Interaction of pen enrichment and sex on growth, physiology and behavioural responses of Windsnyer pigs

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By

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DECLARATION

I, ***Mbusiseni Vusumuzi Mkwanazi***, declare that this dissertation has not been submitted to any University and that it is my original work conducted under the supervision of Prof. M. Chimonyo and Dr. A. Kanengoni. All assistance towards the production of this dissertation and all references contained therein has been fully acknowledged.

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GENERAL ABSTRACT

The broad objective of the study was to determine the interaction of pen enrichment and sex on growth performance, metabolite concentrations, physiological responses and behaviour of Windsnyer pigs. Forty–eight growing Windsnyer pigs, with an average initial body weight of 21.6 (± 9.01) kg, were used until a maximum average of 37.1 (± 11.58) kg of body weight. Four pigs were randomly assigned to either enriched or barren pens at a stocking density of 0.45 m^2 /pig. The average daily feed intake (ADFI), average daily gain (ADG) and feed: gain (F: G) ratio, behavioural and physiological responses were estimated. Blood metabolites were also assessed. Pen enrichment did not affect ADG ($P > 0.05$). There was pen enrichment and sex interaction on ADFI ($P < 0.05$). Females in barren pens had higher ADFI than enriched females but ADFI in barren and enriched pens was similar for male pigs. Sex of pigs affected ADG and F: G ratio ($P < 0.001$), with male pigs growing faster than females. Pigs in barren pens had higher heart rates ($P < 0.001$) than those in enriched pens. There was an interaction of pen enrichment and sex on rectal temperature ($P < 0.001$). Females in enriched pens had higher rectal temperatures ($P < 0.05$) than females in barren pens. There was no interaction of pen enrichment and sex on feeding behaviour ($P > 0.05$). Time spent bullying was influenced ($P < 0.05$) by both pen enrichment and sex. Female pigs in barren pens spent more time on bullying than females in enriched pens. There was interaction of pen enrichment and sex on time spent lying down and walking ($P < 0.05$). Female pigs in enriched pens spent more time lying down than females in barren pens. Males in barren pens spent more time walking than males in enriched pens, while no effect of pen environment was observed in females. There was an interaction of pen enrichment and sex on time spent rolling, pivoting, tail biting and number of injuries ($P < 0.05$). It was concluded that enriched Windsnyer pigs housed at a stocking density of 0.45 m^2/pig, particularly females perform better than those in barren pens.

Pen enrichment improves pig welfare by reducing the number of injuries and anti-social behaviours, particularly in female pigs.

Keywords: aggressive behaviour, albumin, average daily feed intake, average daily gain, blood urea nitrogen, exploratory behaviours, feed: gain ratio, glucose, heart rate, pig welfare, respiratory rate.

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DEDICATIONS

"In the hope of thereby preserving from decay the remembrance of what people have done"

To my precious, ***Mbuyisa family****,*

In particular, my late father (Good Friday umkhosi wephasika umuntu onento yakhe akadle ayisheshise ngoba akazi kusasa kuyobe kunjani). It is so unfortunate that you could not live long to taste the fruits that this thesis will reap in the near future….

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Numbers of good people are dwindling fast………..trying times need courage and resilience

To those who untimely demised while I was still young and in the process of obtaining this qualification.......

Phumla Sethabile Mpungose, Khethiwe Veronica Mkwanazi, Themba Mkwanazi

Nothando Adelaide Mbuyisa and Patti Joshua

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LIST OF ABBREVIATIONS

ADG	Average daily gain
ADFI	Average daily feed intake
BW	Body weight
F: G ratio	Feed: gain ratio
FCR	Feed conversion ratio
ARC	Agricultural Research Council
CW	Carcass weight
HR	Heart rate
RR	Respiratory rate
RT	Rectal temperature
UKZN	University of KwaZulu-Natal
DM	Dry matter
CP	Crude protein
CF	Crude fibre
NDF	Neutral detergent fibre
ADF	Acid detergent fibre
LW	Large White

CHAPTER ONE: General Introduction

1.1 Background

In Southern Africa, pig production is increasing at 4.5 % annually (Phiri *et al*., 2003). Pigs grow fast and are prolific (Etim *et al*., 2014) and efficient feed convertors. Farmers have a challenge to keep producing superior quality pork to meet consumer expectations under high harsh climatic and production conditions. Accompanying extreme temperatures will be water scarcity and droughts. The rapid increase in human population also means that animals have to be sustained on smaller pieces of land, with scarce feed resources. Windsnyer pigs could, therefore, be of much significance under such marginal production conditions (Chimonyo *et al*., 2005).

Windsnyer pigs are a good source of cheap, high quality pork that suits the escalating human population. Pork from Windsnyer pigs is tastier and organoleptically more acceptable than meat from fast-growing breeds (Chimonyo *et al*., 2005). One possible reason could be the low amount of intramuscular fat in Windsnyer pig meat. Pig welfare issues are also becoming a major consideration (Muchenje *et al*., 2013) and this has led to one school of thought proposing the use of extensive pig production systems. Such systems, however, require pigs that are adaptable to high temperatures, require less nutrient dense feeds and have good foraging habits. Windsnyer pigs possess such attributes. The promotion of the improved breeds has shifted local attention to the more specialized fast growing pigs (Halimani *et al*., 2010). In South Africa, for example, the South African Pig Producers Association (SAPPO) that has the mandate to improve pig production mainly deals with fast growing imported pigs such as Large White, Duroc and Landrace breeds. This, however, has resulted in the reduction of genetic diversity of Windsnyer pigs.

The Windsnyer is a short framed breed with long nose, razor back and has less mature weight than the fast growing improved breeds. Windsnyer pigs reach sexual maturity at an early age, with female pigs displaying signs of first oestrous at three months compared to 6.5 months for Large White (Mashatise *et al*., 2005). They are adapted to survive under low planes of nutrition and can reproduce at low dietary protein levels (Kanengoni *et al*., 2004). Windsnyer pigs also have low nutrient requirements for maintenance and growth. In addition, they are raised under extensive management systems with minimal care (Mashatise *et al*., 2005) as they are regarded to be hardy and resistant to most parasite and diseases.

Due to their small frame size and compact body structure Windsnyer pigs could be kept at a higher stocking density than is recommended for fast-growing pigs. The ability of Windsnyer pigs to reach sexual maturity early, is likely to influence the degree of activity within a pen and could, therefore, interact with any attempts to enrich pig pens. Pen enrichment refers to changes that involve adding one or more substrates or materials to an animal's enclosure (Young, 2003). For example, females could be at risk of being pregnant earlier than reaching slaughter weight between 35 and 40 kg. Behaviour and physiological responses, in addition to performance, need to be considered when assessing pig welfare. Injuries and bruising enables the determination of the extent to which pen enrichment improves pig welfare (Caldara *et al*., 2012). The role of pen enrichment on welfare of Windsnyer pigs is poorly understood. The extent to which pen enrichment can improve growth performance, behaviour, injury levels and physiological responses of Windsnyer pigs in a densely stocked environment is unknown.

1.2 Justification

Windsnyer pigs have the potential to increase food security, reduce poverty and improve livelihoods of farmers, yet they are threatened with extinction due to replacement by the fast growing breeds. Unclean or ill define policies and unbalanced admixture through uncontrolled cross breeding are other factors (Chimonyo *et al*., 2005). The Agricultural Research Council (ARC) of South Africa, however, is keeping a satellite population of Windsnyer pigs for conservation and research purposes. To control the genetic erosion of Windsnyer pigs, identification of factors that promote their welfare and utilization need to be understood. It is, therefore, pertinent that the information on how pen enrichment and sex can be exploited to improve the performance, sustenance and welfare of Windsnyer pigs.

The understanding of interaction between pen environment and sex on growth performance, physiological responses and behaviour of Windsnyer pigs will benefits farmers, researchers, consumers and extension officers. Farmers will be able to adopt practices that optimise the performance and welfare of Windsnyer pigs as information on their appropriate management practices will be understood. It also assists farmers to increase their returns as less carcasses may be discarded due to improved pig welfare. Consumers will also be able to get cheap quality pork that is socially acceptable.

Slaughterhouses and butcheries will all be rewarded by improvements in pig welfare and the quality of pork produced. Researchers will use this information as a build-up on future research in enhancing productivity of Windsnyer pigs. Extension officers will be able to extract the information and make it available and accessible to all the farmers. This is also likely to inform policy-makers and plan implementers on decision making regarding the use of Windsnyer pigs in crossbreeding programmes for breed complementarity and heterosis.

1.3 Objectives

The broad objective of the study was to determine the interaction of pen environment and sex on growth performance, physiological responses and behaviour of Windsnyer pigs. The specific objectives were to:

1. Assess the interaction of pen environment and sex on growth performance and metabolite concentrations of Windsnyer pigs; and
2. Determine the interaction of pen environment and sex on physiological responses, behaviour and injury levels on Windsnyer pigs.

1.4 Hypotheses

The hypotheses tested are that:

1. The influence of pen enrichment on growth performance and metabolite concentrations in Windsnyer pigs depends on their sex; and
2. There is interaction between pen enrichment and sex on physiological responses, behaviour and injury levels on Windsnyer pigs.

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CHAPTER TWO: Literature Review

The paper has been submitted to Animal

2.1 Introduction

Intensive production systems often fail to address the needs of pigs to perform their natural behaviours. This is because these systems are too different from those the pigs evolved in. The environment is usually barren with concrete floor pens lacking appropriate rooting or foraging substrates. Such environments hinder the expression of natural pig behaviours such as rooting and foraging. Provision of appropriate rooting substrates is, therefore, indispensable as this enhances the development of natural explorative behaviour, reducing anomalous behaviours and stress responses (Oostindjer *et al*., 2014). Substrates or objects used for enriching the environment and liked by the pigs are those which are chewable, deformable, destructible, odorous and ingestible (Van de Weerd *et al*., 2003). The current chapter offers a critical overview of the existing literature concerning the use of environmental enrichment to improve performance, behaviour and welfare of pigs in intensive production systems.

2.2 Overview of pig production systems

Livestock production is increasing more rapidly than any other agricultural sector worldwide (Faustein *et al*., 2003). The total consumption of pork in the developing world has increased by 70 % between 1971 and 1995, while the consumption has increased by 26 % in the developed world (Delgado *et al*., 1999). Over the past decade pork production in South Africa has increased extensively. In, South Africa pork is produced throughout the nine provinces. The South African Pork Producers Organization (SAPPO) reported that 80 % of the total pig numbers are found in commercial areas and 20 % to developing areas. The total number of pigs in commercial areas is estimated to be 1 240 487 and these include Large White, South

African Landrace and Duroc breeds. In communal areas, however, the total number of pigs per province is estimated to be 315 513 and these are largely indigenous breeds (SAPPO, 1999).

Pig production is mainly practiced in areas nearest to the maize production areas (Visser, 2004; Chaora, 2013). The areas that are distant to the maize production regions are not economically sustainable. An estimated number of 400 commercial producers and 19 stud breeders are found in South Africa (SAPPO, 1999). The pork industry is estimated to employ 10 000 workers consisting of about 4000 farm workers and 6000 in the processing and abattoir sectors (DAFF, 2010). Most of the pork produced in South Africa is exported to SADC countries, such as Mozambique, Mauritius, Angola and Zambia. The production of pork has increased over the past years, due to an increase in the market prices and unavailability of red meat substitutes (DAFF, 2010). Pork production is profitable because it has a faster turnaround period than other red meats such as beef.

Despite these advantages, the pork industry has some weaknesses (Chaora, 2013). One of the current threats faced by the industry is the effect of climate change. These include increased ambient temperatures, drought and water scarcity. Pigs have a poor thermoregulatory system and are highly susceptible to heat stress (Madzimure *et al*., 2012). Heat stress has a potential to reduce feed intake in hot climates, negatively affecting pig productivity. In commercial systems, the main pig breeds used are Large White, Landrace and their crossbreds. It is therefore, important to plan ahead for the future especially in relation to issues such as building designs, breeding patterns and use of indigenous pig breeds. Chimonyo *et al*. (2005) suggested that improvement should, ideally be based on indigenous breeds such as Windsnyer pigs. Partly, because this breed has demonstrated the ability to survive these conditions and can efficiently utilize agricultural by products, such as maize cobs (Kanengoni *et al*., 2004). Therefore, it is imperative that their performance and welfare is improved.

In South Africa, pig rearing is mainly differentiated into large scale commercial and communal production systems. Communal production systems in South Africa involve the use of local and non-descript breeds. Pigs kept under this production are able to survive under low planes of nutrition which are experienced under communal production (Chimonyo e*t al*., 2005; Petrus *et al*., 2011). In communal production systems, pigs are widely reared for household consumption and to ensure the livelihoods of the farmers. The most common communal production system practiced in South Africa is the scavenging production system (Madzimure, 2011). This system is cheap and requires little capital investment and management. Indigenous pig breeds are commonly kept under this system, but one can also find crosses of indigenous and exotic breeds as well. One advantage of the scavenging system is that pigs roam around freely, expressing their natural pig born behaviours such as rooting and foraging (Chimonyo *et al*., 2005).

Commercial pig production systems include the indoor and outdoor production systems (Gentry & Mc Glone, 2003). In South Africa, the indoor production system is the widely practiced compared to outdoor systems where pigs are usually grown on pastures (Thornton, 1990). Common breeds such as Large White, Landrace and Duroc are used under this system due to their lean growth potential. In the indoor system, pigs are usually confined in a controlled environment, with pigs largely reared in concrete slatted floors with no rooting substrates. This results in a myriad of unwanted anomalous behaviours that reduce their performance and are a reflection of poor welfare. Conditions of the current pig production systems need to be improved to minimize the limitations of pigs (Honeyman, 1996). One approach would be to use environmental enrichment to satisfy the behavioural needs of pigs with the constraints imposed by housing system.

2.3 Attributes of Windsnyer pigs

A considerable number of positive attributes have been demonstrated in Windsnyer pigs. Most of the attributes relate to their hardiness and adaptation to survive under smallholder farming environments. The Windsnyer pigs are predominantly found in Mozambique, Malawi, Zimbabwe and South Africa (Nengomasha *et al*., 1997).

2.3.1 Small body size and low nutrient requirements

Windsnyer pigs are small in size, with mature weights of less 100 kg. They have low maintenance and growth nutrient requirements. For example, Chulu *et al*. (2002) indicated that Windsnyer pigs have less dietary protein requirements than the fast-growing breeds. More work is, however, needed to determine their optimum protein requirements and metabolism. The requirement for lower amounts of nutrients is of importance in rural areas, where resources are limiting. Accompanying slow growth rates, Windsnyer pigs are early maturing and deposit body fat earlier than fast-growing improved pigs.

2.3.2 Ability of utilising agricultural by-products and fibrous diets

In smallholder areas, feed resources are limiting, if available prices are prohibitive (Chimonyo *et al*., 2005). Windsnyer pigs have enhanced ability to utilise agricultural by products and fibrous diets compared to improved breeds (Kanengoni *et al*., 2002). The use of alternative agricultural by-products, such as maize cobs (Ndindana *et al*., 2002), which are usually thrown away, increases the interdependence of farm enterprises, as products from crop production are channelled towards pig production whilst manure will be used to fertilise crops. Utilisation of agricultural by-products and crop residues increase the options and number of feed ingredients or feedstuffs that can be used in pig production.

2.3.3 Utilisation of tannin-rich diets

Windsnyer pigs are traditionally fed on feeds such as forages, pumpkins and kitchen wastes (Mashatise *et al*., 2005). White sorghum has been used in feeding pigs as a substitute for maize. Red sorghums are not used because of their high content of tannins. However, it has been established that Windsnyer pigs are better able to utilise red sorghum than Large White pigs (Mushandu *et al*., 2005). The mechanism is not clear, although it could be linked to the production on proline-rich proteins in the saliva or the superior hindgut fermentation. Hindgut fermentation is likely to increase the digestibility of the fibre and increase the utilisation of volatile fatty acids from the caecum and colon. Utilisation of high tannin sorghum varieties could boost smallholder pig productivity, since most smallholder farmers grow red sorghums, as they resist attack by birds.

2.3.4 Tolerance and resistance to parasites and diseases

Windsnyer pigs, which are traditionally raised under extensive management systems with minimal health care are regarded to be hardy and resistant to most parasites and diseases. Zanga and co-workers (2003) reported that Windsnyer pigs are less susceptible to *Ascaris suum*. These authors demonstrated Windsnyer pigs to be less susceptible to *A. suum* infection than the fast growing improved Large White, Duroc and Landrace breeds. In the same experiment, the reduction in body weight gains was also low in Windsnyer pigs as compared to growing

Large White pigs (Zanga *et al*., 2003). *Ascaris suum* is one of the major factors that reduce productivity in pigs. However, it is not clear whether the tolerance is genetically influenced.

2.4 Improving pig productivity through pen enrichment

Although Windsnyer pigs have several attributes to make them suitable for extensive production systems, it is also important to understand how their productivity under intensive management systems can be improved. Enriching the pen environment could be one such strategy.

2.4.1 What is pen enrichment?

Pen enrichment refers to changes that involve adding one or more substrates or materials to an animal's enclosure (Young, 2003). Likewise, Newberry (1995) defined pen enrichment as the modification of a barren environment to improve the biological functioning of animals. The main goal of pen enrichment is that the environment should (1) increase the species - specific behaviour, (2) improve the level of pig performance and health status (3) prevent the development of unwanted anomalous behaviours and (4) improve the utilization of the environment (Van de Weerd *et al*., 2005) like space allocation.

2.4.2 Characteristics of effective enrichment materials

There are different substrates that can be used for enrichment purposes. These substrates may be chewable, deformable, destructible and ingestible (Van de Weerd *et al*., 2003). These include substrates like straw bedding, suspended rope and wood shavings, toys, rubber tubing, coloured plastic keys, table tennis balls, chains and strings (Lindberg & Nicol, 1994; Jones *et al*., 2002). The behaviour of pigs towards enrichment substrates or materials can reveal whether the objects are effective enough as enrichment properties. Enrichment structures suspended at the pig eye level as opposed to the floor are more favourable in maintaining attractiveness to pigs (Blackshaw *et al*., 1997; Van de Weerd *et al*., 2003; Trickett *et al*., 2009). This is partly because substrates or materials presented on the floor can quickly get dirty with feaces and thus become unattractive to pigs. These materials can also even become a means of transmitting diseases to pigs.

Therefore, presentation and position of an object becomes an important factor when enriching the environment. Blackshaw *et al*. (1997) reported that an object maintains interest if suspended at the pig eye level as opposed to being presented on the floor. Furthermore, substrates such as straw, peat or combining ropes with rubber hoses also serves as effective forms of enrichment (Bracke *et al*., 2006). Likewise, structures such as chains and used car tyres are not recommended for long term use. These structures quickly lose their novelty factor since habituation to a substrate or material occurs rapidly in pigs, as a result reducing their usefulness in stimulating exploration. One way in which novelty can be maintained is by regularly replacing existing objects with new objects to keep the pigs continually exploring.

Pigs are more attracted to open rope ends and torn rope ends because they are easier to tear up further (Studnitz *et al*., 2007). In most reports, straw or objects suspended at the pig eye level are commonly used, although much preference is given to straw as effective form of enrichment. Its utilization can, however, be problematic to a certain extent as it can create blockages in the slurry systems. To combat this disadvantage, it is pertinent to ensure that whenever straw is applied it is thoroughly chopped especially in slatted floor systems.

Pig preferences for different materials have been studied (Table 2.1). From the comparison of these studies, it can deduced that straw may be considered as the baseline above or below which other materials can be ranked. This is based on the assumption that straw holds the greatest potential to meet the four criteria that defines enrichment as successful. Materials such as peat, mushroom compost, sand, wood shavings, branches and silage rank above straw. Among the enrichment materials ranking below straw, pigs prefer ropes and rags which are destructible and indestructible objects such as beams, tyres and chains (Studnitz *et al.*, 2007). Pigs prefer different materials or substrates for enrichment. However, these findings have not revealed much information on breed preferences of objects or materials, and this opens gaps for future research. Identifying such information will help pig farmers on valuable enrichment materials that can be used for different pig breeds. There is no clear information on how long an object or structure can keep the pigs exploring. It is, therefore, pertinent that future research should further explore these areas.

Table 2.1 shows the ranking of enrichment materials. Within each column the materials tested in the same study are listed in order of priority. Thus materials ranking the highest are mentioned at the top. Materials which are encircled are ranked equally. The ranking is measured in various ways e.g. time spent with the material or the most frequent choice of the material. Materials mentioned in different columns are listed on the same line in order that the ranking of the individual studies may be compared to each other.

2.5 Impact of pen enrichment on behaviour of pigs

Enrichment of the pig environment has been found to influence normal feeding, aggressive, harmful social, foraging, exploratory, manipulative and play behaviours of pigs.

2.5.1 Influence of pen enrichment on behavioural responses

Pig behaviour is a fast and positive indicator of an animal's welfare condition. Behavioural responses can be used to determine whether the animal is experiencing stress, as changes in behavioural patterns are frequently reported when experiencing adverse conditions. Behaviour can be measured through video recordings, visual observations and analyzing pigs that are expressing their natural behaviour (Adeniji *et al*., 2012). The use of video cameras to measure behaviour gives unbiased behavioural data, as these eliminate human disturbances during observation.

Natural instinctive pig behaviour is a repertoire of different behaviours pigs' exhibit in environments that allow them to carry out behaviours created in the evolutionary process (Lidfors *et al*., 2005). A good understanding of the natural behaviour of pigs can help to identify and improve pig welfare by designing systems that enhance positive welfare. Current pig systems, however, do not allow for that as they are often barren slatted concrete floors (Van de Weerd *et al*., 2005). Therefore, altering their environment with enrichment substrates or materials for play or rooting is one solution.

Table 2. 1 Ranking of enrichment materials

Beattie et al (1998)	Pederson et al (2005)	Madsen (2001)	Van de Weerd (2003)	Day et al (2002)	Lidewing & Matthew (1996)	Jensen & Pederson (2006)
			Carrots on a string			Maize silage + straw
	Peat branches		Coconuts in halves			
Peat						
Mushroom			Compost		Wood shavings	Compost
Compost	Unchopped straw	Unchopped straw			Saw dust	Rope
Sawdust	Chopped straw	Floor				
			Chopped straw	Chopped straw	Chopped straw	Chopped straw
Sand		Alfalfa				
Bark chips				Destructible+ vitamin	Sand	
			Rope		Straw + dispenser	
Straw				Chain		
			Paper			
			Sand			
Concrete						

Source: Studnitz *et al* (2007)

2.5.2 Effect of pen enrichment on aggressive behaviour

Aggression among pigs is a common and normal behaviour primarily driven by formation of social or dominance hierarchy. Fighting and conflicts are expected to last for a period of between 24 and 72 hours. Aggressive interactions are performed to determine dominance order, with the dominant pigs ranking above the sub-dominant and submissive pigs (Turner *et al*., 2006). However, high levels of aggression can be a detrimental challenge to pig welfare, partly because pig welfare represents a significant cost to economic efficiency (Turner *et al*., 2006). Aggressive behaviours preferentially occur when the natural behaviour of pigs is impeded and they are deeply dissatisfied.

Factors such as uncomfortable environment, poor management, and genetics (Blokhuis, 1989) also increase this behaviour. In addition, limiting housing systems with no enrichment substrates or materials can exacerbate this overt behaviour. Pigs are rooting and foraging species and, when prevented such opportunities, tend to react aggressively towards their pen mates. Bolhuis *et al*. (2005) reported that pigs in barren environments display more aggression than pigs in enriched environments.

The use of straw has been shown to be effective in reducing aggressive behaviour among pigs that are unfamiliar (Van de Weerd *et al*., 2003). In contrast to this notion, Morgan *et al*. (1998) reported an increase in aggression when pigs were in an environment enriched with straw. Arey and co-workers (1995), however, found that straw increased activity among pigs but did not reduce fighting between newly mixed pigs. The number of fights between pigs was not eliminated by provision of straw but was shown to be affected by unfamiliarity to each other. Blackshaw *et al*. (1997) used metal and tethers on the floor as well as suspended at the pig eye level as enrichment substrates and reduced aggression (Table 2.2). However, Madsen *et al*. (2001) used alfalfa hay from a dispenser and reported increased aggression. Interestingly, no reduction of aggression when enriching the environment have been reported (Beattie *et al*., 2000a; Day *et al*., 2002).

Waran & Broom (1993) reported no differences in the amount of aggression between weaner pigs mixed into flat desk and straw pens. Beattie *et al*. (2000) reported that pigs in an enriched environment had less aggressive encounters than their contemporaries in a barren environment. O'Connell *et al*. (1999) reported that environmental enrichment reduced the expression of aggressive behaviour. Pigs from an enriched environment fought less with unfamiliar animals than their counterparts in a barren environment.

Possible explanations to these differences could be due to how these authors define aggression. It is possible that these differences could be due to substrates or materials used in these studies as enrichment structures. These differences could also be due to the fact that some of the objects used as enrichment properties were difficult for pigs to manipulate as they were not chewable or destructible enough to reduce aggression. If the object fails to meet the desired needs of pigs, research report that pigs may perceive the environment as barren even though it is enriched.

2.5.3 Effect of pen enrichment on harmful social behaviours

The welfare of pigs in intensive indoor systems is often compromised by harmful social behaviours like ear and tail biting. Tail biting is arguably the most serious form (Van de Weerd *et al*., 2005) because of its damaging nature. Its welfare and economic implications present an ongoing problem for the pig production industry. Occurrence of harmful social behaviours is an indication that the environment does not meet the behavioural needs of pigs.

Tail-biting and manipulation of pen mates is reduced when bedding or manipulative substrates are provided (Haskell *et al*., 1996). Zonderland *et al*. (2008) reported that provision of objects like chains and rubber hoses were ineffective in preventing tail biting. In contrast, Van de Weerd *et al*. (2005) used straw bedding and concluded that the development of tail biting can be prevented. Furthermore, Beattie *et al.* (2000) reported that pigs in enriched environments showed less harmful social behaviours such as persistent nosing and biting of pen mates than pigs from barren environments.

2.5.4 Effect of pen enrichment on rooting or foraging behaviour

Rooting or foraging is frequently expressed by pigs reared in outdoor production systems (Adeniji *et al*., 2012). Rooting forms an important part of a behavioural repertoire, constituting a rewarding experience and meeting a behavioral need for pigs (Studnitz *et al*., 2003). Rooting can be stimulated by a number of factors which can be ranked as age, sex, genotype and novelty. Rooting or foraging in a natural environment has, however, a potential to increase the effect of environmental damage. Henceforth, it is imperative that at least two factors are considered when allocating rooting materials. The rooting material should be allocated in a way that allows proper manipulation and fighting for access to the material should be minimal (Adeniji *et al*., 2012).

If pigs are denied access to rooting materials, they begin to chew and manipulate available materials such as pen fixtures (Day *et al*., 1995). Studnitz *et al*. (2003b) examined gilts with either rooting or no rooting substrates and reported that gilts in a group that were prevented from rooting, a higher level of anomalous behaviour was seen. On the other hand, gilts with rooting materials rooted more. This indicates that pigs not provided with rooting materials are able to substitute rooting with other behaviours. However, anomalous behaviours like biting and fighting become more prominent. Haskell *et al*. (1996) reported that pigs root more when they would find novelty. This could explain why pigs provided with rooting material were found to root more. Rooting is an exploratory behaviour of high priority and depriving pigs of such leads to increase in abnormal behaviours. There is also clear evidence that continuous access to new environment increases rooting behaviour partly by stimulating inspective exploration.

2.5.5 Effect of pen enrichment on exploratory behaviour

Exploratory behaviour is a form of appetite behaviour that is orientated by a search for feed or concerned about examination of areas that are unfamiliar to the pig (Studnitz *et al*., 2007). The behaviour to explore serves different purposes. Exploratory behaviour includes; nosing floors, nosing fixtures, scraping floors, manipulating fixtures and chewing (Bolhuis *et al*., 2005; Beattie *et al*., 1996). Furthermore, in spite of the type of exploratory behaviour, pigs use the same behavioural elements to explore such as, rooting, sniffing and chewing. Pigs explore to obtain feed, an attractive place to sleep or to collect general information on their surroundings. The desire to explore can, however, be motivated by hunger, boredom and novelty (Trickett *et al*., 2009).

Hunger is an immediate goal for exploration and is motivated by an acute need. If pigs are hungry they search for feed until found and consume sufficient amounts. Hunger increases the level of exploratory behaviours and *ad libitum* feeding does not eliminate the motivation to explore. Exploratory behaviour can also be motivated by novelty (Studnitz, 2007).

Novelty is the quality or state of being new, unusual and interesting. Novelty is an important property involved in initiating and maintaining exploration (Trickett *et al*., 2009). The motive to explore may arise if the pig discovers unfamiliar objects or when the pig searches for novelty (inquisitive exploration). This means that pigs will explore and obtain information in an object as long as they have the audacity to do so and no other motivation becomes more pronounced than the motivation to explore. Bolhuis *et al*. (2005) reported that pigs spent substantial proportions of their time on exploratory behaviour. Interestingly, when analysis was done per behavioural element; pigs in enriched environments displayed more of nosing, scraping floor and chewing than pigs in barren environments. Pigs in barren environments, however, showed more inclinations of manipulating fixtures. Beattie *et al*. (1996) reported that pigs in barren environments spent more time nosing fixtures than pigs in enriched environments.

Pigs in enriched environments and having lower floor space, spend most time nosing the ground. Scott *et al*. (2009) evaluated exploratory behaviour in pigs housed in straw bedding and reported that pigs with straw beds spend at most 20 % of their time exploring straw. Pigs that were given a toy stimulated little exploratory behaviour. A study that evaluated space requirements, pigs in high stocking density and enriched with bars, rags and tyres performed more of exploratory behaviour than pigs in lower density and no enrichment. Pigs in enriched environments spend most of their active time on exploratory activities than their counterparts in barren environments. Presumably, because pigs find exploration of pen fixtures or pen mates less satisfying as they prefer objects that are chewable, rootable and destructible for exploratory activities.

2.5.6 Effect of pen enrichment on manipulative behaviours

The increase in the amount of manipulative social behaviours to pen mates may be injurious and thus leading to negative implications to pig welfare (De Jong *et al*., 1998). Manipulative social behaviours can be ranked from belly nosing, ear biting, tail biting and manipulation of other parts other than the above. Behaviours which are termed manipulating other pigs can be mainly nibbling, chewing of pen mates' belly and paw chewing (Bolhuis *et al*., 2005).

Peeters *et al*. (2006) reported that pigs provided with enrichment substrates spent 27.5 ± 1.7 % of their most active time manipulating the substrate. Pigs in an enriched environment spent less time in pen manipulation than pigs in barren environment (Beattie *et al*., 2000; Guy *et al*., 2002). Bolhuis *et al*. (2005) grouped pigs and reported that pigs housed in barren environments showed more of manipulative behaviour than their counterparts in enriched environments. Furthermore, De Jong *et al*. (1998) noticed that pigs in enriched environments spent less time showing manipulative behaviours like nibbling, nosing and massaging. The reduction in pen mate and pen fixtures manipulation observed could be explained by findings from other researchers that introduction of chewable objects to pigs has a huge potential to decrease abnormal behaviours directed towards conspecifics.

2.5.7 Effect of pen enrichment on play behaviour

Play behaviour is not common. However, research suggests that pigs in enriched environments exhibit more of play behaviour than pigs in barren environments (Newberry *et al*., 1988; Kelly *et al*., 2000; Bolhuis *et al*., 2005). Bolhuis *et al*. (2005) categorized play behaviour in terms of pivoting, rolling, shaking objects and gamboling. Kelly *et al*. (2000) used deep straw and reported an increase in play behaviours. On the contrary, Bolhuis *et al*. (2005) reported a decrease in play behaviour of pigs from week 5 to 6. Newberry *et al.* (1988) noted an increase in play behaviour of pigs from week 2 to 6. Nonetheless, the positive effect of enrichment was evident as pigs in enriched environments showed more of play behaviour than pigs in barren environments in both studies.

Diminution of play behaviour in pigs kept in barren environments could indicate endangered health or welfare because regardless of being in a barren environment or not pigs should be keen to play. Spinka *et al*. (2001) reported that altered play behaviour reduces social skills and behavioural flexibility thus reducing welfare in the long term. Table 2.2 gives an overview of commonly used enrichment materials and their effect on different behavioural activities in pigs.

In the left column, the enrichment materials are listed, in the second column the behaviour is listed in the following order; behaviour redirected towards pen mates, aggression, harmful social behaviours e.g. tail biting, behaviour redirected towards materials or substrate, play behaviour. In the effect column, arrows indicate if the relevant behaviour has been increased or reduced, while equal signs indicate if the behaviour was unaffected. If the desired effects have been achieved arrows are pointing downwards, while if the desired effects have not been achieved the arrows are pointing upwards.

Table 2. 2 Effects of different enrichment substrate or materials on behavioural activities

Material	Behaviour	Effect	References
Peat + Straw	Aggression	↓	Beattie *et al* (1996)
	Exploration directed towards pen mates	↓	
	Exploration directed towards materials	↑	
Tyres in chains	Aggression	=	Schaefer *et al* (1990)
Rubber toys	Aggression	↓	Schaefer *et al* (1990)
Chain + bars + rages + tyres (Change once a week)	Exploration	↑	Pearce & Paterson (1993)
Deep straw bedding	Aggression	↓	Bolhuis *et al* (2005)
	Exploration	↓	
	Play behaviour	↓	
	Manipulation directed pen mates	↓	
Straw bedding	Aggression	↓	Beattie *et al* (2000)
Straw	Exploration directed towards pen mates	↓	Morgan *et al* (1998)
	Harmful social behaviour	↓	
	Aggression	↑	
Straw bedding	Tail biting	↓	Van de Weerd *et al* (2005)
Piece of wood	Tail biting	=	Peterson *et al* (1997)
	Exploratory + play	↑	

2.6 Impact of pen enrichment on physiological measurements

Enrichment of the pig environment has been reported to influence body temperature, respiration rate, heart rate, concentration of stress hormones, concentration of metabolites and number of injuries.

2.6.1 Effect of pen enrichment on body temperature

Body temperature may be useful as an indicator of chronic stress as stressors induce a rise in body temperature (De Jong *et al*., 2000). De Jong *et al*. (1998) investigated the effects of straw bedding on physiology of pigs kept in straw bedded and barren environments. Pigs from both environments exhibited similar reactions in body temperature in response to stressors such as relocation, isolation and restraint. Pigs in barren environments had a higher body temperature than pigs in enriched environments. The differences in baseline body temperature may be explained by differences in circadian rhythm. Caldara *et al*. (2012) reported that body temperature from the neck, shoulders and leg were similar in pigs kept on compact floor, wood shavings and coffee husk. The rectal temperature was, however, higher in pigs enriched with coffee husks as compared to wood shavings and compact floor. However, further research still needs to be done to evaluate how environmental enrichment affects circadian rhythm or body temperature.

2.6.2 Influence of pen enrichment on heart and respiration rates

Heart rate is a relatively new method used to assess stress (Valerie *et al*., 2012). Measuring heart rate is effective because it is instant, quantitative and non-invasive measure of the control of autonomic nervous system (Gehreke *et al*., 2011). If pigs are placed in stressful conditions, stressors either increase or decrease heart rate. Heart rate frequency is measured in response to stressors using external heart rate monitors (Geverink *et al*., 1996). Changes that occur in the heart rate can be caused by physical as well as physiological factors.

Beattie *et al*. (2000) reported that pigs from enriched environments have higher average and maximum heart rate when given objects than pigs in barren environments. De Jong *et al*. (1998) found that the heart rate of pigs in enriched and barren environments did not differ. Stress changes the balance between the sympathetic and parasympathetic branch of the autonomic nervous system. Stressors may cause a shift in balance between these systems and thus result in psychological stress. If the heart rate variability is higher that represents a shift of the autonomic balance towards a parasympathetic prevalence whereas lower heart rate represents a shift towards sympathetic prevalence (Stein *et al*., 1994).

Heart rate variability refers to physiological variation in the time interval between heart beats. These changes are revealed to be an occasion of stress, however, research does not clearly indicate whether they are due to the environment. Therefore, more research still needs to be done, more importantly looking at how the environment instigates these changes in the balance of the autonomic nervous system.

Caldara *et al*. (2012) assessed the effect of rearing pigs in deep bedding, coffee husks and compact floor and found that the respiratory rate did not differ between treatments. The respiratory rate was, however, above the threshold range considered normal for the species at this stage of rearing.

2.6.3 Influence of pen enrichment on stress hormone concentrations

Cortisol is the primary hormone secreted when pigs are subjected to stressful conditions. This is a steroid hormone secreted by the adrenal gland. Cortisol in plasma or saliva is widely used across species to indicate stress. Fluctuations in cortisol levels may be a reflection of physiological stress, physical stress and animal response to a particular environment (Bergamasco *et al*., 2010). The use of salivary cortisol has been noted to be more useful than plasma cortisol as a measure of stress (Ruis *et al*., 1997). This is due to difficulty in understanding the relationship between the hypothalamic pituitary adrenal axis (HPA) and exposure to stress. The HPA axis can become accustomed to stress stimuli thus affecting plasma cortisol levels and therefore reducing it reliability as a measure of stress.

Plasma cortisol is also influenced by diurnal rhythm, with the time of the day affecting cortisol levels. Cortisol levels are higher during light hours and lower during dark hours (Geverink *et al*., 2002). Furthermore, cortisol can be produced in increased levels, during exciting events such as feeding. This means that cortisol response can increase due to excitement rather than stress. This makes cortisol an unreliable measure or indicator of stress. Enrichment studies, however, have shown that pigs reared in barren environments experience more stress than pigs in enriched environments (De Jong *et al*., 1998; Peeters *et al*., 2006; Van de Weerd *et al*., 2009). Notably, due to the fact that pigs in enriched environments spend less time engaging in stressful conditions as they are provided with materials or substrate to play.

Pearce & Paterson (1993) reported that provision of enrichment substrates to crowded male pigs did not influence cortisol concentration. Pigs not provided with substrates had a higher cortisol concentration indicating a response to stress. In contrast, other researchers have reported that pigs in enriched environments had a higher salivary cortisol concentration than pigs in barren environments prior to transport (Geverink *et al* 1996; De Jong *et al*., 2000; Kloet *et al*., 2001). Similarly, De Jong *et al*. (1998) studied physiological effects of using straw bedding and found that pigs in enriched environments had higher cortisol concentrations than pigs in barren environments. As an explanation, differences in cortisol concentration between these environments may be attributed to HPA axis. De Kloet *et al*. (1993; 1994) reported that corticosteroid hormone binds two types of receptors in the brain called glucocorticoid receptors (GR) and mineralocorticoid receptors (MR). These receptors give pigs the ability to respond adaptively to their environment whether barren or enriched depending on the balance between these receptors. This simply implies that a disturbed balance may lead to reduced or enhanced responsiveness to the environment. However, researchers have not clearly outlined the mechanism behind these phenomena. It would therefore, be of interest to further research on how the pig environment causes disturbances of these two receptors.

2.6.4 Influence of pen enrichment on number and severity of injuries

Injury scoring is a measurement of aggression and fighting that occurs among pigs. Injury scoring involves the counting of injuries subjectively present over the whole body of the animal (Karlen *et al*., 2007).

The number of external injuries or wounds counted at regular intervals is often used in studies as a measure of social unrest (Van de Weerd *et al*., 2009). Injury scores are generally lower for pigs housed in enriched environments compared to barren housed pigs. Van de Weerd *et al*. (2006) tested the effect of using different enrichment structures (bite rite tail chew device, straw rack, feed dispenser, straw and liquid dispenser) and reported no significant differences between treatments on skin injuries. Scott *et al*. (2009) reported that adding enrichment objects to straw bedded pens did not affect skin injuries. Peeters *et al*. (2006) found no differences in skin lesions between control pigs and straw bedded pigs. Manciocco *et al*. (2011) found no evidence of environmental enrichment on injuries. However, sex differences were observed with male pigs having higher percentage of injuries than female pigs.

2.6.5 Effect of pen enrichment on blood metabolites in pigs

Blood metabolites interact with the central nervous system (CNS) to regulate different behavioural patterns of pigs (Bakare *et al*., 2014). Blood metabolites can also give an indication of the animal's nutritional status (Pambu–Gollah *et al*., 2000). Peeters *et al*. (2006) studied the use of straw bedding at different weeks on blood metabolites. The study reported no enrichment effect on blood metabolites such as glucose, lactose and non-esterified fatty acids. On the other hand, pigs enriched with straw bedding for six weeks had lower creatine kinase compared to pigs that were not provided straw bedding. There is, however, a large gap of research which still needs to be conducted in this area such as (1) understanding the role of environmental enrichment on changes in metabolism, (2) and the use of different enrichment substrates to explain whether the environment does affect metabolism.

2.6.6 Influence of enrichment on growth performance

Performance of pigs is crucial as it reflects their response particularly to feed given and their living environment. It is therefore imperative to understand variations in performance of pigs in different rearing environments be it indoor, outdoor, enriched and barren environments. This enables pig producers to manage pigs differently to improve the performance and welfare of their pigs. Performance of pigs housed under barren and enriched environments has been studied by a number of authors (Beattie *et al*., 1995; 1996; Hill *et al*., 1998; Peeters *et al*., 2006; Van de Weerd *et al*., 2006; Caldara *et al*., 2012; Gracner *et al*., 2013). Though the environments used in these studies was of similar design, however, performance variables varied. For example, Beattie *et al*. (2000) observed that pigs in enriched environment had higher growth rates, which was attributed to high average daily feed intake (ADFI). Furthermore, pigs in enriched environment had a better feed conversion ratio (FCR) than their counterparts from barren environments. Pederson *et al*. (1993) housed pigs enriched using hiding areas and mezzanine tier and barren housed pigs. Average daily gain (ADG) and FCR did not differ between the treatments, however, pigs in barren environment had a higher ADG than pigs in enriched environment.

Caldara *et al*. (2012) reared pigs on compact floor and deep bedding with wood shavings and reported no differences in performance in the growth phase. However, in the finishing phase pigs housed in compact floor showed better results of weight gain, feed intake and feed conversion. Peeters *et al*. (2006) reported that ADFI and FCR were the same in all treatments. Both environments affected pig performance similarly. Pigs that were enriched for a period of six weeks, however, had higher ADG than other treatments. In a study that compared different enrichment substrates, it was reported that pigs housed in straw bedded pens had a higher ADFI than pigs enriched with liquid dispenser and bite rite tail chew device. Furthermore, pigs housed in straw bedded pens had a higher daily weight gain than their counterparts (Van de Weerd *et al*., 2006).

Conversely, Jordan *et al*. (2013) reported that straw and hay did not influence growth rates of pigs. Schaefer *et al*. (1990) found that enriching the environment improved the growth rates of pigs. The predisposition to increase stress levels in barren environments could be the reason why these pigs had lower performance than pigs in enriched environments. Barnett *et al*. (1983) reported that higher level of stress adversely affect FCR. Differences in management and potential differences in behaviour may have altered the performance of pigs in barren environments. The differences in space allowance used in these studies could also explain the variation in performance of pigs. Pearce & Paterson (1993) reported that space allowance has a huge potential to affect the performance of pigs due to changes in behavioural requirements.

2.6.7 Environmental enrichment has a bearing on carcass and pork quality

Carcass characteristics of pigs reared in barren and enriched environments have shown to differ significantly (Beattie *et al*., 2000; Peeters *et al*., 2006). Pigs in enriched environments have been reported to have heavier carcass weights and greater levels of backfat thickness than their counterparts from barren environments (Beattie *et al*., 2000). On the contrary, Warris *et al*. (1983) reported a decrease in backfat thickness for animals in enriched environments housed in outside pens. Peeters *et al*. (2006) used straw bedding for different weeks and reported that pigs which had straw for 4 weeks had lower meat percentage than pigs given straw for two weeks. Moreover, during slaughter no differences were observed in carcass weight and backfat thickness among pigs in all treatments (Table 2.3). Kloet *et al*. (2001) also reported no effect of enriched and barren environments on carcass weight, meat percentage and backfat thickness. No differences were observed in carcass quality (cold carcass weight and backfat thickness measured at P2) in pigs reared in straw bedded pens or object-enriched partly slatted floors (Van de Weerd *et al*., 2009).

Hill *et al*. (1998) compared different enrichment substrates on carcass characteristics and reported no treatment effects for backfat opposite the first rib. However, pigs in a negative treatment had a lower backfat opposite the last rib compared to other treatments. Pigs in the control treatment and enriched with toys plus human interaction had a lower last rib backfat than pigs in human treatment alone. Backfat thickness measured opposite the last lumbar

Table 2. 3 Carcass characteristics from pigs in different housing environment and using different enrichment types

Environment + enrichment type	Carcass weight (kg/day)	Backfat (mm)	Carcass length	Meat percentage	S.E.M	References
Barren	73.9	77.8	-	-	0.91	Beattie *et al*. (2000)
Enriched	11.9	15.1	-	-	0.57	
Control	-	2.77	83.10	-	-	Hill *et al*. (1998)
Toys	-	2.51	83.10	-	-	
Human	-	2.69	83.39	-	--	
Human +Toys	-	2.79	82.93	--	--	
Negative treatment	-	2.34	83.72	-		

vertebrae, pigs in a negative treatment were leaner than other treatments. These measures show that pigs in the negative treatment were leaner than other treatments.

Consumers are increasingly becoming concerned about pig rearing conditions and pork quality. This is because when pigs are reared in confinement there are certain environmental factors and animal-human interactions that are at play. It is pertinent that rearing conditions are improved to reduce the effect they impose on pork quality. Muchenje *et al*. (2013) reported that if pigs are precluded in behaving normally, anomalous and aggressive interactions occurrence increases. Such problems may influence their behaviour, welfare, physiology and subsequently pork quality.

Meat produced by pigs in enriched environments had lower cooking losses and shear force values than pork from pigs reared in barren environments. These improvements in meat quality were not associated with differences in pre slaughter stress because pH values were similar in all treatments (Beattie *et al*., 2000; Van de Weerd *et al*., 2006). There were no significant effects found on other meat quality parameters because of rearing environment (Beattie *et al*., 2000). Warris *et al*. (1983) found that pigs reared indoor compared to outdoor reared pigs in enriched environment produced paler pork products than counterparts in a barren environment. Furthermore, postmortem pH and water holding capacity for pigs reared outdoor was reduced. However, loin muscle for pigs reared outdoors had a lower ultimate pH, higher drip loss and higher shear force values (Warris *et al*., 1985). Differences captured from these results may be explained by that pigs in an enriched environment had higher levels of intramuscular fat which is associated with improved tenderness and water holding capacity in pork (Beattie *et al*., 2000).

Nutritional factors gained by pigs enriched with straw could be another possible reason pigs in an enriched environment produced better meat quality than their counterparts in a barren environment. Maw *et al*. (2001) reported that straw has a potential to influence eating quality because pigs reared on straw produced bacon with stronger meat flavor than pigs reared without bedding.

Hill *et al*. (1998) reported that meat quality measured by shear force, calorimeter scoring and human sensory evaluation was not affected by rearing conditions. Measurements of pork quality (flavor, tenderness, juiciness) was not different between the treatments. Similarly, Peeters *et al*. (2006) also found no effect of rearing environments on meat quality measurements.

2.7 Summary of the literature review

There has been an increase in the number of studies on environmental enrichment as a way of improving the welfare and performance of pigs in the intensive system. The barren or uninsulated environment of the intensive system hinders the expression of key behaviours exhibited by pigs under normal circumstances. This environment is also considered the major cause of anomalous and damaging behavioral patterns which impair animal welfare and performance. Environmental enrichment by the use of object or materials has, therefore, beneficial influence in animal behaviour and performance. Also, a number of enrichment materials have been used, including the (1) enlargement of available floor area, (2) provision of objects for manipulation and play, (3) establishment of suitable structure of the enclosure such as hide boxes and visual barriers. When enrichment materials are to be provided it is, therefore, of paramount importance to assess the outcomes to ensure that the enrichment program is effectively meeting the intended goals. These studies are, however, all based on imported pig breeds such as Large White and Landrace. Therefore, there is also a need to evaluate the impact of environmental enrichment on indigenous breeds as these breeds are useful in the Southern African countries. Partly, because these breeds have exhibited the ability to survive under extreme conditions that are currently experienced in Southern Africa.

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CHAPTER THREE: Interaction of pen environment and sex on growth performance and metabolite concentrations of Windsnyer pigs kept in a high stocking density

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Abstract

The objective of the study was to determine the interaction of pen enrichment and sex on growth performance and blood metabolite concentrations of Windsnyer pigs. Forty-eight growing Windsnyer pigs, with an average initial body weight of 21.6 (± 9.01) kg were used. Four pigs were randomly assigned to either enriched or barren pens at a stocking density of 0.45 m^2 /pig. Daily feed intake per pen and weekly body weights of each pig were measured. Blood was collected at the end of the experiment for determination of metabolite concentrations. Pen environment did not affect average daily feed intake (ADFI) and average daily gain (ADG) ($P > 0.05$). There was pen environment and sex interaction on ADFI ($P < 0.05$). Females in barren pens had higher ADFI than enriched females but ADFI in barren and enriched pens was similar for male pigs. Sex of pigs affected ADG and F: G ratio ($P < 0.001$), with male pigs growing faster than females. Pigs in enriched environment were more efficient in converting feed into body weight than those in barren environment. There was an interaction of pen environment and sex on glucose, blood urea nitrogen (BUN) and alkaline phosphatase (ALP) ($P < 0.05$). Females in barren environment had higher glucose ($P < 0.05$) than enriched females. Enriched males had higher albumin than males ($P < 0.05$) in barren environment. Enriched females had higher BUN than females ($P < 0.05$) in barren environment. Likewise, enriched females had higher ALP than females ($P < 0.05$) in barren environment. It was concluded that enriched Windsnyer pigs housed at a stocking density of 0.45 m^2/pig, particularly females perform better than those in barren environments. The differences in glucose, albumin, TP and BUN in male and female pigs suggest that the commercial pig grower diet has higher nutrient levels than the requirements for Windsnyer pigs.

Keywords: average daily gain, average daily feed intake, feed: gain ratio, albumin, blood urea nitrogen, glucose

3.1 Introduction

Windsnyer pigs are predominantly found in Mozambique, Malawi, Zimbabwe and South Africa (Nengomasha *et al*., 1997). In Southern African countries, however, breeds such as Windsnyer are discriminated against, for a number of reasons. Such reasons include their slow growth rate and compact body structure. Decreasing availability of natural resources, lack of markets and viable marketing strategies are other challenges (Halimani *et al*., 2013). There are also policy disincentives that disapprove the production of indigenous pigs or encourage their replacement (Chimonyo & Dzama, 2007). The genetic diversity of Windsnyer pigs is also under pressure from several drivers of change such as increasing human population, inbreeding, changes in the traditional production environment and unpredictable effects of climate change (Halimani *et al*., 2010). Some of these reasons are driven by lack of information on their production potential, profitability and pork quality. The bias against Windsnyer pigs has resulted in lack of improvement of the breed.

The value of Windsnyer pigs lie in their various attributes such as adaptability and tolerance to endemic diseases and parasites. Their slower growth, for example, can be a strength under feed shortages and harsh climatic conditions (Madzimure *et al*., 2011) experienced in Southern Africa. These breeds also utilise fibrous feed sources better than imported breeds (Kanengoni *et al*., 2004) and are more suited in hot environments. Chimonyo *et al*. (2005) reported that indigenous pigs mature early, causing early deposition of fat than the fast growing pigs. If such traits are not exploited, the outcomes are that these breeds are at risk of being replaced by the exotic breeds.

The Agricultural Research Council (ARC) of South Africa is keeping a satellite population of Windsnyer pigs for conservation and research purposes. The optimum stocking density for this breed is, however, unknown. The ideal stocking density for growth performance based on the large framed imported breeds is 0.75 m^2/pig. Windsnyer pigs being compact and smaller in frame size should in principle be kept at higher stocking densities. Their temperament, which has not been properly documented could dictate that they need greater space allowances.

The extent to which pen enrichment can improve growth performance of slow-growing Windsnyer pigs is unknown. Furthermore, studies that have been done on pen enrichment have ignored changes that occur on blood metabolite concentrations. Therefore, to understand the effectiveness of pen enrichment on growth performance, blood metabolite concentrations should also be assessed. These include metabolic markers and indicators of liver health. In the current study, therefore, the stocking density was increased to 0. 45 m^2/pig from the recommended 0.75 m^2/pig. The objective of the study was, therefore, to determine whether an interaction of pen enrichment and sex exist on growth performance and metabolite concentrations of Windsnyer pigs. It was hypothesized that the influence of pen enrichment on growth performance and metabolite concentrations in Windsnyer pigs depends on their sex.

3.2 Materials and methods

3.2.1 Study site

The trial was carried out at the Pig Production unit of the Agricultural Research Council (ARC) Animal Production Institute at Irene, South Africa. It lies at about 25°34′0″S and 28°22′0″E and is approximately 1526 m above sea level. The average annual temperature is 18.7 °C.

The experimental procedures were performed according to the ethical guidelines specified by the Certification of Authorization to Experiment on Living Animals provided by the ARC - Animal Ethics Committee (Reference No: APIEC 16/016).

3.2.2 Pigs, feeding and housing management

Forty-eight clinically healthy growing Windsnyer pigs (WS), with a mean (± SD) body weight of 21.6 (± 9.01) kg were used. Pigs were selected randomly from the pig herd at the ARC and assigned four to each pen. Pigs were left to adapt to their new environment for seven days to get accustomed to the experimental treatments then monitored for 42 d. Pigs were housed in 1.0 × 0.9 m^2 pens with slatted concrete floors. They were fed on a commercial standard diet (Supreme Grower, Meadow Feeds Ltd, South Africa) throughout the duration of the study. Pigs in each pen were provided with 4 kg of feed every day. In addition, feed was weighed and added regularly into the feeding troughs such that feed was available at all times during the day. Water was provided *ad libitum* from low pressure nipple drinkers. Low pressure nipple drinkers and feeders were positioned in a manner that allowed access to all the pigs in a pen. The temperature and humidity in the building were maintained at 24.5 (± 1. 9) °C and 62.7 (± 15.07) %, respectively. The housing facility was cleaned and disinfected using Virkons disinfectant (Dodecyl benzene sulphuric acid, potassium peroxymonosulphate, sodium chloride) before the commencement of the trial. The accommodation was provided with a 24-hour lighting programme. The room temperature and pig health were checked daily.

3.2.3 Analyses of physicochemical properties of the diet

Ash, dry matter (DM), crude protein (CP), and crude fibre (CF) were determined according to the method of AOAC (2005). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed using filter bags by means of a fibre analyzer (Ankom 220, Ankom Technology Corp. Macedon, NY, USA). A bomb calorimeter was used to determine gross energy of feed. Bulk density of the feeds was measured according to the water displacement method described by Peterson & Baumgardt (1971). Water holding capacity was determined by centrifugation (Robertson & Eastwood, 1981). The chemical and physical properties of the diet are shown in Table 3.1.

3.2.4 Experimental design, treatments and enrichment materials

The study was conducted through a 2 × 2 (pen environment × sex) factorial arrangement. Pigs were blocked by sex and randomly allocated to 12 pens resulting in 4 pigs per pen. The pigs were allocated to either enriched or barren pens. The pigs were kept at a higher stocking density of 0.45 m^2/pig. Enriched pens contained 2 litre bottles filled with stones and suspended at head level on ropes stretching across the pens (Figure 3.1). The bottles were 35 cm long and placed 65 cm apart. In addition, two plastic balls (9 cm in diameter) supplied by (PLEXX BV, Elst, Netherlands) and 500 ml bottles (23.5 cm long) were placed on the floor of each enriched pen. The enrichment items used were chosen on the basis of their ease of availability and low cost.

Figure 3. 1: The experimental setting and enrichment materials used in the study, plastic balls and 500 ml bottles lay free on the floor, 2 litre bottles hung at the centre of the pens at the head level

Table 3. 1: Chemical and physical properties of the diet

Feed ingredients	Diet composition (g/kg DM)
Dry matter (DM)	90.14
Crude protein (CP)	160.0
Lysine	8.5
Calculated digestible energy	10.75
Ether extract	3.73
Crude fat	25.0
Neutral detergent fibre	430.93
Acid detergent fibre	68.39
Ash	5.52
Phosphorus	5.0
Calcium	8.0
Bulk density (g DM/mL)	1.83
Water holding capacity (g water/gDM)	4.6

The digestible energy was calculated as: 949+ (0.789×GE)– (43×% Ash)– (41×% NDF) (Noblet & Perez, 1993)

3.3 Measurements

3.3.1 Growth performance

Performance variables were determined every week for an experimental period of 42d following an adaptation of 7d. Weekly feed intake for each pen were determined by calculating the difference between the weight of the feeder bin at the beginning and end of each week. Weekly feed intake was divided by seven to obtain average daily feed intake (ADFI) for each pen. Pigs were weighed every week. Average daily gain (ADG) was determined by dividing the difference between body weight at the beginning and end of each week by seven. The feed: gain (F: G) ratio for each pig was determined by dividing the ADFI/ADG.

3.3.2 Metabolite concentrations

A blood sample was collected from the jugular vein using a needle and syringe set (Promex syringe) from each pig at the end of the trial (day 42) between 0800h and 1000h. For each treatment combination, two pigs were randomly selected for bleeding. The blood was centrifuged for separation of serum from blood using Beckman model T.J-6 Centrifuge PBC 14 at the dairy laboratory at ARC, Irene. The blood was stored in ice – filled cooler boxes and then transported to the laboratory. Blood urea nitrogen (BUN), creatinine, phosphorus, calcium, alkaline phosphatase (ALP), glucose, cholesterol, albumin and total protein (TP) were assayed using an automated chemistry analyser with kits from Labtest diagnostics (Labmax Plenno, Labtest, Lagoa - Santa, Brazil).

3.3.3 Statistical analyses

Interaction of pen environment and sex on growth performance was determined using SAS (2009). The PROC MIXED for repeated measures was used to analyse growth performance.

Pair - wise comparisons of means were performed using the PDIFF procedure. The model used was:

$$Y_{ijklm} = \mu + S_j + P_k + W_l + (S \times P)_{jk} + (S \times W)_{jl} + (P \times W)_{kl} + (S \times P \times W)_{jkl} + \beta_1 BWT + \beta_2 D + \varepsilon_{ijklm}$$

Y_{ijk} - is the response variable (average daily gain, average daily feed intake and feed: gain ratio and metabolite concentrations); μ - is the overall mean common to all observation; S_j – is the effect of sex (male, female); P_k – is the effect of pen environment (enriched, barren); W_l – is the effect of week; $(S \times P)_{jk}$ - is the interaction of sex and pen environment; $(S \times W)_{jl}$ – is the interaction of sex and week; $(S \times P \times W)_{jkl}$ - is the interaction of sex, pen environment and week, BWT- is the effect of initial body weight; β_1 BWT – is the partial regression coefficient of the dependent variable on BWT; D -is the effect of pen stocking density; $\beta 2D$ - is the partial regression coefficient of the dependent variable on pen stocking density; and ε_{ijkl} - is the residual error. Differences among the least square means were considered significant at $P < 0.05$.

The interaction of pen environment and sex on blood glucose, cholesterol, albumin, TP, BUN, calcium, phosphorus, ALP and creatinine concentrations was determined using the PROC GLM procedure of SAS (2009). The model used was:

$$Y_{ijk} = \mu + S_j + P_k + (S \times P)_{jk} + \varepsilon_{jk}$$

Where: Y_{ijk} - is the response variable (metabolite concentrations); μ - is the overall mean common to all observation; S_j – is the effect of sex (male, female); P_k – is the effect of pen environment (enriched, barren); $(S \times P)_{jk}$ - is the interaction of sex and pen environment; ε_{jk} -

is the residual error. Differences among the least square means were considered significant at $P < 0.05$.

3.4 Results

3.4.1 Feed intake

There was a significant effect of pen stocking density ($P < 0.001$) and initial body weight on ADFI, which were incorporated as covariates ($P > 0.05$) (Table 3.2). There was a significant interaction between pen environment and sex on ADFI ($P < 0.05$). Female pigs in barren environment had higher ADFI compared to female pigs in enriched environment. Pen environment, however, did not affect ADFI in male pigs (Table 3.3).

3.4.2 Average daily gain

Pen stocking density, incorporated as a covariate, affected ADG ($P < 0.001$), but there was no effect of initial body weight on ADG. There was no interaction of environment and sex on ADG ($P > 0.05$). Sex, however, affected ADG ($P < 0.001$), with male pigs growing faster than females. There were no differences in ADG in males and females in barren pens than their contemporaries in enriched environments (Table 3.3).

3.4.3 Feed: gain ratio

Pen stocking density and initial body weight, incorporated as covariates, affected F: G ratio ($P < 0.001$). Pen environment did not affect F: G ratio ($P > 0.05$). Pen environment and sex interaction

Table 3. 2: Significant level of the factors and covariates included in the analysis

Traits	ADFI	ADG	F: G ratio
Covariates			
BWT	*	ns	***
D	***	***	***
Main effects			
Sex	*	***	***
Pen environment	*	ns	ns
Week	***	***	***
Interaction effects			
Pen environment × sex	*	ns	ns
Sex × week	***	*	ns
Pen environment × week	*	ns	ns
Pen environment × sex × week	***	***	***

Abbreviations: ADG – Average daily gain, ADFI – Average daily feed intake, feed: gain (F: G) ratio, BWT –Initial body weight, D – Pen stocking density

Level of significance: *** $P < 0.001$, *$P < 0.05$, ns $P > 0.05$

Table 3. 3: Interaction of pen environment and sex on growth performance of Windsnyer pigs

	ADFI (kg/day)		ADG (kg/day)		F: G ratio	
	Enriched	Barren	Enriched	Barren	Enriched	Barren
Sex						
Male	1.12 ± 0.043[a]	1.10 ± 0.041[a]	0.42 ± 0.030[b]	0.45 ± 0.029[b]	0.25 ± 0.031[a]	0.39 ± 0.027[b]
Female	1.13 ± 0.046[a]	1.29 ± 0.046[b]	0.30 ± 0.034[a]	0.27 ± 0.034[a]	0.28 ± 0.032[a]	0.38 ± 0.028[b]

[ab] Values with different superscripts on growth performance differ significantly (P < 0.05)

Abbreviations: ADG (kg/day) – Average daily gain, FI (kg/day) – Feed intake, F: G – Feed: gain ratio was also not significant on F: G ratio. Sex, however, affected F: G ratio ($P < 0.001$). Males in enriched environment had a better F: G ratio than those in barren environment. Likewise, female pigs in an enriched environment had better F: G ratio than females in a barren environment. As also shown in (Table 3.3), pigs in an enriched environment were more efficient in converting feed into body weight than their contemporaries in a barren environment.

3.4.4 Metabolite concentrations

The interactions between pen environment and sex on metabolite concentrations of Windsyner pigs housed in an increased stocking density of 0.45 m^2/pig are shown in Table 3.4. There was no significant effect of pen environment on cholesterol, albumin, total protein, calcium, phosphorus, ALP and creatinine concentrations ($P > 0.05$). There was an interaction between pen environment and sex on glucose ($P < 0.05$). Female pigs in barren environment had significantly higher glucose concentrations than females in an enriched environment. The pen environment, however, did not affect glucose concentrations in males.

There was an interaction between pen environment and sex on albumin and BUN concentrations ($P < 0.05$). Male pigs in an enriched environment had higher albumin concentrations than males in a barren environment. The females in barren and enriched environments had similar albumin concentrations. Female pigs, housed in an enriched environment had higher BUN concentrations than females in a barren environment. There was, however, similar BUN concentrations in male pigs. The interaction between pen environment and sex was significant on ALP ($P < 0.05$). Female pigs housed in enriched environment had higher ALP than female pigs in barren environment but male pigs in both treatments had similar ALP (Table 3.4).

Table 3. 4: Least square means (± standard errors) of interaction between pen environment and sex on metabolite concentrations on Windsyner pigs

Metabolite	Pen environment				S.E.M	Significance		
	Enriched		Barren			P	S	P × S
	Male	Female	Male	Female				
GL (mg/dL)	70.3[a]	73.3[a]	72.2[a]	98.3[b]	4.61	ns	ns	*
CHO (mg/dL)	70.0	70.5	68.2	74.2	3.97	ns	ns	ns
ALB (g/dL)	3.79[b†]	3.22[a]	2.97[a]	3.07[a]	0.219	ns	*	*
TP (g/dL)	7.19	7.25	7.18	6.52	0.62	ns	ns	ns
BUN (mg/dL)	38.3[a†]	64.3[b†]	38.8[a†]	45.7[a†]	6.29	ns	*	*
CA (mg/dL)	6.8	7.0	5.3	5.5	1.23	ns	ns	ns
PHOS (mg/dL)	15.7[†]	12.9[†]	11.9[†]	12.3[†]	1.24	ns	ns	ns
ALP (U/L)	83.6[a]	106.7[b]	83.7[a]	75.7[a]	11.1	ns	ns	*
CREAT (mg/dL)	0.99	1.39	0.70	0.95	0.26	ns	ns	ns

[ab] Values with different superscripts for each metabolite differ ($P < 0.05$ *** $P < 0.001$; * $P < 0.05$; ns $P > 0.05$, †Denotes values above the normal range , P- Pen environment, S – Sex, P × S – Pen environment and sex interaction, Abbreviations: GL- Glucose, CHO – Cholesterol, ALB - Albumin, TP – Total Protein, PHOS- Phosphorus, CA –Calcium, BUN- Blood urea nitrogen, ALP – Alkaline phosphatase, CREAT – Creatinine

3.5 Discussion

To control the genetic erosion of Windsnyer pigs, identification of factors that promote their welfare and utilization need to be understood. In the present study, density was increased by 40 % to determine possible interactions between pen environment and sex on growth performance and metabolite concentrations of Windsnyer pigs. The observed interaction between pen environment and sex on ADFI was unexpected, with female pigs in the barren environment consuming more feed than females in enriched pens. It is likely that female pigs in enriched environment spent more of their time exploring the substrates than feeding. The higher ADFI for female pigs in the barren environment could be explained by that pigs could have felt bored and could only spend time feeding. Morgan *et al*. (1998) reported that pigs in a barren environment have higher ADFI as a consequence of increased gut fill.

The lack of interaction between pen environment and sex on ADG is, however, difficult to explain. A probable explanation for the similar ADG could be that pigs were viewing the environment as similar. Gracner *et al.* (2013) reported that if the enrichment material fails to capture the attention of pigs for a long time, they perceive the environment as similar. The finding that male pigs were growing faster than females could be the influence of testosterone in enhancing growth of males (Chimonyo *et al*., 2005). Another explanation could be due to female pigs having a suppressed feed intake as a result of reaching sexual maturity. Thus, Windsnyer pigs should be slaughtered between 12 and 16 weeks post weaning. Keeping Windsnyer pigs for longer periods than is optimum will reduce the efficiency of feed conversion into muscle since most of the dietary nutrients are converted into fat.

The higher efficiency of feed utilization for body weight gain in enriched male and female pigs than those in barren environment could suggest that when Windsnyer pigs are enriched they require less feed. This could mean that there is less cost of feed required to produce pork which is an advantage to farmers who cannot purchase the expensive feed. This also could indicate a higher potential for lean deposition when pigs are enriched than in barren environment. It is also possible that the ability of pigs in enriched environment to convert nutrients efficiently is a result of being in an environment that allows them to perform more to their true potential.

Glucose, in general, indicate the efficiency in utilization of energy in a given diet. When glucose falls below the normal ranges, pigs respond by eating more to restore normal glucose levels (Bakare *et al*., 2016). The observed interaction of pen environment and sex on glucose, could be ascribed to female pigs in barren environment getting more glucose from the diet as a consequence of high ADFI. The lower glucose level in enriched environment could indicate that pigs were producing more energy due to spending most time in playful activities, thereby, decreasing their glucose level. Cholesterol is synthesized from fats consumed and endogenously synthesized within the cells. The finding that there was no interaction of pen environment and sex on cholesterol is, however, difficult to explain. Table 3.5 shows the normal values for the metabolites measured in the current study.

Table 3. 5: Normal metabolite concentrations in pigs

Metabolite	Normal range
Glucose (mg/dL)	85 - 160
Cholesterol (mg/dL)	18 - 79
Albumin (g/dL)	1.8 – 3.3
Total protein (g/dL)	6.0 – 8.0
Blood urea nitrogen (mg/dL)	6 - 30
Calcium (mg/dL)	6.5 – 11.4
Phosphorus (mg/dL)	3.6 – 9.2
Alkaline phosphatase (U/L)	92 - 294
Creatinine (mg/dL)	0.5 – 2.1

Source: Kaneko (1963)

Total protein is comprised of albumin and globulin. The observed pen environment and sex interaction on albumin, with enriched male pigs producing more albumin could suggest that enrichment enhances the ability of male pigs to increase their protein status. It is possible, therefore, that the dietary protein levels that are recommended in a standard pig grower diet are higher than the requirements (Mashatise *et al*., 2005) for the slow growing Windsnyer pigs. Therefore, more research need to done to determine the appropriate protein requirements for Windsnyer pigs.

The similar total protein could suggest that pigs in both treatments had a better nutritional status and were getting similar amount of protein from the diet. The observed interaction of pen environment and sex on BUN, with enriched females producing more BUN concentrations than females in barren pens could suggest that enriched female pigs were assimilating higher amount of nitrogen from the diet. Mashatise *et al*. (2005) suggested that Windsnyer pigs require less dietary nitrogen. This could also mean that enriched females assimilated more protein levels than needed thus, excess protein was deaminated leading to high BUN. These also further indicate the need to low protein requirements for the slow growing pigs. The locally available fibrous feeds are likely to supply the required nutrients for the slow growing pigs like Windsnyer pigs (Kanengoni *et al*., 2004).

Creatinine is a normal by - product of physical activity because of the breakdown of creatine phosphate found in the muscle (Ambrosy *et al*., 2015). Ideally, creatinine levels indicate the adequacy of proteins in terms of quality and quantity in the diet of animals (Mashatise *et al*., 2005). The finding that there was no interaction of pen environment and sex on creatinine concentrations could suggest that the urea that was detected in the blood is likely to have been coming from the elevated dietary protein. The observation that there was no interaction of pen environment and sex on phosphorus and calcium concentrations is not clear. On the other way, it can be said that this could have been due to increase availability of minerals because of improved digestibility of the diet. This could mean that there is a need of identifying potential local feed sources that would supply mineral content that will meet the requirements for the local Windsnyer pigs.

Alkaline phosphatase is important in the determination of the bone cell activity. Conditions that affects bone growth or causes increased activity of bone cells can affect ALP concentrations in the blood (Ambrosy *et al*., 2015). The observed pen environment and sex interaction on ALP, with enriched females producing more ALP than female pigs in barren environment could indicate that bone cells of females in enriched environment were more active as a result of increased activities.

3.6 Conclusions

Windsnyer pigs housed in enriched pens, especially females, performed better than those in barren pens. The female pigs in barren environment had higher glucose concentrations than their contemporaries in enriched environment. Likewise, there was an increase in BUN and ALP for female pigs in enriched environment than those in barren environment. The male pigs in enriched environment had higher albumin concentrations than females enriched. More research, therefore has to be done to determine the physiological responses, as well as the behaviour of female and male Windsnyer pigs that are kept in pens that are enriched.

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CHAPTER FOUR: Interaction of pen environment and sex on physiological responses and behaviour of Windsnyer pigs

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Abstract

The objective of the study was to determine the interaction of pen enrichment and sex on physiological responses and behaviour of Windsnyer pigs. Forty- eight growing Windsnyer pigs, with an average initial body weight of 21.6 (± 9.01) kg were used. Four pigs were randomly assigned to either enriched or barren pens at a stocking density of 0.45 m^2 /pig. Pigs in barren environments had higher heart rates ($P < 0.001$) than those in enriched pens. There was an interaction of pen environment and sex on rectal temperature ($P < 0.001$). Females in enriched pens had higher rectal temperatures ($P < 0.05$) than females in barren pens. There was no interaction of pen environment and sex on feeding behaviour ($P > 0.05$). The time spent bullying was influenced ($P < 0.05$) by pen environment and sex. Female pigs in barren environment spent more time on bullying than females in enriched pens. There was an interaction of pen environment and sex on time spent lying down and walking ($P < 0.05$). Female pigs in enriched pens spent more time lying down than females in barren pens. Males in barren pens spent more time walking than males in enriched pens while no effect of pen environment was observed in females. There was an interaction of pen environment and sex on time spent rolling, pivoting, tail biting and number of injuries ($P < 0.05$). It can be concluded that pen enrichment improves pig welfare by reducing the number of injuries and anti-social behaviours, particularly in female pigs enriched.

Keywords: Exploratory behaviour, aggressive behaviour, animal welfare, pen fixtures, heart rate, respiration rate.

4.1 Introduction

Pig production is generally increasing in the sub Saharan Africa as a result of the growing human population. Local genotypes, such as the Windsnyer pigs that are adapted to local conditions and thrive on fibrous feeds can be of much value with regard to feeding the growing population. The Windsnyer pig is short framed, with long nose and razor back, and has a lower mature weight than the fast growing pigs (Halimani *et al*., 2010). Windsnyer pigs are heat tolerant and are likely to survive extreme temperatures (Nengomasha, 1997). The merits of this breed are, however, not fully exploited to improve food security and livelihoods. The emphasis by national institutions on increasing productivity has led to the dominance of improved breeds in Southern Africa (Chimonyo & Dzama, 2007).

In South Africa, for example, the South African Pig Producers Organization (SAPPO), which has the mandate to improve pig production exclusively deals with improved breeds such as Large White, Landrace and Duroc. The bias has contributed to the lack of improvement of slow growing Windsnyer pigs, thereby threatening their existence. The welfare of growing–finishing pigs can directly influence performance variables such as average daily gain (ADG), average daily feed intake (ADFI) and feed: gain (F: G) ratio. Deen *et al*. (2005) reported that growth performance alone cannot accurately reflect and assess the extent to which the welfare of the pigs is met. In addition to growth performance, indicators related to behavioural and physiological responses should be considered. Information on physiological responses during exposure to pen environment is limited but could be measured by variations in heart rate, respiration rate and rectal temperature. Injuries and bruising also assess pig welfare (Caldara *et al*., 2012).

De Jong *et al*. (1998) reported that enriching the pen environment improves welfare and physiological responses of pigs. These studies, however, only focused on improved breeds and also did not determine the possible interactions between pen environment and sex on behaviour and physiological responses of pigs. Since a significant interaction on growth performance between sex and pen enrichment was reported in Chapter 3, it is important to assess whether the behaviour and physiological responses in the pigs would show a similar pattern. There is need to determine the extent to which pen environment can influence the behaviour and physiological responses of male and female Windsnyer pigs when kept in a high stocking density environment. The objective of the study was, therefore, to determine the interaction of pen environment and sex on physiological responses and behaviour of Windsnyer pigs. It was hypothesized that there is interaction between pen environment and sex on physiological responses and behaviour of Windsnyer pigs.

4.2 Materials and Methods

4.2.1 Study site

Details of the study site are described in section 3.2.1

4.2.2 Pigs, feeding and housing management

Details on pigs, feeding and housing management are described in section 3.2.2

4.2.3 Experimental design, treatments and enrichment structures

The experimental design, treatments and enrichment structures are described in section 3.2.4. The weather conditions during the trial period are given in Table 4.1.

Table 4. 1: Mean hourly temperatures and relative humidity for 42 days study period

Time (hrs)	Humidity (%)	Temperature (°C)
0800	72	21.3
0900	65	23.2
1000	57	24.7
1100	51	25.9
1200	48	26.9
1300	45	30.0
1400	43	28.3
1500	42	28.3
1600	42	28.3

4.2.4 Measurements

To measure physiological responses pigs were confined in a 1.3 × 0.5 × 0.8 m metal cage with minimum restraint and heart rate, body temperature and respiratory rates were measured. The pigs were handled three times a day for period of seven days before the experiment began for them to get accustomed to the stockmen and measurement routine.

4.2.4.1 Rectal temperature

The rectal temperature (RT) of the pigs was measured every day for a period of 12 days at 0800h to the nearest 0.1ºC using a digital thermometer (Uniontech) at the same time when body weight (BW) was measured. Rectal temperature was measured and recorded before the provision of feed to each pig. The thermometer was inserted in the rectum to full depth until a stable automated reading was obtained.

4.2.4.2 Respiratory rate

The respiratory rate (RR) (in beats per minute) for each pig was measured every day for a period of 12 days at 0800h on the same day when BW and RT were measured. The measurements were done visually by observing and counting the movements of the flank of each pig. The movements of the flank were observed for 15 seconds.

4.2.4.3 Heart rate

The heart rate (HR) of the pigs was measured using a stethoscope. The stethoscope was placed on the artery below and slightly inside the jaw. The heart rate was observed for 15 seconds and multiplied by four to obtain the number of heat beats per minutes. The heart rate was expressed as beats per minute.

4.2.4.4 Pig behavioural changes

Behavioural activities of pigs in each pen were recorded continuously using a ceiling mounted video camera, starting from 0800h and ending at 1600h (Bakare *et al*., 2014). Pigs were identified with paint markings at the back for accurate identification during observation. Time spent on different behavioural activities and frequency was observed for a period of three weeks (21 d), six times a week to avoid the effect of novelty. Individual observations lasted for 5 min. In each pen, two focal pigs were selected. These were selected on the basis of their body weight and sex, pigs with an expected weight of between 20 and 30 kg, 7 days after the beginning of the experiment. The same focal pigs were observed throughout the trial. Behavioural activities observed in the study are partly based on descriptions of behavioural activities given in Table 4.2. All behavioural observations were conducted by one trained individual to eliminate inter observer discrepancy.

4.2.4.5 Injury scores

Injuries emanating through aggression and frequency of fighting were assessed on individual pigs in each pen. Recordings were done on fresh lesions (Bakare *et al*., 2014). Injuries on each side of the pig were then added to obtain a total of each side then score based on the total number of injuries.

Table 4. 2: Ethogram of behavioural activities in barren and enriched environments

Aggressive behaviour	
Fighting	Mutual pushing or lifting pen mate and pen mate retaliates
Bullying	If one pig is dominant over the other in a fight
Exploratory behaviour	
Explore substrates	Sniffing, rooting or pushing the object or substrate
Explore pen fixtures	Rooting, sniffing, touching the walls or the ground of the pen except object or substrate
Postures	
Standing Active	Body weight supported by all four legs
Lying down	Body weight supported by belly side
Walking	Moving from one position to another position within a pen
Feeding behaviour	
Feeding	Consumption of feed material from the feeder
Drinking	Drinking from the nipple drinker
Social behaviour	
Mounting	Placing front hoofs on the back of the pen mate
Head thrusting	When pigs rub heads without causing harm to each other
Others	When the pig is involved in any behaviour other than the listed behaviours

Source: Beattie (2000)

The scoring method used followed that of Gonyou *et al*. (1988) which is;

0 = no scratches   1 = 1- 3 scratches   2 = 4- 6 scratches   3= more than 6 scratches

For the purposes of assessment, the body of the pigs was divided into three zones per side (head; neck and shoulders and other parts). Each zone received an injury score based on the number of scratches on it (Figure 4.1).

4.2.5 Statistical analyses

For the analyses of the behavioural data, PROC UNIVARIATE (SAS, 2009) was used to check the data for normality. Logarithmic transformation was used to normalize data for injuries. Data for physiological responses and behavioural activities were analysed using PROC MIXED for repeated measures. The effect of day was used as a within-subjects variable. During the analyses of HR, RT and RR, data for each pig was used as the experimental unit. For behavioural activities the pen was the experimental unit. The model used was:

$$Y_{ijk} = \mu + S_j + P_k + W_l + (S \times P)_{jk} + (S \times W)_{jl} + (P \times W)_{kl} + (S \times P \times W)_{jkl} + \beta_1 BWT + \beta_2 D + \varepsilon_{ijkl}$$

Y_{ijk} - is the response variable (Pig behaviour, injury scores, RT, HR, RR); μ - is the overall mean common to all observation; S_j – is the effect of sex (male, female); P_k – is the effect of pen environment (enriched, barren); W_l – is the effect of week; $(S \times P)_{jk}$ - is the interaction of sex and pen environment; $(S \times W)_{jl}$ – is the interaction of sex and week; $(S \times P \times W)_{jkl}$ - is the interaction of sex, pen environment and week, BWT- is the effect of initial body weight; β_1 BWT – is the partial regression coefficient of the dependent variable on BWT; D -is the effect of pen stocking density; $\beta 2D$ - is the partial regression coefficient of the dependent variable on pen stocking density; and ε_{ijkl} - is the residual error. Differences among the least square means were considered significant at $P < 0.05$.

1. Head 2. Neck & Shoulders 3. Other parts

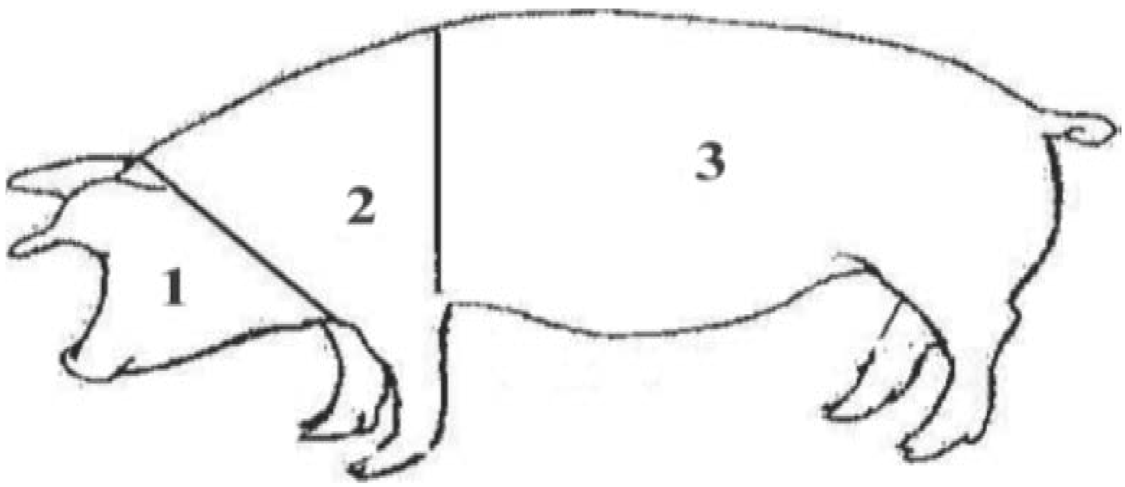

Figure 4. 1: Injury score template used to count and score injuries on pigs

4.3 Results

4.3.1 Summary statistics

Table 4.3 shows the summary statistics and levels of significance of the interaction between pen environment and sex on HR, RR and RT of Windsnyer pigs. Interactions of pen environment and sex on physiological responses of Windsnyer pigs are shown in Table 4.4.

4.3.2 Heart rate

There was a significant effect of pen stocking density and initial body weight incorporated as covariates ($P < 0.001$) on heart rate (HR) (Table 4.3). There was no interaction of pen environment and sex on HR ($P > 0.05$). The HR was, however, influenced by pen environment ($P < 0.001$). Pigs in barren environment had higher HR than pigs in enriched environment (Table 4.4), respectively.

4.3.3 Respiration rate

Initial body weight incorporated as a covariate affected respiration rate (RR) ($P < 0.05$). Pen stocking density incorporated as covariates was, however, not significant (Table 4.3). There was an interaction of pen environment and sex on RR ($P < 0.05$). Female pigs in barren environment had higher RR than female pigs in enriched pens; however, male pigs had similar RR (Table 4.4).

4.3.4 Rectal temperature

There was a significant effect of pen stocking density and initial body weight incorporated as covariates on rectal temperature (RT) ($P < 0.05$). There was an interaction between pen

Table 4. 3: Significance levels of the factors and covariates included in the analysis on physiological responses

Traits	HR (beats/min)	RR (beats/min)	RT (°C)
Covariates			
Initial body weight	**	*	*
Pen stocking density	***	ns	*
Main effects			
Pen environment	***	*	ns
Sex	ns	ns	ns
Day	ns	***	***
Interaction effects			
Pen environment × sex	ns	*	***
Pen environment × day	***	***	ns
Sex × day	ns	ns	*
Pen environment × sex × day	ns	*	***

Abbreviations: HR – Heart rate (Beats/min), RR – Respiration rate (Beats/min), RT – Rectal temperature (°C), Level of Significance: *** $P < 0.001$; *$P < 0.05$; ns $P > 0.05$

Table 4. 4: Interaction between pen environment and sex on physiological responses of Windsnyer pigs

	HR (Beats/min)		RR (Beats/min)		RT (°C)	
Pen environment	**Enriched**	**Barren**	**Enriched**	**Barren**	**Enriched**	**Barren**
Sex						
Male	82.1 ± 0.69[a]	88.4 ± 0.66[b]	18.7 ± 0.32[a]	18.8 ± 0.31[a]	38.4 ± 0.06[a]	38.7 ± 0.06[b]
Female	82.5 ± 0.73[a]	83.4 ± 0.73[b]	18.5 ± 0.34[a]	19.9 ± 0.34[b]	38.7 ± 0.06[b]	38.5 ± 0.06[a]

[ab] Values with different superscripts differ significantly ($P < 0.05$)

Abbreviations: HR – Heart rate (Beats/min), RR – Respiration rate (Beats/min), RT – Rectal temperature (°C) environment and sex on RT ($P < 0.001$). Males in barren environment had higher RT than enriched male pigs, respectively. Enriched female pigs had higher RT than females in the barren environment (Table 4.4).

4.3.5 Feeding behaviour

Feeding behaviour consisted of time spent feeding and drinking. There was no interaction of pen environment and sex on time spent on feeding and drinking ($P > 0.05$). Time spent on feeding and drinking was similar regardless of whether the environment was enriched or barren (Table 4.5).

4.3.6 Aggressive behaviour

Aggressive behaviour consisted of time spent on fighting and bullying. There was no interaction of pen environment and sex on time spent on fighting ($P > 0.05$). Pen environment, however, affected time spent on fighting and bullying ($P < 0.001$). Female and male pigs in barren environments spent more time fighting than female and male pigs in enriched environments (Table 4.5). There was an interaction of pen environment and sex on time spent bullying ($P < 0.05$). Female pigs in barren environments spent more time on bullying than females in enriched pens while no effect of pen environment was observed in males (Table 4.5).

4.3.7 Postures

There was no interaction of pen environment and sex on time spent actively standing ($P > 0.05$). However, there was an interaction of pen environment and sex on time spent lying down and walking ($P < 0.05$). Female pigs in enriched pens spent more time lying down than females in barren pens whilst male pigs spent similar amount of time lying down regardless of whether they were in enriched or barren pens (Table 4.5). Males in barren pens spent more time walking than males in enriched pens, but females regardless of whether they were in enriched or barren pens spent similar amount of time walking. Environment affected time spent walking ($P < 0.05$).

4.3.8 Social behaviour

There was an interaction of pen environment and sex on time spent mounting other pigs ($P < 0.05$). Female pigs in barren pens spent more time mounting than females in enriched pens. The pen environment did not affect time spent mounting in male pigs (Table 4.5). The interaction of pen environment and sex on time spent head thrusting was not significant ($P > 0.05$).

4.3.9 Exploratory behaviours

The proportion of time spent on exploratory behaviours was unaffected by the interaction of pen environment and sex ($P > 0.05$). Female pigs in enriched pens spent similar amount of time exploring the substrates with male pigs. Time spent exploring pen fixtures was affected by the pen environment ($P < 0.001$), with males and females in barren pens spending more time exploring pen fixtures than male and female pigs in enriched pens (Table 4.5). There was a significant interaction between pen environment and sex on time spent rolling, pivoting and tail biting ($P < 0.05$). Male pigs in barren pens spent more time on tail biting, rolling and pivoting than females, whilst, enriched male and female pigs spent similar amount of time on tail biting, rolling and pivoting (Table 4.5), respectively.

Table 4. 5: Interaction between pen environment and sex on time spent (min) (mean ± standard error) on different behavioural activities

Behaviour	Environment				S.E.M	P	S	P × S
	Enriched		Barren					
	Male	Female	Male	Female				
Feeding behaviour								
Feeding	63	64	65	64	1.62	ns	ns	ns
Drinking	22	23	22	23	0.99	ns	ns	ns
Aggressive behaviour								
Fighting	15^{a}	14^{a}	28^{b}	24^{b}	1.49	***	ns	ns
Bullying	14^{b}	10^{a}	21^{bc}	18^{b}	1.51	***	ns	*
Postures								
Lying down	125^{ab}	134^{b}	133^{b}	115^{a}	5.27	ns	ns	*
Standing active	58	65	68	64	2.93	ns	ns	ns
Walking	58^{a}	65^{b}	68^{b}	64^{ab}	2.43	*	ns	*
Social behaviour								
Mounting	16^{ab}	13^{a}	18^{b}	17^{b}	1.21	ns	ns	*
Head thrusting	15	15	13	14	1.31	ns	ns	ns
Exploratory behaviour								
Explore substrates	51^{a}	58^{a}	-	-	2.99	ns	ns	-
Explore pen fixtures	35^{a}	34a	62^{b}	62^{b}	2.63	***	ns	ns
Others	19^{a}	21^{a}	28^{b}	24^{a}	2.57	ns	ns	*

^{ab} Values with different superscripts differ significantly (P < 0.05) Level of significance *** P < 0.001; * P < 0.05; ns P > 0.05 P- Pen environment, S – sex, P × S – pen environment and sex interaction

4.3.10 Injury scores

Table 4.6 shows the interaction of pen environment and sex on injury scores. There was an interaction of pen environment and sex on injury scores found in the head region, neck and shoulder region and other parts ($P < 0.05$). Female pigs in barren pens had more head injuries compared to females in enriched pens. The pen environment, however, did not affect the number of head injuries in male pigs. Female pigs in enriched pens had less injuries on the neck and shoulder region compared to females in barren pens. However, pen environment did not affect number of injuries on the neck and shoulder region in male pigs. Female pigs in enriched pens had less injuries on the other parts of the body compared to female pigs in barren pens. The pen environment, however, did not affect injury scores in male pigs.

4.4 Discussion

The preference by authorities of fast growing pigs has led to a decline in the population of indigenous breeds such as Windsnyer pigs. An estimated 16 % of the uniquely adapted genotypes have been lost over the last century. In some Southern African countries, when a number of indigenous breeds is reduced by natural disasters or civil wars, it is replaced by commercial breeds, leading to a reduction of genetic diversity (Jeong *et al.*, 2014). Lack of interest in Windsnyer pigs has also been caused by indiscriminate cross breeding, political instability and globalisation (Chimonyo & Dzama, 2007). To conserve the Windsnyer population, factors that promote their utilisation need to be documented.

Table 4. 6: Interaction between pen environment and sex on injury levels (mean ± standard error)

	Head region		Neck & Shoulder region		Other parts	
	Enriched	**Barren**	**Enriched**	**Barren**	**Enriched**	**Barren**
Sex						
Male	0.23 ± 0.03[a]	0.22 ± 0.03[a]	0.34 ± 0.03[b]	0.42 ± 0.03[b]	0.37 ± 0.02[b]	0.37 ± 0.02[b]
Female	0.33 ± 0.03[a]	0.41 ±0.03[b]	0.21 ± 0.03[a]	0.39 ± 0.03[b]	0.23 ± 0.02[a]	0.32 ± 0.02[b]

[ab] Values with different superscripts differ significantly ($P < 0.05$)

The heart rate was within the normal range for the pigs. The normal heart rate range is between 70 and 107 beats/min (Hannon *et al*., 2012). The observation that HR was influenced by pen environment was not surprising. The higher HR for male pigs in barren pens could mean that pen enrichment improves welfare of pigs. The finding that pigs in enriched environment had lower HR could be a reflection of being calmer and resting more as a result of spending more time on exploratory behaviours (Caldara *et al*., 2012).

Respiration rate is the first indicator of heat stress and can be affected by temperatures as low as 21.3 °C (Lorschy, 2005). The normal respiration rate for pigs is between 15 and 30 beats/min (Silanikove *et al*., 2000). On the contrary, Lorschy (2005) reported that 50 beats per minute is also comfortable for pigs. Caldara *et al*. (2012) reported that respiration rate did not differ between pigs enriched with wood shavings, compact floor and coffee husks bedding. The observed interaction between pen environment and sex on respiration rate is difficult to explain. The finding that female pigs in barren pens had higher RR than females in enriched pens could indicate increased stress levels in the female pigs.

The observed interaction between pen environment and sex on RT could be due to changes in behavioural activities and climatic conditions under study. The higher RT for male pigs in barren environment could suggest that they were trying to maintain a temperature gradient between core and skin temperature (Renaudeau *et al*., 2008). Rectal temperature is an indicator of the core body temperature that does not vary much because of the thermoregulatory control at the hypothalamic level (Hahn, 1990). Madzimure *et al*. (2011) reported that RT is a delayed indicator of heat stress only responding at temperatures above 27 °C. Stress can affect body temperature rhythm and body temperature level (De Jong *et al*., 2000). These differences in RT can also be explained by differences in circadian rhythm. The sex difference may be explained by the effect of puberty with most pigs coming to oestrus during the study.

The finding that there was no interaction between pen environment and sex on time spent feeding and drinking was surprising because in the absence of enrichment substrates in the barren environment you would expect pigs to spend more time feeding and drinking. The lack of differences on feeding behaviour in barren and enriched pen environments was difficult to explain (Beattie *et al*., 1996). A possible explanation could be that pigs in enriched pens were restricted in their use of enrichment substrates because of the size and pen design such that when one pig is feeding, it would effectively block the movement of others. More time spent on drinking by pigs in barren environment was expected as a result of boredom, therefore, pigs would be playing with the nipple drinker.

Windsnyer pigs have a calmer temperament (Chimonyo & Dzama, 2007) which could possibly suggest the lack of interaction of pen environment and sex on time spent fighting. The finding that pigs in barren environment spent more time fighting than pigs in enriched environment could have emanated out of frustration when queuing at the feeder or due to competition of resources within the pen. Fighting could have been reduced if more feeders were made available to reduce competition for access of food. Fighting may also have been elicited by discomfort, irritability and annoyance in pigs. The reduction of fighting with enrichment may not be a direct consequence of the enrichments but rather a secondary result associated with the decrease in harmful social behaviour that is brought by the enrichment (Beattie *et al*., 1996). Bullying behaviour in the study was defined as one pig being dominant over the other in a fight. The observed interaction on bullying with female pigs in barren environment spending more time bullying may be a reflection of a dominant pig being more in control of the pen environment and submissive pigs not retaliating to avoid social encounters or choosing to wait for the dominant pig to stop its activity before it does what it desires to do.

The unexpected observation that there was no interaction between pen environment and sex on time spent actively standing is surprising because Windsnyer pigs in their natural habitat dedicate greatest part of their time foraging and on exploratory behaviours such as grazing and rooting. Since most of the pigs were observed to be on heat it was anticipated that there would be an interaction of pen environment and sex on time spent actively standing. During observations, in the morning when feed was offered there would be lot of activity as they were anticipating a share of feed. It is likely, therefore, that time spent on this activity was taken up in more, lying down.

The finding that females in enriched environment spent more time lying down could be because it was the hottest hours of the day. More- so time spent lying down could be explained as a sign of enhanced satiety for the pigs in enriched environments. Increased time spent lying down came directly from decreased time spent eating (Bakare *et al*., 2014). Such results could also suggest that females were resting more frequently because they were more satisfied and calmer. More time spent on walking in male pigs in barren environment could have emanated when male pigs were walking around sniffing the floor. De Leeuw *et al*. (2005) referred this action as a substrate directed behaviour. Substrate directed behaviour may occur when pigs in a barren environment perceive that their pen environment is different from the other pen environment, thus, they spent time walking around looking for rootable objects.

The observation that female pigs in barren environment spent more time mounting could have been signs of heat as a consequence of sexual maturity. The finding that there was no interaction on head thrusting is not simple to explain. The observed similar time spent exploring substrates in enriched environment agrees with the commonly held view that when pigs are given access to substrates they spend considerate amount of time exploring them. In the absence of substrates, they spend their time exploring pen or pen fixtures (Beattie *et al*., 2000). The observation that male and female pigs in barren environment spent more time exploring pen fixtures could be a reflection of rooting behaviour in pigs. The anticipated finding that enriched pigs spent less time exploring pen fixtures is presumably because the exploration of pen fixtures was less satisfying compared to manipulation of the substrates (Bolhuis *et al*., 2005) as pigs appear to prefer chewable, destructible and rootable object for exploration (Van de Weerd *et al*., 2003).

The finding that male pigs in barren environment spent more time rolling and pivoting could be a reflection of play behaviour or pigs realising frustration and boredom as they were not provided with substrate. When pigs are housed in a barren environment, levels of tail biting are very high (Van de Weerd *et al*., 2006) and the occurrence of tail biting in a barren environment could be a reflection of re-directed foraging behaviour. It is suggested that when pigs are housed indoors and cannot perform foraging behaviour due to lack of rootable substrates or space they redirect foraging to rooting and chewing of pen mates, usually tails become a major targets of rooting and chewing because it always readily available for manipulation.

The major cause of skin injuries is fighting among the mixed groups and unfamiliar pigs (Faucitano, 2001). The observed interaction of pen environment and sex on skin injuries could be due to difficulty in avoiding an attack by an aggressor at higher stocking densities in the pen (Geverink *et al*., 1996). The finding that female pigs in barren environment had more head injuries compared to enriched females was expected. Partly, because the provision of enrichment materials was expected to reduce the incidence of fighting since most of the pigs will be devoting their time exploring the substrates.

The observation that pen environment did not affect the number of head injuries in male pigs could suggest a low level of aggressiveness in this genetic line of pigs. The observed finding that enriched females had less injuries on the neck and shoulder region compared to females in barren environment was expected because when pigs are fighting they position themselves so that their heads align on each other's shoulders. Therefore, slamming of their heads into each other's shoulders could have resulted in more cuts or injuries on the neck and shoulder region of females in barren environment. The results that enriched female pigs had less injuries on the other parts of the body could mean being less involved in fighting and bullying as a result of exploring substrates more. The observation that pen environment did not result in any difference in male pigs could be a result of some male pigs admitting defeat from the opponent and running away.

4.5. Conclusions

From the pigs used in the present study, it can be concluded pen enrichment reduced the number of injuries, especially for female pigs in enriched environment. Female pigs in enriched spent less time bullying each other than male pigs. Male and female pigs in enriched environment spent less time on tail biting, rolling and pivoting than those in barren environments. The lower time spent on aggressive interactions gives a clear indication that pen enrichment reduced anti-social behaviours.

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CHAPTER FIVE: General discussion, Conclusions and Recommendations

5.1 General discussion

The main hypothesis tested was that the influence of pen environment on growth performance, metabolite concentrations, physiological responses and behaviour of Windsnyer pigs depends on their sex. The Windsnyer pigs reach sexual maturity about three months younger than the fast growing improved pigs (Mashatise *et al*., 2005). Most commercial farmers mix male and female pigs during fattening. The female Windsnyer pigs are, however, likely to exhibit oestrus before they are ready for slaughter. Furthermore, puberty is also likely to influence any degree of activity within a pen and could, therefore, interact with any attempts to enrich pig pens. Such interaction could, therefore, be measured through growth performance. In addition to growth performance parameters, indicators related to behaviour, metabolite concentrations and physiological responses need to be considered to get an accurate assessment on pig welfare.

The interaction of pen environment and sex on growth performance and blood metabolite concentrations was determined in Chapter 3. There was an interaction of pen environment and sex on average daily feed intake (ADFI). Females in barren pens had higher ADFI than females in enriched environment but ADFI was similar for male pigs. This was likened to female pigs in enriched environment spending more of their time exploring the substrates than feeding. The higher ADFI of female pigs in barren environment was explained by that pigs from this environment could have felt bored and could only spend time feeding. Pen environment did not affect ADFI and average daily gain (ADG). Sex of pigs affected ADG and F: G ratio. Male pigs grew faster than females. This could have been due to the influence of testosterone to enhance growth (Chimonyo *et al*., 2005). Pigs in enriched environment were more efficient in converting feed into body weight than those in barren environment. The hypothesis that the influence of pen environment on growth performance depends on sex is accepted based on the view that female pigs in enriched environment performed better than those in a barren environment.

Studies that have been done on enrichment have ignored possible changes that occur on blood metabolite concentrations as a result of pen environment. There was an interaction of pen environment and sex on glucose, blood urea nitrogen (BUN) and alkaline phosphatase (ALP). Females in barren environment had higher glucose than enriched females. This was attributed to female pigs in barren environment getting more glucose from the diet as a consequence of high ADFI. Enriched females had higher BUN than females in barren environment. This was attributed to dietary protein levels being higher than the requirements (Mashatise *et al*., 2005) for the slow growing Windsnyer pigs. This could also suggest that enriched females assimilated more protein levels than needed thus, excess protein was deaminated leading to high BUN. Enriched females had higher ALP than females in barren environment suggesting that bone cells of females in enriched environment were more active as a result of increased activities. In this respect, the hypothesis that the influence of pen environment on metabolite concentrations depend on sex is accepted as female pigs in enriched environment had higher BUN and ALP than those in barren environments.

In Chapter 4, the interaction between pen environment and sex on physiological responses, behaviour and injury levels of Windsnyer pigs was assessed. Pigs in barren environment had higher heart rate than enriched pigs. The higher HR for male pigs in barren environment could mean that pen enrichment improves welfare of pigs. There was an interaction of pen environment and sex on rectal temperature. This was attributed to changes in behavioural activities and climatic conditions during the study. Enriched females had higher rectal temperature than males. The sex difference could be explained by the effect of puberty with most pigs coming to oestrus during the study.

The lack of differences on feeding behaviour in barren and enriched pen environments was difficult to explain. More time spent on drinking by pigs in barren environment was expected as a result of boredom, pigs could have been playing with the nipple drinker. The observed interaction on bullying with female pigs in barren environment spending more time bullying may be a reflection of a dominant pig being more in control of the pen environment and sub missive pigs not retaliating to avoid social encounters or choosing to wait for the dominant pig to stop it activity before it does what it desires to do.

The observation that female pigs in barren environment spent more time mounting could have been signs of heat as a consequence of sexual maturity. The similar time spent exploring substrates in enriched environment agrees with the commonly held view that pigs given access to substrates spend considerate amount of time exploring them. In the absence of substrates they spend their time exploring pen or pen fixtures (Beattie *et al*., 2000). The observation that male and female pigs in barren environment spent more time exploring pen fixtures could have been a reflection of rooting behaviour in pigs. The observed interaction of pen environment and sex on skin injuries could be due to difficulty in avoiding an attack by an aggressor at higher stocking densities in the pen (Geverink *et al.,* 1996). The observation that pen environment did not affect the number of head injuries in male pigs suggest a low level of aggressiveness in this genetic line of pigs. The hypothesis that there is an interaction between pen environment and sex on physiological responses, behaviour and injury levels on Windsnyer pigs is accepted. Housing female pigs in enriched environment reduced the number of injuries than those in barren environment. Male and female pigs in enriched environment had less heart rate than those

5.2 Conclusions

Female pigs in enriched environment performed better than those in barren environment. The female pigs in barren environment had higher glucose concentrations than their contemporaries in enriched environment. Likewise, there was an increase in BUN and ALP for female pigs in enriched environment than those in barren environment. The male pigs in enriched environment had higher albumin concentrations than females enriched. Pen enrichment reduced the number of injuries, especially for female pigs in enriched environment. The lower time spent on agonistic interactions gives a clear indication that pen enrichment reduced anti-social behaviours. Female pigs in enriched environment spent less time on bullying each other than male pigs. Male and female pigs in enriched environment spent less time on tail biting, rolling and pivoting than those in barren environments.

5.3 Recommendations and further research

For promotion of Windsnyer pigs it should be borne in mind that farmers need information that promote their utilisation. When keeping Windsnyer pigs it is indispensable to enrich their environment, especially female pigs as enrichment improves F: G ratio and ADFI. Furthermore, for effective pen enrichment in male pigs it is recommended that farmers should provide more enrichment substrates than in female pigs. Enrichment substrates for male pigs should be strong enough to produce changes in behaviour and improve growth performance.

Further research should focus on alternative ways that can be used to improve the Windsnyer genotype. Possible aspects that need further research include:

1. Utilization of ingestible and chewable enrichment materials to improve the growth performance of indigenous pigs.
2. Impact of the length of exposure to pen environment on behavioural expression and stress response of Windsnyer pigs.
3. Influence of pen environment and sex on circadian rhythm and glucocorticoid receptor (GR) and mineralocorticoid receptor (MR) of the corticosteroid hormone.
4. Impact of pen environment and sex on gene expression and proteomics
5. Interaction of pen environment and sex on carcass characteristics and pork quality of Windsnyer pigs.

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Appendix 1: Ethical certificate from Agricultural Research Council (ARC)

ARC • LNR

Excellence in Research and Development

Date: 04 June 2016

Dear Mbusiseni Mkwanazi,

Re: Ethical evaluation of the project entitled "Interaction between stocking density and breed on the behaviour and growth performance of growing pigs".

Your application for the ethical evaluation of the project entitled "Interaction between stocking density and breed on the behaviour and growth performance of growing pigs" has been finalized and approved. Its Ref no is **APIEC16/016**.

I would like to inform you that the project was evaluated and found to be ethically acceptable.

Please note that should any amendments or changes be made to the protocol, you are obliged to submit an application to the Ethics committee and that the protocol should be resubmitted for review annually.

Regards,

Dr. C. M. Pilane (Ph.D.)

Interim-Chairperson ARC-API Ethics Committee

Tel. No. -012-672-9337

Fax / Faks (012) 665-1604

E-mail / E pos: cyril@arc.agric.za

Appendix 2: Methods for determining serum concentration of serum nutritionally-related blood metabolites and liver enzymes

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1. Determination of serum phosphorus (P)

Serum phosphorus was determined colorimetrically according to the method of Young (1990). The method is based the reaction between ammonium molybdate and P in the sample under acidic conditions to form phosphomolybdate. In the completion of the reaction, the absorbance of the sample reagent mixture is read bichromatically at 340 nm/378nm. The difference between these two absorbance values is proportional to the amount of SIP in the sample.

2. Determination of serum total protein

Serum total protein was estimated by the Biuret method described by Weicheselbaum (1946). In this method, biuret reagent was allowed to complex with the peptide bonds of protein from the sample under alkaline condition to form a violet-coloured compound. Sodium potassium titrate was used as an alkaline stabilizer, and potassium iodine was used to prevent auto-reduction of the copper sulfate. The amount of the violet complex formed was proportional to the increase in absorbance when measured bichromatically at 544 nm/692 nm.

3. Determination of total cholesterol concentration

Total cholesterol was determined using enzymatic method described by Allain *et al*. (1974). The method involves complete hydrolysis of cholesterol esters in the serum to free fatty acids by pancreatic cholesterol esterase. Thereafter, cholesterol liberated by esterase, plus any free cholesterol originally present in the serum, are both oxidized by cholesterol oxidase. The liberated peroxide reacts with phenol and 4 aminoantipyrine in a peroxide catalyzed reaction to form a quinoeimine dye, which absorbs at 500 nm. The change in absorbance is measured bichromatically at 505 nm/692 nm and is directly propotional to amount of cholesterol present in the sample. 92

4. Determination of enzyme concentration

Alkaline phosphatase (ALP) was determined by the spectrophotometric nitrophenol method of Tietz *et al.* (1993). In this method, ALP in the serum catalyzes the hydrolysis of colourless p-nitorphenyl phosphate to p-nitrophenol and inorganic phosphate. In alkaline solution of pH = 10.5, p-nitrophenol is in the phenoxide form and has a strong absorbance at 408 nm. Zinc and magnesium act as activators for this reaction while 2-amino-2menthly-l-prdopanol buffer acts as an acceptor for the phosphate ions, which prevent the enzyme. The rate of increase in absorbance, monitored bichromatically at 408 nm/486 nm, is directly proportional to the ALP concentration in the sample.