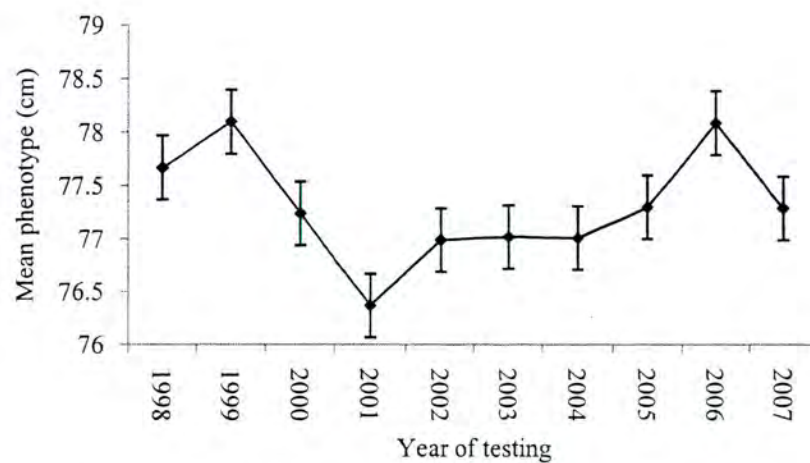


Figure 4.2e Phenotypic trend for carcass length

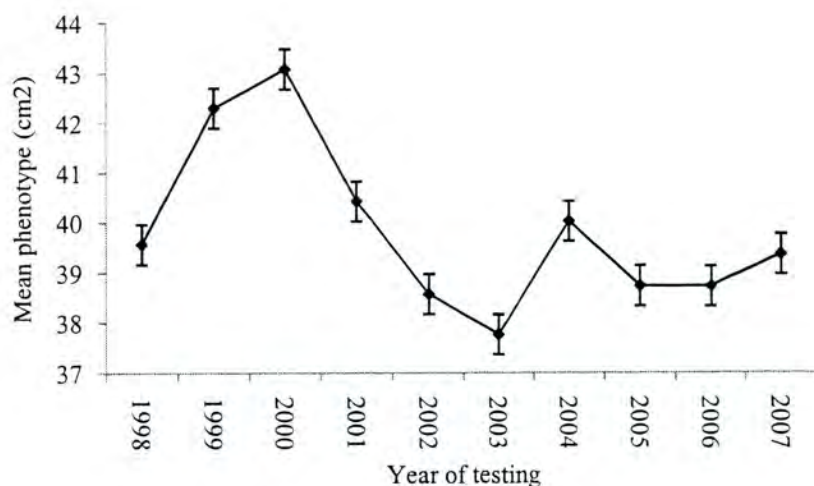


Figure 4.2f Phenotypic trend for eye muscle area

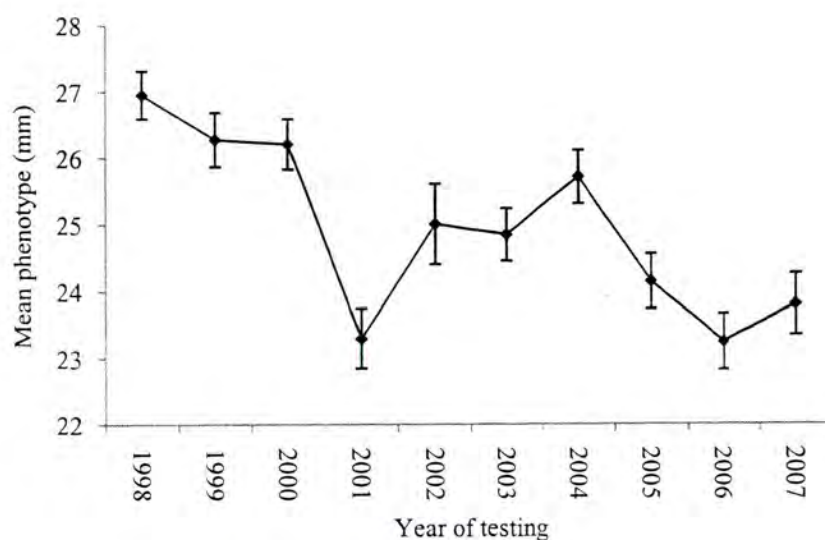


Figure 4.2g Phenotypic trend for carcass fat

4.3.3. Effect of season of testing

The effects of season of testing on growth and carcass traits are shown in Table 4.4. Differences were observed in FCR, with summer-tested pigs being more ($P < 0.001$) efficient than winter-tested pigs, which is consistent with the findings of (Le Dividich *et al.*, 1987). These authors

attributed this to the fact that pigs eat more feed in cold weather to compensate for the greater metabolic demand for heat production. No significant effect ($P > 0.05$) of season of testing on BFAT, AGES, TPG and LTG was observed. However, Chikwanha *et al.* (2007) reported an increase and decrease in body condition score in mature boars and lactating sows, respectively, due to season. Environmental temperature is known to affect the performance, voluntary energy intake, and heat production of growing pigs (Close, 1987; Le Dividich *et al.*, 1987; Bee, 2004). Trezona *et al.* (2004) observed that pigs were fattest and leanest during spring and autumn, respectively. Winter-tested pigs produced 0.28 cm shorter ($P < 0.001$) carcasses than the summer-tested pigs. The animals were brought to the testing station after weaning; hence the pre-test growth period for pigs tested in summer was in winter. During this season they consumed more feed to keep warm and had heavier weights (Rinaldo *et al.*, 2000). Since these pigs were tested under similar conditions, the differences may thus be attributed to the carry-over effects of the pre-test rearing seasons. Such effects have been confirmed by Nilzen *et al.* (2001) and Gentry *et al.* (2002; 2004), who reported the effects of birth and rearing environment on carcass traits. The results from this study suggest that performance testing has best results when done in winter.

Table 4.4 Least squares means ($\pm$ s. e.) for the effect of season of testing on growth and carcass traits

	N	Summer	N	Winter
BFAT (mm)	9195	12.91 ^a $\pm$ 0.031	10884	12.93 ^a $\pm$ 0.030
TPG(g/day)	9195	989.12 ^a $\pm$ 1.521	10884	983.91 ^a $\pm$ 1.161
LTG (g/day)	9195	652.22 ^a $\pm$ 0.673	10884	649.21 ^a $\pm$ 0.641
FCR (kg/kg)	9195	2.22 ^a $\pm$ 0.010	10884	2.31 ^b $\pm$ 0.012
AGES (days)	9195	132.80 ^a $\pm$ 0.142	10884	133.43 ^a $\pm$ 0.132
LEAN (%)	1926	68.72 ^a $\pm$ 0.061	3480	68.70 ^a $\pm$ 0.051
DLEAN (%)	1926	56.12 ^a $\pm$ 0.084	3480	56.12 ^a $\pm$ 0.082
DRIP (%)	1926	3.743 ^a $\pm$ 0.072	3480	3.652 ^a $\pm$ 0.064
DRESS (%)	1926	77.74 ^a $\pm$ 0.090	3480	77.53 ^a $\pm$ 0.091
CRLTH (cm)	694	77.50 ^a $\pm$ 0.130	1573	77.22 ^b $\pm$ 0.112
AREA (cm ²)	694	40.52 ^a $\pm$ 0.304	1573	40.01 ^a $\pm$ 0.272
CFAT (mm)	694	24.93 ^a $\pm$ 0.326	1573	25.42 ^b $\pm$ 0.309

N – number of records; BFAT – backfat thickness; TPG – test period weight gain; LTG – weight gain from birth to slaughter; FCR – feed conversion ratio during test; AGES – age at slaughter; LEAN – lean percentage; DLEAN – drip-free lean; DRIP – drip loss; CRLTH – carcass length; DRESS – dressing percentage; AREA – eye muscle area; CFAT – carcass fat; values with the same superscript within row are not significantly different

4.3.4. Effect of sex

Table 4.5 shows the effects of sex on growth and carcass traits, where castrates had thicker ($P < 0.001$) backfat than females. This may be attributed to the larger ($P < 0.001$) quantities of feed

consumed during the test period. Weight gains for castrates were lower ($P < 0.001$) compared to those of females. These results are in agreement to those observed by Latorre *et al.* (2003). Although there were no sex differences in FCR in the current study, Nieuwhof *et al.* (1991), Friesen *et al.* (1994) and Latorre *et al.* (2003) observed poorer feed conversion ratios in males. Females were leaner ($P < 0.001$) than castrates, while smaller ($P < 0.01$) eye muscle areas were observed females. Serrano *et al.* (2008) observed that castrates produced more carcass yield, were fatter and had shorter carcasses. Castrates have a low capacity for protein deposition and a high rate of fat accretion (Campbell & Taverner, 1985). Mayoral *et al.* (1999) and Lattore *et al.* (2003) found no differences in carcass characteristics attributable to sex. These results may favour the testing of females.

Table 4.5 Least squares means ($\pm$ s.e.) for the effect of sex on growth and carcass traits

	N	Castrates	N	Females
BFAT (mm)	5417	13.31 ^a $\pm$ 0.041	14662	12.63 ^b $\pm$ 0.031
TPG(g/day)	5417	948.63 ^a $\pm$ 1.752	14662	1024.42 ^b $\pm$ 1.372
LTG (g/day)	5417	637.72 ^a $\pm$ 0.774	14662	663.70 ^b $\pm$ 0.601
FCR	5417	2.31 ^a $\pm$ 0.014	14662	2.21 ^a $\pm$ 0.013
AGES (days)	5417	135.73 ^a $\pm$ 0.16	14662	130.52 ^b $\pm$ 0.123
LEAN (%)	2557	68.64 ^a $\pm$ 0.062	2849	68.84 ^b $\pm$ 0.061
DLEAN (%)	2557	55.90 ^a $\pm$ 0.081	2849	56.33 ^b $\pm$ 0.082
DRIP (%)	2557	3.851 ^a $\pm$ 0.073	2849	3.543 ^b $\pm$ 0.061
DRESS (%)	2557	78.44 ^a $\pm$ 0.093	2849	76.91 ^b $\pm$ 0.092
CRLTH (cm)	1058	77.21 ^a $\pm$ 0.122	1209	77.41 ^b $\pm$ 0.124
AREA (cm ²)	1058	41.63 ^a $\pm$ 0.284	1209	39.02 ^b $\pm$ 0.274
CFAT (mm)	1058	25.90 ^a $\pm$ 0.310	1209	24.76 ^b $\pm$ 0.306

N – number of records; BFAT – backfat thickness; TPG – test period weight gain; LTG – weight gain from birth to slaughter; FCR – feed conversion ratio during test; AGES – age at slaughter; LEAN – lean percentage; DLEAN – drip-free lean; DRIP – drip loss; CRLTH – carcass length; DRESS – dressing percentage; AREA – eye muscle area; CFAT – carcass fat; values with the same superscript within row are not significantly different

4.3.5. Effect of testing environment

The effect of the testing environment on growth traits is shown in Table 4.6, where animals were tested at the central testing station (Phase B) and the farms (Phase D), respectively. Phase D animals were leaner ($P < 0.001$) than Phase B animals. Animals tested under Phase B had better

($P < 0.001$) feed conversion ratios than Phase D animals. This may have resulted in higher ($P < 0.001$) growth rates observed in Phase B animals, which caused these animals to reach slaughter weight earlier ($P < 0.001$). The differences in growth performance due to the testing phase may be attributable to differences in the two testing environments. Rearing environment has been reported to influence subsequent growth performance (Beattie *et al.*, 2000; Gentry *et al.*, 2004). The differences in performance between the phases show that central performance testing is more beneficial. Testing phase may be confounded in the herd effect for Phase D animals, but not for those in Phase B. Although there are differences due to testing environment, data from both environments should be analyzed jointly. Traits from each testing environment can only be analyzed as different traits if they are genetically different.

Table 4.6 Least squares means ($\pm$ s. e.) for the effect of testing phase on growth traits

	N	Station	N	Farm
BFAT (mm)	5890	13.9 ^a $\pm$ 0.04	14189	11.9 ^b $\pm$ 0.04
TPG(g/day)	5890	993.5 ^a $\pm$ 1.62	14189	979.5 ^b $\pm$ 1.63
LTG (g/day)	5890	654.7 ^a $\pm$ 0.71	14189	646.7 ^a $\pm$ 0.72
FCR (kg/kg)	5890	2.33 ^a $\pm$ 0.01	14189	2.18 ^b $\pm$ 0.01
AGES (days)	5890	131.2 ^a $\pm$ 0.15	14189	133.5 ^b $\pm$ 0.15

N – number of records; BFAT – backfat thickness; TPG – test period weight gain; LTG – weight gain from birth to slaughter; FCR – feed conversion ratio during test; AGES – age at slaughter

4.3.6. Effect of feed intake

The effects of feed intake on growth and carcass traits are shown in Table 4.7. Total test period feed intake was associated with reductions ($P < 0.001$) in weight gains. Affentranger *et al.* (1996) and Akdag *et al.* (2008) reported the effect of feed intake on growth performance in pigs. Contrasting results showing increased weight gains with increasing level of daily feed intake have been reported (Garcia-Valverde *et al.*, 2008). This may suggest that animals consuming less feed under *ad-libitum* conditions are more efficient. Increasing BFAT due to increased total test period feed intake observed in the current study is consistent with the observations of Garcia-Valverde *et al.* (2008). Similarly, CFAT increased with increasing feed intake. This can be attributed to the increased activity of lipogenic enzymes associated with increased energy intake (Daza *et al.*, 2007). These observations suggest an optimum feed intake to achieve the desired growth performance. Increasing total test period feed intake was associated with decreasing ($P < 0.001$) LEAN, DLEAN, DRIP and DRESS. These results are in agreement to earlier reports (Affentranger *et al.*, 1996; Akdag *et al.*, 2008). Ramaekers *et al.* (1996) observed contrasting results showing increased lean content with increasing feed content when daily feed intake was restricted. Nutrient digestibility increases with level of feed intake (Haydon *et al.*, 1984) and the absorbed nutrients are used for maintenance and lean gain (Scharlach & Kleyn, 1996). When energy consumption exceeds requirements, the extra energy is converted to fat and stored (Scharlach & Kleyn, 1996). The differences may be attributed to the fact that total test period feed intake was used in the current study, instead of average daily feed intake. Pigs that grow slowly have a longer test period and therefore require more total feed. On a daily basis, slow growth is associated with less daily feed intake.

Table 4.7 Regression coefficients of feed intake and age at the beginning of test on growth and carcass traits

	N	FEED (kg)	N	AGEB (days)
BFAT (mm)	21000	0.027±0.0011	21000	-0.014±0.0022
TPG(g/day)	21000	-2.438±0.0441	21000	-0.984±0.1031
LTG (g/day)	21000	-0.436±0.0151	21000	-4.268±0.0362
FCR (kg/kg)	2100	ns		ns
AGES (days)	2100	0.141±0.0043		¥
LEAN (%)	5406	-0.037±0.0013	5406	-0.021±0.0042
DLEAN (%)	5406	-0.051±0.0020	5406	-0.031±0.0061
DRIP (%)	5406	-0.010±0.0021	5406	0.007±0.0033
DRESS (%)	5406	-0.065±0.0082	5406	ns
CRLTH (cm)	2267	ns	2267	ns
AREA (cm ²)	2267	ns	2267	ns
CFAT (mm)	2267	0.041±0.0059	2267	ns

N – number of records, BFAT – backfat thickness, TPG – test period weight gain, LTG – weight gain from birth to slaughter, FCR – feed conversion ratio during test, AGES – age at slaughter, LEAN – lean percentage, DLEAN – drip-free lean, DRIP – drip loss, CRLTH – carcass length, DRESS – dressing percentage, AREA – eye muscle area, CFAT – carcass fat; FEED – total feed intake during test period, AGEb – age at the beginning of the test period, ns – effect not significant, ¥ – effect not included in the analysis

4.3.7. Effect of starting age

Table 4.7 contains the effects of AGE_B on growth and carcass traits. Age at the beginning of the test period affected ($P < 0.001$) BFAT, growth rates and lean percentages. Daza *et al.* (2007) reported contrasting results, where higher growth rates were observed in pigs that started the test at an older age. They attributed this to compensatory growth, as such pigs had shown slower growth rates during the pre-test period, which were however not measured in the present study. Higher average daily gain and carcass weight, as a consequence of older age at the beginning of the free-range fattening period has been reported previously (Daza *et al.*, 2007). Variations in carcass characteristics due to age have been reported (Mayoral *et al.*, 1999; Daza *et al.*, 2005; Daza *et al.*, 2007). Contrary to the current results, younger pigs at the beginning of the fattening period had inferior carcass characteristics in Iberian pigs (Daza *et al.*, 2007). These results portray an unfavourable relationship between starting age and weight gains. An optimum age should be established for commencing testing. Observations from the current study may encourage the testing of younger animals at the beginning of the test.

4.3.8. Interaction effects

The only interaction observed in this study was between herd of origin and year of testing, which affected ($P < 0.001$) all traits. This suggests that there are inconsistent growth performances and carcass characteristics in animals tested and carcass-evaluated from different herds over the years. These results are in agreement with those reported by Cassady *et al.* (2004). Wallenbeck *et al.* (2009) observed a herd-year-season interaction when they investigated the genotype $\times$ environment interaction in Hampshire boars. These results emphasize the influences of pre-testing period treatments on growth performance and carcass characteristics being carried over to

slaughter, despite uniform treatment during the test period. Therefore, during genetic evaluation these effects may be combined to adjust for their effect on carcass traits.

4.4. Conclusions

In South Africa, there is a paucity of information on non-genetic factors affecting carcass characteristics of centrally tested Large White pigs. The purpose of this study was to evaluate the non-genetic effects on growth and carcass traits in one major South African commercial pig breed. These results point out that optimum management at farm level is a prerequisite for optimum growth performance and carcass quality and yield, which cannot be compensated for by on-test treatments. Castrates produce higher carcass yield, while females produce better carcass quality. If growth performance and carcass characteristics are to be improved, central performance testing should be done on females at a younger age in winter. Feeding pigs *ad libitum* during testing may be counterproductive and separate genetic evaluation procedures for the two testing phases may be necessary. The investigation of the effect of feed intake on growth and carcass traits may be improved by use of test-day data. These results underline the need to adjust for fixed effects when performing genetic evaluations.

Chapter 5

Estimation of Genetic Parameters for Sow Productivity Traits

5.1. Introduction

In pig production systems, enterprise income is dependent upon the weight and number of animals marketed. Sow productivity is a key factor affecting the efficiency and economic viability of the pig industry and is a leading concern of commercial producers and breeders (Kim, 2001). Productivity per farrowing is usually considered the basis for evaluating the genetic merit of animals in a herd (Bereskin, 1984). It is imperative that sow productivity is improved as it substantially reduces production costs per pig (Irgang *et al.*, 1994). Thus, genetic improvement of sow productivity is an effective means of improving the efficiency of pig production. Estimates of genetic parameters for sow productivity traits reported in previous studies have shown that these traits are generally of low heritability (Ferraz & Johnson, 1993; Chimonyo *et al.*, 2006; Roehe *et al.*, 2009). Differences among females due to parity may cause the bias of genetic parameter estimates (Roehe & Kennedy, 1995)

Different models have been used in the estimation genetic parameters for sow productivity. Some authors analyzed litter size in different parities as repeated measures of the same trait (See *et al.*, 1993; Crump *et al.*, 1997b; Chimonyo *et al.*, 2006), while some treated litter size in different parities as different traits (Roehe & Kennedy, 1995; Rydhmer *et al.*, 1995; Hanenberg *et al.*, 2001). Since the physiological development of reproductive organs differs with parity, gilt and sow records should be considered as separate reproductive traits (Oh *et al.*, 2006). If

repeatability of these traits is high, then it would be appropriate to consider records in different parities as repeated measures of the same trait. However, if repeatability is low, it may be appropriate to analyze records in different parities as independent traits. This will make the analyses more accurate and computationally faster. Information on genetic parameters for sow productivity traits is lacking in South African Large White pigs. The purpose of this study is to estimate genetic parameters for sow productivity traits in different parities as repeated measures of the same trait.

5.2. Materials and Methods

5.2.1. Data and traits

The data and traits are described in Sections 3.2.1 and 3.2.2, respectively, while the distributions of data across parities and the summary statistics are shown in Tables 3.1 and 3.2, respectively.

5.2.2. Statistical analyses

Analysis of variance procedure in SAS (2003) was used to study the effects of contemporary group and parity on number born alive, litter weight at birth, litter size and weight at 21 days. The effect of age at service of sow (AGS) was determined using analysis of covariance. Random effects included in the analyses were determined using the log-likelihood ratio tests. The difference between the two log-likelihoods was multiplied by two and compared with Chi-squared values, with degrees of freedom equal to the difference between the original and the reduced model. Table 5.1 shows the fixed and random effects included in the analysis of the respective traits.

Table 5.1 Fixed and random effects included in the model for sow productivity traits

Trait	Fixed			Random	
	HYS	AGS	AGS ²	animal	pe
NBA	×	×	×	§	§
LBWT	×	×	×	§	§
D21LS	×			§	§
D21LWT	×			§	§
IFP	×	×	×	§	§

HYS – herd; year and season of farrowing; AGS – service age of sow; NBA – litter size at birth; LBWT – litter weight at birth; D21LS – litter size at 21 days; D21LWT – litter weight at 21 days; IFP – inter-farrowing period; pe – permanent environmental effect; × – factor included and significant; § – random effect fitted

All traits analyzed in this study were treated as traits of the dam in order to evaluate sow productivity in this population. The genetic parameters were estimated using univariate and bivariate analyses in ASREML (Gilmour *et al.*, 2006). Genetic parameters obtained from these analyses were used to estimate heritabilities and genetic correlations between the traits. Estimated breeding values were used to plot genetic trends for the traits. The mixed model equation used was as follows.

$$y = X\beta + Zu_a + Wu_{pe} + e \quad [\text{Equation 5.1}]$$

where, y is the vector of observations for sow productivity traits, β is the vector of fixed effects, vectors of random effects consisted of random animal additive genetic (u_a), permanent

environmental (u_{pe}) and residual (e) effects. Incidence matrices X , Z and W relate fixed, direct genetic and permanent environmental effects, respectively to observations. Fixed effects fitted in the analysis of each trait are shown in Table 5.1. In each trait analysis, only significant fixed effects were considered in the final model. Random effects were assumed to be sampled from a normal distribution with a mean of zero and variance covariance structure as shown:

$$E \begin{bmatrix} y \\ u_a \\ u_{pe} \\ e \end{bmatrix} = \begin{bmatrix} X\beta \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$V \begin{bmatrix} e \\ u_a \\ u_{pe} \end{bmatrix} = \begin{bmatrix} I\sigma_e^2 & 0 & 0 \\ 0 & A\sigma_a^2 & 0 \\ 0 & 0 & I\sigma_{pe}^2 \end{bmatrix}$$

where, A is the numerator relationship matrix, I is an identity matrix, σ_a^2 is the direct genetic variance, σ_{pe}^2 is the permanent environmental variance and σ_e^2 is the residual variance.

5.3. Results and Discussion

5.3.1. Heritability estimates

Estimates of heritabilities for the traits analyzed, contained in Table 5.2, were generally low and maternal genetic effects were not significant. This is probably because the study evaluated sow performance and maternal genetic effects may be very low as the traits analyzed occur late (after puberty) in the pig's life. Heritability estimates for litter traits ranged from 0.01 ± 0.010 for IFP to

0.10±0.011 for LBWT. The generally low heritability estimates for sow productivity traits are in agreement with most results from previous studies (Noguera *et al.*, 2002; Chimonyo *et al.*, 2006; Roehe *et al.*, 2009). The heritability estimate for number born alive of 0.05±0.012 is lower than that obtained in previous studies (Noguera *et al.*, 2002; Damgaard *et al.*, 2003). Litter size at 21 days had a low heritability estimate of 0.10±0.011, which was lower than 0.54±0.13 obtained by Irvin & Swiger (1984).

Table 5.2 Estimates of direct genetic (h^2), permanent environmental (p^2) and environmental effects (e^2) as proportions of the phenotypic variance (σ^2_P)

	h^2	p^2	e^2	σ^2_P
NBA	0.05±0.012	0.08±0.012	0.87±0.012	5.85±0.064
LBWT	0.10±0.011	0.05±0.011	0.84±0.013	11.64±0.123
D21LS	0.03±0.011	0.07±0.011	0.90±0.010	2.87±0.033
D21LWT	0.07±0.013	0.08±0.012	0.85±0.012	121.80±1.492
IFP	0.01±0.010		0.99±0.012	355.30±4.121

NBA – litter size at birth; LBWT – litter weight at birth; D21LS – litter size at 21 days; D21LWT – litter weight at 21 days; IFP – inter-farrowing period.

Litter size has been recognized as the most important economic component of sow productivity (Estany *et al.*, 2002). Litter size is a complex physiological trait affected by several component traits expressed sequentially, e.g. ovulation, fertilization, embryo survival and foetal survival (Leymaster *et al.*, 1986). The low heritability for litter size may be probably due it being a component trait. Johnson *et al.* (1984) considered litter size as a product of ovulation rate and embryonic survival, while Bennett & Leymaster (1989) proposed a model in which litter size

equals the minimum number of viable embryos or uterine capacity. This implies that mean litter size is a function of ovulation rate and uterine capacity, plus their interaction. Thus, selection for litter size would correspond to selection for the most limiting component. Some authors observed greater response in litter size after selecting for litter components (Neal & Johnson, 1986; Neal *et al.*, 1989; Bennett & Leymaster, 1990). Haley & Lee (1992) concluded that genetic variation in ovulation rate is largely responsible for the genetic variation in number of live pigs born, with no contribution from genetic variation in prenatal survival.

Litter birth weight reflects maternal genetic potential of the sow and accumulates genetic information per sow over its litter (Roehe, 1999). The results from this study show that generally, litter weight is more heritable than litter size. The low heritability estimates may also be attributed to small additive genetic variance, excessive environmental variability, negative correlations between direct genetic and maternal effects or negative genetic correlations between the component traits (Robison, 1972). Revelle & Robison (1973) suggested that a negative covariance between direct genetic and postnatal maternal effects could be responsible for the low heritability estimates. Chimonyo *et al.* (2006) attributed low heritabilities to large differences in the genetic pool of the breeding sows. In the current study, the low heritability of the sow productivity traits may also be due to reduced genetic variation as a result of long-term selection for these traits.

5.3.2. Permanent environmental effects

Estimates of permanent environmental effects are shown in Table 5.2. They ranged from 0.05 ± 0.011 for LBWT to 0.08 ± 0.012 for NBA and D21LWT. The estimates were generally higher than the direct genetic components. Permanent environmental effects indicate the maternal ability of the sow and reflect the extent to which each record can be repeated over the production period of a sow. Fernandez *et al.* (2008) considered mothering ability measured by D21LWT as a composite trait, combining litter size and average piglet weight at 21 days, which depend on the number of piglets born and the piglets' preweaning survival and growth. In the current study, 21-day litter records for first parity sows were missing which may suggest the inability of gilts to raise piglets to 21 days. Milk production in gilts may be 20% lower than in multiparous sows, as a consequence of lower feed intake and additional requirements of energy for tissue growth (Walker & Young, 1993). These results indicate that the sow's performance is unlikely to be repeated during the production period. This may be due to the fact that physiological development of reproductive organs differs with parity (Oh *et al.*, 2006). Therefore, sow performance during the first parity may not be used to predict its performance in future parities.

5.3.3. Genetic correlations

Table 5.3 contains genetic correlations among sow productivity traits. The genetic correlations for litter traits ranged from nearly zero between NBA and D21LWT to 0.57 ± 0.031 between NBA and LBWT. Inter-farrowing period had very low genetic correlations with litter traits, implying that it can be improved by being included in the breeding objective during selection.

The genetic correlation between LBWT and NBA is higher than 0.263 ± 0.033 reported by Chimonyo *et al.* (2006). Litter size and weight at 21 days had a genetic correlation lower than the literature mean value of 0.93 reported by Rothschild (1996). Litter weight at birth can be improved by selecting for NBA, which may also improve pre-weaning survival and thus improve 21-day litter size. Selecting for NBA may eliminate the need to handle and weigh piglets at birth. The correlation may be associated with the hormones and milk production triggered by the milk that the piglets draw from the teats (English & Morrison, 1984). Contrary to this, Damgaard *et al.* (2003) suggested that genetic selection for sows' ability to give birth to an increased number of piglets born alive might impair their ability to give birth to homogeneous litters, which is vital for postnatal survival of piglets. The genetic correlation between litter birth weight and 21-day litter weight may reflect the influence of birth weight on growth potential. Rehfeldt & Kuhn (2006) observed the effect of birth weight on postnatal growth performance. Heavier piglets suckle more milk from the sow and gain more weight, hence are heavier at 21 days. Larger piglets may therefore stimulate or drain teats more effectively (English & Morrison, 1984), which may direct a larger fraction of hormones and nutrients involved in milk production to their respective teats (Algers *et al.*, 1991). These results show that litter size can be improved by selecting for litter weight or vice versa. Litter size is however negatively correlated to individual birth weight (Milligan *et al.*, 2002; Damgaard *et al.*, 2003). Therefore, the effort should be to improve both litter size and weight by including both traits in the breeding objective.

Table 5.3 Genetic correlations among sow productivity traits

	LBWT	D21LS	D21LWT	IFP
NBA	0.57±0.031	0.50±0.050	0.06±0.046	-0.02±0.132
LBWT		0.34±0.053	0.32±0.038	0.06±0.129
D21LS			0.68±0.038	-0.01±0.164
D21LWT				-0.02±0.141

NBA – litter size at birth; LBWT – litter weight at birth; D21LS – litter size at 21 days; D21LWT – litter weight at 21 days; IFP – inter-farrowing period.

5.3.4. Genetic and phenotypic trends

The genetic and phenotypic trends, shown in Figures 5.1a to 5.1e, point out that there were discernible trends in sow productivity traits. There have been general increases in the trends for litter traits at birth. The improving phenotypic trends for sow productivity traits may be partly attributed to responses to genetic selection, as shown by the genetic trends that were similar to the phenotypic trends. This indicates that genetic selection is possible even in traits of low heritability, and this may interact positively with management to improve phenotypic performance. Neal & Johnson (1986) and Haley & Lee (1992) observed an increase in litter size after selecting for its components. Genetic trends were however not as smooth as phenotypic trends, which may highlight the role played by management in improving phenotypic performance. The oscillating trends for 21-day litter traits may suggest lack of consistent application of proper breeding objectives by farmers. Positive trends in number born alive and number weaned were reported by Southwood & Kennedy (1991) for Canadian Large White and Landrace. They suggested that annual rates of genetic change of half a pig per litter are

theoretically possible using an index including relatives. There was no discernible genetic trend for inter-farrowing period, whereas its phenotypic trend was improving. These results underscore the importance of the role played by genetic selection in improving phenotypic performance. Farmers are therefore advised to select their animals based on breeding values so that there is consistent genetic improvement and performance in this population.

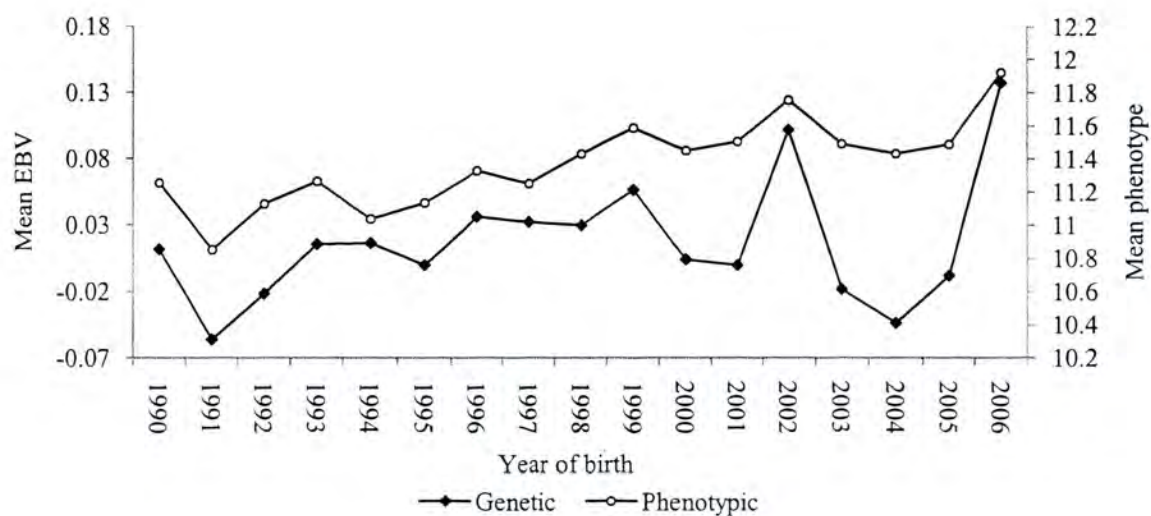


Figure 5.1a Genetic and phenotypic trends for number born alive

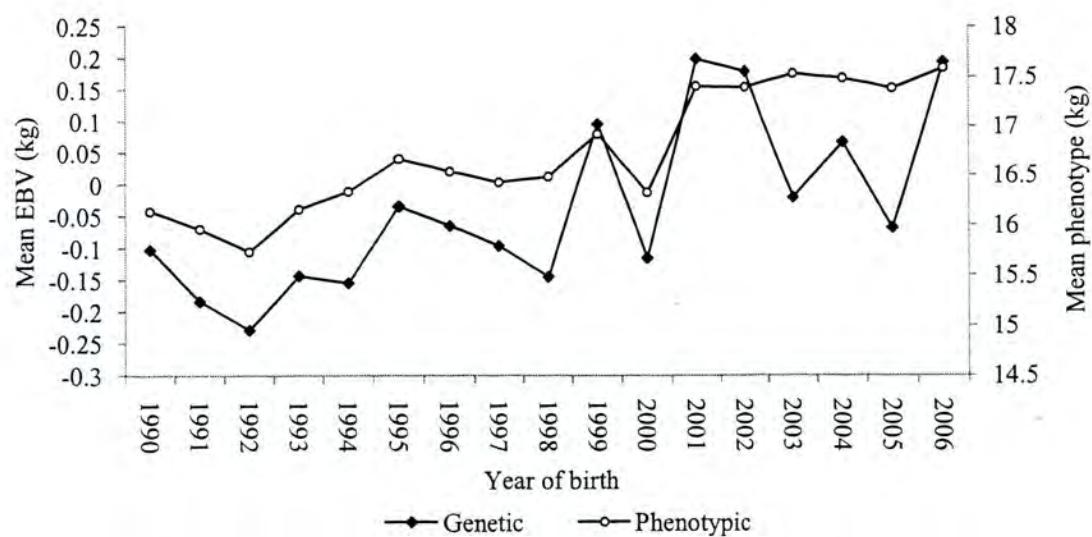


Figure 5.1b Genetic and phenotypic trends for litter weight at birth

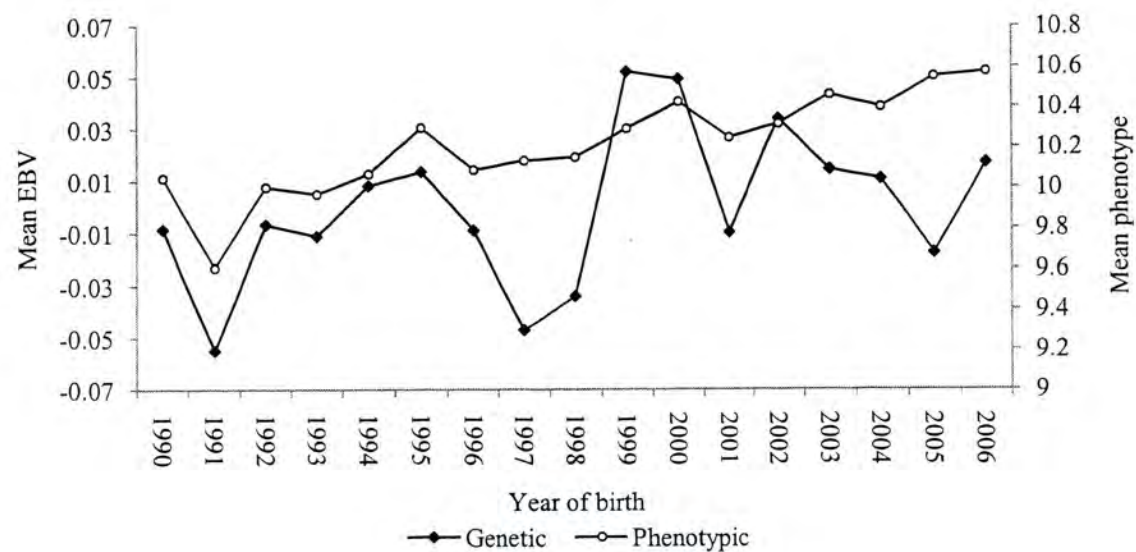


Figure 5.1c Genetic and phenotypic trends for 21-day litter size

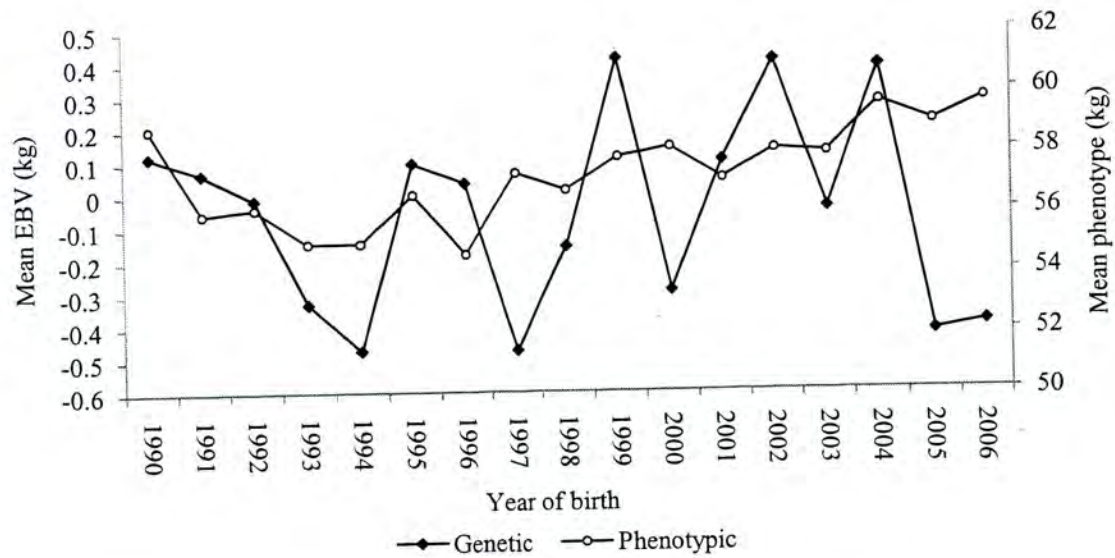


Figure 5.1d Genetic and phenotypic trends for 21-day litter weight

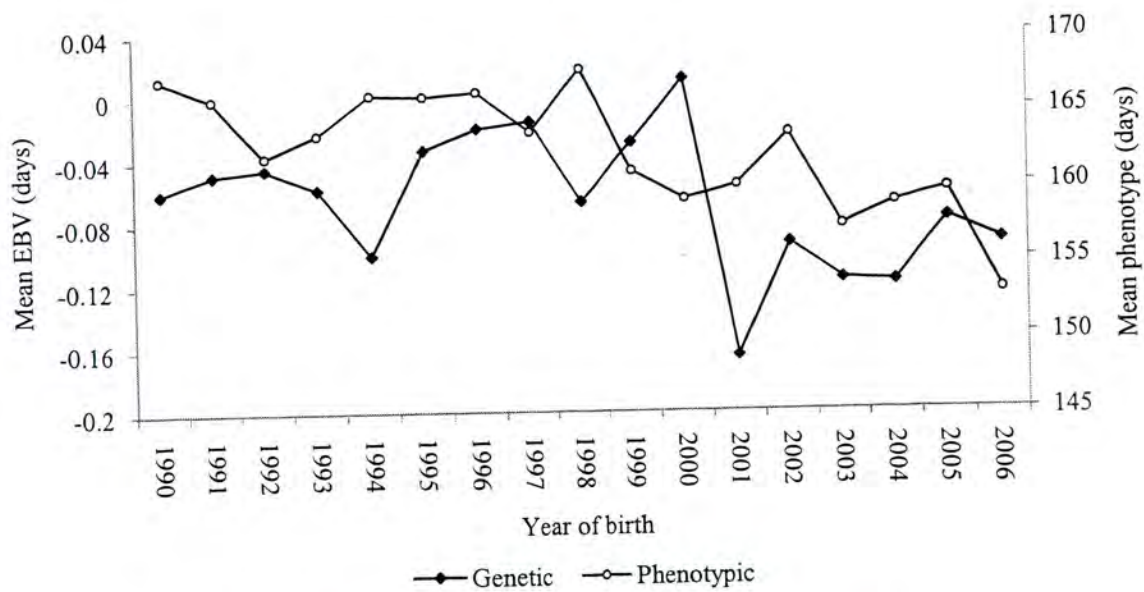


Figure 5.1e Genetic and phenotypic trend for inter-farrowing period

5.4. Conclusions

Sow productivity traits are generally of low heritability in this population. Permanent environmental effects were higher than direct genetic effects, which underlines the importance of the maternal non-genetic component in litter traits. Genetic correlations show that litter size can be improved by selecting for litter weight or vice versa. Sow productivity only addresses one aspect of the pig production system. The products that reach the consumers are obtained from terminal production systems. Therefore, non-genetic effects on growth and carcass traits should be determined to enable the estimation of genetic parameters, to be used in genetic improvement programs.

Chapter 6

Estimation of Genetic Parameters for Growth and Carcass Traits

6.1. Introduction

The South African Pig Performance Testing Scheme is conducted to extend and improve the national pig herd by means of scientifically founded and proven methods and practices. Selection objectives in pigs have changed from growth performance traits to meat yield and quality (Ollivier *et al.*, 1990; Suzuki *et al.*, 2005; van Wijk *et al.*, 2005). Even though meat quality parameters are important from the consumer viewpoint, it is essential to take cognizance of the value of the inputs when rearing pigs.

The South African pig industry has been selecting mainly for average daily gain and reduced backfat thickness (Hicks *et al.*, 1998; van Wijk *et al.* 2005). Pig characteristics that are positive for profitability are high growth rate, low food conversion ratio and low carcass fatness (McPhee & MacBeth, 2000). Backfat is the primary factor that affects the ease with which meat is cut (Herring *et al.*, 1994), and fat content is related to both carcass yield and quality (Pariacote *et al.*, 1998). Drip loss is important for meat quality as it affects consumer perception, and can only be determined under laboratory conditions. Combining lean percentage and drip loss into one trait helps to select for these traits simultaneously. It would be beneficial to the meat industry if drip-free lean percentage is determined in commercial abattoirs. The fact that meat quality measurements are only made on dressed carcasses necessitates the identification and implementation of ways to determine meat quality in live animals. To this end, non-invasive

methods, such as, ultrasonic backfat thickness measurements (Turner *et al.*, 1990), video image analysis (McClure *et al.*, 2003), magnetic resonance imaging (Monziols *et al.*, 2005) and computerized tomography (McEvoy *et al.*, 2009) have been used in the determination of carcass fat content in live pigs.

In South Africa, despite there being a fairly sophisticated commercial pig industry, the evaluation of the genetic potential and performance is not equally developed. Genetic parameters for growth and carcass traits are essential for genetic evaluations, and have been reported in literature (Chen *et al.*, 2002; Suzuki *et al.*, 2005; Hoque *et al.*, 2006). Surprisingly, there are very few studies (e.g. Chimonyo *et al.*, 2006; Norris *et al.*, 2006; Chimonyo *et al.*, 2008) on pig genetic parameters in Southern Africa. Since its development, drip-free lean percentage has not been genetically evaluated to estimate the prospects of its contribution to genetic improvement. The objectives of this study were to: (i) estimate heritability and genetic correlations for growth and carcass traits, and (ii) compute genetic trends in order to evaluate the performance of the improvement scheme.

6.2. Materials and Methods

6.2.1. Pig management, data, measurements and traits

Pig management, data, measurements and traits are explained in Sections 4.2.1 to 4.2.4, and the feed composition and summary statistics for the data is contained in Tables 4.1 and 4.2, respectively.

6.2.2. Statistical analyses

Preliminary analyses were performed using the Mixed Procedures of SAS (SAS, 2003) to determine the significance of the fixed effects and the conditional F-tests were implemented. In the final analyses, the fixed effects included were of sex and the contemporary group effects. The description of the creation of contemporary groups is given in Section 4.2.3. Random effects included in the analyses were determined using the log-likelihood ratio tests, which are described in Section 5.2.2. Tables 6.1 and 6.2 show the fixed and random effects included in the final analysis of growth and carcass traits, respectively.

Table 6.1 Fixed and random effects included in the analyses of growth traits

Trait	Fixed						Random	
	HYS	SEX	TFI	TFI ²	AGEB	AGEB ²	animal	Dam
BFAT	×		×	×	×		§	§
TPG	×	×	×	×	×		§	§
LTG	×	×	×	×	×	×	§	§
FCR	×				×		§	§
AGES	×	×	×	×			§	§

× - factor included and significant; § - random effect fitted; (P < 0.05); HYS - herd, year and season of testing interaction; Sex - the sex of the animal; TFI - test period total feed intake; AGE_B - age at the start of the test; BFAT - ultrasonic backfat thickness; TPG - test period weight gain; LTG - lifetime weight gain; FCR - test period feed conversion ratio; AGE_S - age at slaughter

Table 6.2 Fixed and random effects included in the analyses of carcass traits

Trait	Fixed						Random	
	HYS	SEX	TFI	TFI ²	AGEB	AGEB ²	animal	Dam
LEAN	×	×	×	×	×	×	§	§
DLEAN	×		×	×	×	×	§	§
DRIP	×	×					§	§
DRESS	×	×					§	§
CRLTH	×						§	§
AREA	×	×					§	§
CFAT	×		×	×			§	§

× - factor included and significant; § - random effect fitted; (P < 0.05); HYS - herd, year and season of testing interaction; Sex - the sex of the animal; TFI - test period total feed intake; AGEB - age at the start of the test; LEAN - lean percentage; DLEAN - drip-free lean percentage; DRIP - drip loss; DRESS - dressing percentage; CRLTH - carcass length; AREA - eye muscle area; CFAT - carcass fat

Univariate analyses and then bivariate analyses were conducted using a maternal effects model to estimate the variance and covariance components, which were used to calculate genetic parameters. The analyses were done using REML procedures in ASREML (Gilmour *et al.*, 2006). The mixed model equation used was:

$$y = X\beta + Z_1u_a + Z_2u_m + e \quad [\text{Equation 6.1}]$$

where, y is the vector of observations for growth or carcass traits, β is the vector of fixed effects, vectors of random effects consisted of animal additive genetic (u_a), maternal genetic (u_m) and

residual (e) effects. Incidence matrices X and Z_i ($i = 1$ and 2) related fixed, direct genetic and maternal genetic effects, respectively to the observations. Fixed effects fitted in the analysis of each trait are shown in Tables 6.1 and 6.2. In each trait analysis, only significant fixed effects were considered in the final model. Random effects were assumed to be sampled from a normal distribution with a mean of zero and variance covariance structure as shown:

$$E \begin{bmatrix} y \\ u_a \\ u_m \\ e \end{bmatrix} = \begin{bmatrix} X\beta \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$V \begin{bmatrix} u_a \\ u_m \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & A\sigma_{am} & 0 \\ A\sigma_{am} & A\sigma_m^2 & 0 \\ 0 & 0 & I\sigma_e^2 \end{bmatrix}$$

where, A is the numerator relationship matrix, I is an identity matrix, σ_a^2 is the direct genetic variance, σ_m^2 is the maternal genetic variance, σ_{am} is the covariance between direct and maternal genetic effects and σ_e^2 is the residual variance.

6.3. Results and Discussion

6.3.1. Heritability estimates

Table 6.3 shows the estimates of heritabilities and maternal genetic effects. The heritability estimates for growth traits were moderate, while maternal heritabilities were generally low. The heritability estimate for ultrasonic backfat thickness (0.50 ± 0.042) was comparable to 0.48 ± 0.02 obtained by Sonesson *et al.* (1998) on the Dutch Large White. A lower estimate of 0.40 ± 0.001

was reported by Chimonyo & Dzama (2007) for Mukota pigs. The heritability estimate for backfat thickness indicates the potential of fast genetic improvement that could be achieved if selection is focused on reducing backfat thickness. Test period and lifetime growth rates were moderately heritable (0.28 ± 0.06 and 0.25 ± 0.05 , respectively). Nguyen & McPhee (2005) obtained lower estimates for these traits of 0.16 ± 0.03 and 0.19 ± 0.04 , respectively in Australian Large White pigs. Growth rate may be more efficiently improved if selection is targeted at average daily gain before and during the testing period. The estimated heritability for age at slaughter was 0.26 ± 0.083 , which was in the range reported by Li & Kennedy (1994) for Canadian breeds. Feed conversion ratio had a heritability estimate of 0.21 ± 0.030 , which is comparable to 0.16 ± 0.03 observed by Nguyen & McPhee (2005). Even though the heritability estimates for most traits in this pig population are moderate, substantial genetic improvement may be achieved.

Table 6.3 Estimates of the phenotypic variance (σ_p^2), direct genetic (h^2), maternal genetic (m^2), correlation between direct and maternal genetic (r_{am}) and environmental (e^2) effects

	h^2	m^2	r_{am}	e^2	σ_p^2
BFAT	0.50 ± 0.042			0.50 ± 0.041	5.35 ± 0.162
TPG	0.28 ± 0.061	0.09 ± 0.044	-0.39 ± 0.190	0.70 ± 0.040	6528.00 ± 167.503
LTG	0.25 ± 0.050	0.11 ± 0.042	-0.47 ± 0.174	0.71 ± 0.041	862.20 ± 21.610
FCR	0.21 ± 0.030			0.79 ± 0.034	0.041 ± 0.0011
AGES	0.26 ± 0.083	0.24 ± 0.052	-0.41 ± 0.191	0.69 ± 0.041	32.31 ± 0.801

BFAT – ultrasonic backfat thickness; TPG – test period weight gain; LTG – lifetime weight gain; FCR – test period feed conversion ratio; AGES – age at slaughter

The heritability estimates for carcass traits shown, in Table 6.4, ranged from low (0.13 ± 0.062) for drip loss to high (0.63 ± 0.104) AREA. Suzuki *et al.* (2005) obtained a similar estimate for drip loss (0.14 ± 0.01) in Japanese Duroc pigs. These results indicate that drip loss is largely influenced by environmental factors; hence its genetic improvement through selection may be slow. Furthermore, drip loss is impossible to measure in commercial abattoirs and can only be determined in laboratories. The direct genetic effects contributed 32% to the phenotypic variation in lean percentage. On the other hand, drip-free lean percentage had more phenotypic variation (2.86 ± 0.082) and was more heritable (0.34 ± 0.082) than lean percentage. Therefore, there will be faster genetic progress when selection is for drip-free lean percentage as compared to selecting for lean percentage. In addition, there will be simultaneous selection against drip loss. Most of the previous literature estimates for lean percentage (Knapp *et al.*, 1997; Sonesson *et al.*, 1998; Gilbert *et al.*, 2007) in different breeds are higher than the current observation. The heritability estimate for AREA is within the range reported in the literature (e.g. Hicks *et al.*, 1998; Newcom *et al.*, 2002). Most of the phenotypic variation for eye muscle area is under direct genetic control; hence its improvement by direct selection may be recommended. The heritability estimate for carcass fat was lower than 0.43 ± 0.06 and 0.41 ± 0.01 obtained by Nguyen & McPhee (2005) and Gilbert *et al.* (2007), respectively. Carcass fat is not often measured in pigs because of the difficulty of measuring this trait in a large population and the ease with which backfat thickness can be measured. The different populations studied, definition of traits, and selection pressures applied on traits may explain disparities in heritability estimates reported.

Table 6.4 Estimates of the phenotypic variance (σ_p^2), direct genetic (h^2), maternal genetic (m^2), correlation between direct and maternal genetic (r_{am}) and environmental (e^2) effects

	h^2	m^2	r_{am}	e^2	σ_p^2
LEAN	0.32±0.081	0.16±0.081	-0.83±0.150	0.71±0.063	1.54±0.054
DLEAN	0.34±0.082	0.21±0.081	-0.98±0.113	0.71±0.061	2.86±0.082
DRIP	0.13±0.062	0.17±0.062	-0.94±0.274	0.84±0.054	1.45±0.041
DRESS	0.15±0.071	0.25±0.084	-0.95±0.230	0.78±0.053	4.89±0.133
CRLTH	0.32±0.103			0.68±0.103	4.13±0.223
AREA	0.63±0.104			0.37±0.101	23.89±1.381
CFAT	0.25±0.091			0.75±0.092	13.88±0.732

LEAN – lean percentage; DLEAN – drip-free lean percentage; DRIP – drip loss; DRESS – dressing percentage; CRLTH – carcass length; AREA – eye muscle area; CFAT – carcass fat

6.3.2. Maternal genetic effects

The contributions of maternal genetic effects to the phenotypic variances were relatively high (Tables 6.3 and 6.4). However, most of them were less than the corresponding estimates of direct heritabilities. Robison (1972) reported that there is substantial evidence that maternal effects account for a significant portion of the variance for most traits in swine, including those that are manifested relatively late in life. Mohuiddin (1993) pointed out that maternal heritabilities tend to be lower than direct heritabilities, indicating a greater genetic influence of the animal than its dam for the trait. The heritability estimates for maternal genetic effects ranged from 0.09±0.044 to 0.25±0.084 for test period weight gain and dressing percentage, respectively. Maternal genetic effects contributed 11 % to the phenotypic variation of lifetime weight gain. Lean and drip-free lean percentages had maternal genetic effects of 0.16±0.081 and

0.21±0.082, respectively. These estimates were higher than those reported by Chimonyo & Dzama (2007) in Mukota pigs. No maternal genetic effect was observed in backfat thickness, feed conversion ratio, carcass length, eye muscle area and carcass fat in this study. Significant changes to these traits probably occur during the postnatal growth-finishing phase when the maternal genetic influence may be minimal. The relatively large estimates of the maternal genetic effects could be due to confounding between common litter effects and maternal effects, since common litter effects were not included in the current study. A similar problem was encountered by Bryner *et al.* (1992).

The genetic correlations between direct and maternal genetic effects shown in Tables 6.3 and 6.4 were all negative. These results are consistent with previous reports on different populations (Crump *et al.*, 1997a; Chen *et al.*, 2002; Chimonyo & Dzama, 2007). The estimates in this study were of greater magnitude than estimates reported previously, and ranged from -0.39±0.190 to -0.41±0.194 for growth traits and from -0.83±0.150 to -0.98±0.113 for carcass traits. The antagonism suggests that both direct and maternal genetic components should be taken into account to achieve optimum genetic progress (Roehe & Kennedy, 1993; Johnson *et al.*, 2002). Ignoring maternal genetic effects causes biased heritability estimates with wide standard errors or reduced precision (Solanes *et al.*, 2004). In this study, the model used for estimating the correlation between direct and maternal genetic effects assumed a zero environmental dam-offspring covariance. However, failure to account for a non-zero environmental covariance between dam and offspring may bias the estimates of the correlation between the direct and the maternal genetic effects (Koerhuis & Thompson, 1997). The negative correlation between direct and maternal genetic effects may be due to different management factors (Van Vleck *et al.*,

1996). MacNeil *et al.* (1998) found negligible covariances between direct and maternal genetic effects in Hereford under equal management conditions. In this study, the negative correlation may be due to the different herd management conditions where the pigs originated.

6.3.3. Genetic correlations

6.3.3.1. Growth traits

Table 6.5 contains genetic correlations among growth traits, which ranged from nearly zero to very high. The genetic correlation between test period and lifetime weight gain was 0.96 ± 0.024 . This is higher than 0.60 ± 0.11 obtained by Nguyen & McPhee (2005) between these traits. The high genetic correlation between these traits is not surprising and indicates that they are influenced by similar genetic effects. Thus, there is no need to measure both traits for genetic improvement purposes. Test period and lifetime weight gain had genetic correlations of -0.56 ± 0.083 and -0.85 ± 0.030 , respectively, with feed conversion ratio. Nguyen & McPhee (2005) obtained higher negative genetic correlations between these traits. Selecting for improved feed conversion ratio may result in improved growth rates, thereby reducing the time taken to reach slaughter weight. This is confirmed by the very high negative genetic correlations for age at slaughter (-0.94 ± 0.011 and -0.99 ± 0.012 , respectively) with test period and lifetime weight gain. There was a genetic correlation of -0.15 ± 0.071 between age at slaughter and ultrasonic backfat thickness. A similar genetic correlation (-0.13 ± 0.12) was reported by Lo *et al.* (1992) between backfat thickness and age at 103.6 kg in US Duroc pigs. Breeders should only aim to reduce age at slaughter to an optimum, as it has a slightly unfavourable relationship with backfat thickness.

Table 6.5 Estimates of genetic correlations among test period growth traits

	TPG	LTG	FCR	AGES
BFAT	-0.26±0.121	-0.08±0.082	0.37±0.082	-0.15±0.071
TPG		0.96±0.024	-0.56±0.083	-0.94±0.011
LTG			-0.85±0.030	-0.99±0.012
FCR				0.93±0.033

BFAT – ultrasonic backfat thickness; TPG – test period weight gain; LTG – lifetime weight gain; FCR – test period feed conversion ratio; AGES – age at slaughter

6.3.3.2. Carcass traits

The genetic correlations among the carcass traits are shown in Table 6.6. The highest genetic correlation was between lean and drip-free lean percentage (0.98 ± 0.011). Genetic improvement of drip-free lean percentage would be expected to result in a corresponding improvement in lean percentage. The respective genetic correlations for eye muscle area with lean and drip-free lean percentage were 0.73 ± 0.194 and 0.64 ± 0.202 . This suggests that carcass yield can be improved by selection programmes that improve carcass leanness. Genetic correlations for drip loss with lean and drip-free lean percentages were unreliable and characterized by large standard errors (0.27 ± 0.254 and 0.30 ± 0.242), which may be attributed to the few records used. Knapp *et al.* (1997) obtained estimates which ranged from 0.25 to 0.39 between lean percentage and drip loss. Carcass fat had genetic correlations of -0.43 ± 0.242 and -0.49 ± 0.221 with lean and drip-free lean percentage, respectively. Nguyen & McPhee (2005) observed a comparable estimate (-0.57 ± 0.08) between lean percentage and carcass fat. Carcass fat may be reduced better if selection is done for drip-free lean percentage than when selection is done for lean percentage. Dressing percentage was highly correlated with eye muscle area (0.65 ± 0.320), which is higher

than 0.36 ± 0.07 reported by Hicks *et al.* (1998). Selecting for improved dressing percentage may be expected to increase carcass yield. There were negative genetic correlations between carcass length and other carcass traits, which were difficult to explain.

Table 6.6 Estimates of genetic correlations among carcass traits

	DLEAN	DRIP	DRESS	CRLTH	AREA	CFAT
LEAN	0.98 ± 0.011	0.27 ± 0.254	0.08 ± 0.241	-0.70 ± 0.340	0.73 ± 0.194	-0.43 ± 0.242
DLEAN		0.30 ± 0.242	0.06 ± 0.231	-0.40 ± 0.335	0.64 ± 0.202	-0.49 ± 0.221
DRIP			0.14 ± 0.350	-0.12 ± 0.484	0.23 ± 0.381	-0.69 ± 0.560
DRESS				-0.70 ± 0.471	0.65 ± 0.320	0.42 ± 0.464
CRLTH					0.09 ± 0.190	-0.26 ± 0.231
AREA						0.02 ± 0.190

LEAN – lean percentage; DLEAN – drip-free lean percentage; DRIP – drip loss; DRESS – dressing percentage; CRLTH – carcass length; AREA – eye muscle area; CFAT – carcass fat.

6.3.3.3. Growth and carcass traits

Table 6.7 contains the genetic correlations between growth and carcass traits, which had generally high standard errors, probably due to few records used. Very high negative genetic correlations of -0.91 ± 0.031 were observed for BFAT with lean and drip-free lean percentages. These results are similar to -0.98 obtained by van Wijk *et al.* (2005) between lean percentage and backfat thickness. Thus, lean percentage may be improved in live animals by selecting for reduced backfat thickness. Ultrasonic backfat thickness and carcass fat had a high positive genetic correlation of 0.66 ± 0.223 , which is lower than 0.81 ± 0.07 reported by Nguyen & McPhee (2005). Ultrasonic backfat thickness may be used as an indicator of carcass fat with limited

accuracy as shown by their less than perfect genetic correlation. The relationship between backfat thickness and eye muscle area was moderately favourable, with a genetic correlation of -0.31 ± 0.250 . This indicates that selecting for reduced backfat thickness may increase carcass yield. Feed conversion ratio had moderate negative genetic correlations with lean and drip-free lean percentages (-0.27 ± 0.020 and -0.28 ± 0.021 , respectively). Nguyen & McPhee (2005) obtained a higher estimate of -0.53 ± 0.12 between feed conversion ratio and lean percentage. The genetic correlation between feed conversion ratio and carcass fat was 0.22 ± 0.031 , which is lower than 0.58 ± 0.12 reported by Nguyen & McPhee (2005). Improving feed conversion ratio may be associated with better protein accretion, while reducing fat accretion, resulting in leaner carcasses. The genetic correlations between age at slaughter and carcass traits were not significant, suggesting that slaughter age may be improved without significantly compromising on carcass traits.

Table 6.7 Estimates of genetic correlations between growth and carcass traits

	BFAT	TPG	LTG	FCR	AGES
LEAN	-0.91±0.031	0.09±0.204	0.09±0.284	-0.27±0.020	-0.27±0.202
DLEAN	-0.91±0.031	0.05±0.193	0.18±0.270	-0.28±0.021	-0.28±0.202
DRIP	0.14±0.272	-0.02±0.284	0.01±0.191	-0.03±0.020	0.29±0.294
DRESS	-0.10±0.231	-0.02±0.262	0.56±0.473	-0.07±0.024	0.18±0.263
CRLTH	0.32±0.351	-0.07±0.372	0.16±0.234	-0.05±0.353	-0.35±0.371
AREA	-0.31±0.250	0.34±0.270	0.06±0.388	-0.13±0.042	0.51±0.273
CFAT	0.66±0.223	-0.13±0.364	-0.51±0.481	0.22±0.031	0.02±0.224

BFAT – backfat thickness, TPG – test period gain, LTG – lifetime gain, FCR – feed conversion ratio, AGES – age at slaughter, LEAN – lean percentage, DLEAN – drip-free lean percentage, DRIP – drip loss, DRESS – dressing percentage, CRLTH – carcass length, AREA – eye muscle area, CFAT – carcass fat

6.3.4. Genetic and phenotypic trends

6.3.4.1. Growth traits

The genetic trends for growth traits are shown in Figures 6.1a to 6.1e, which show improvements from 1993 to 1997. Thereafter, there was deterioration in most growth traits, which lasted until around 2000. This was followed by some indiscernible trends in age at slaughter and growth rates. Backfat thickness and feed conversion ratio showed some improvements from 2000 until 2006. Chen *et al.* (2002) reported improvements for backfat thickness and days to 113.5 kg for four different US breeds. Likewise, Kennedy *et al.* (1996) suggested that a 1.7 to 2.9 % improvement per year for backfat thickness and 1.5% per year for days to slaughter would be realistic for industry breeding programs. The potential for genetic improvement shown by the

heritability estimates is not reflected in the genetic trends, probably because farmers do not select animals based on genetic merit. The genetic trends are different from what is portrayed at phenotypic level, which may mislead farmers to assume that there is improvement. Phenotypic improvements may therefore be attributed to improved management.

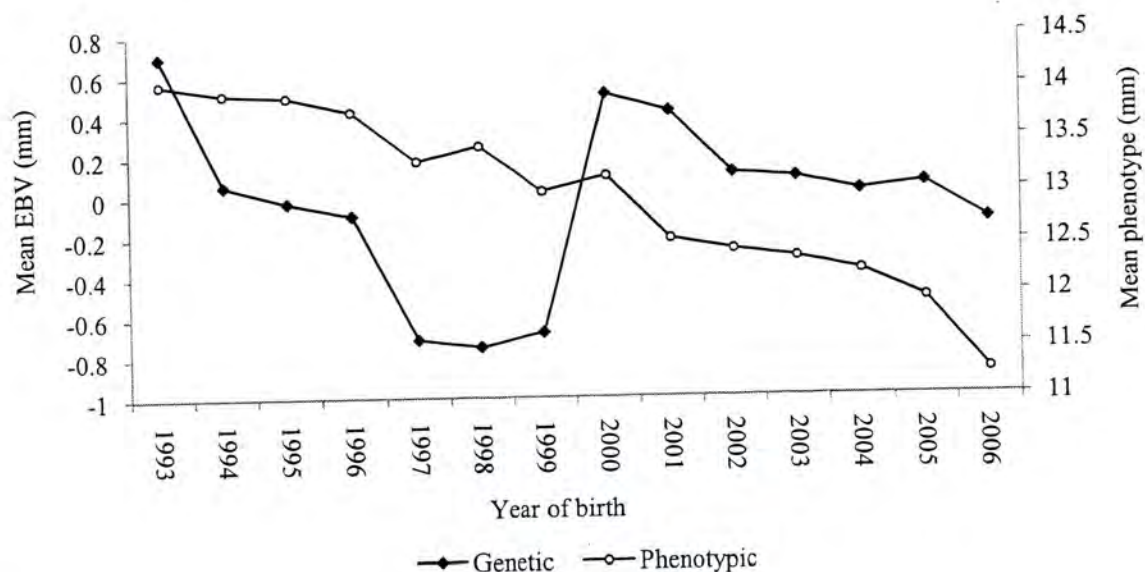


Figure 6.1a Genetic and phenotypic trends for backfat thickness

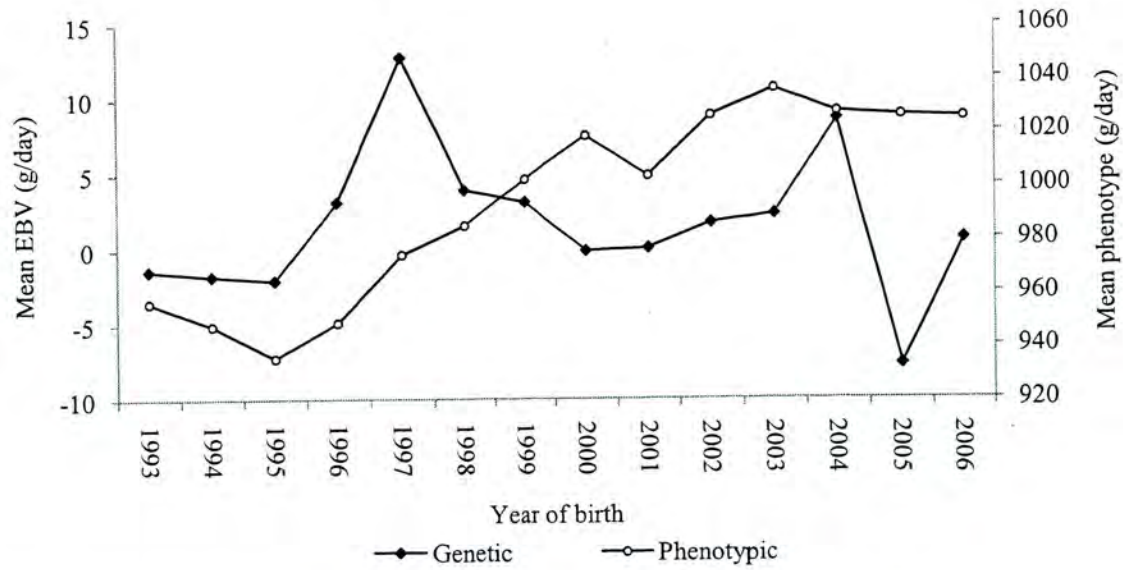


Figure 6.1b Genetic and phenotypic trends for test period weight gain

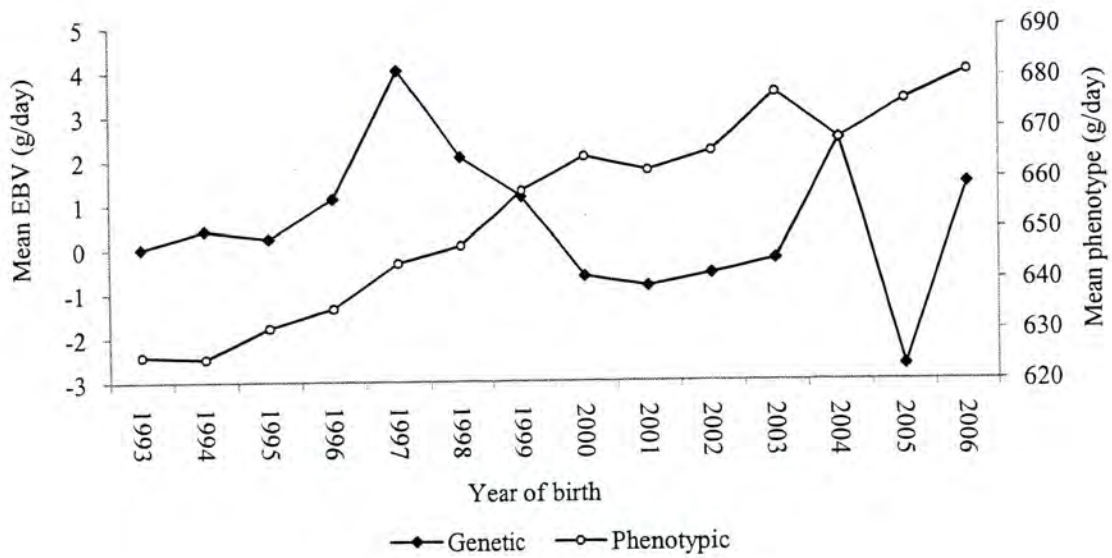


Figure 6.1c Genetic and phenotypic trends for lifetime weight gain

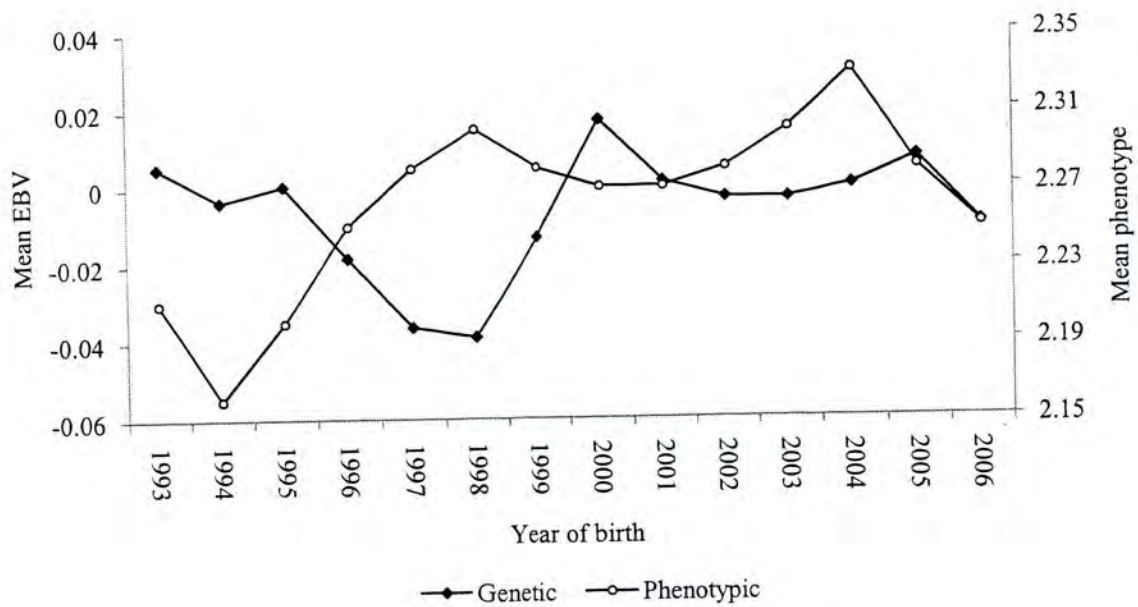


Figure 6.1d Genetic and phenotypic trends for feed conversion ratio

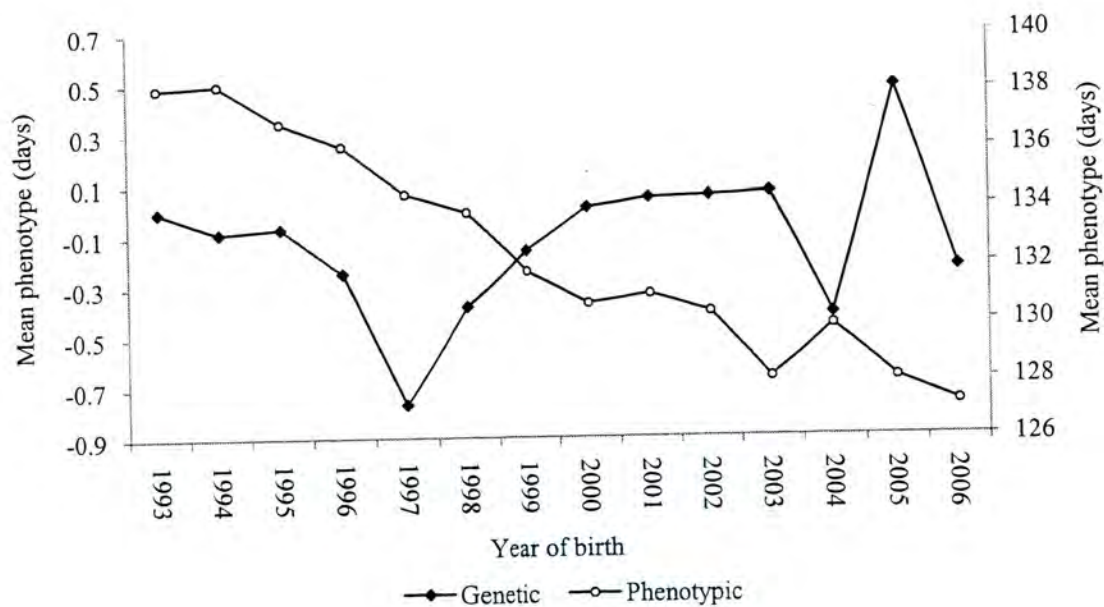


Figure 6.1e Genetic and phenotypic trends for age at slaughter

6.3.4.2. Carcass traits

Genetic trends for carcass traits are shown in Figures 6.2a to 6.2g. Lean and drip-free lean percentages were oscillating between 0 and 0.06, and 0 and 1 %, respectively from 1993 to 2001, followed by a sudden dip, after which there was an increase. Chen *et al.* (2002) observed increasing breeding values for lean growth rate in four US pig breeds. There was an increase in dressing percentage from 1993 to 1995, which was followed by a decrease until 2000. A general increase was then observed until 2006 when the breeding value for dressing percentage recorded 0.07 % above the mean value. Eye muscle area was constant from 1993 to 1998, after which it oscillated between -0.02 and 0.04 cm². Increasing trends for loin eye area were observed by Chen *et al.* (2002). They reported genetic changes in loin eye area of 0.42 % of its mean per year. These trends generally show lack of genetic improvement in all the carcass traits studied, despite the potential shown by their heritabilities. On the other hand, some of these traits showed improvement at phenotypic level, which may be due to improved management.

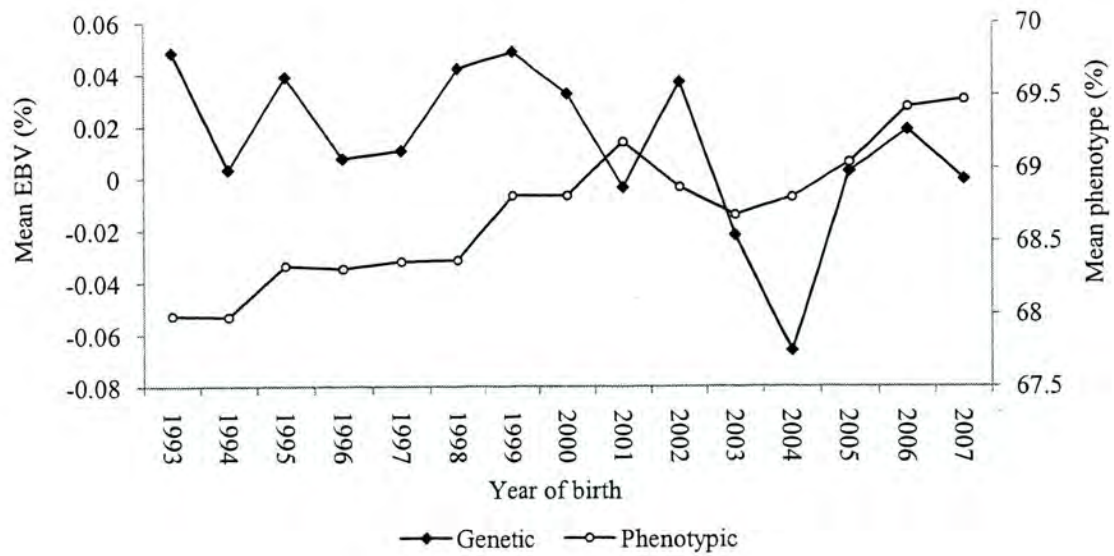


Figure 6.2a Genetic and phenotypic trends for lean percentage

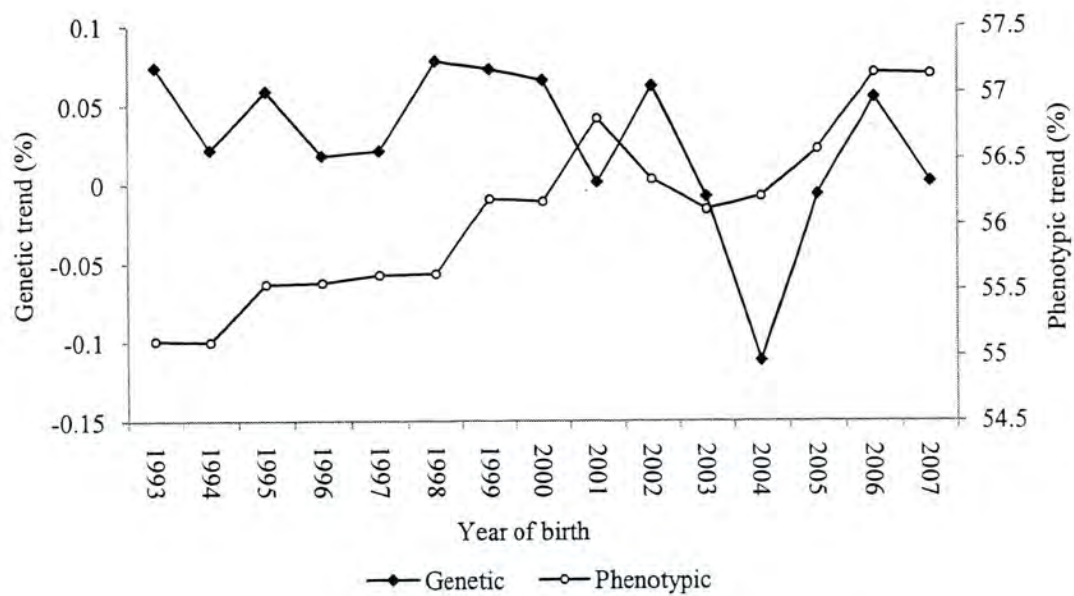


Figure 6.2b Genetic and phenotypic trends for drip-free lean percentage

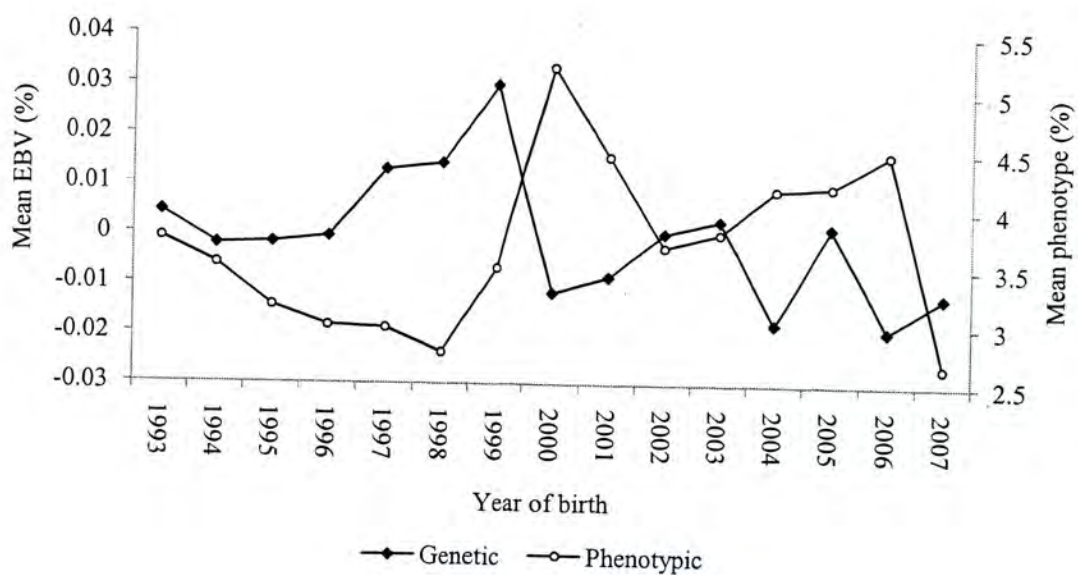


Figure 6.2c Genetic and phenotypic trends for drip loss percentage

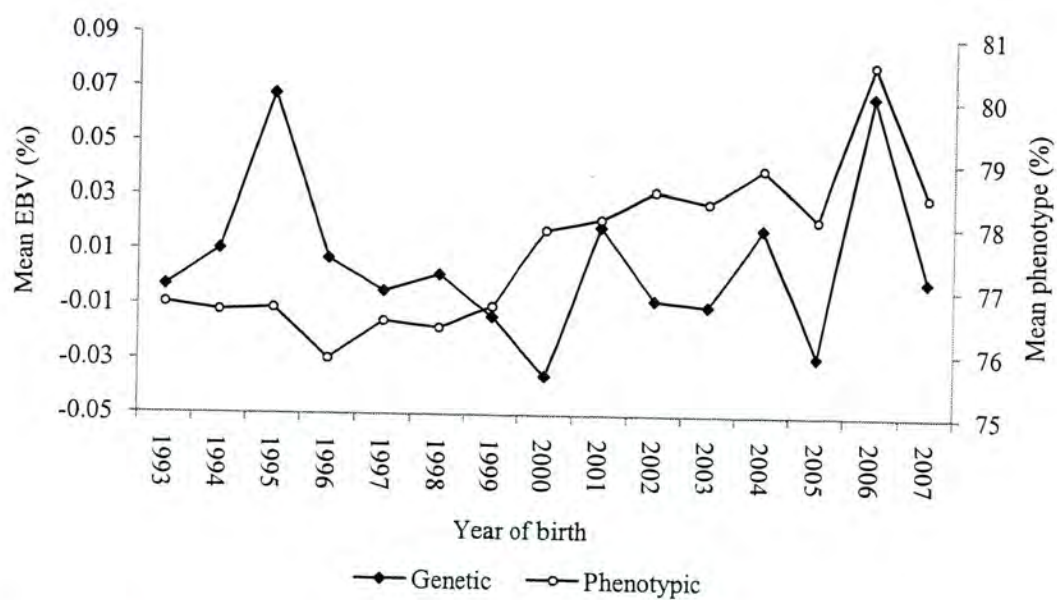


Figure 6.2d Genetic and phenotypic trends for dressing percentage

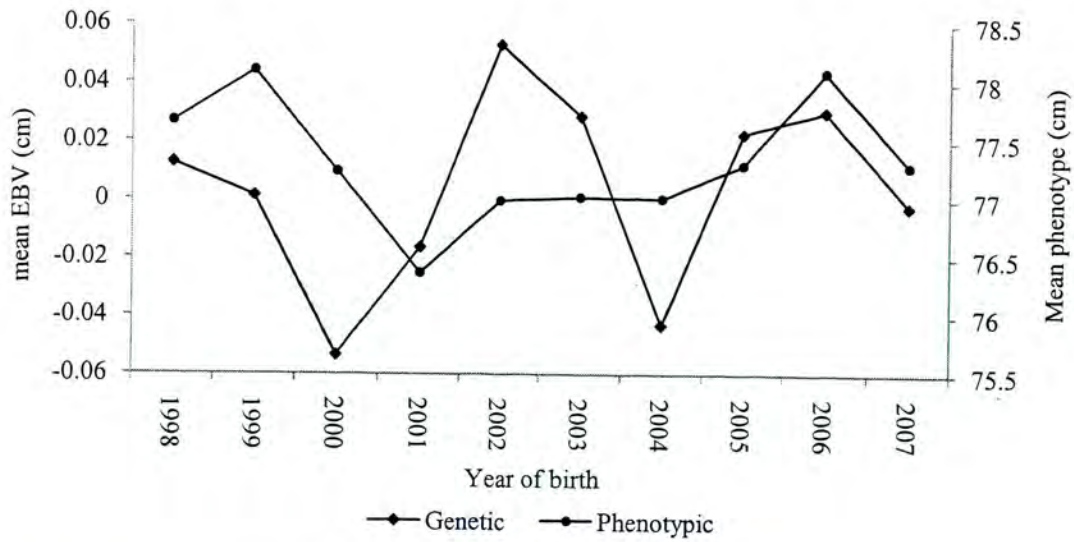


Figure 6.2e Genetic and phenotypic trends for carcass length

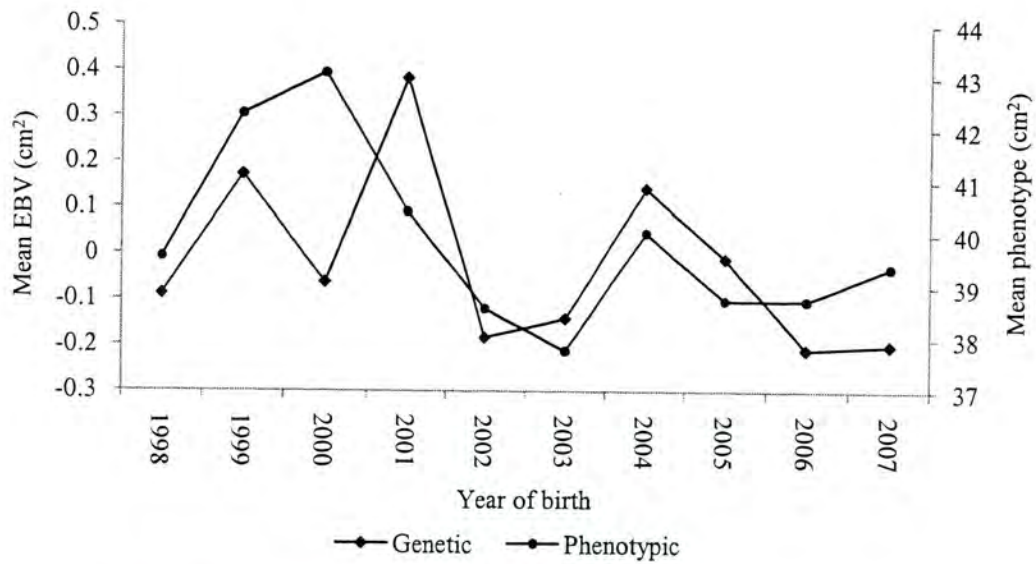


Figure 6.2f Genetic and phenotypic trends for eye muscle area

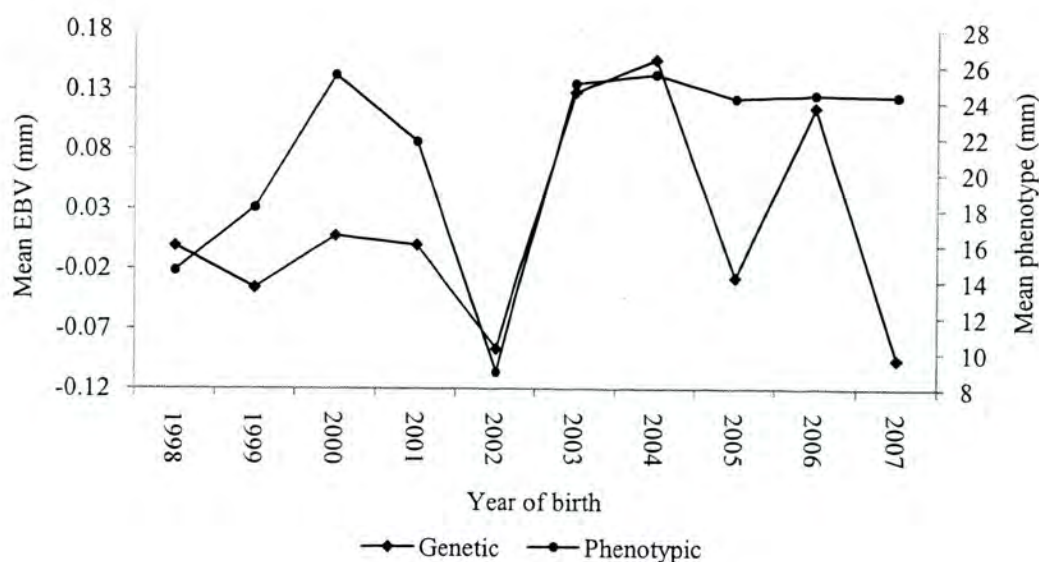


Figure 6.2g Genetic and phenotypic trends for carcass fat

6.4. Conclusions

Most of the traits analyzed have high genetic variation, suggesting that there is room for genetic improvement of these traits. Considerable maternal influence was noted on some of the traits, suggesting that maternal genetic effects should be considered in selection programmes. Carcass quality and yield can be improved by targeting drip-free lean percentage for improvement. Although there was a less than perfect relationship between backfat thickness and carcass fat, carcass leanness may be improved by selecting for reduced backfat thickness. Improvement of test period weight gain may improve feed conversion ratio and reduce slaughter age without compromising carcass quality and yield. Indications are that there has been no consistent selection based on genetic merit in the South African Large White population. It is imperative; therefore, that the South African pig industry selects pigs based on breeding values for growth

and carcass traits. Genetic parameters may be utilized efficiently in selection programs when combined with economic parameters for production systems.

Chapter 7

Derivation of Economic Values for Sow Productivity, Growth and Carcass Traits

7.1. Introduction

Pig breeding programs aim to obtain a successive generation of pigs that will produce desired products more efficiently under future farm economic and social circumstances than the present generation of pigs. Improvement should be done to those traits that improve enterprise profitability. Thus, economic relevance of traits in the breeding objective is of paramount importance. Designing a comprehensive animal breeding program with a specific objective involves economic considerations (Charfeddine, 2010). Therefore, the breeding objective involves calculation of economic values for all biological traits that have an impact upon profitability (James, 1982).

Terminal sire and dam lines from nucleus populations have been playing an important role in improving growth performance, carcass characteristics and sow productivity of South African pigs. For pig enterprises to be profitable, correct emphasis should be placed on all economically relevant traits. Genetic selection, however, has mainly been based on estimated breeding values, without incorporating economic components into the program. Economic values should be derived in order to direct and optimize genetic selection. The purpose of this study is to conduct simulations of pig production systems to derive economic values for sow productivity, growth

and carcass traits. These economic values will be used together with genetic parameters in genetic improvement programs.

7.2. Materials and Methods

7.2.1. Biological traits affecting profit

Growth traits included in the analysis were average daily (lifetime) gain (ADG), feed conversion ratio (FCR), age at slaughter (AGES) and ultrasonic backfat thickness (BFAT), while carcass traits were lean content (LEAN) and dressing percentage (DRESS). Ultrasonic backfat thickness indicates the level of fatness; hence it can be considered an indicator trait for LEAN. Average daily gain is economically important to pig production since it is directly related to the number of days required to reach market weight; hence it affects production costs. The amount of feed consumed for a unit weight gain should be reduced to improve profits. Thus, FCR has been identified as an important variable in reducing production costs (See *et al.*, 1995). Even though LEAN should be improved, producers are also paid per kg carcass; hence the need to improve DRESS. The sow productivity traits were number born alive (NBA), 21-day litter size (D21LS) and weight (D21LWT). Number born alive is directly related to the number of animals surviving to weaning, hence the number of animals marketed. Twenty-one day litter weight affects post weaning growth performance.

7.2.2. Base herd structure

One simulation study for each line was performed to derive economic values for the traits. In both simulations, maiden females were purchased at the age of 143 days and mated at the first

oestrus. Mating was by artificial insemination with purchased semen. Females that failed to conceive after three consecutive services were culled. Pregnant sows were fed according to the nutrient requirements for pregnancy with the standard sow meal. After a 114-day gestation period, the sows farrowed and the number of male and female piglets was assumed to be same. Male piglets were castrated at 10 days of age. The lactating sow was switched to a lactation diet and creep feeding commenced when piglets were 13 days old until weaning at 28 days of age. After weaning, the sows were mated at the first oestrus, while the piglets were fed on the growers' meal. Productive sows were allowed to have a maximum of eight litters. For the terminal production system, growing and finishing commenced at 45 days of age until the gilts and castrates reached 86 kg live weight, when they were all marketed. In the simulation for sow productivity, growing and finishing commenced at 45 days of age for castrates until they reached 86 kg live weight, when they were marketed. Gilts started the growing and finishing phase at the age of 45 days until they reached 120 kg live weight, when they were marketed. Twenty-five percent of the gilts were kept as replacement females. Culled-sows were marketed 45 days after weaning so that they could be fattened. Table 7.1 shows proportions of breeding sows, sows culled, live weights of culled sows and litter sizes per parity. Input parameters for the production system are shown in Table 7.2.

Table 7.1 Proportions of sows, culled sows and their live weights and litter size in each parity

Parity	Proportion of breeding sows (%)	Sows culled after weaning (%)	Live weight of culled sows (kg)	Litter size
1	27.6	15	138	9.71
2	21.7	15	147	10.41
3	16.5	15	170	11.07
4	12.2	30	188	11.24
5	8.8	30	196	11.24
6	6.2	30	210	11.10
7	4.2	50	220	11.00
8	2.8	100	220	10.76

Table 7.2 Input parameters for the base herd structure

Parameter (unit)	Value	Parameter (unit)	Value
Number of sows	100	Interval from weaning to 1 st insemination (days)	7
Farrowing percentage (%)	90	Proportion of purchased gilts culled without farrowing (%)	15
Gestation period (days)	114	Live weight of culled gilts (kg)	130
Maximal number of farrowings	8	Lactation length (days)	28
Conception rate (%)	90	Number born alive (pigs)	10.59
Number of litters per sow per year	2.5	Gilts as percentage of NBA	50
Prewaning mortality (%)	10	Piglet birth weight (kg)	1.5
Post weaning mortality (%)	5	Mature pig weight (kg)	250
Culling rate (%)	20	Pre-weaning weight gain (g/day)	183
Replacement rate (%)	25	Post weaning weight gain (g/day)	713.84
Gestation maternal weight gain (kg)	20	Post weaning feed conversion ratio	2.08
Production percentage (%)	95	Lean percentage (%)	655
Age of gilts at purchase (days)	143	Backfat thickness (mm)	12.27
Purchase price of gilts (ZAR/pig)	1500.00	Sale weight for porkers (kg)	86.00
Interval from purchase to culling of gilts not becoming pregnant (days)	63	Marketing price for porkers (ZAR/kg live weight)	15.00
Interval from purchase to 1 st mating of gilts (days)	30	Marketing price for porkers (ZAR/kg carcass weight)	13.00
Maximum estrus cycles after weaning	3	Transport costs (ZAR/km)	10.00
Interval from the last weaning to culling of sows (days)	45		

7.2.3. Model description and definitions

A hypothetical 100-sow-herd was used for convenience of calculations. Five pig categories were distinguished according to age: (1) piglets (0 – 28 days old); (2) weanlings (29 – 44 days old); (3) gilts (>45 days and ≤ 120 kg); (4) castrates (>45 days and ≤ 86 kg); (5) breeding sows (>120 days).

Total annual profit of the herd was derived as the difference between costs and revenues of the system as shown in Equation 7.1. All costs and prices are expressed in South African Rand (ZAR) and the time unit is one year, assuming 2.5 litters per sow per year. The inputs for the production system were feed (creep, grower and finisher, and sow meal), management (i.e. labour, spraying or dipping and veterinary services), marketing (i.e. transport of live pigs) and fixed costs (housing, electricity, stationery and interests). The outputs are the revenues from sale of porkers, maiden gilts and cull-for-age sows. Supply of labour by the farmer was set to be fixed per pig per year but varied with the size of the herd. It was considered equal for all animal categories except for replacement stock. Replacement stock was assumed to need less care than the young stock and breeding pigs, thus it was considered to require half the amount of labour per pig. Veterinary care was assumed to be optimal and therefore, reasonable average costs have been used. Other costs not related to herd size were included in the fixed costs. Mating was done by artificial insemination and, cost of semen and insemination costs were included in the veterinary costs.

7.2.4. Profit functions

Total annual profitability of the herd (T_h) was described by Equation 7.1.

$$T_h = [N_e \times (R_e - C_e)] - C_{FCH} \quad [\text{Equation 7.1}]$$

where, N_e is the number of sows in the herd per year, R_e is average revenue per sow per year, C_e is average variable costs per sow per year, and C_{FCH} is fixed costs for the herd per year. The revenue (R_e) was calculated from the sale of porkers, maiden gilts and cull-sows (Equation 7.2).

$$R_e = \sum_{i=3}^5 [N_i \times f_i \times (1 - m_i) \times I_m] \quad [\text{Equation 7.2}]$$

where i in this and the following equations refers to pig category, N in this and the following equations refers to number of pigs, f the fraction of pigs that are marketed, m the mortality rate of pigs (%), and I_m the income from marketed pigs and carcasses, defined as follows:

$$I_m = (LW \times P_k) + (CW \times P_c) + (MG \times P_a) \quad [\text{Equation 7.3}]$$

Where, LW refers to LW in kg, P_k the price kg^{-1} of live weight, CW the carcass weight (kg), P_c the price kg^{-1} of carcass, MG the maiden gilts and P_a the price per pig.

The variable costs (C_e) consisted of feed, management and marketing (Equation 7.4).

$$C_e = N_i \times \left[\sum_{i=1}^5 (C_{fi} + C_{hi}) + \sum_{i=3}^5 C_{mi} \right] \quad [\text{Equation 7.4}]$$

where, C_f is the feed costs per pig, C_h the management costs per pig, and C_m the marketing costs per pig. Feed costs (C_f) were calculated as:

$$C_f = (L_i \times P_{rf}) \times \left[\sum_{i=1}^4 (K_i \times KF_i) + (B_i \times BF_i) \right] \quad [\text{Equation 7.5}]$$

where, L is the number of days a pig is present in the year, P_{rf} the price kg^{-1} of DM feed, K is the number pigs in the herd minus breeding sows, KF is the daily DM feed requirements for maintenance and growth per pig in the herd minus breeding females, B the breeding sows in the herd, and BF is the daily DM feed requirements for maintenance, growth and reproduction per pigs for breeding sows. Management costs (C_h) were calculated as:

$$C_h = \sum_{i=1}^5 [N_i \times (P_{bi} + C_{vi})] \quad [\text{Equation 7.6}]$$

where, P_b is the cost of labour per year per pig, C_v the average cost of veterinary services (drugs for incidental sicknesses, service charge, vaccinations, castration, tail-docking, insemination, etc.) per year per pig.

Marketing cost (C_m) per pig sold was computed:

$$C_m = \sum_{i=3}^5 [N_i \times f_i \times C_t] \quad [\text{Equation 7.7}]$$

where, f is the fraction of pig that were sold, C_t the cost of transport of live pig to the market per pig. The annual costs of production (variable and fixed costs) are contained Table 7.3, while feed costs were derived from energy requirements of the pigs.

Table 7.3 Estimated annual variable and fixed costs of production, excluding feed costs

Cost	Amount (ZAR) per herd
Administration fees	12000.00
Bank charges	3000.00
Cell phone costs	3000.00
Depreciation	105075.00
Electricity and water	18000.00
Fuel and oil	24000.00
Interest paid – Long term loan	246042.00
Printing and stationery	1800.00
Protective clothing	3000.00
Repairs and maintenance	9000.00
Salaries	96000.00
Veterinary costs	36000.00
Wages	36000.00

Source: South African Pork Producers Organization (2010)

7.2.5. Energy requirements

Energy requirements for maintenance and production (growth, reproduction and lactation) were used to calculate feed intake. Pigs were assumed to consume standard commercial feeds *ad libitum*. Feed intake was defined in terms of dry-matter intake and the price of feed was set in terms of ZAR/kg. It was assumed that piglets start consuming creep feed at 13 days of age. Both males and females were assumed to have the same growth rate and consumed the same

amount of feed. The Gompertz growth function, which was viewed as best describing the growth of a pig (Wellock *et al.*, 2004), was used to predict live weights that were used in the calculations.

$$W = A \times \exp(-\exp(-G_0 - (B \times t))) \quad [\text{Equation 7.8}]$$

where, A is the mature weight set at 250 kg, B is the growth rate parameter estimated to be 0.0136 per day, t is the age of the pig in days and G_0 (Equation 7.9) is a transformed initial degree of maturity at birth.

$$G_0 = -\ln\left(-\ln\left(\frac{W_b}{A}\right)\right) \quad [\text{Equation 7.9}]$$

where, W_b is birth weight.

The energy requirements obtained from the NRC (1988) were used to derive feed intake for the different pig categories. The relationship between metabolisable energy (ME) and digestible energy (DE) was $ME = 0.96 \times DE$. Kielanowski (1965) proposed that energy intake is regressed on protein and lipid deposition.

$$E = E_m + \frac{E_{Pr}}{k_{Pr}} + \frac{E_{Lr}}{k_{Lr}} \quad [\text{Equation 7.10}]$$

This model states that energy (E) is used for maintenance (E_M), protein retention (Pr ; $E_{Pr} = 23.8Pr$ (MJ/kg)) and fat retention (Lr ; $E_{Lr} = 39.6Lr$ (MJ/kg)). The efficiencies of energy for protein and fat retention are $k_{Pr} = 0.54$ and $k_L = 0.74$, respectively (ARC, 1981).

7.2.5.1. Maintenance

The energy requirement for maintenance (E_m) includes the needs of all body functions and moderate activity, and is dependent upon metabolic body weight ($BW^{0.75}$). This relationship is shown in Equation 7.11 (NRC, 1998).

$$ME_m = 106 \text{ kcal ME/kg} \times BW^{0.75} \quad [\text{Equation 7.11}]$$

7.2.5.2. Pregnant sows

The energy requirement for pregnant sows (ME_p) is the sum of the energy for maintenance (ME_{ms}) for the pregnant sow and the requirement for pregnancy (ME_c), viz., the conceptus (NRC, 1988).

$$ME_p = ME_{ms} + ME_c \quad [\text{Equation 7.12}]$$

$$\text{where, } ME_{ms} = 106 \text{ kcal ME/kg } BW^{0.75} \quad [\text{Equation 7.13}]$$

The energy requirements of the conceptus (ME_c) depend upon the number of foetuses carried (NRC, 1998).

$$ME_c = 35.8 \text{ kcal ME/pig/day} \quad [\text{Equation 7.14}]$$

7.2.5.3. *Lactation*

The daily energy requirements during lactation include maintenance of the lactating sow (ME_{ms}) (Equation 7.12) and a requirement for milk production (ME_l) (Noblet & Etienne, 1987). The energy requirement for milk production was estimated from the growth rate of the suckling pig and the number of pigs in the litter (Equation 7.15) (Noblet & Etienne, 1987).

$$ME_l (\text{kcal/day}) = (6.83 \times \text{ADG} \times \text{pigs}) - (125 \times \text{pigs}) \quad [\text{Equation 7.15}]$$

where, ADG is the growth rate of the suckling pig averaged over the lactation period (g/day), and pigs is the number of piglets in the litter.

7.2.5.4. *Growth*

This energy is for maintenance (Equation 7.11), protein retention (ME_{Pr}) and fat deposition (ME_{Lf}), which are provided for by voluntary feed intake. The dry matter intakes for growth in the different animal categories were derived by NRC (1987). The dry matter requirements were calculated from estimates of the mean intake of digestible energy at the various ages, physiological categories and weights of the pigs.

7.2.5.4.1. *Suckling pigs*

The DE intake of creep feed by the suckling pig can be expressed by the following relationship (Equation 7.16) (NRC, 1987).

$$\text{DE intake (kcal/day)} = -151.7 + (11.2 \times \text{day}) \quad [\text{Equation 7.16}]$$

where, day is age of the pig.

7.2.5.4.2. Weanling pigs

Digestible energy intake for weanling pigs is as shown in Equation 7.17, which describes the relationship between BW and DE intake of the 5- to 15-kg pig (NRC, 1987).

$$\text{DE intake (kcal/day)} = -1531 + (455.5 \times \text{BW}) - (9.46 \times \text{BW}^2) \quad [\text{Equation 7.17}]$$

7.2.5.4.3. Growing-finishing pigs

This prediction of digestible energy intake for the growth of animals from 15 kg until marketing is shown by the relationship in Equation 7.18 (NRC, 1987).

$$\text{DE intake (kcal/day)} = 13162 \times (1 - e^{-0.0176\text{BW}}) \quad [\text{Equation 7.18}]$$

7.2.6. Economic value derivation

Three methods are used to calculate economic values, viz., the partial budget approach, partial differentiation method (Brascamp *et al.*, 1985; Smith *et al.*, 1986) and the bio-economic models (Bourdon, 1998). The partial budgeting method accounts for marginal returns and marginal costs arising from the improvement, and does not take into account fixed costs. In the partial differentiation method, the partial derivative of the profit function with respect to the trait of interest is obtained. The partial differentiation method requires setting an equation that describes

the change in net economic returns as a function of a series of physical, biological, and economic parameters (Bett *et al.*, 2007). Bio-economic models consist of numerous equations relating biological, physiological, management and economic parameters, which was not possible with the available data in this study.

Economic values for sow productivity traits, ADG, FCR, DRESS and AGES were derived through the partial budget approach. The partial differentiation of the profit function was used to derive economic values for LEAN and BFAT. Change in profit was calculated by evaluating herd profit (T_{f1}) numerically for each trait, then evaluating it after incrementing by one unit of that trait (thus obtaining T_{f2}), and taking the difference $T_{f2}-T_{f1}$ (Ponzoni, 1992). In this study, traits were incremented by more than one unit and then divided by the incremental value as illustrated hereunder.

$$a_i = \frac{P(\mu_i + d_i)}{d_i} = \frac{\Delta P}{\Delta i} \quad [\text{Equation 7.19}]$$

where, μ_i is the average value of the trait, d_i is the change in trait i by one unit, $P(\dots)$ is the net profit for a given value of trait i , ΔP is the difference in net profit, which was expressed per unit product and Δi is the difference in trait i . The profit difference was then multiplied by the genetic standard deviation to produce an economic value per genetic standard deviation (Wolfova *et al.*, 2007a). This was followed by computing relative economic values by setting backfat thickness as a base trait by which all comparisons for growth and carcass traits would be made. Relative economic values for sow productivity traits were computed by setting NBA as a base trait.

7.2.6.1. Number born alive

An increase in the average number of piglets born alive per litter was followed by a proportionate increase in the average number of piglets weaned, taking into account preweaning mortality. Feed costs for sows and creep in the lactation period were expected to increase, but no change in the average piglet weight at birth and weaning was expected. The feed as well as non-feed costs and the revenues for the extra pigs weaned were accounted for in the feeder and fattening periods.

7.2.6.2. Twenty-one-day litter size

Improving 21-day litter size without increasing litter size at birth was achieved by improved survival of piglets. This entailed increased nutritional requirements of the suckling sow as it had to nurse more piglets for an extended period of time. An increase in the piglets weaned resulted in more pigs being raised to marketing.

7.2.6.3. Twenty-one-day litter weight

Increasing 21-day litter weight was a result of improved pre-21-day weight gain, which was assumed to be catered for by the sow's milk. Birth weight, hence pregnancy costs remained unchanged. Increased preweaning daily gains were followed by increased post weaning daily gain and live weights. This resulted in an increase in daily feed intake for subsequent growth stages. Although feed costs increased at specific ages/weights, slaughter weight was reached earlier.

7.2.6.4. *Average daily gain*

Average daily gain considered in this study was calculated from lifetime weight gain. The Gompertz growth function was used to predict the weight of a pig based on their age. Weight gain per day was calculated as the derivative of weight with respect to age. The energy needed for the daily gains was calculated using the formulae for energy requirements for the different pig categories. Increasing average daily gain was associated with a reduction of days to reach market weight.

7.2.6.5. *Feed conversion ratio*

Feed conversion ratio, defined as the kg of feed consumed to gain 1 kg of live weight, was considered. Improving feed conversion efficiency resulted in improved growth rate.

7.2.6.6. *Age at slaughter*

Age at slaughter was defined as the number of days taken to reach 86 kg, which is the age adopted from the South African pig performance testing scheme. Improving age at slaughter was associated with improvement in FCR and ADG.

7.2.6.7. *Dressing percentage*

Carcasses consist of lean (protein) and fat, therefore increasing dressing percentage resulted in an increase in protein and fat, which entailed more energy required for deposition. Fat and protein content were determined and the respective deposition energies were computed. Whittemore (1993) established the relationship between live weight and fat (P2) (Equation 7.20).

$$\text{DRESS (\%)} = 66 + 0.09 \times \text{BW} + 0.12 \times \text{P2} \quad [\text{Equation 7.20}]$$

Energy for protein deposition was the sum of energy for protein turnover (Px) and protein retention (Pr) as illustrated in Equation 7.21 (Whittemore *et al.*, 2001).

$$E_{\text{Pr}} = 7.3\text{Px} + 23.6\text{Pr} \quad [\text{Equation 7.21}]$$

Maximum protein retention (Pr_{max}) was derived from the Gompertz growth function as shown in Equation 7.22 (Whittemore *et al.*, 2001).

$$\text{Pr}_{\text{max}} = \text{Pt} \times B \times \ln\left(\frac{\text{Pt}_{\text{max}}}{\text{Pt}}\right) \quad [\text{Equation 7.22}]$$

where, Pt = current protein, B = growth rate parameter taken to be 0.012 and Pt_{max} = mature size protein mass taken to be 40 kg. Current protein (Pt) was determined using Equation 7.23 (Whittemore *et al.*, 1995).

$$\text{Pt} = 0.44 \times (0.41 \times \text{BW} - 0.52 \times \text{P2} + 2.4) \quad [\text{Equation 7.23}]$$

Protein turnover was estimated from protein retention and degree of maturity shown by Equation 7.24 (Millward *et al.*, 1974).

$$\text{Px} = \frac{\text{Pr}}{\left(0.23 \left(\frac{\text{Pt}_{\text{max}} - \text{Pt}}{\text{Pt}_{\text{max}}}\right)\right)} \quad [\text{Equation 7.24}]$$

Efficiency of use of ME for protein retention was as follows (Whittemore *et al.*, 2001):

$$k_{Pr} = \frac{Pr \times 23.6}{((Px \times 3.92) + (Pr \times 23.6))} \quad [\text{Equation 7.25}]$$

Increasing dressing percentage was associated with increased protein and fat content, which was assumed to include backfat thickness. Growth rate, feed conversion ratio, age at slaughter and backfat thickness remained constant.

7.2.6.8. *Lean content*

Lean content was calculated by first determining the amount of fat deposited using the following relationship with body weight (Whittemore *et al.*, 1995).

$$Lt = 1.12 \times (0.19 \times BW + 0.78 \times P2 - 9.2) \quad [\text{Equation 7.26}]$$

where, Lt is current fat content and P2 is carcass backfat thickness taken to be 12.27 mm. Then carcass fat was subtracted from carcass weight to obtain lean content (McManus, 2007). Energy for protein deposition is as described in Equations 7.22 to 7.26. The energy obtained was added to maintenance (Equation 7.11) and the total energy was used to calculate the amount of feed required. Feed costs for protein deposition were then computed and added to non-feed costs. Hovenier *et al.* (1993) developed a method to calculate marginal income functions and to derive economic values for traits with an intermediate optimum, such as meat quality. They expressed income per carcass as a function of the trait means and assumed that carcasses were classified

into quality classes with different prices. This assumption was extended to the South African pig industry pricing system, a situation in which a trait can show several quality classes, each having a different price level (Table 7.4). A further extension was that carcasses were classified according to live weight, where there are four different live weight classes.

Table 7.4 South African pricing based on PORCUS classification system

Class	Lean (%)	BFAT (mm)	Price (ZAR/kg carcass)			
			20-55 kg	56-65 kg	66-80 kg	81-100 kg
P	≥70	≤12	16.85	15.91	15.40	13.89
O	68-69	13-17	16.41	15.54	15.35	13.81
R	66-67	18-22	12.98	13.65	14.42	13.06
C	64-65	23-27	6.81	7.72	9.52	11.61
U	62-63	28-32	6.22	8.78	9.61	10.15
S	≤61	>32	5.25	8.81	8.15	8.21

BFAT – backfat thickness

Source: SAMIC (2007)

The economic value derivation adopted was that developed by Hovenier *et al.* (1993). Calculation of the economic value required definition of quality classes for lean content. Given the population mean μ and the probability distribution of lean content $f(x|\mu)$, the fraction of the population within the defined quality classes was determined and income per carcass $I(\mu)$ was calculated as the average value of carcasses in the population as follows:

$$I(\mu) = \sum_{i=1}^n P_i \times F_i = \sum_{i=1}^n P_i \times \int_{B_{i-1}}^{B_i} f(x | \mu) dx \quad [\text{Equation 7.27}]$$

where, $I(\mu)$ = average income per carcass, μ = population mean, n = number of quality classes, P_i = price per carcass within the i^{th} lean class, F_i = fraction of the population within the i^{th} lean class, B_{i-1} = lower boundary for the i^{th} lean class, B_i = upper boundary for the i^{th} lean class and $f(x|\mu)$ = probability distribution.

Because income $I(\mu)$ is nonlinear in μ , the economic value $EV(\mu)$ is also a function of μ (Equation 7.28).

$$EV(\mu) = \frac{\partial I(\mu)}{\partial \mu} = \frac{\partial}{\partial \mu} \left\{ \sum_{i=1}^n P_i \times \int_{B_{i-1}}^{B_i} f(x | \mu) dx \right\} = \sum_{i=1}^n P_i \times \int_{B_{i-1}}^{B_i} \frac{\partial}{\partial \mu} \{f(x | \mu)\} dx \quad [\text{Equation 7.28}]$$

Assuming the trait is normally distributed,

$$f(x | \mu) dx = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Then,

$$EV(\mu) = \sum_{i=1}^n P_i \times \int_{B_{i-1}}^{B_i} \frac{\partial}{\partial \mu} \left\{ \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \right\} dx = \frac{1}{\sigma\sqrt{2\pi}} \sum_{i=1}^n P_i \times \left(e^{-\frac{1}{2}\left(\frac{B_{i-1}-\mu}{\sigma}\right)^2} - e^{-\frac{1}{2}\left(\frac{B_i-\mu}{\sigma}\right)^2} \right) \quad [\text{Equation 7.29}]$$

Therefore, income was obtained from the product of average carcass weight and price per kilogram, while feed costs for lean deposition were added to maintenance costs. Table 7.4 shows the SAMIC carcass pricing system. Lean content (kg) was obtained from lean percentage of carcass weight, where dressing percentage was computed as shown in Equation 7.20. Incrementing lean content was expected to increase feed costs only.

7.2.6.9. *Backfat thickness*

The definition of quality classes and economic value derivation are as described for lean content. The amount of fat needed to synthesize backfat was calculated with the assumption that 1.5 kg of fat is used in 1 mm of backfat thickness (Young, 2003). Energy for fat deposition is 39.6 MJ/kg with efficiency 0.74 (ARC, 1981). Energy used in backfat synthesis was computed and added to maintenance. The total energy was used to calculate feed costs which were added to non-feed costs and to the income lost per 1 mm increase in backfat thickness. According to the SAMIC pricing system, the average loss of income (ZAR) due to an increase in backfat thickness per mm backfat increase was -0.39.

7.2.7. **Sensitivity analysis**

Due to the uncertainty of future feed and marketing prices, sensitivity analyses were performed on economic values to price changes. Different types of feed were used for different categories of animals, with each feed type having a different price; therefore an average price was used in the sensitivity analyses. The average price of feed was increased from ZAR 3.75/kg to ZAR 5.25/kg. Marketing prices for carcasses of ZAR 13.00/kg were increased by 5.5 % up to 15.5 %, while those for maiden gilts of ZAR 1500.00 per animal, were increased by 0.5 % up to 5.5 %.

7.3. Results and Discussion

7.3.1. Economic values

Economic values were computed at 95 % production from a profit function by taking the difference between revenues and costs (Ponzoni, 1988). The economic values for the traits analyzed are shown in Table 7.5 and depended on population means. Figure 7.1 shows the relative economic values for sow productivity traits, while the relative economic values for growth and carcass traits are shown in Figure 7.2. These economic values indicate the direction and emphasis of genetic selection to be applied on the respective traits. Relative economic values indicate how much additional profit can be earned by making an improvement of one standard deviation in one trait relative to NBA or BFAT. From an animal improvement point of view, only the range around the actual population mean is interesting for short-to-medium-term considerations (von Rohr *et al.*, 1999). This is probably because the economic environment is constantly changing, which requires the continual update of the economic values. Since the economic environment varies from one environment to another and from herd to herd, genetic programs can be custom-made for a particular environment or herd.

The benefits resulting from corrections of inefficiencies in the production system, such as feeding management or pre-slaughter handling, should not be accounted for when estimating economic values (Smith *et al.*, 1986). Since management was assumed to be optimum, our economic values fulfil the requirements of Smith *et al.* (1986). Selection has the effect of changing population means, which might, in turn, result in changes in optimum management (Amer & Fox, 1992). Such potential changes were not considered in the current study.

Table 7.5 Economic values for the different terminal and sow productivity traits

	Economic value (ZAR)
Sow productivity	
NBA (pigs)	61.26
D21LS (pigs)	38.02
D21LWT (kg)	210.15
Terminal	
ADG (g/day)	33.34
FCR (kg/kg)	-21.81
AGES (days)	-68.18
DRESS (%)	5.78
LEAN (kg)	4.69
BFAT (mm)	-1.48

EV – economic value; NBA – number born alive; D21LS – 21-day litter size; D21LWT – 21-day litter weight; ADG – average daily gain; FCR – feed conversion ratio; AGES – age at 86 kg; DRESS – dressing percentage; LEAN – lean content; BFAT – ultrasonic backfat thickness

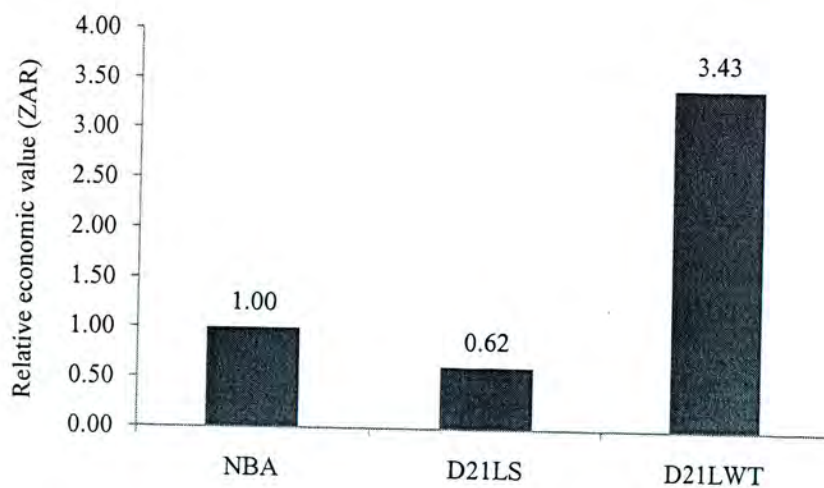


Figure 7.1 Relative economic values for sow productivity traits

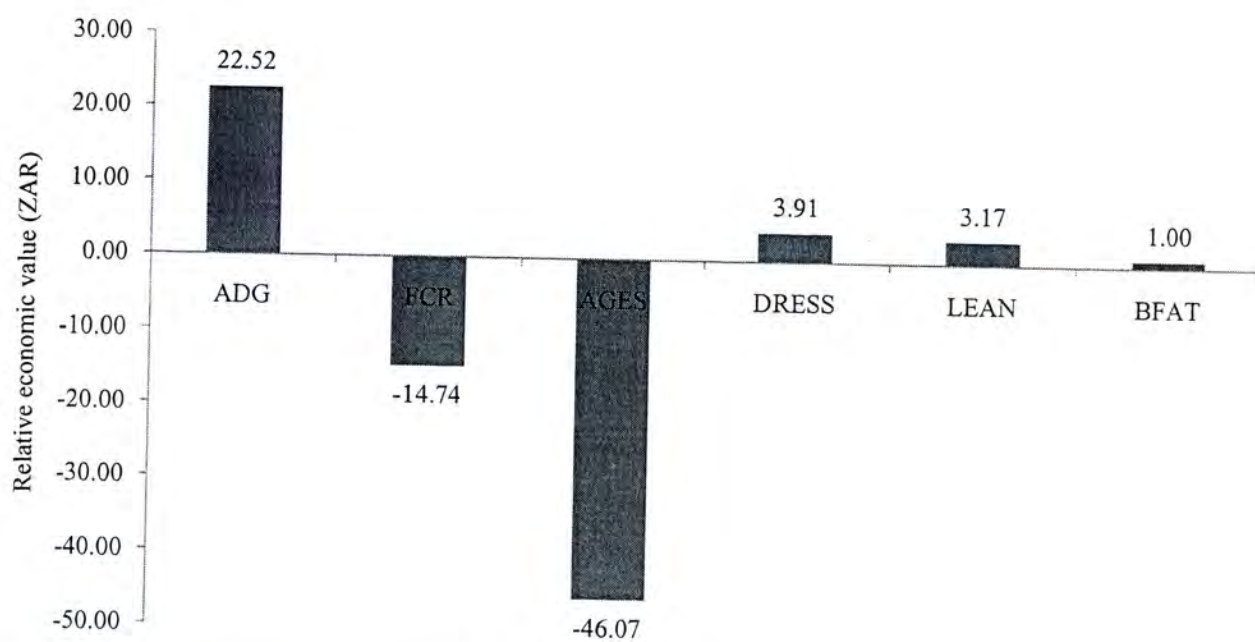


Figure 7.2 Relative economic values for growth and carcass traits

7.3.2. Sensitivity analyses

Since the economic world is not constant, the sensitivity analyses of the respective economic values for traits to feed prices and marketing prices of castrates/carcasses and maiden gilts were performed. The sensitivity of economic values of traits to circumstances also gives information on the likely direction of future genetic improvement and production system (Smith, 1988; Kosgey *et al.*, 2003). Figures 7.3a to 7.3g show the sensitivities of economic values for sow productivity traits to price changes. The economic values of NBA and D21LS decreased with increasing feed prices, while the economic value of D21LWT increased as feed prices increased. The income obtained from increasing NBA and D21LS offsets the increase in feed cost. There was no response in the economic value for D21LWT as marketing prices increased, while the economic values for NBA and D21LS increased. Marketing is done at fixed weight; hence marginal income is only obtained from improvements in NBA and D21LS. This analysis shows that when feed prices increase beyond ZAR 4.55 and 4.25 per kg, it would be a loss to improve NBA and D21LS, respectively. Simultaneous increases in marketing prices of castrates or carcasses and maiden females may counteract the loss due to feed price increases. This is indicated the by the positive responses of economic values for NBA and D21LS to increasing marketing prices of carcasses/castrates and maiden females.

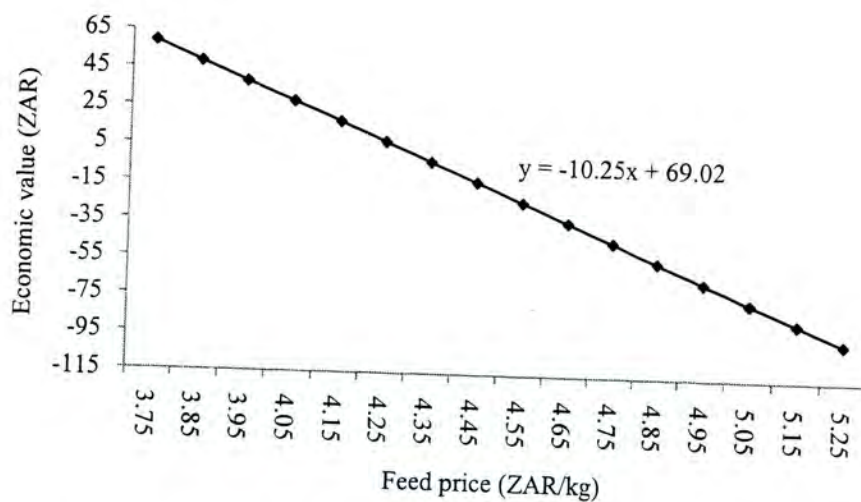


Figure 7.3a Sensitivity of the economic value for NBA to feed price changes

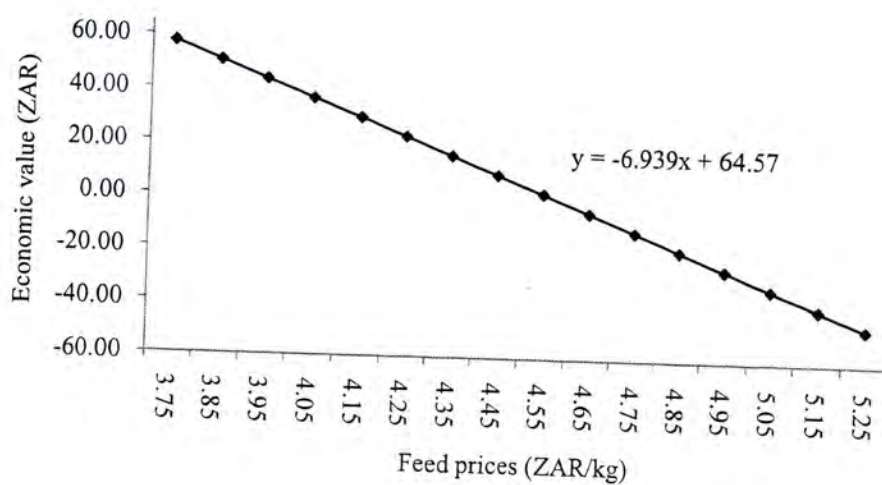


Figure 7.3b Sensitivity of the economic value for D21LS to feed price changes

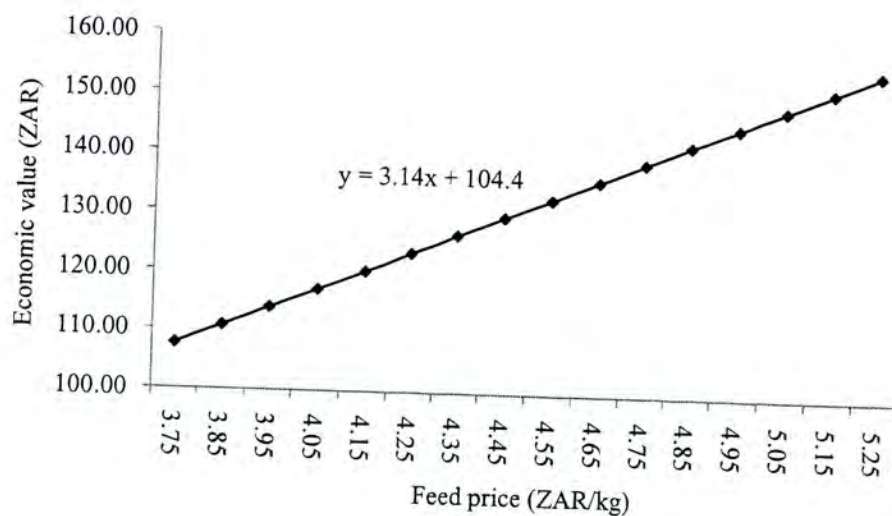


Figure 7.3c Sensitivity of the economic value for D21LWT to feed price changes

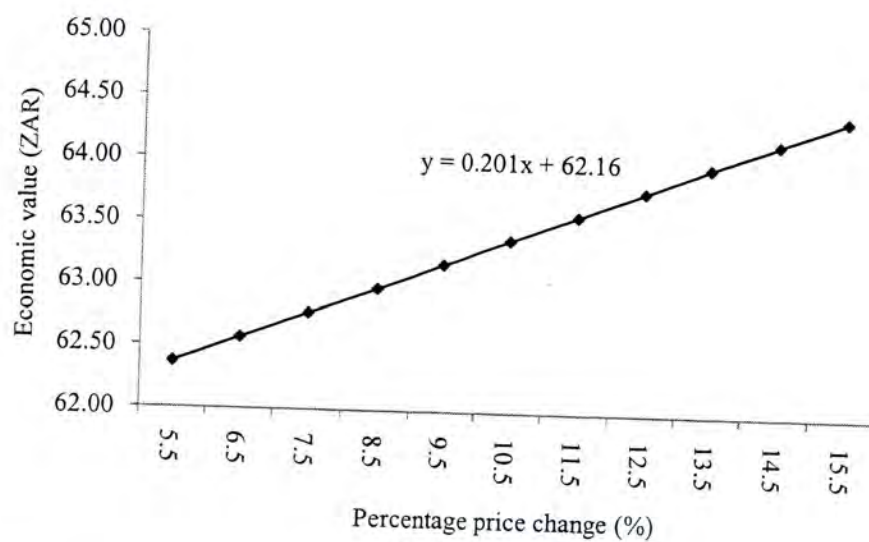


Figure 7.3d Sensitivity of the economic value for NBA to carcass price changes

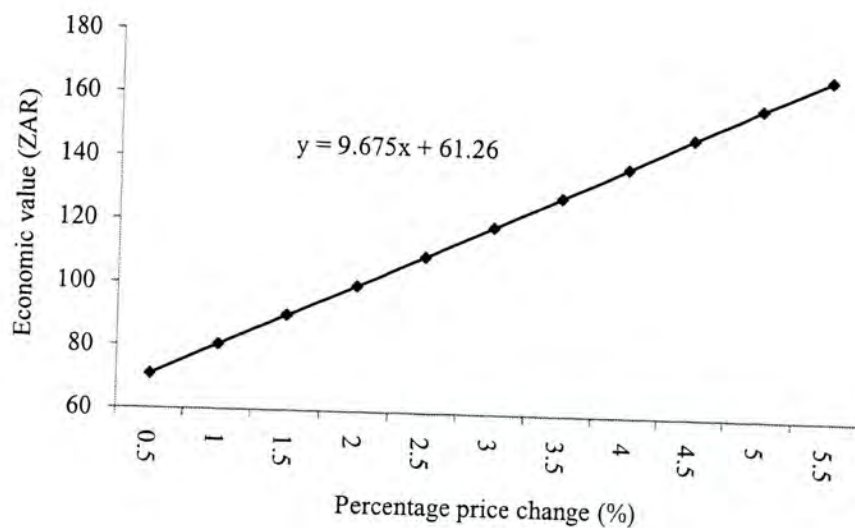


Figure 7.3e Sensitivity of the economic value for NBA to maiden gilt price changes

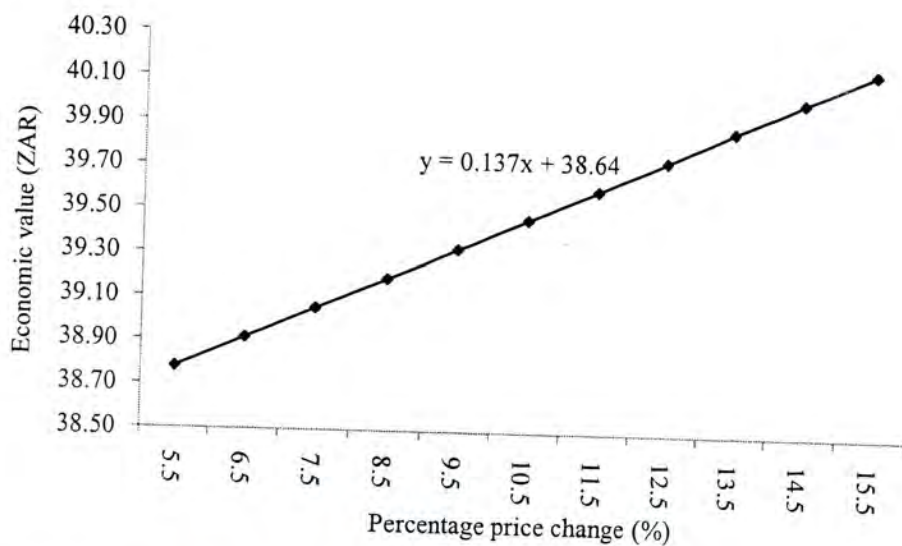


Figure 7.3f Sensitivity of the economic value for D21LS to carcass price changes

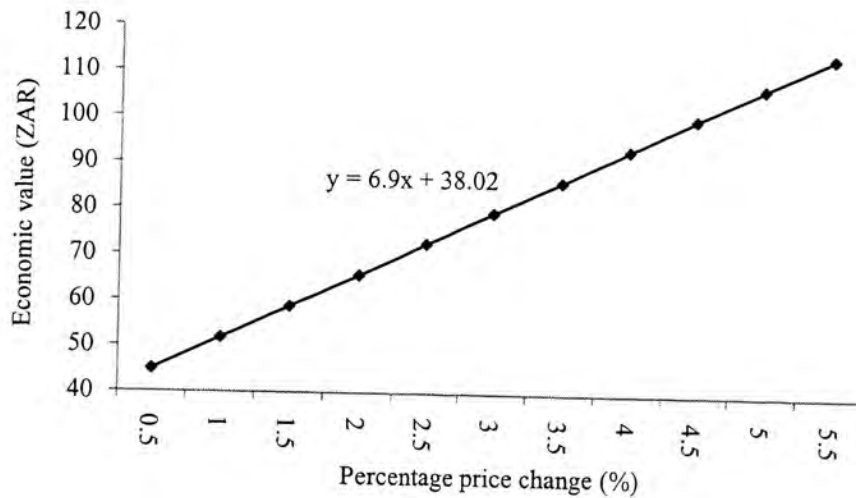


Figure 7.3g Sensitivity of the economic value for D21LS to maiden gilt price changes

Sensitivities of economic values for growth and carcass traits to price changes are shown in Figures 7.4a to 7.4g. The economic value of BFAT was not sensitive to changes in prices of feed, carcasses and animals. The greatest response to feed prices was observed in the economic value of DRESS. Economic values of LEAN and DRESS had decreasing responses to feed price increases. The results indicate that when feed prices increase beyond a ZAR 32.37 and ZAR 58.70, it would be unprofitable to improve LEAN and DRESS, respectively. Economic values for LEAN and DRESS increased with increasing carcass marketing prices. Assuming carcass marketing prices increase simultaneously with feed prices, the reduction in economic values due to feed price increases may be counteracted. On the other hand, EVs of ADG and FCR increased with increases in feed prices. Average daily gain had the lowest response to changes in feed price, while FCR had the highest.

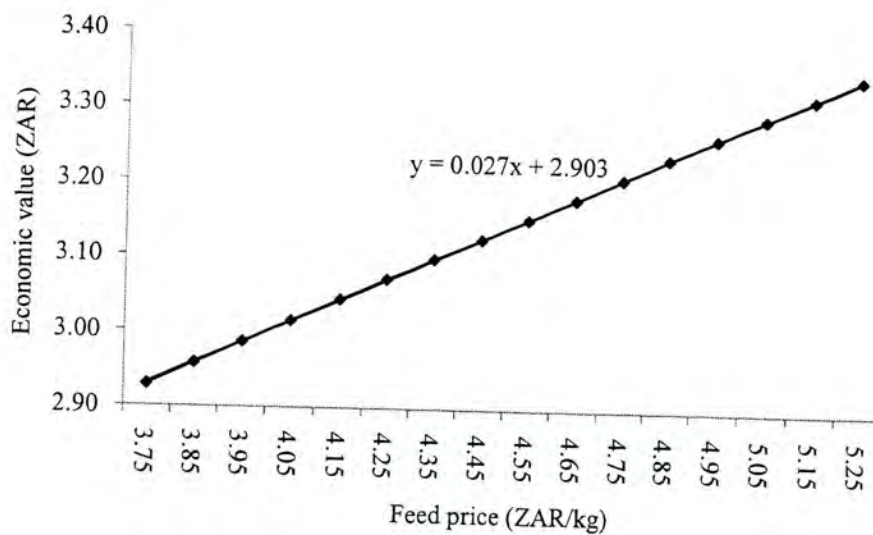


Figure 7.4a Sensitivity of the economic value for ADG to feed price changes

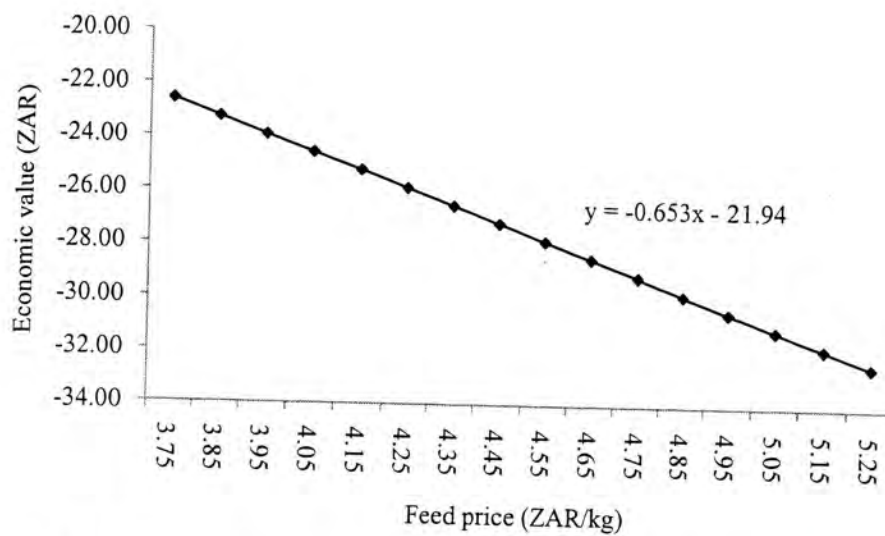


Figure 7.4b Sensitivity of the economic value for FCR to feed price changes

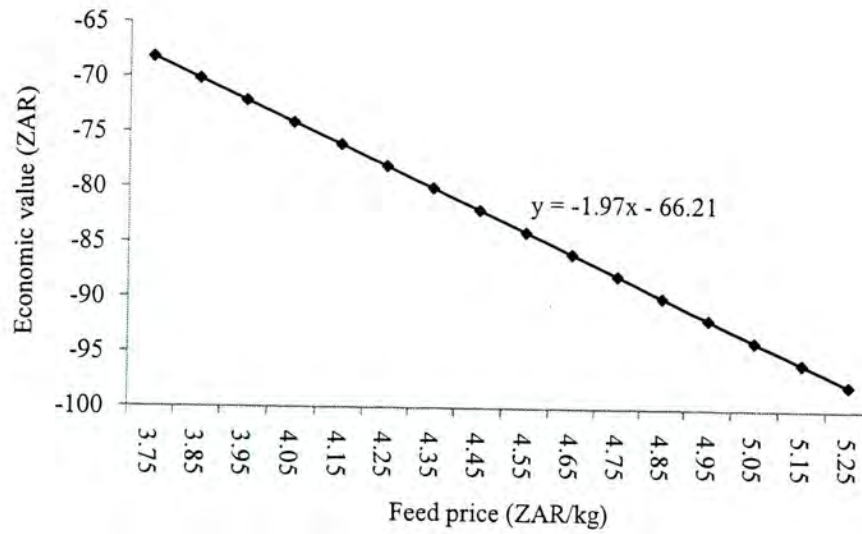


Figure 7.4c Sensitivity of the economic value for AGES to feed price changes

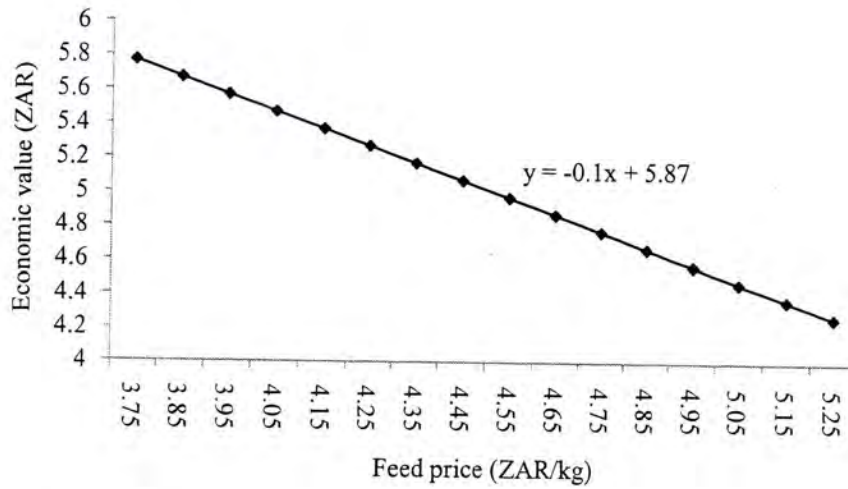


Figure 7.4d Sensitivity of the economic value for DRESS to feed price changes

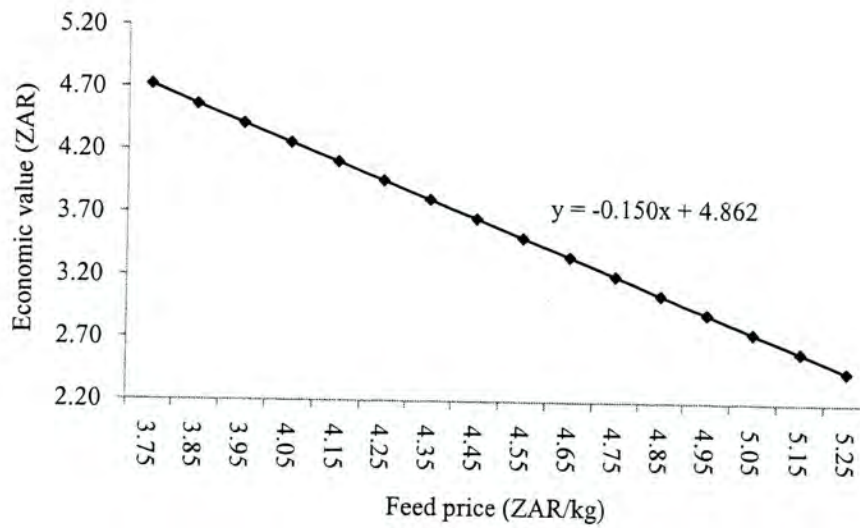


Figure 7.4e Sensitivity of the economic value for LEAN to feed price changes

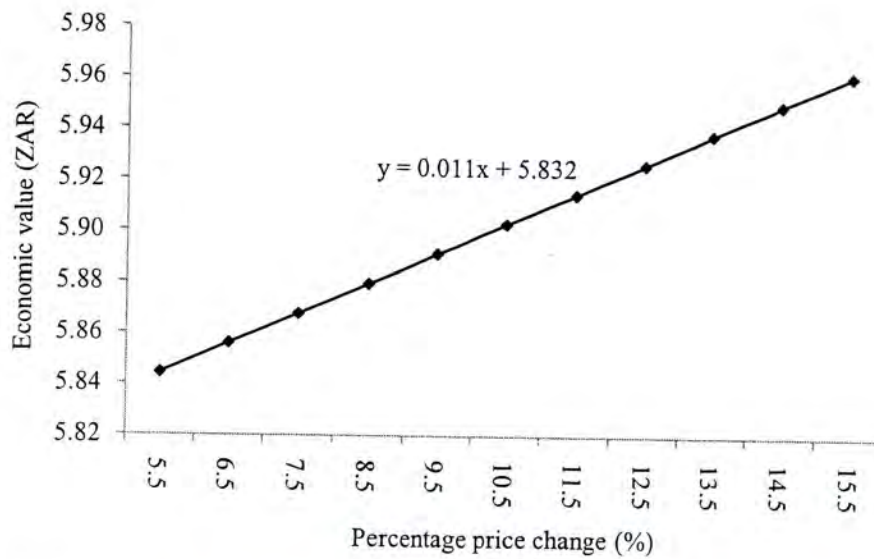


Figure 7.4f Sensitivity of the economic value for DRESS to carcass price changes

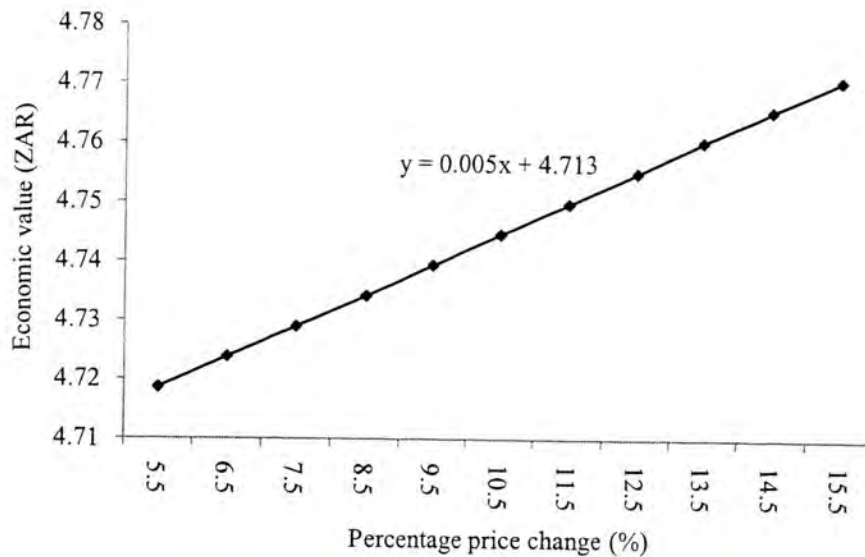


Figure 7.4g Sensitivity of the economic value for LEAN to carcass price changes

It is demonstrated that future economic values for responsive traits might change depending on changes in feed, carcass and live animal marketing prices. Kogsey *et al.* (2003) pointed out that the effort it takes to change a trait can vary considerably between traits, i.e. the trait can be of great economic importance but cannot be changed easily. Where profitability is a primary concern, decisions about which traits to target for genetic improvement should be based on the extent to which each trait affects profitability.

7.4. Conclusions

Incorporating economic considerations into breeding programs is made possible by the availability of economic values of economically relevant traits. The economic values provide the emphasis and direction of selection for each trait. These estimates of economic values can be useful and reliable as they are based on energy requirements of animals from the population in

which genetic selection would be practiced. In addition, information was obtained from major role players in the South African pig industry. The breeding objective developed using economic values reflect future developments in the pig industry. This study revealed the responsiveness of economic values for traits of economic importance to changes in feed and marketing prices of carcasses/castrates and maiden females. Genetic improvement of lean content, carcass yield and number born alive would only benefit the producer up to a certain point where feed prices would discourage any further improvement. This can be counteracted by simultaneous increases in marketing prices.

Chapter 8

Development of Selection Indices

8.1. Introduction

The genetic component of pigs is a major input of most pig production systems as it is related to the costs and revenue of the enterprise. To improve and sustain production, genetic improvement is one of the aims of breeders and producers. This has caused pig enterprises to shift from production to productivity and sustainability (Olesen *et al.*, 2000). Genetic improvement is achieved through genetic selection, which has since replaced the use of phenotypic records in selection programs. Terminal sire lines aim to improve post-weaning growth performance and carcass traits, while dam lines target sow productivity for improvement. These traits are targeted for simultaneous genetic improvement in modern pig production systems. The purpose of this study is to develop selection indices, using genetic parameters and economic values for the SA Large White population.

Selection index methodology was originally developed for purposes of multi-trait selection and is the best method of selecting for many traits (Hazel & Lush, 1942). The original selection index developed by Hazel (1943), generated weights for phenotypic records. These indices have been discouraged for genetic improvement because of the reasons outlined by Bourdon (1998). Thus, an index that utilizes breeding values weighted by economic values has been recommended for modern genetic selection programs (Bourdon, 1998; Wolfova *et al.*, 2007b). Use of economic values allows animals to be ranked based on their aggregate genetic values,

which will be in monetary terms, instead of biological values. Furthermore, economic return for the breeding program can also be estimated, which makes it possible to evaluate a breeding program (Connington *et al.*, 2001).

The cost of a multi-trait analysis in terms of computing time and space increases with the number of traits included in the analysis (Gilmour *et al.*, 2006). This suggests the need to minimize the number of traits in the analysis, while optimizing genetic improvement in all breeding objective traits. Since the goal is profit maximization, the selection index that will maximize economic return should be developed. Selection indices used by the South African pig industry do not incorporate economic parameters, which may not optimize genetic improvement in traits of economic importance nor maximize profits. The objective of this study is to develop selection indices which will optimize genetic improvement in all traits and maximize economic return for growth and carcass traits and for sow productivity traits.

8.2. Materials and Methods

8.2.1. Genetic parameters and economic values

The traits included in the study were described in Section 7.2.2. Genetic parameters for sow productivity traits were generated in Chapter 5, while those for growth and carcass traits were generated in Chapter 6. The derivation of economic values was done in Chapter 7 and these economic values are shown in Table 7.5. Genetic variances and covariances among the traits analyzed are contained in Table 8.1. Economic values were used with genetic variances and covariances to develop selection indices to be used in multi-trait selection programs.

Table 8.1 Genetic variances and covariances among growth, carcass and sow productivity traits

	NBA	D21LS	D21LWT	ADG	FCR	AGES	DRESS	LEAN	BFAT
NBA	0.31	0.20	0.22						
D21LS		0.09	1.35						
D21LWT			8.81						
ADG				129.9	-1.71	-77.92	1.14	0.22	-0.19
FCR					0.009	0.68	-0.02	-0.01	0.06
AGES						17.36	0.60	-0.81	1.71
DRESS							0.67	0.05	-0.12
LEAN								0.49	-0.89
BFAT									1.98

ADG – average daily gain, FCR – feed conversion ratio, AGES, age at slaughter; DRESS – dressing percentage, BFAT – backfat thickness; LEAN – lean content; NBA – number born alive; D21LS – 21-day litter size; D21LWT – 21-day litter weight

The fact that the importance of each trait in a pig enterprise varies according to its relationship with profit, may suggest the need to use economic values as weights for estimated breeding values in multi-trait selection programs. Where the EBVs are simply weighted by their respective economic values, the original selection indices **I** were written simply as (Gibson, 1995; Banga, 2009):

$$I = \sum_{i=1}^n a_i EBV_i \quad [\text{Equation 8.1}]$$

where, i is the trait, n is the number of traits and a is the economic value.

Simulations were conducted to estimate responses and correlated responses in the traits analyzed. Average daily gain shows how fast the animal is growing and this is reflected in the number of days an animal takes to reach slaughter weight. Thus, AGES was considered either as an indicator of ADG or as a breeding objective trait. This was to establish which of the two traits, ADG or AGES can be recommended for selection programs to improve growth performance. Lean content is measured in carcasses, which requires the animal to be slaughtered and results in few records used in genetic selection programs. Thus, most breeding programs select against backfat thickness and expect a correlated improvement in lean content because of the negative correlation between these traits (Nguyen & McPhee, 2005). Breeding programs however do not specify whether backfat thickness is included as a breeding objective trait or indicator of lean content. Backfat thickness was thus included in the selection index either as a breeding objective trait or an indicator of LEAN. Inclusion of AGES and BFAT as breeding objective traits was made possible by the availability of their economic values. This caused changes in breeding objectives, resulting in different breeding objectives to be tested.

Feed conversion ratio is not easily and accurately measured since it involves meticulous recording of feed intake, but its breeding value can be estimated from a multi-trait analysis. The value of including FCR in the selection criteria was determined by removing it from the selection criteria, while including it in the breeding objective. In the US, the terminal sire index includes

feed conversion ratio in the breeding objective and excludes it from the index (Schinckel *et al.*, 1998). In sow productivity traits, different selection criteria were developed to optimize genetic improvement of the same breeding objective traits and maximize economic returns. In situations where the breeding objective was different from the selection criteria, the index proposed by Scheeberger *et al.* (1992) and Gibson (1995) was used, where the index weights ($\mathbf{b}_I$) were:

$$\mathbf{b}_I = \mathbf{C}_I^{-1} \mathbf{C}_{IH} \mathbf{a} \quad [\text{Equation 8.2}]$$

where, $\mathbf{C}_{IH}$ is a matrix of genetic covariances between traits in the breeding objective and traits in the selection criteria and $\mathbf{C}_I$ is the genetic variance-covariance matrix among the selection criteria. The index weights would be used as weights for EBVs for the selection criteria during selection.

As a result of the different combinations of selection criteria and breeding objectives, four indices developed for sow productivity traits, shown in Table 8.2. There were 12 indices developed for growth and carcass traits (Table 8.3). The development of several indices enabled comparisons among indices to determine the best selection index and its corresponding breeding objective.

Table 8.2 Breeding objective and selection criteria for sow productivity traits

Index	Selection criteria	Breeding objective
1	NBA, D21LS, D21LWT	NBA, D21LS, D21LWT
2	D21LS, D21LWT	NBA, D21LS, D21LWT
3	NBA, D21LWT	NBA, D21LS, D21LWT

NBA – number born alive; D21LS – 21-day litter size; D21LWT – 21-day litter weight

Table 8.3 Breeding objective and selection criteria for growth and carcass traits

Index	Selection criteria	Breeding objective
4	ADG, FCR, DRESS, LEAN	ADG, FCR, DRESS, LEAN
5	ADG, DRESS, LEAN	ADG, FCR, DRESS, LEAN
6	AGES, DRESS, LEAN	ADG, FCR, DRESS, LEAN
7	AGES, DRESS, LEAN	AGES, FCR, DRESS, LEAN
8	ADG, FCR, DRESS, BFAT	ADG, FCR, DRESS, BFAT
9	ADG, DRESS, BFAT	ADG, FCR, DRESS, BFAT
10	AGES, DRESS, BFAT	ADG, FCR, DRESS, BFAT
11	AGES, DRESS, BFAT	AGES, FCR, DRESS, BFAT
12	ADG, FCR, DRESS, BFAT	ADG, FCR, DRESS, LEAN
13	ADG, DRESS, BFAT	ADG, FCR, DRESS, LEAN
14	AGES, DRESS, BFAT	ADG, FCR, DRESS, LEAN
15	AGES, DRESS, BFAT	AGES, FCR, DRESS, LEAN

ADG – average daily gain, FCR – feed conversion ratio, AGES, age at slaughter; DRESS – dressing percentage, BFAT – backfat thickness; LEAN – lean content

8.2.2. Response to selection

The methodology to predict responses to index selection was done as described by Groen (1990). The vector of predicted selection responses of the traits in the aggregate genotype when breeding objective ($\mathbf{R}_H$) traits were similar to the selection criteria was:

$$\mathbf{R}_H = i \frac{\mathbf{a}'\mathbf{C}_H}{\sqrt{\mathbf{a}'\mathbf{C}_H\mathbf{a}}} \quad [\text{Equation 8.3}]$$

where, i is the selection intensity set at 1.4 (best 20 % using truncation selection) and $\mathbf{C}_H$ is the genetic variance-covariance matrix for breeding objective traits. Genetic change was expressed per year, where the generation interval was assumed to be three years. When breeding objective traits and selection criteria were different, the method developed by Groen (1990), which was consistent with the method proposed by Schneeberger *et al.* (1992), was adopted to calculate genetic change. Thus, the responses for breeding objective traits were calculated as:

$$\mathbf{R}_H = i \frac{\mathbf{b}'\mathbf{C}_{IH}}{\sqrt{\mathbf{b}'\mathbf{C}_{IH}\mathbf{a}}} \quad [\text{Equation 8.4}]$$

where, $\mathbf{C}_{IH}$ is a matrix of genetic covariances between traits in the breeding objective and traits in the selection criteria. When breeding goal traits and selection criteria were different, the responses for the selection criteria ($\mathbf{R}_I$) were calculated as:

$$\mathbf{R}_I = i \frac{\mathbf{b}'\mathbf{C}_I}{\sqrt{\mathbf{b}'\mathbf{C}_I\mathbf{b}}} \quad [\text{Equation 8.5}]$$

where, C_I is the genetic variance-covariance matrix among the selection criteria

8.2.3. Economic return

Total economic return (**ER**) in ZAR from selection using the index was calculated by multiplying the vector of economic values by the vector of selection responses for breeding objective traits (Wolfova *et al.*, 2007b).

$$\mathbf{ER} = \mathbf{a}'\mathbf{R}_H \quad [\text{Equation 8.6}]$$

8.2.4. Sensitivity analyses

In Section 7.3.2, economic values were shown to change with changes in feed prices and carcass and/or animal marketing prices. Due to this changing nature of economic values, sensitivity analyses were conducted to determine the effect of price changes on economic return from the recommended selection indices (Indices 3 and 14). The sensitivity analyses were conducted in two ways. Firstly, the economic values for all traits were simultaneously increased successively by 10 % starting from 10 to 40 %, and then decreased by the same amounts. Then, the economic value for each trait was increased successively by 10 % starting from 10 to 40 %, while keeping other traits' economic values constant, and then reduced by the same amounts. Responses to selection for breeding objective traits and economic returns were evaluated in the sensitivity analysis.

8.3. Results and Discussion

8.3.1. Index weights

The index weights are shown in Tables 8.4 and 8.5, where economic values have been used as index weights in Indices 1, 4 and 8. Removing feed conversion ratio from the index caused the weights for the remaining traits to increase. Including age at slaughter in the index as a breeding objective trait resulted in a decrease in the weights for dressing percentage, lean content and backfat thickness. On the other hand, including age at slaughter as an indicator trait for average daily gain increased the weight for dressing percentage. In addition, when age at slaughter was considered an indicator for average daily gain, the weight for backfat thickness was positive while that for lean content was negative. The index weights for sow productivity traits in other indices were generally higher than the economic values. Index weights for 21-day litter size were negative when 21-day litter size was included in a two-trait index.

Table 8.4 Index weights for sow productivity traits

Index	NBA	D21LS	D21LWT
1	61.26	38.02	210.15
2		-51.18	225.34
3	82.45		215.44

NBA - number born alive; D21LS – litter size at 21 days; D21LWT – litter weight at 21 days

Table 8.5 Index weights for growth and carcass traits

Index	ADG	FCR	AGES	DRESS	LEAN	BFAT
4	33.34	-21.81		5.78	4.69	
5	33.63			5.89	4.92	
6			-172.31	238.81	-288.10	
7			-69.15	7.36	3.30	
8	33.34	-21.81		5.78		-1.48
9	33.63			5.79		-2.09
10			-174.98	249.98		160.83
11			-69.10	7.27		-1.23
12	33.27	-27.87		5.71		-1.95
13	33.63			5.73		-2.73
14			-174.99	249.93		160.20
15			-69.11	7.22		-1.86

ADG – average daily gain; FCR – feed conversion ratio; AGES – age at slaughter; DRESS – dressing percentage; LEAN – lean content; BFAT – backfat thickness

8.3.2. Responses to selection and economic returns

Genetic responses and economic returns for sow productivity traits are shown in Table 8.6. The index that consisted of all the three sow productivity traits did not produce the best results in terms of economic return. The lowest economic return was obtained when 21-day litter weight was excluded from the index, but included in the objective. Excluding 21-day litter size from the index and including it in the objective produced the highest economic return. This economic return was ZAR 0.11 more than that obtained from the index that consisted of all sow

productivity traits. Thus, for sow productivity traits, economic return may not be maximized by weighting estimated breeding values for number born alive, 21-day litter size and weight with their respective economic values. This index is also different from the STAGES Sow Productivity Index (Schinckel & Einstein, 1999). In the sow productivity index for STAGES, number born alive, number weaned and 21-day litter weight, are weighted by their respective economic values.

Table 8.6 Genetic responses and economic returns (ER) from index selection for sow productivity traits

Index	Genetic response			
	NBA (pigs)	D21LS (pigs)	D21LWT (kg)	ER (ZAR)
1	0.053	0.216	1.382	301.89
2	0.037	0.215	1.414	301.13
3	0.050	0.225	1.417	302.00

NBA – number born alive; D21LS – 21-day litter size; D21LWT – 21-day litter weight

Table 8.7 contains genetic responses and economic returns from index selection for growth and carcass traits. Different breeding objectives and indices were developed to determine an index that would result in optimum genetic improvement of the traits. Selection indices provide the optimal selection emphasis on different traits, based on their relative economic importance (Connington *et al.*, 2001). These selection indices depend highly on genetic parameters and economic values, suggesting estimation of these components should be done with utmost

accuracy. MacNeil *et al.* (1997) noted that small errors in economic weights or genetic parameters may only lead to minor losses in efficiency of selection.

Table 8.7 Genetic responses and economic returns (ER) from index selection for growth and carcass traits

Index	Genetic response						
	ADG (g/day)	FCR	AGES (days)	DRESS (%)	LEAN (kg)	BFAT (mm)	ER (ZAR)
4	5.318	-0.070		0.052	0.012		179.19
5	5.318	-0.070		0.052	0.012		179.19
6	9.408	-0.082	-1.803	0.029	0.007		315.64
7		-0.076	-1.944	-0.059	0.094		134.29
8	5.318	-0.070		0.052		-0.014	179.15
9	5.318	-0.070		0.052		-0.014	179.16
10	9.497	-0.0.8	-1.786	0.029		-0.008	318.50
11		-0.076	-1.944	-0.060		-0.197	134.14
12	5.318	-0.070		0.052	0.012	-0.015	179.19
13	5.318	-0.070		0.052	0.012	-0.015	179.19
14	9.497	-0.078	-1.786	0.029	0.007	-0.009	318.52
15		-0.076	-1.944	-0.059	0.094	-0.199	134.29

ADG – average daily gain; FCR – feed conversion ratio; AGES –age at slaughter; DRESS – dressing percentage; LEAN – lean content; BFAT – backfat thickness

Some studies have used selection indices based on BLUP, where estimated breeding values are weighted by economic values (Wolfova *et al.*, 2007b). The current study was based on this method of index development. Indices 1 and 4 were based on the complete breeding objectives, which also the measured traits. This study determined whether these are the best indices to be recommended for selection programs and also evaluated the prospects of utilizing alternative selection indices to optimize genetic improvement and maximize economic return. The complete indices (Indices 1 and 4) did not produce the best results in terms of responses to selection and economic returns.

Several breeding programs select directly for average daily gain to improve growth performance (e.g., Lo *et al.*, 1992; Suzuki *et al.*, 2005), including the South African pig breeding program. The current study evaluated the best way to improve growth performance. This was facilitated by the availability of genetic parameters and economic values for average daily gain and age at slaughter. Including age at slaughter as a breeding objective trait may have unfavourable responses in carcass yield as evidenced decreasing genetic gains for dressing percentage. Economic return was also lower when age at slaughter was included as a breeding objective trait. Including age at slaughter as a breeding objective trait however resulted in improvements in feed conversion ratio, lean content and backfat thickness. When age at slaughter was included as an indicator trait for average daily gain, there was a greater genetic response in average daily gain to selection than from direct selection for average daily gain. This may suggest that slower genetic progress may be expected in growth rate when selection for average daily gain is done by including it in an index. Conversely, age at slaughter, which is determined once during marketing, may be utilized to improve growth rate. Use of age at slaughter is consistent with the

terminal sire index used by the US Swine Testing and Genetic Evaluation System (STAGES); where days to slaughter, is included in the index, instead of average daily gain (Schinckel & Einstein, 1999). In STAGES however, age at slaughter is included as a breeding objective trait weighted by its economic value.

Breeding programs prefer to improve carcass leanness by reducing backfat thickness measured on live animals (Lo *et al.*, 1992; Suzuki *et al.*, 2005). The South African pricing system makes use of the two traits (backfat thickness and lean content), such that during marketing, either of the two traits is evaluated, depending on whether it is a live pig or a carcass being marketed. In this study, economic values and genetic parameters for the two traits were available. The current study was also meant to establish the most appropriate way to include backfat thickness in breeding programs. Including backfat thickness as an indicator of lean content produced results similar to including lean content in the index (Indices 4-7 and 12-15). On the other hand, including backfat thickness as a breeding objective trait resulted in lower economic returns. The best way to include backfat thickness in breeding programs for this population is to include it as an indicator trait for carcass leanness. Improving average daily gain and backfat thickness may result in increased daily maintenance costs due to the increased nutrient requirements of the growing pig (Cleveland *et al.*, 1983). This kind of selection is expected to result in increased mature size and increase maintenance requirements of the breeding herd. In the current study, however, inclusion of feed conversion ratio in the breeding objective may mitigate against such unfavourable responses.

Removing feed conversion ratio from the index and including it in the breeding objective did not change responses and economic return of the breeding objective. Feed conversion ratio may be improved by selecting for improved growth performance, carcass yield and quality. These results are consistent with previous reports where, improvements in feed conversion ratio due to selection for increased average daily gain and reduced backfat thickness were reported (Vangen, 1980). Jungst *et al.* (1981) reported poor responses to direct selection for feed conversion ratio and greater improvements from index selection for growth rate and backfat thickness. Feed conversion ratio is growth per kg of feed consumed. Therefore, including feed conversion ratio and average daily gain in the same breeding objective may result in double-counting of the economic value for growth rate. This may reduce the accuracy of the selection index.

The best selection index to improve growth and carcass traits consisted of age at slaughter, backfat thickness and dressing percentage (Index 14). Age at slaughter and backfat thickness, are included as indicator traits for average daily gain and lean content, respectively. The favourable results were, however, obtained from an index that had positive weights for backfat thickness. Producers may be reluctant to weight backfat thickness positively and prefer indices that place negative weight on backfat thickness. Under such circumstances, the producers may utilize the index that consists of average daily gain, dressing percentage and backfat thickness (Index 12), despite the lower economic returns expected. In this case, backfat thickness should still be included as an indicator trait for lean content. Gibson (1995) suggested the use of a restricted selection index in the case where producers are not willing to place positive weights on backfat thickness. The recommended indices are different from the indices currently utilized by the South African pig industry.

The method for calculating responses to selection when the traits in the objective are different from those in the index was adopted from Groen (1990) and is consistent with the method suggested by Schneeberger *et al.* (1992). In the approach by Schneeberger *et al.* (1992), a matrix of estimated breeding values for the selection criteria is first constructed. Adopting the method proposed by Groen (1990) may be a more direct method of computing responses to selection from indices based on BLUP as it bypasses the computation of the EBV variance-covariance matrix. The need to estimate breeding values for all breeding objective traits, each time selection is implemented, may be eliminated. Thus, economic values and genetic parameters for breeding objective traits might suffice for selection purposes. Breeding values can only be estimated for a few selection criteria, which might save computing time and space, hence cost. This study highlights the contribution of indirect selection using indicator traits for economically relevant traits to herd improvement.

8.3.3. Sensitivity analyses

Since pig enterprises aim to maximize profit, their selection programs which ensure that this is achieved, depend on economic values. The economic climate is constantly changing due to various economic factors, which changes economic values. In order for breeding programs to place the correct emphasis on traits during selection, the changes in economic values should be considered. The sensitivity of genetic changes and economic returns to changes in economic values were determined for the recommended selection indices for growth and carcass traits and for sow productivity. Genetic changes and economic returns were responsive to changes in economic values.

Changes in genetic responses and their economic returns for sow productivity traits are shown in Table 8.8, while those for growth and carcass traits are shown in Table 8.9. The sensitivity analyses were performed on the recommended indices for sow productivity, and growth and carcass traits. In sow productivity traits, the greatest and lowest changes occurred in 21-day litter size and number born alive, respectively. When economic values were changed for all traits simultaneously, the greatest changes for growth and carcass traits were for average daily gain, while the lowest were for lean content. Genetic changes and economic return increased when economic values increased and decreased when economic values decreased. Generally, the magnitude of decrease was greater than the magnitude of the increase. This may suggest that when economic values decrease, the losses in genetic progress and economic return may be greater than the gains obtained when economic values increase by the same magnitude.

Table 8.8 Sensitivity analysis for the sow productivity index to changes in economic values

%Δ	NBA (pigs)	D21LS (pigs)	D21LWT (kg)	ER (ZAR)
+10	0.005	0.032	0.007	7.29
-10	0.000	-0.106	-0.015	-22.95
+20	0.008	0.097	0.018	21.37
-20	-0.003	-0.181	-0.027	-39.34
+30	0.010	0.158	0.028	34.88
-30	-0.006	-0.261	-0.040	-56.78
+40	0.012	0.218	0.037	47.88
-40	-0.009	-0.347	-0.053	-75.53

%Δ – percentage change; NBA – number born alive; D21LS – 21-day litter size; D21LWT – 21-day litter weight

Table 8.9 Sensitivity analysis for the growth and carcass traits index to changes in economic values

%Δ	ADG (g/day)	DRESS (%)	LEAN (kg)	FCR (kg/kg)	ER (ZAR)
+10	0.463	0.002	0.001	-0.003	15.55
-10	-0.487	-0.001	0.000	0.004	-16.34
+20	0.906	0.003	0.001	-0.007	30.40
-20	-1.003	-0.003	0.000	0.009	-33.62
+30	1.331	0.004	0.002	-0.010	44.65
-30	-1.551	-0.005	-0.001	0.013	-52.02
+40	1.740	0.005	0.002	-0.014	58.36
-40	-2.782	-0.008	-0.002	0.023	-93.29

%Δ – percentage change; ADG – average daily gain; DRESS – dressing percentage; LEAN – lean content; FCR – feed conversion ratio; ER – economic return

When economic values were changed for one trait at a time, genetic change for lean content responded to changes in economic values for all traits, while feed conversion ratio only responded to changes in the economic value for average daily gain. The genetic change for average daily gain was only sensitive when economic values for average daily gain and feed conversion ratio changed. Genetic changes for all traits were sensitive changes in the economic value for average daily gain. The greatest change in economic return for growth and carcass traits occurred when the economic value for average daily gain changed. On the other hand, the lowest was observed when there was a change in the economic value for lean content. Connington *et al.* (2001) reported changes in genetic progress due to changes in economic weights in sheep. This indicates that changes in economic parameters that modify economic values for breeding goal traits may alter genetic progress and economic returns. Breeders should

therefore constantly update economic values to apply the appropriate selection pressures on traits.

8.4. Conclusions

Multi-trait selection that optimizes genetic improvement in breeding objective traits and maximizes profits is made possible by the development of selection indices, which combine genetic and economic parameters. Growth performance, and carcass yield and quality may be improved by selecting on an index comprising of AGES, DRESS and BFAT. Improvement of sow productivity may be achieved by selecting on an index that consists of NBA and D21LWT. The index traits' EBVs would be weighted by factors generated using genetic parameters and economic values. Highest economic returns may be expected when these indices are utilized. For South African Large White pigs, inclusion of AGES and BFAT in the selection program improves growth rate and carcass leanness, respectively. The positive weighting of BFAT may encourage some producers to use the index that consists of ADG, DRESS and BFAT. Economic values for breeding goal traits should be updated periodically, as genetic progress and economic returns change with changes in economic values.

Chapter 9

General Conclusions and Recommendations

9.1. Exploiting genetic variation

The genetic merit of pigs is pivotal to the profitability and sustainability of the pig industry. To accurately evaluate the genetic merit of pigs, identification and adjustment for environmental factors affecting the traits should be done. For the pig industry to be competitive and remain profitable and sustainable, the genetic component of pigs should be continuously improved. Substantial genetic variation exists in South African Large White pigs for growth and carcass traits, suggesting genetic improvement is possible if selection is applied. However, the observed genetic change shows that genetic improvement has not been consistent over the past fourteen years. On the contrary, phenotypic performance has been improving in some growth and carcass traits, which may be due to improved management. Sow productivity traits show some evidence of genetic improvement, despite them being lowly heritable. To improve the performance of pigs in all traits, farmers should be advised to select their animals based on genetic merit by using estimated breeding values. For breeders and producers to maximize genetic change, they also have to consider maternal genetic effects in selection programs for growth and carcass traits.

9.2. Developing breeding objectives

Breeding objectives should be related to the profitability of the enterprise as they should benefit the producer and the consumer. Growth, carcass and sow productivity traits are targeted for

genetic improvement; hence they should be included in breeding objectives of pig breeding programs. Identification of traits to include in the breeding objective should be based on the extent to which the trait affects profit. Therefore, only economically relevant traits should be included in breeding objectives. Once the traits that constitute the breeding objective are identified, they should be considered for simultaneous genetic improvement. Inclusion of several traits in selection programs entails placing appropriate weights on the traits. The fact that these traits have been considered because of their effect on profit, suggests the extent to which they affect profit should be proportional to their weights in selection programs. Economic values, defined as the change in profit per unit change in a trait, are used as weights for traits in the breeding objective. All economic parameters affecting the operation of the enterprise should be considered in the derivation of economic values. The economic values indicate the direction and emphasis of selection of a particular trait. Economic values in this study showed that they are sensitive to changes in feed prices and marketing prices of carcasses and live animals. This implies that economic values should be continually updated for selection based on them to be effective.

9.3. Implementing multi-trait selection

After developing the breeding objective, selection should be implemented on the several traits of economic importance. In order to implement multi-trait selection successfully, genetic parameters and economic values should be used. Combining genetic parameters and economic values is done through the use of a selection index. The best selection method is based on genetic parameters, rather than phenotypic parameters that have been utilized before. Estimation

of breeding values for all traits in the breeding objective is done through BLUP, which utilizes the relationships among traits and animals to increase the accuracy of the estimated breeding values. During selection, these estimated breeding values are weighted by economic values. However, not all traits in the breeding objective can be included in the genetic analyses. Some traits, such as feed conversion ratio and some carcass traits may be difficult or expensive to measure. Indicator traits may be used as selection criteria in selection programs and correlated responses expected in breeding objective traits. Since the selection criteria are not in the breeding objective, their economic values are not needed. Therefore, weights for the selection criteria should be calculated using their variances and covariances with breeding objective traits and economic values for breeding objective traits.

The selection indices for growth and carcass traits currently used by the South African pig industry are based on inadequate breeding objectives that were not properly developed because: (i) drip-free lean percentage and backfat thickness are in the same index, where backfat thickness can be considered an indicator trait of drip-free lean percentage; and (ii) average daily gain and age at slaughter are included in the same index, where age at slaughter can be considered an indicator trait of average daily gain. Indices for sow productivity traits are not available, which may result in inappropriate weights being placed on traits during multi-trait selection. Index weights derived from genetic and economic parameters may be recommended for the South African pig industry. Use of economic selection indices enables breeders and producers to evaluate different breeding programs in monetary terms. Since genetic progress and economic return are sensitive to changes in economic values, the economic values should be updated periodically. Updating economic values entails recalculating index weights for selection

purposes. This would help breeders and producers to place appropriate weights on index traits, which may benefit the breeding program.

The index that may be recommended for the South African Large White pigs consists of age at slaughter, dressing percentage and backfat thickness. This index is expected to improve growth rate, carcass yield and carcass quality. In this index age at slaughter is the indicator trait for average daily gain, while backfat thickness is the indicator trait for lean content. For sow productivity, the recommended index may consist of number born alive and 21-day litter weight. The current study focused on separate indices to improve growth and carcass traits and sow productivity traits. This is because the terminal and sow productivity production systems are performed separately and selection is done on animals at different growth stages. The South African Large White breeders and producers may be advised to redesign the pig breeding programs to benefit from the available genetic resources.

9.4. Recommendations for further research

Although numerous studies have been conducted on genetic parameter estimates for sow productivity, growth and carcass traits, there is paucity of information for the SA pigs. This study showed very little or no genetic improvement in the traits analyzed. To assist in the genetic improvement of SA pigs, studies should be conducted to estimate the genetic parameters for sow productivity, growth and carcass traits. Studies utilizing test-day data should be done to improve the accuracy of genetic parameter estimation. Estimated breeding values for the pigs

can then be computed for use by the farmers, which will promote genetic improvement of the national herd.

This study focused on the development of economic breeding goals for the national herd of the Large White population. Implementing an efficient breeding program for one breed in a multi-breed industry might result in faster genetic improvement in one breed compared to other breeds. Developing economic breeding programs for other breeds as well, may be the way forward for the SA pig industry. Since crossbreeding is a major activity in this industry, comparing economic breeding programs for purebreds and crossbreeds may also be useful to the industry. This may be used to evaluate the usefulness of crossbreeding in economic terms.

Central data used for the genetic evaluations and economic parameters were collected from the major role players in the pig SA pig industry. Such an approach may be considered to be too general given the diverse nature of the SA pig industry. Different farms are located in different provinces and are also characterized by different economic dynamics. This may be utilized to develop customized breeding programs for different regions and/or farms, to maximize the efficiency of genetic selection. Furthermore, the economic environment is constantly changing and has an effect of changing the economic values. Development of selection indices readily responsive to such changes, and can be implemented without re-calculating economic values, might help improve the efficiency of economic selection indices.

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