EFFECT OF ADVANCED REPRODUCTIVE TECHNOLOGIES ON SMALLHOLDERS' PIG PRODUCTIVITY IN GAUTENG PROVINCE

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DECLARATION

I declare that the thesis hereby submitted to the University of Limpopo, for the degree of Doctor of Philosophy (Animal Production) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

_____   <u>04 September 2018</u>

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DEDICATION

This thesis is dedicated to my best friend, love of my life, confidant and my pillar of strength, my supportive husband, Phenyo Matabane and our beautiful children, Dia and Kerileng Matabane, whom all inspired me to pursue this dream of studying further, supported and encouraged me through all the hardships I had experienced during the compilation of this thesis. Moreover, to my parents (Lukie and Rebone Masenya), parents in-law (Babsy and Ingrid Matabane), my sisters (Stephina and Myrtle), my nieces (Mpho, Koketso and Boipelo) and my nephew (Sibusiso) for their moral support and encouragement. Lastly, to my grandmother, Bailekae "Magogo" Phokanoka, my biggest cheerleader. Thank you for your prayers and continuous support.

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LIST OF ABBREVIATIONS

AI	Artificial insemination
ALH	Amplitude of Lateral Head Displacement
ARC	Agricultural Research Council
ASF	African Swine Fever
BCF	Beat Cross Frequency
BTS	Beltsville Thawing Solution
CASA®	Computer Aided Sperm Analyser®
DAFF	Department of Agriculture, Forestry and Fisheries
FAO	Food and Agricultural Organization
GDARD	Gauteng Department of Agriculture and Rural Development
GDP	Gross Domestic Product
IPAP	Industrial Policy Action Plan
LSM	Least Square Mean
LIN	Linearity
MED	Percentage of spermatozoa with medium velocity
MTSF	Medium Term Strategic Framework
NDP	National Development Plan
NGP	New Growth Path
NPM	Non-progressive motility
NRC	National Research Council
PI⁻	Propidium Iodide
PM	Progressive Motility
RAP	Percentage of rapidly moving spermatozoa

SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SAPPO	South African Pig Producers Organization
SEM	Standard error of the mean
SLW	Percentage of slow moving spermatozoa
STC	Percentage of static spermatozoa
STR	Straightness
SYBR-14$^+$	Synthetic binding CD-R-14
TM	Total motility
UNFPA	United Nations Fund for Population Activities
USA	United States of America
WOB	Wobble
VAP	Velocity Average Pathway
VCL	Velocity Curvilinear
VSL	Velocity Straight Line

ABSTRACT

Pigs are of high economic importance, especially among the smallholder pig farmers as they contribute to human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for the rural community. However, reproductive inefficiency is the main limiting factor due to inaccessibility to superior germplasm. Therefore, advances in reproductive technologies such as oestrus synchronization and artificial insemination (AI) offers unprecedented opportunities for livestock improvement for smallholder pig farmers. The first objective determined the status of pig productivity in smallholder farms of Gauteng Province prior to the introduction of advanced reproductive technologies (ARTs). The population was divided into four strata, namely West Rand, Ekurhuleni, Tshwane and Sedibeng district municipalities. A proportional stratified random sampling procedure was used to select 71 smallholder pig farmers with the assistance of extension officers from Gauteng Department of Agriculture and Rural Development (GDARD). The majority of the respondents were males (67%) and were above 50 years of age (67%), whilst 56% of the respondents had high school education. Majority of the respondents privately owned the farms (62%) and the farm infrastructure had facilities with low cost housing and modern facilities. Additionally, 47% of the respondents fed their pigs with feed swill. A large proportion of the respondents did not vaccinate their pigs (81%). Majority of respondents did not identify their pig herds (63%). Interestingly, majority of the respondents did not have breeding boars (73%) and sold their pigs at auctions (70%). The second objective determined semen characteristics evaluated by a Computer Aided Sperm Analyser® (CASA®) as a measure of boar fertility to be used for artificial insemination (AI). Sixteen ejaculates were collected from three Large White boars that are routinely used for semen collection purposes using the gloved-hand technique. The semen was extended with a commercial semen extender; Beltsville Thawing Solution, and the AI dose used consisted of 80mL semen sample (3×10^9 spermatozoa/mL). Aliquots of diluted semen were evaluated for spermatozoa motility using CASA®. Spermatozoa viability was evaluated using Synthetic Binding CD-14 (SYBR⁺)/Propidium Iodide (PI⁻), whereas spermatozoa morphology was evaluated using Eosin Nigrosin stain. The average semen volume, concentration and pH were 210 mL, 264.8 x 10^6 spermatozoa/mL and 7.1, respectively. The average values for total spermatozoa motility was 95.1%, ranging from 82.7 and 98.5%. However,

there were lower values found for progressive spermatozoa motility, ranging from 13.6 to 39.0%. The mean values for morphologically normal spermatozoa ranged from 47.8-60.9% and live spermatozoa ranged from 71.8-77.7%. The third objective determined sow fertility following AI at smallholder farms A total of 73 multiparous sows were artificially inseminated. Conception rates, farrowing rates, litter size and number born alive were recorded. The average conception and farrowing rates were 78.1 and 57.5%, respectively. Furthermore, AI resulted in acceptable fecundity (i.e., 11.8 litter size and 10.0 number of piglets born alive). The fourth objective determined the relationship between spermatozoa quality characteristics and sow fertility at smallholder farms in Gauteng Province. Of all fertility characteristics studied, conception rate was significantly related to total spermatozoa motility rate (r= 0.37, $P<0.01$), progressive motility (r= 0.31, $P<0.01$) and rapid motility (r= 0.40, $P<0.01$), although relatively low. There was a low negative relationship between spermatozoa morphological characteristics and fertility ($P>0.05$). The fifth objective determined the pre-weaning growth performance of piglets born following AI at smallholder farms of Gauteng province. Individual piglets were weighed using an electronic weighing scale. Litter size, number of piglets born alive, number of piglets weaned, the average piglet birth weight and average piglet weaned weight were recorded. The average litter size was 11.8 ± 0.2. The average birth weight and weaning weights were 1.9 and 6.2 kg, respectively. No significant differences were found between male and female piglets for all the growth performance characteristics. Piglets born during winter had a significantly higher ($P<0.05$) birth and weaning weight as compared to autumn and summer months. Season had a significant effect on birth and weaning weight ($P<0.01$). However, sex of piglets had no effect on all the characteristics recorded ($P>0.05$). The interaction between sex and season was only observed on the total number of weaned piglets ($P<0.01$). A highly significant positive correlation was found between litter size and number of piglets born alive (r= 0.86) and total number of piglets weaned (r= 0.50). A highly significant correlation was found between total number of piglets born alive and total number of piglets weaned (r= 0.55). In conclusion, the study demonstrated the potential benefit of adopting AI technology under smallholder production systems to disseminate superior genetic material to smallholder pig farmers in Gauteng Province. The total spermatozoa motility, progressive and rapid spermatozoa motility were the only spermatozoa motility characteristics significantly correlated

with conception rate. Conversely, litter size and number born alive were not correlated with CASA® spermatozoa motility attributes. No relationships existed between spermatozoa morphological characteristics and fertility. The sex ratio percentage of piglets born following AI was 52:48% (females: males). The number of piglets born alive was 10.2 and 9.5 for number piglets weaned. Season influenced birth to weaning weight. However, sex had no significant influence at birth and weaning weight. Litter size affects the number of piglets born alive and weaned. The study showed that the introduction of advanced reproductive technologies improved productivity of pigs at smallholder pig farms in Gauteng Province.

Keywords: Gauteng Province, Smallholder pig farmers, artificial Insemination, SYBR-14⁺, birth weight, weaning.

CHAPTER 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

1.1. Background

Gauteng Province is the smallest of all the provinces in South Africa, covering an area of approximately 2.4 million hectares which is about 1.4% of the country's land mass. It consists of Ekurhuleni, City of Tshwane and City of Johannesburg Metropolitan Municipalities. According to Statistics South Africa (Stats SA). (2013), Gauteng has a population of 13.2 million people, almost 24% of the country's population. However, it has been predicted that urbanization and population of Gauteng will double. Moreover, the populations of people in Africa will double by 2030, with 80% of all urban populations residing in developing countries (United Nations Fund for Population Activities (UNFPA), 2007). Consequently, rapid growth among urban poor will increase and the prevalence of food insecurity especially in Gauteng Province will be an obstacle (Rudolph *et al.*, 2011; De Wet *et al.*, 2008). Climate change is another major factor that will likely reduce production and negatively affect vulnerable farmers as well as crucial food distribution infrastructure (De Wit, 2010). Hence, it is crucial to improve the quality and quantity of livestock to feed the increasing population.

Livestock is a major source of livelihood for many communities worldwide, particularly smallholder farmers (Wanzala *et al.*, 2005). Smallholder farmers typically depend directly on agriculture for their livelihoods with limited resources and skills; therefore, any decline in agricultural production have a major impact on their nutrition, food security and income (Hertel & Rosch, 2010; McDowell & Hess, 2012). In terms of agriculture, Gauteng Province is characterised by multi facets economic clusters, in which agriculture plays a vital role on the contribution towards the gross domestic product (GDP). However due to limited land size, farmers in the province are constrained to certain specific commodities such pig, poultry production and other intensive production models. Pigs are an important source of animal protein for human consumption. Furthermore, pigs have a shorter generation interval and high fecundity as compared to other livestock such as sheep, goats and cattle. The South African pork industry is large in terms of the South African agricultural sector as it contributes around 2.05% to the primary agricultural sector (DAFF, 2015). Furthermore, in South

Africa there is an estimation of 4000 commercial pig farmers, 19 stud farmers and the remaining being smallholder pig farmers (DAFF, 2011; 2012; 2013; 2015). However, the smallholder pig farming sector has constraints that impede their ability to grow and contribute towards food security, such as inaccessibility to superior breeding stock and markets, low quality feed and lack of access to veterinary services (Matabane *et al.*, 2015; Lekule & Kyvsgaard, 2003; Lemke & Zárate, 2008). According to Rege *et al.* (2011), advances in reproductive technologies offers unprecedented opportunities for livestock improvement for smallholder pig farmers.

Reproductive technologies such as artificial insemination (AI) play an important role in genetic improvement programmes (Nicholas, 1997; Van Arendonk & Bijma, 2003). It allows one animal to have multiple progeny, allows for significant increases in the intensity of selection and has great potential for speeding up genetic improvement. An AI service for smallholder farmers was effectively implemented in smallholder pig farms at Nan province, northern Thailand and further yielded improved reproductive performance (Am-in, 2005; 2010). However, smallholder pig farmers have limited access to superior genetics in Gauteng Province. Hence, establishment of an AI centre may provide smallholder pig farmers accessibility to superior sire line genetics. This may potentially result in offspring with exceptional feed conversion ratios, improved average daily gains and superior carcass quality thus improving productivity and profitability of their herds.

1.2. Problem statement

To date, AI is widely applied in organized commercial pig farms (Rege *et al.*, 2011). However, lack of knowledge and information has led to limited use of the technology at smallholder pig farms (Kadirvel *et al.*, 2013). Noteworthy, it is imperative to evaluate semen characteristics as it is a major pre-requisite for AI and can be used as a measure for boar fertility. Spermatozoa motility rate is the main characteristic that is related to male fertility. However, semen was assessed by subjective visual examination under a phase contrast microscope previously (Broekhuijse *et al.*, 2012). Such microscopic methods have restrictions such as biasness, inconsistency and poor correlation with fertility (Rijsselaere *et al.*, 2005). According to Broekhuijse *et al.* (2012), there are large disparities in sow fertility following AI. The CASA® technology

is a useful tool to determine the motion characteristics of spermatozoa samples and gives detailed information on spermatozoa movement; it has not been correlated with sow fertility at smallholder farms. Furthermore, the relationship between spermatozoa quality characteristics and sow fertility has been studied extensively in the commercial sector (Holt *et al.*, 1997; Alm *et al.*, 2006) than in smallholder pig production sector. Hence, there is a need to determine the relationship between spermatozoa characteristics and sow fertility characteristics at smallholder pig farms. In Ethiopia, there were often complaints by farmers regarding the imbalance of female and male ratio from offspring born following AI (Bekele, 2005). Hence, the study also determines pre-weaning growth performance following AI at smallholder pig at Gauteng Province.

1.3. Objectives

The broad objective of this study was to determine effect of introducing advanced reproductive technologies (AI, oestrus synchronization and CASA®) on smallholders' pig productivity in Gauteng Province.

The specific objectives of the study were:

(i) To determine the status of pig productivity in smallholder farms of Gauteng Province prior to the introduction of advanced reproductive technologies (ART).

(ii) To determine spermatozoa characteristics evaluated by CASA® as a measure of boar fertility to be used for AI at smallholder farms of Gauteng Province.

(iii) To determine sow fertility characteristics as measured by conception rate, farrowing rate, litter size and number of piglets born alive following ART at smallholder farms of Gauteng Province.

(iv) To determine the relationship between semen characteristics and sow fertility (conception rate, farrowing rate, litter size and number of piglets born alive) at smallholder farms of Gauteng Province.

(v) To determine pre-weaning growth performance of piglets following AI at smallholder farms of Gauteng Province.

1.4. Hypothesis

(i) The productivity of pigs prior to introduction of ARTs in smallholder farms of Gauteng Province will be low.

(ii) Large White boar semen characteristics will not be used as a measure of boar fertility for AI.

(iii) Sow fertility will not be improved following AI at smallholder farms;

(iv) There will be no relationship between semen characteristics and sow fertility in smallholder farms;

(v) Advanced reproductive technologies will have no effect on the sex ratio of the piglets born.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1. Food security

According to FAO-UN. (2003), food security is the accessibility by all people to adequate, safe and nutritious food for a healthy and productive life. The outlook for the world's food security is considered by growth in the demand for food mostly in developing countries (Alston *et al.*, 2009), declining natural resource base, and ambiguous production prospects due to climate change (Nelson *et al.*, 2010). Increasing climate unpredictability will unquestionably increase livestock production risks and cause substantial declines in the ability of farmers to manage these risks. At the 2009 World Food Summit, the Food and Agricultural Organisation of the United Nations (FAO-UN) documented that agricultural output need to increase by 70% by 2050 to feed the rapidly growing population, which is expected to exceed 9 billion (FAO, 2009). Even though South Africa has the second largest economy in Africa and has sufficient food supply at the national level, this however has not translated into food security at the household level (Shisana *et al.*, 2014). Statistics indicated that a marginal percentage of South Africans are food secure (45.6%), approximately 28.3% are at risk of hunger, whereas 26% are food insecure (Shisana *et al.*, 2014).

There is a link between household income and household food security in South Africa, emphasizing the importance of smallholder agriculture relative to food security. Of all agricultural commodities, livestock agriculture accounts for 42.4%, mixed farming for 21.8% and crop farming for 31.2% (Stats SA, 2013). According to the DAFF (2012; 2013), the amount of agricultural land used by livestock farmers is estimated to be 70% (Meissner *et al.* 2013). Livestock farming plays a central role in the agricultural sector for many countries as it offers high quality animal-source food in combination with a multitude of associated economic and social benefits to communities worldwide (Capper, 2013). Moreover, Imai. (2003) reported that livestock farming also plays a major role as livestock provides diversification of income sources so that farmers are able to sell their livestock for income. Whilst livestock is an important sub-sector within agriculture, there is a perturbing decline in the agricultural sector's contribution to the country's economic growth as well as in the sector's provision of employment opportunities.

2.2. South African pork industry

The South African pig industry is relatively small in terms of the total South African agricultural sector contributing only about 2.05% to the primary agricultural sector (DAFF, 2015). Furthermore, South Africa contributes approximately 0.2% of the world pig population (Muchenje & Ndou, 2010). Pig production had increased over the years particularly in developing countries (Steinfeld, 2003). Moreover, in sub-Saharan Africa, it has increased slightly from 0.5 million tonnes to 0.8 million tonnes in 2007 (FAO, 2009). According to FAO. (2011), in sub-Saharan Africa there will be an estimated increase of up to 155% in annual pork consumption from 2000 to 2030. However, pig production in South Africa is lagging behind countries such as a China and the United States of America which are prominent pig producers in the world (FAO, 2009). According to Phiri *et al.* (2003), South Africa has the high pig populations in southern Africa and 25% are free ranging in the resource-poor areas (Krecek *et al.*, 2004).

There are almost 400 commercial producers and 19 stud breeders in South Africa (DAFF, 2013; 2015). Pig numbers were estimated at 1572 million in 2013 (DAFF, 2013), this is a decrease of 0.8% compared to 2011. It is estimated that the meat processing industry for production of bacon, sausages, hams and other meat products, utilizes about half of all South African pork. This processed pork is produced by commercial pig producers, in an industry that employs 10 000 employees. According to DAFF. (2013), South Africa's production of pork is far higher than its consumption, this may be due to consumption of pork in the rural areas being influenced by some debates ranging from human health, religion to cultural beliefs. Religion and cultural beliefs played a vital role in prohibiting the consumption of pork. In South Africa, members of the Zionist Christian Church (ZCC) do not consume pork (Anderson, 1999).

2.3. The smallholder pig sector

Smallholder farmers constitutes a significant portion of the world's population, with an estimated 450-500 million smallholder farmers worldwide (Nagayet, 2005). Moreover, it has been estimated that smallholder farmers represent half of the hungry worldwide and probably three-quarters of the hungry in Africa (Sanchez & Swaminathan, 2005). According to Harvey *et al.* (2014), smallholder farmers depend on agriculture for their livelihoods and have limited resources. Hence, any declines in agricultural productivity may have a significant impact on their food security, nutrition and income. Pigs are of high economic importance, especially among the resource-poor. They contribute to human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for the rural community (Antwi & Seahlodi, 2011). Additionally, they provide a less-expensive source of animal protein for urban diets compared with cattle, sheep and goats (Ironkwe & Amefule, 2008). However, pig production husbandry, nutrition and marketing of the products are the most important limiting aspects for smallholder pig farmers. Similarly, North West, Limpopo and Mpumalanga provinces showed that main constraints are feeding costs, proper breeding practices, disease control, performance recording, access to formal markets and marketing system (Mtileni *et al.*, 2006). Moreover, outbreaks of disease, slow growth rates, difficulty in sourcing feed and high mortality of piglets were the main challenges identified at Vientiane, Thailand (Phengsavanh *et al.*, 2011).

2.4. Constraints facing smallholder pig sector

2.4.1. Inaccessibility to land

The probable total land size belonging to developing farmers in Gauteng Province is 37 560 ha (GDARD plan, 2010-2014); however, about 13 190 (35%) is privately owned. The estimated number of agricultural farms in the Province ranges between 18 000 and 21 000, only a few depend on agriculture for their income (GDARD plan, 2010-2014). However, it is indicated that accessibility to land is a key impediment of urban agriculture (Rogerson, 2003; Hovorka, 2005), primarily affecting women farmers (Jacobs *et al.*, 2000; Crush *et al.*, 2011). Subsequently, rural areas consist of communal and traditional land with issues pertaining to tenure security, which has

shown to affect agriculture productivity (Kameri-Mbote, 2006). It is apparent that smallholder livestock farmers seldom have access to the large pasture land that is a prerequisite for cattle (Humane Farm Animal Care, 2004) or small stock production (Humane Farm Animal Care, 2005). However, pigs and poultry may be housed under enclosed, environmentally controlled, conditions on small plots of land (Mpofu & Makuza, 2003; Humane Farm Animal Care, 2008; Seavey & Porter, 2009).

The land reform programme has three distinct components, namely tenure reform, restitution and redistribution (Department of Land Affairs (DLA), 1997). Land reform, mostly the redistribution and restitution programmes, have supported poor rural people to gain access to land (Jacobs, 2003). The majority of land reform beneficiaries anticipate to use the land for agricultural production. Land restitution mainly deals with historic rights and is intended at returning land to people who were evicted due to legislations such as the Native Land Act of 1913 and the Native Trust and Land Act of 1936. Tenure reform deals with forms of land holdings and the programme aimed to introduce new systems of land holdings, land rights and forms of ownership while Land Redistribution Programme is specifically aimed at changing the racial patterns of land ownership (Jacobs, 2003). The Proactive Land Acquisition Strategy (PLAS) is aimed at supporting local government to develop area-based planning and improve coordination among the institutions responsible for land reform. The purposes of PLAS are to contribute towards growth, employment creation and equity (DLA, 2006). This strategy is intended to accelerate the transfer of land through the proactive acquisition of the land by the government for redistribution purposes. Under PLAS, the land is assigned to beneficiaries after they have proven that their production competences in three seasons of monitoring by Agricultural officials (DLA, 2008).

2.4.2. Lack of training

There are dual economies in the agricultural sector in South Africa (DoA, 2001), namely the commercial farmers and smallholder farmers. Moreover, there are land-reform policies that are devoted to transferring at least 30% of commercial farms to emerging commercial farmers (Xingwana, 2008). However, this cannot transpire if these farms lose productivity and place the country at risk of food insecurity. It is therefore imperative for extension and advisory services to contribute towards

ensuring that these transferred farms remain productive and even increase in productivity. According to van Niekerk *et al.* (2009), the agricultural extension and advisory service in South Africa is generally challenged to support farmers to assist themselves and to facilitate optimal and sustainable resource utilisation, which would have a direct contribution in solving the problems of rural poverty, food insecurity, and income and employment losses. However, extension activities, from the public sector, are aimed mostly at smallholder farmers, but these efforts have been largely ineffective in solving the above-mentioned problems (DoA, 2001).

There is a general lack of pig production skills that may be addressed through provision of training and extension services to smallholder pig farmers (Nompozolo, 2000; Ajala, *et al.*, 2007). Some South African organisations, such as the Agricultural Research Council (ARC), South African Pork Producer Organisation (SAPPO) and educational organisations in South Africa offer training and advisory services to smallholder farmers (Louw, *et al.*, 2011). Moreover, it is envisaged that the only way for smallholder pig farmers to overcome market failures and sustain their market position is through organizing into farmer working groups or producers' organizations. Smallholder are able to reduce transaction costs for their market exchanges, attain necessary market information, secure access to new technologies, and tap into high-value markets, when they organize themselves collectively (Markelova *et al.*, 2009).

2.4.3. Feed costs

Feed is the most essential and expensive pig farming input and feed costs contributes 75–80% of the total production costs (Smith, 2006). Moreover, grains makes up between 55-70% of pig feed formulations and it is also used for human and other livestock feeds (Smith, 2006). Providing pigs with the required protein under smallholder conditions may be problematic due to the costs involved (Lekule & Kyvsagaard, 2003). These high feed costs are due to high transportation costs associated with the long distances to the feed suppliers as well as poor road infrastructure at rural areas (Mtileni *et al.*, 2006; Kagira *et al.*, 2010). Thus, smallholder pig farmers use alternative feed sources such as swill feed. However, feed swill is problematic as the diets are unbalanced and cannot supply the essential nutrients for pigs (Kagira *et al.*, 2010). Moreover, feeding pigs on feed swill may lead to outbreaks

of Salmonella, Campylobacter, Foot-and-mouth disease and Classical Swine Fever (CSF), that have the ability to survive in processed meat products (Beltrán-Alcrudo, *et al.*, 2008). Additionally, smallholder pig farmers lack the scale of operations to secure bulk discounts from feed suppliers (Lapar & Staal, 2010).

There is a link between deficiencies of trace minerals and vitamins, inadequate carbohydrate intake and protein imbalance as major influences to poor growth performance (Esonu, 2006; Izunobi, 2006). The availability of these nutrients is dependent on their voluntary intake and for this reason, feed intake is one of the most significant factors that determines both productivity and growth performance (Lanyasunya *et al.,* 2005). By consuming good quality feed, the animals will have the ability to deposit sufficient nutrients in the body to support vital body maintenance processes, growth, milk production and reproduction (Fanimo *et al.,* 2002).

2.4.4. Low productivity

Agricultural productivity is one of the key determinants of sustainable agricultural growth. Productivity for smallholder pig farmers is relatively low in terms of both quantity and quality due to breeds of low productivity and poor nutrition and husbandry methods. Hence, improvement of breeds and breeding programs as well as nutrition and feeding strategies for smallholder pig farmers are fundamental to improving pig productivity and the incomes of the poor. Another major challenge is early mortalities which are due to poor mothering abilities of the sow, poor viability of piglets, exposure and anaemia (Oosterwijk *et al.*, 2003). Post-weaning deaths are attributed to environmental exposure, malnutrition and diseases (Kyriazakis & Whittemore, 2006). Phengsavanh *et al.* (2011) argued that diarrhoea and low levels of management are the main reasons for high mortalities in piglets. Diarrhoea in piglets manifest in smallholder production systems and has caused major economic loss (Tuyen *et al.*, 2005). This is associated with poor hygiene, lack of biosecurity measures as well as poor quality feed during both pregnancy and lactation (Phengsavanh *et al.*, 2010). Similarly, Hong *et al.* (2006) indicated that poor quality of feed and inadequate nutrient supply are significant factors related to high occurrences of diarrhoea.

2.4.5. Low reproductive rates

Reproductive performance of pigs in smallholder systems is normally unsatisfactory, as it is mainly due to nutritionally imbalanced diets and underfeeding (Phengsavanh & Ogle, 2010). Poor quality feed affects production of sows that are lactating and sows with a poor body condition (Phengsavanh & Ogle, 2010). Majority of smallholder farmers use semi-intensive production systems, where pigs of all ages wander freely. As a result, this increases porcine cysticercosis occurrences (Lekule & Kyvsagaard, 2003; Krecek *et al.*, 2004). Another challenge related to reproduction is boar selection and management. Smallholder farmers tend to use boars that are young and underfed for breeding purposes (Phengsavanh & Ogle, 2010). Moreover, smallholder farmers have a tendency of selecting breeding boars from within their herds thus leading to inbreeding and a failure to use superior boars for mating (Thorne, 2005).

2.4.6. Lack of vaccination programs and biosecurity measures

Outbreaks of Porcine Respiratory and Reproductive Syndrome (PRRS) in the Western Cape and Classical Swine Fever (CSF) in the Eastern Cape were reported in 2004 and 2007, respectively. According to the FAO (2008), PRRS is a viral disease that is spread through direct contact to vulnerable pigs and vertically to foetuses. It spreads rapidly in confined pig herds and leads to major losses due to increased mortalities, abortions and still-births (Robinson, 2004; Robinson, 2009). This disease is regarded as a reproductive failure in sows and respiratory problems in piglets and fattening pigs, which, combined with its potential for rapid spread, can cause substantial production and economic losses. In Africa, the disease prevalence is unknown. Outbreaks were first reported at Jacobsdal area, Kuilsriver district (South Africa) in June 2004 (OIE, 2004). Two other outbreaks were reported in the same area in October 2005 (OIE, 2005). In August 2007, the same European strain was also reported in the Western Cape (ProMED, 2007).

Classical swine fever is a deadly viral disease of pigs that displays as a haemorrhagic fever and can kill up to 100% of affected pigs. It accounts for a big proportion of pig deaths in all pig rearing systems (Vongthilath & Blacksell, 1999). Outbreaks of CSF spread of the diseases are through pigs, people, vehicles, feed, other animals, water

or birds. Numerous procedures were recommended to control disease outbreaks in smallholder pig production systems. These procedures focused on isolating and controlling pig movement. Outbreaks of CSF in South Africa have been recorded in close proximity to the CSF control zones ever since 1951 (Penrith & Vosloo, 2009). The CSF control zones are located at the north-eastern parts of South Africa, including parts of Limpopo, North West, Mpumalanga and Kwazulu-Natal Provinces.

2.4.7. Limited access to markets

Participation of smallholder farmers in the mainstream formal market in Sub-Saharan Africa and other developing regions of the world remains a challenge (Demeke & Haji, 2014). There is a huge gap between commercial and smallholder farmers that hinder smallholder farmers from gaining the high returns that may be obtained from. This may be due to limited access to high value markets due to the inability to produce large quantities and to meet strict supply chain requirements (Vermeulen *et al.*, 2008). Additionally, the costs involved in meeting these requirements poses as a serious challenge (Kirsten & Sartorius, 2002).

Large retailers prefer large-scale production to take advantage of the economies of scale and to run efficiently (Marcoul & Veyssiere, 2008). As a result, smallholder farmers tend to sell their pigs at informal markets to the community and at auctions (Musemwa *et al.*, 2008; Groenewald & Jooste, 2012). Furthermore, the major limitations of the informal markets are poor market information on both prices and the quality required (Groenewald & Jooste, 2012). The value and quality of pigs that are marketed is determined by physical characteristics used by the classification system. Conversely, carcass classification are not barely used by smallholder pig farmers. The carcass classification system should act as mechanism to the traders and farmers and it should guarantee quality to the consumers.

2.4.8. Climate change challenges

Agriculture plays an important role in the economy and it contributes about 2.9% of GDP (Benhin, 2008). Conversely, the agricultural sector is vulnerable because it is dependent highly on the climate and also because of the semi-arid nature of South

Africa. Climate change will severely affect smallholder farmers by further worsening the risks that smallholder farmers face. The influences of climate change on agriculture has been reported to be important for smallholder production systems in developing countries (Rosenzweig & Parry, 1994; Kates, 2000; McGuigan *et al.*, 2002). Furthermore, climate change may lead to severe reductions in productivity if no adaptation actions are considered (El-Shaer *et al.*, 1997, Kurukulasuriya & Rosenthal, 2003). It is expected that climate change will modify pest and disease outbreaks, thus increasing the frequency and severity of droughts and floods, and increase livestock mortalities (Morton, 2007; Kevan, 1999). High disease incidences are associated with increasing temperatures where most farmers in smallholder production systems cannot afford to purchase veterinary medicines. Hence, it is crucial to develop strategies to assist smallholder farmers to deal with risks associated with climate change.

2.5. Prediction of boar fertility

Prediction of spermatozoa fertilizing ability has a major economic significance to breeding herds, as it is crucial for the selection of boars with a good reproductive performance. Furthermore, the most critical aspect of predicting fertility is to conduct a precise and accurate fertility test. The fertilizing ability of a semen dose is related to the spermatozoa quality (Vyt *et al.*, 2008; Tsakmakidis *et al.*, 2010). The prediction of the fertilizing ability is highly dependent on high quality fertility data that is compared to standardized laboratory tests. Semen assessment comprises of semen quantity (macroscopic evaluation) and quality evaluations (microscopic evaluation). In general, macroscopic evaluations includes semen volume, pH and the spermatozoa concentration, whereas microscopic evaluations measure spermatozoa motility, viability as well as morphology. However, the traditional laboratory tests are inadequate for predicting fertility measures such as farrowing rate and litter size (Gadea *et al.*, 2004; Gadea *et al.*, 1998; Woelders, 1991). Therefore, the use of combined tests may provide additional information for evaluating spermatozoa quality (Woelders, 1991).

2.5.1. Semen collection and processing

Boar semen collection in AI centres is usually done by the gloved hand technique (Vyt *et al.*, 2007; Knox *et al.*, 2004). The quantity of a single boar ejaculate may vary between 150-300 ml and subject to considerable variation. This variation may be due to individual boar's genetics, boar behaviour such as libido, the management of the boar, along with the environment in which it is housed (Setchell, 1991). Oliveras. (2008) identified three prominent fractions in a boar ejaculate. The first fraction of the boar ejaculate is the pre-spermatozoa fraction. It is a watery fluid, does not contain spermatozoa and has a high bacterial count (Althouse, 2008). The second phase of the boar ejaculate is the spermatozoa rich fraction. It is chalky in appearance and contains 80-90% of spermatozoa. Once the sperm-rich fraction is complete, the last phase is the gelatinous phase of the boar ejaculate, which is a clearer and watery fluid that should be discarded.

Following ejaculation, boar spermatozoa motility and vitality is retained for several hours (Johnson *et al.*, 2000). Therefore, to prolong boar spermatozoa survivability, the metabolic activity should be inhibited by chemical inhibitors and by lowering the temperature (Johnson *et al.*, 2000). Semen extenders contain nutrients that provide boar spermatozoa the opportunity to remain viable for three or more days following collection (Kuster & Althouse, 1999). Boar spermatozoa is highly susceptible to temperatures below 15ºC. This is attributed to the phospholipid composition in their plasma membrane (De Leeuw *et al.*, 1990). Rapid cooling of the boar ejaculate from body temperature (39°C) to temperature below 15ºC results in lipid phase separation that alters the spermatozoa membrane permeability with subsequent loss of spermatozoa vitality (De Leeuw *et al.*, 1990; Johnson *et al.*, 2000).

2.5.2. Spermatozoa motility

Spermatozoa motility is an essential characteristic in prediction of fertility (Holt *et al*, 1997). Alterations in spermatozoa movement patterns may reflect physiological events within the spermatozoa (Cremades, 2005). Standard laboratory semen analysis previously used light microscopy to evaluate spermatozoa motility. However, even though this analysis is inexpensive and rapid, the precision of the results is dependent

on the subjective estimations that are made by indivicuals (Vyt *et al.*, 2004; Quintero-Moreno *et al.*, 2004). A Computer Aided Sperm Analysis® (CASA®) system provides the most effective way for semen assessment and further ensures optimal dilution rate. These systems are available commercially, but due to high costs, they are seldom used in commercial AI centres (Verstegen *et al.*, 2002). It is a useful tool to determine spermatozoa motility as it is subjective, gives detailed information on spermatozoa movement and it is independent of interpretation by the technician (Quintero-Moreno *et al.*, 2004). However, analyses that are more functional are required to make the spermatozoa motility an effective spermatozoa characteristic (Vyt *et al.*, 2004; Love *et al.*, 2003). Moreover, the accuracy of CASA® systems has permitted detection of subtle changes in spermatozoa movement and the improvement of differences among treatments in laboratory studies using new seminal extenders, cryoprotectant and centrifugation.

The use of CASA® permits for calculation of several spermatozoa motility characteristics, which represent the movement of individual spermatozoa. These characteristics consist of the curvilinear velocity (VCL), straight line velocity (VSL), average path velocity (VAP), straightness (STR), linearity (LIN), wobble (WOB), amplitude of lateral head displacement (ALH) and beat cross frequency (BCF), subpopulation of rapid (RAP), medium (MED) and slow (SLW) cells (Niżański *et al.*, 2009). Spermatozoa motility characteristics evaluated using CASA® system are summarized in Table 2.1.

Motion of each spermatozoa is recorded as changes in centroid location in successive frames (Figure 2.1) and computations provide output measures describing the motion (e.g., VCL, VSL, VAP, LIN, STR, WOB, ALH and BCF). Values for each individual spermatozoon, compiled across all fields examined, are summarized for >500 spermatozoa and ideally >1000 spermatozoa per sample. One of the fundamental benefits of the CASA® technology is the large amount of data it provides from the analysis of spermatozoa in each sample. Conversely, the CASA® technology has been criticized due to the head-centroid-derived characteristics that are dependent on the sampling frequency of the sequential images and the software-specific measures that are used to analyse the sampled path (Dunson *et al.*, 1999). For example, the CASA®

kinetic characteristics such as VAP, STR, BCF and ALH are derived from the average path of the spermatozoa and the calculation of the average path is dependent on the averaging method used (Mortimer & Swan, 1995; Davis *et al.*, 1992; Davis & Katz, 1992;).
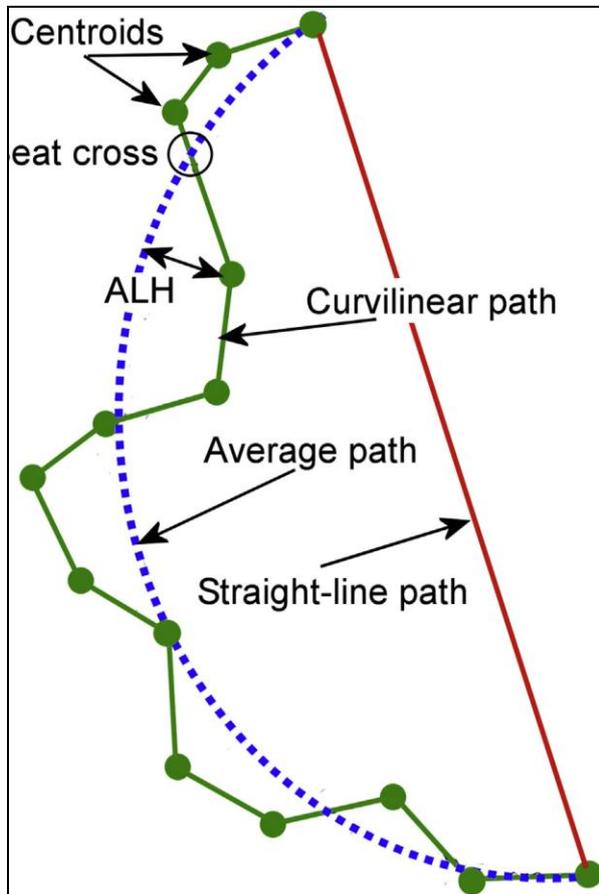
Figure 2.1. Different spermatozoa velocity characteristics measured by CASA® systems (Niżański *et al.*, 2009)

Table 2.1. Selected characteristics of spermatozoa motility measured by CASA® systems

Characteristics	Unit	Description
Spermatozoa motility	%	The population of spermatozoa moving at or above a minimum speed as determined by values defined under set up
Progressive spermatozoa motility	%	The population of spermatozoa moving actively forward
VCL	µm/sec	The average spermatozoa velocity measured over the actual point-to-point track
VAP	µm/sec	The average velocity over smoothed average position of the cell
VSL	µm/sec	Straight line between the beginning to the endof the spermatozoa cell track
STR	%	A measure of VCL side-to-side movement. The ratio is VSL/VAP
LIN	%	A measure of the departure of the spermatozoa cell track from a straight line. The ratio of VSL/VCL
ALH	µm/sec	The mean width of the head oscillation as the cell moves.
BCF	Hz	The frequency at which the spermatozoa head moves back and forth across the cell path
Rapid	%	Subpopulation of rapidly moving spermatozoa
Medium	%	Subpopulation of medium moving spermatozoa
Slow	%	Subpopulation of slow moving spermatozoa
Static	%	Subpopulation of static spermatozoa

2.5.3. Spermatozoa morphology

Spermatozoa morphology is used as an indicator of the boar's capability to produce high quality spermatozoa capable of fertilizing oocytes (Gadea, 2005). The outcome of poor spermatozoa morphology within an ejaculate result in lower pregnancy rates and reduced litter size following AI (Tsakmakidis *et al.*, 2010; Alm *et al.*, 2006). Hence,

spermatozoa morphology should be analysed to identify sub-fertile boars. Eosin Nigrosin stain has been extensively used for boar semen analysis because it is easy, it allows morphological and membrane integrity examination and was correlated with sow fertility (Tsakmakidis *et al.*, 2010; Bjorndahl *et al.*, 2004). Eosin is a cytosolic stain that enters disrupted plasma membranes and dyes the cytoplasm within the plasma membrane thereby marking these spermatozoa with a bright pink colour. Nigrosin is used as a background stain to assist in detection of the spermatozoa that do not uptake Eosin.

A summary of the criteria for the use of porcine semen in AI is indicated in Table 2.2. The criteria for normal spermatozoa morphology should be at least 70% (Shipley, 1999). Moreover, the primary and secondary defects at commercial AI centres should be 10 and 20%, respectively (Shipley, 1999). The presence of proximal cytoplasmic droplets and abnormal spermatozoa heads are correlated to infertile boars due to either over-collection of boars or testicular damage (Gadea, 2005). Studies have also reported a correlation between normal morphological characteristics with conception rate and litter size, which are mainly sensitive to normal head morphology (Gadea, 2005).

Table 2.2. The cut-off values for porcine semen quality at commercial AI-centres

Semen characteristics	Requirements (%)			
	Kuster & Althouse, 1999	Martin-Rillo *et al.*, 1996	Shipley, 1999	Britt *et al.*, 1999
Abnormal spermatozoa	< 20		< 20	
Cytoplasmic droplets	< 15		< 15	
Proximal droplets		0-20		< 20
Distal droplets		0-30		
Coiled tail		< 5		
Primary defects				< 10
Secondary defects				< 20

A high percentage of morphologically abnormal spermatozoa on embryo development may be related to defective binding of the spermatozoa to the zona pellucida, and this process is highly selective against spermatozoa with abnormal morphology (Amann *et al.*, 1999). Waberski *et al.*, (1994b) reported that spermatozoa with a high percentage of distal and proximal cytoplasmic droplets have a negative relationship with both conception rate and litter size. Furthermore, in comparative terms, the percentage of morphologically normal bull spermatozoa is related to fertility following AI (Nagy *et al.*, 2013; AlMakhzoomi *et al.*, 2008; Phillips *et al.*, 2004) reflecting the degree of spermatogenesis and spermatozoa maturation within a herd of sires. Boar morphologically abnormal spermatozoa are indicated in Figure 2.2.
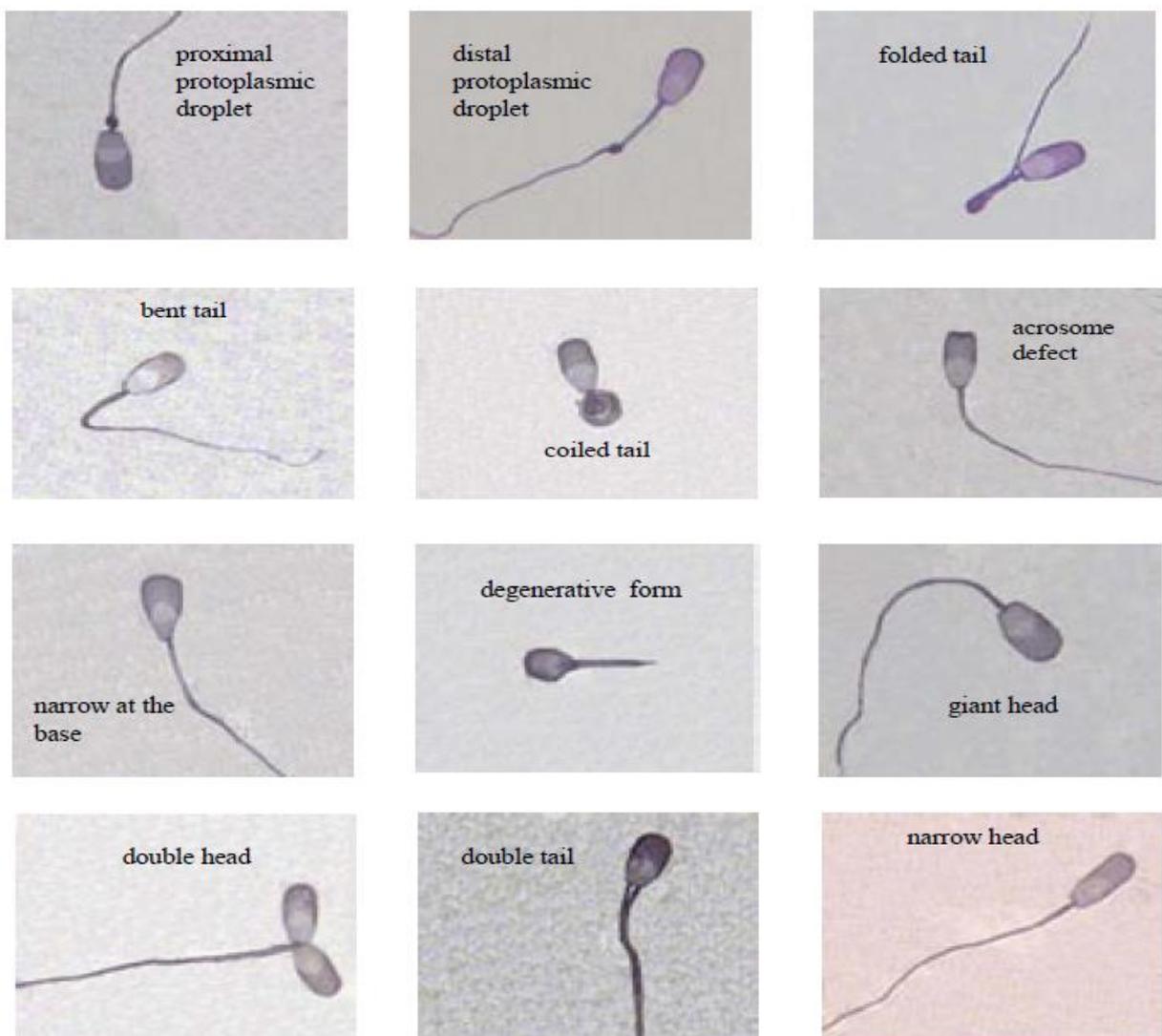
Figure 2.2. Boar morphologically abnormal spermatozoa (Čeřovský *et al.*, 2005)

2.5.4. Spermatozoa viability

Spermatozoa quality is closely related to spermatozoa plasma membrane status, as the plasma membrane aids as a cell boundary and in cell-to-cell interaction (i.e. binding to oviduct epithelium or penetration of oocyte vestments) (Rodriguez-Martinez, 2003). The assessment of spermatozoa viability using fluorescent stains has become a valid assessment method. The SYBR-14^{+} is the most effective stain used in combination with a counter stain such as the propidium iodide (PI) or Hoechst 33258 that attains dead spermatozoa (Garner & Johnson, 1995). The membrane permeant nuclear stain, SYBR-1^{+}4, which brightly fluoresces the nuclei of living cells, has been used in combination with PI to determine the proportion of living spermatozoa in semen from several different mammals and has been proven effective for assessing spermatozoa viability (Garner *et al.*, 1994; Garner & Johnson, 1995).

Spermatozoa that are stained with SYBR-14^{+} are considered as viable (green) whereas the spermatozoa that are stained with PI[-] are considered non-viable (red) (Figure 2.3). Non-viable cells are determined by means of membrane-impermeable nucleic acid stain that identifies dead spermatozoa by penetrating cells with damaged membranes. An intact plasma membrane will inhibit the membrane-impermeable nucleic acid stains from entering the spermatozoa. Propidium iodide (PI) is a membrane impermeant fluorescent stain that stains DNA. The PI only enters cells with damaged membranes; it is commonly used as a test for no viability. The mechanism whereby the dual staining works is that when cells are stained with SYBR-14, the cells allow the entrance of the membrane-impermeant dye (PI), which substitutes the SYBR-14^{+} dye from the nuclear DNA.
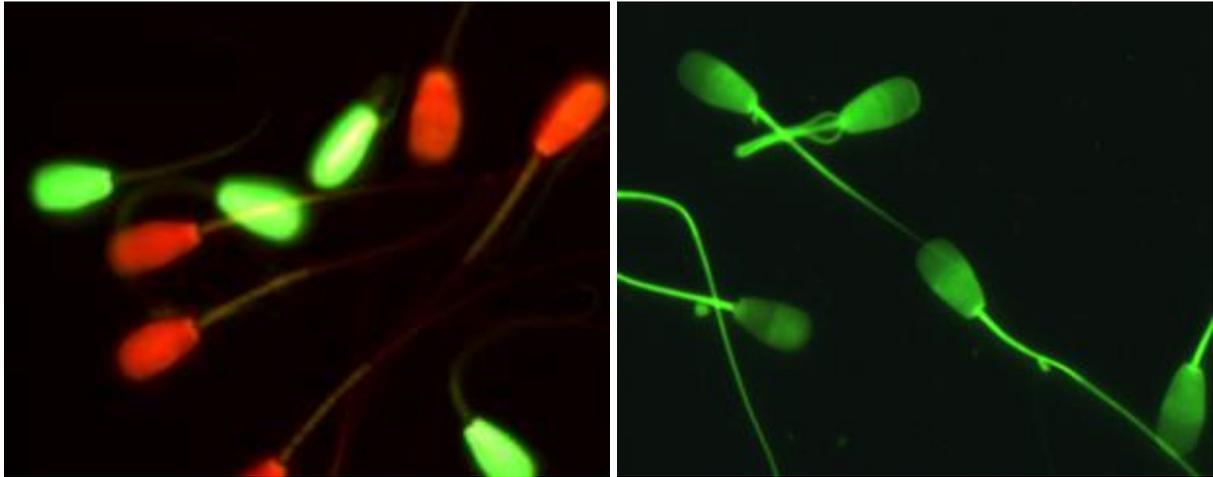
Figure 2.3. Boar spermatozoa stained with SYBR-14$^+$/PI$^-$ and Eosin Nigrosin staining solution

2.6. Application of AI

Agricultural reproductive technology has the potential to contribute towards pig productivity advances and improvement for smallholder pig farmers in developing countries, such as South Africa. Improving smallholder pig genetics will improve the quality and quality of the herds and should be integrated along with the creation of reliable markets, agricultural extension support and links to output. However, for smallholder pig farmers to be penetrate into the market, these farmers require knowledge, information, innovation and skills that enable them to sustain more intensive, market-oriented production and overcome production constraints. Nowadays, AI has been practices in the swine industry worldwide. However, AI is rarely used in smallholder pig farming systems. The introduction of AI to introduce improved and superior genetics would result in improvements in the reproductive performance of sows.

High reproductive efficiency is a fundamental factor for optimum economic successin the swine industry (Gröhn & Rajala-Schultz, 2000). It is the oldest and most common advanced reproductive technology in animal production (Vishwanath, 2003). Outcomes from AI has been reported to be similar or better than natural mating as it allows for improved genetic progress, reduces costs for feeding the breeding boars and reduces the risk of infectious reproductive disease (Vargas *et al.*, 2009; Wolf, 2009; Leiding, 2000; Lamberson & Safranski, 2000). The AI technology was

successfully implemented at smallholder pig farms at Nan province, northern Thailand and it resulted in higher farrowing rates and litter size (Am-in 2005; 2010).

2.7. Relationship between boar spermatozoa quality and reproductive performance of sows

Fertilizing potential is measured as the proportion of females that have conceived or farrowed after AI or natural mating (Foote, 2003). These measures are suggestive of the efficacy with which oocytes are fertilized with spermatozoa capable of sustaining embryonic development (Watson, 1996). The evaluation of boar fertility is through obtaining pregnancies and offspring after *in vivo* inseminations. However, fertility from field trials are inaccurate due to high variability related to the female (Clark *et al.*, 1989) and with the conditions of insemination (Foote, 2003).

Semen evaluation is used to predict the probability that gilts or sows will be able to conceive following AI. However, there can be no certainty, as it is only possible to provide an estimation of probability. A multitude of factors, including semen quality (Gadea, 2005), influences the probability. Furthermore, the problem is worsened by variations in spermatozoa characteristics among different ejaculates form the same boar (Gadea, 2005). The likelihood of relationship between detailed motility data and fertility has been confirmed in humans (Larsen *et al.*, 2000), swine (Holt *et al.*, 1997) and bulls (Budworth *et al.*, 1988). However, the relationship between spermatozoa characteristics assessed *in vitro* and field fertility has been problematic (Rodriguez-Martinez, 2003). There were studies that yielded inconsistent results due to large disparities between laboratories, operator biasness and the differences in the number of breeding females used to determine fertility (Rodriguez-Martinez, 2006). Furthermore, kinematic characteristics using CASA® has revealed variable associations between spermatozoa motility and field fertility (Broekhuijse *et al.*, 2012; Januskauskas *et al.*, 2003; Holt *et al.*, 1997).

2.8. Sex ratio percentage

The sex of the animal influences the growth performance of piglets (Peaker & Taylor, 1996). It also plays an integral role in the growth rate of the developing foetus. Alfonso.

(2005) reported that at birth male piglets tended to be heavier than female piglets. This may be due to hormonal differences between males and females and subsequent effects of foetal growth. The circumstances that have an influence on the sex ratio are recognized but not well understood therefore manipulating them to advance on within-litter birth weight differences may be problematic (James, 2001).

2.9. Factors affecting reproductive performance of pig herds

Causes of poor reproductive performance, including nutrition, environment, infectious causes, parity, management and genetics, but seasonal infertility remains a challenge.

2.9.1. Season of farrowing

Season is the most significant environmental aspects directly affecting the reproductive performance of pigs (Love *et al.*, 1993). High temperature that leads to heat stress may be related with seasonal infertility. This is apparent not only in tropical areas, such as Africa and Thailand where temperatures tend to exceed 30°C (Tantasuparuk *et al.*, 2000). It is also evident in temperate areas, such as in the northern Europe and United States of America (USA) (Tummaruk *et al.*, 2000; Peltoniemi *et al.*, 1999). The adverse effects of high ambient temperature and the effect of heat stress are well documentd. Janse van Rensburg & Spencer (2014) reported that ambient temperature has an impact on farrowing rate and litter size. When Ai is practices at higher temperatures, the litter size was marginally reduced especially breeding units where environmental temperature is uncontrolled (Janse van Rensburg & Spencer, 2014). However, heat stress has resulted in higher embryonic mortalities during the first trimester (Love *et al.*, 1993), elevated the number of stillbirths (Babicz *et al.* 2012; Vanderhaeghe *et al.* 2010; Tummaruk *et al.* 2010) and consequently a decline in litter size (Xue *et al.*, 1994). Furthermore, Edwards *et al.* (1968) reported that gilts are more susceptible to heat stress prior to day 15 of pregnancy rather than during days 15-30 post breeding. It is assumed that a reduction in reproductive performance particular in summer months takes places through a combination of high temperatures that reduce GnRH secretions and impairment of ovarian follicle development that subsequently compromises the corpus lutea

functioning thus ultimately results in low progesterone concentrations (Bertoldo *et al.*, 2012).

2.9.2. Sow parity

Parity order is associated with physiology, primarily with growth and the development of the reproductive system. In principle, an increase in the number of parities translates to an improved reproductive performance thus reaching a peak between parity 2-5. According to Milligan *et al.* (2002), younger parity sows tended to produce fewer piglets per litter than multiple parity sows. Conversely, the proportion of piglets that are stillborn tended to be higher in older sows (Milligan *et al.*, 2002). Similarly, Smits & Collins. (2009) reported that litters resulting from parity 3 or higher tended to have a higher number of piglets born alive and the mean birth weight compared to gilts. Koketsu *et al.* (2017) reported that piglets born alive was higher between parities 3-5, while the farrowing rate was the highest between parities 2 and 4. Furthermore Engblom *et al.* (2007) reported that an increase in parity is related to an increase in the number of live born and weaned piglets. This may be due to the fact that as sows age, the duration of parturition increases, thus increasing the risk of stillborns incidences due to asphyxia (Cutler *et al.*, 1992). Parity 1 sows tended to have a prolonged weaning to first mating interval, this may be due to the immature endocrine system in gilts and by inadequate feed intake during lactation thus leading to restricted follicle growth (Koketsu *et al.*, 1996).

2.9.3. Timing of insemination

To achieve a high conception rate and litter size, mating strategies and timing of breeding is of utmost importance (Colenbrander *et al.*, 1993). In the early 1990s, repeated rectal ultrasound were used to determine the optimum ovulation time in gilts and sows (Waberski *et al.*, 1994a). From these and subsequent studies, it became evident that AI should take place within 0 and 24 hours prior to ovulation for optimal fertilization rates. The age of the ova is essential, reduced fertilization rates are evident when the ova age has exceeded 8 hour and embryo survival is compromised when the ova age has exceeded only 4 hours (Waberski *et al.*, 1994a). When the 6-hour capacitation time is factored in, the timing of insemination becomes critical to success.

Furthermore, the proportion of viable spermatozoa for fertilization will have an influence on sow fertility. This is reliant on the proportion of spermatozoa entering the spermatozoa reservoir such as the interval between spermatozoa entry to the reservoir as well as the redistribution at the time of ovulation; the latter being affected by timing of insemination relative to ovulation.

2.9.4. Nutrition

Inadequate energy intake during pregnancy is the main cause of low birth weight. Body condition and feed intake prior to and post farrowing are important aspects of foetal growth and development (Campos *et al.*, 2011). It has been reported that the role of nutrition during lactation, post weaning, and prior to and post ovulation, influences to reproductive performance of the sow and overall productivity (Peltoniemi *et al.*, 1999). High levels of feed intake during short lactation periods positively influenced weaning to service interval as well as subsequent farrowing rates. Inadequate feeding of sows results in competition for nutrients hence an increase in within-litter weight variation. Furthermore, Kim *et al.* (2009) reported that sows that were unable to provide adequate nutrients to the developing foetus during pregnancy tended to have a high within litter weight variation. As a result, sows with declining body condition during lactation tended to produce piglets with low birth weights (Foxcroft *et al.*, 2006).

2.10 Summary

Assessing demographics, land profiles and infrastructures, challenges, prospects, impacts and other factors associated with the productivity of smallholder pig farmers at Gauteng Province is of utmost importance. Moreover, to improve livestock development, it is essential to have basic understanding of the current pig production systems and the willingness of smallholder pig farmers to adopt technologies to improve the productivity of their herds. Hence, the major findings of this study may be relevant making informed decisions to improve the smallholder pig sector and further build on the current knowledge of the farmers. Information from this study assisted in making informed decisions aimed at improving pig production in the smallholder pig industry. It built on current knowledge of the smallholder farmers. This study further

generated valuable information on boar and sow fertility following the introduction of advanced reproductive technologies such as oestrus synchronization and AI in smallholder pig farms. Moreover, information from this study generated information on the effect advanced reproductive technologies on the sex ratio of piglets born at smallholder farms of Gauteng Province.

STATUS OF PIG PRODUCTIVITY IN SMALLHOLDER FARMS OF GAUTENG PROVINCE PRIOR TO THE INTRODUCTION OF ADVANCED REPRODUCTIVE TECHNOLOGIES (ART)

Abstract

Pig farming is an important area of pig production among smallholder farmers in Gauteng Province. The objectives of the study were to identify the demographics, farm infrastructure, type of feed, animal health, management and marketing channels within the smallholder pig sector in Gauteng Province. The population was divided into four strata, namely the four district municipalities. A simple random sampling within each strata was done to select the 71 smallholder pig farmers at West Rand, Sedibeng, Tshwane and Ekurhuleni district municipalities. Descriptive statistics was performed using SAS software. The results demonstrated that the majority of the pig farmers were males (67%) and were above 50 years of age (67%), while 56% of the smallholder pig farmers had high school education. Moreover, majority of the pig farmers privately own the farms (62%) and the farm infrastructure had facilities with low cost housing and modern facilities. Moreover, 47% of the farmers feed their pigs with feed swill. A large proportion of the farmers did not vaccinate their pigs (81%). Additionally, majority of farmers were found to not identify their pig herds (63%). Noteworthy, majority of the pig farmers did not have breeding boars (73%) and sold their pigs at auctions (70%). In conclusion, the study indicated that males dominate Gauteng Province smallholder pig farming sector and participation of the youth is limited. Majority of the smallholder pig farmers have high school education. In general, there was lack of information about basic pig management and husbandry.

3.1. Introduction

There is a need for increased animal protein especially in developing countries thus leading to animal production coming under pressure to meet the demand from the rapidly increasing human population. Pigs are genetically superior at converting feed to meat when compared to ruminant livestock (Mpofu & Makuza, 2003). Furthermore, pigs contribute towards human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for rural communities (Antwi & Seahlodi 2011; Dietze 2011). Although South Africa has the highest pig population in southern Africa (Phiri *et al.*, 2003), 25% are free ranging in the resource poor areas (Krecek *et al.*, 2004). Gauteng Province dominated pork exports from 2002 to 2011 followed by Western Cape and Kwa Zulu Natal Provinces. This was due to the fact that these provinces are the main exit points and have requisite infrastructure that facilitate trade (Department of Agriculture, Forestry and Fisheries, 2012).

According to Department of Agriculture, Forestry and Fisheries (2013), South African commercial pig farmers were estimated at 4000 and stud farmers at 19 with the remaining being non-registered, medium scale and smallholder pig farms. Although these smallholder pig farmers contribute towards the national herds, the smallholder pig farming sector is faced with challenges that include inaccessibility to superior breeding stock and markets, low quality feed, insufficient veterinary services and breeding services (Lekule & Kyvsgaard, 2003; Lemke & Zárate, 2008). Hence, the objectives of the study were to identify the demographics, farm infrastructure, type of feed, animal health, management and marketing channels within the smallholder pig sector in Gauteng Province.

3.2. Materials and methods

3.2.1. Study location

The study was done at various district municipalities of the Gauteng Province where there is significant pig production activity, namely: Sedibeng, City of Tshwane, Ekurhuleni and West Rand district municipalities (Figure 3.1).
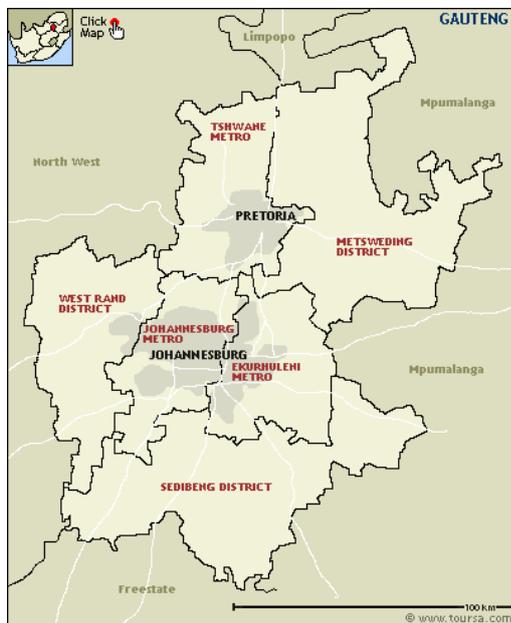
Figure 3.1. Map of Gauteng Province
Source:
http://www.toursa.com/travel_south_africa/southafrica_gauteng_accommodation_info.aspx.

3.2.2. Questionnaire design

Questionnaires contains a list of questions or statements to which the respondents are asked to respond in writing during an interview (Wiersma, 1986). According to Cohen & Marion (1989), the questionnaire can be administered under the supervision of a researcher or as a postal survey. However, in the present study, the researcher conducted the interviews. The questionnaires comprised of both open-ended and closed questions (see Appendix). The open-ended questions were included to offer the respondent the freedom to respond while the closed questions were coded.

3.2.3. Experimental design

The population was allocated into four strata based on the four district municipalities. A proportional stratified random sampling procedure was used for selection of 71 smallholder pig farmers with the aid of extension officers from Gauteng Department of Agriculture and Rural Development (GDARD) as indicated in Table 3.1. Selection of farmers from each district municipality was not the same due to the variability of the number of smallholder pig farmers at the different districts. The 50% sample size was considered representative to provide satisfactory results. The inclusion criterion was smallholder pig farmers with less than 50 pigs. Face-to-face interviews were conducted by means of a semi-structured questionnaire with mainly closed and a few open questions (Figure 3.2). The survey was focused on identifying the demographics, farm infrastructure, animal nutrition, animal health, husbandry and marketing at smallholder pig farms in Gauteng Province.

Figure 3.2. Collection of data using face-to-face interviews at Tshwane district municipality

Table 3.1. Number of smallholder pig farmers interviewed at Gauteng Province

Region	Number of smallholder pig farmers	Selected population (50%)
West Rand	51	26
Sedibeng	28	14
City of Tshwane	56	28
Ekurhuleni	5	3
Total	137	71

3.2.4. Statistical analysis

The questionnaire data was filtered with the Microsoft Excel® (Microsoft, USA) spreadsheet. The descriptive statistics were performed using Statistical Analysis System (SAS). Descriptive statistics was computed using FREQ COUNTS procedures to describe the characteristics of smallholder pig farmers. The analyses performed included: simple proportions and graphic displays of farm characteristics, production characteristics, management and health characteristics.

3.3. Results

The profile of the respondents by demographics are indicated in Figure 3.3. In the present study, majority of the respondents were males (67%) as compared to females (33%). Furthermore, farmers older than 50 years of age represented the (67%), suggesting that the involvement of youth in pig farming is limited. Majority of the respondents (56%) of the respondents had high school education. The educational level of a farmer does not only improve productivity but also assists to understand and evaluate the information on new technologies disseminated through extension services.
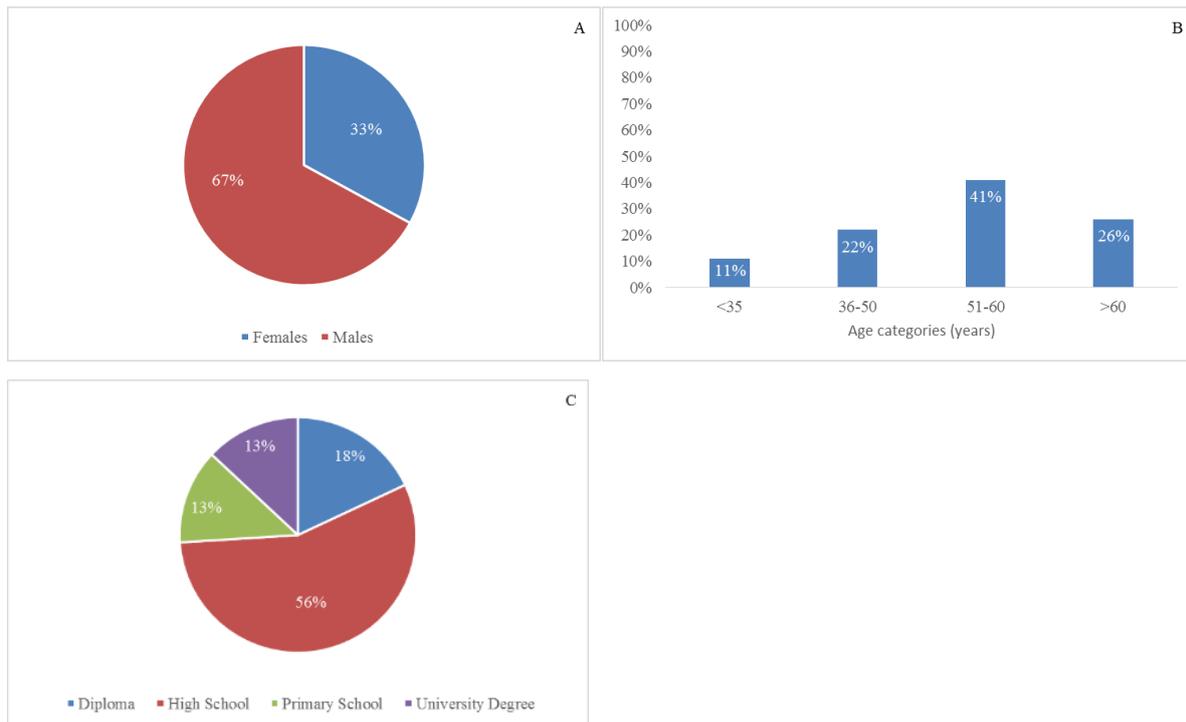
Figure 3.3. Demographic characteristics based on gender (A), age (B) and educational level (C) of smallholder pig farmers at Gauteng Province

The profiles of the respondents for experience in pig farming are indicated in Table 3.2. The results indicated that the majority of the respondents had less than 5 years' experience in pig farming (46%). Moreover, only 23% of the respondents had more than 10 years' experience, thus suggesting that of the respondents had less experience in pig farming.

Table 3.2. Years of experience in pig farming at Gauteng Province

Years of experience in pig farming (years)	% of respondents
<5	46
5-10	31
11-15	10
>15	13

The profiles of the respondents by farm profiles are indicated in Table 3.4. The results indicated that 62% of the smallholder pig farmers had ownership of land Additionally, 18% of the smallholder pig farmers were either renting or leasing the farms and 10% had acquired the land by both land reform programs such as Land Redistribution for Agricultural Development (LRAD) and Proactive Land Acquisition Strategy (PLAS), respectively. Furthermore, the majority of the smallholder pig farmers were using intensive farming systems (88%) as opposed to extensive (3%) and semi intensive farming systems (9%) (Figure 3.4).

Figure 3.4. Extensive and intensive production systems at Tshwane district municipality.

Table 3.3. Farm profile characteristics for smallholder pig farmers in Gauteng Province

Characteristics	Variables	% of respondents
Production systems	Intensive	88
	Extensive	3
	Semi-intensive	9
Land ownership	Private	62
	Rent/Lease	18
	PLAS	10
	LRAD	10

PLAS (Proactive Land Acquisition Strategy), LRAD (Land Redistribution for Agricultural Development)

The pigs were housed in a wide range of infrastructure, ranging from full earthen floors using low cost building material to more modern facilities containing cement floors and running water. The following figures (Figure 3.5 A-B) show typical housing and management practices and give a good indication of the infrastructure and systems used.

Figure 3.5. Some pigs were housed in wire fenced houses with shade (A) and cement floors (B)

About 47% of the respondents fed pigs with feed-swill as opposed to total mixed rations (53%) (Figure 3.6). Furthermore, majority of the feed were purchased at feed manufacturing companies (68%). Feed is arguably the most important pig farming

input. Consequently, smallholder pig farmers use swill feed as an affordable feed source due to high feed costs (Figure 3.7).
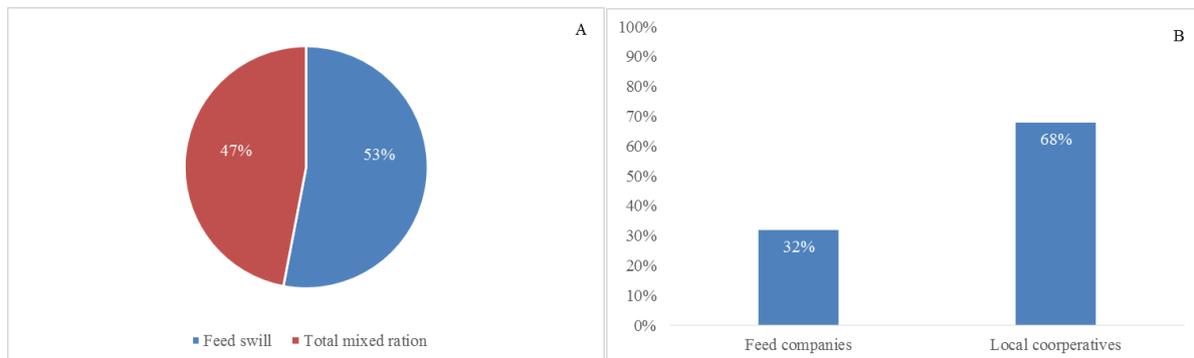
Figure 3.6. Feed types that are used by smallholder pig farmers (A) and source of the feed (B) at Gauteng Province

Figure 3.7. Kitchen waste fed to pigs at Ekurhuleni district municipality

The majority of the respondents did not vaccinate their pigs (81%) whereas the 19% of smallholder pig farmers vaccinated their pigs against Ecoli and Parvovirus only (Figure 3.8). The smallholder pig farmers had no biosecurity measures. Thus suggesting that there was limited knowledge regarding vaccination programs and biosecurity amongst the respondents.
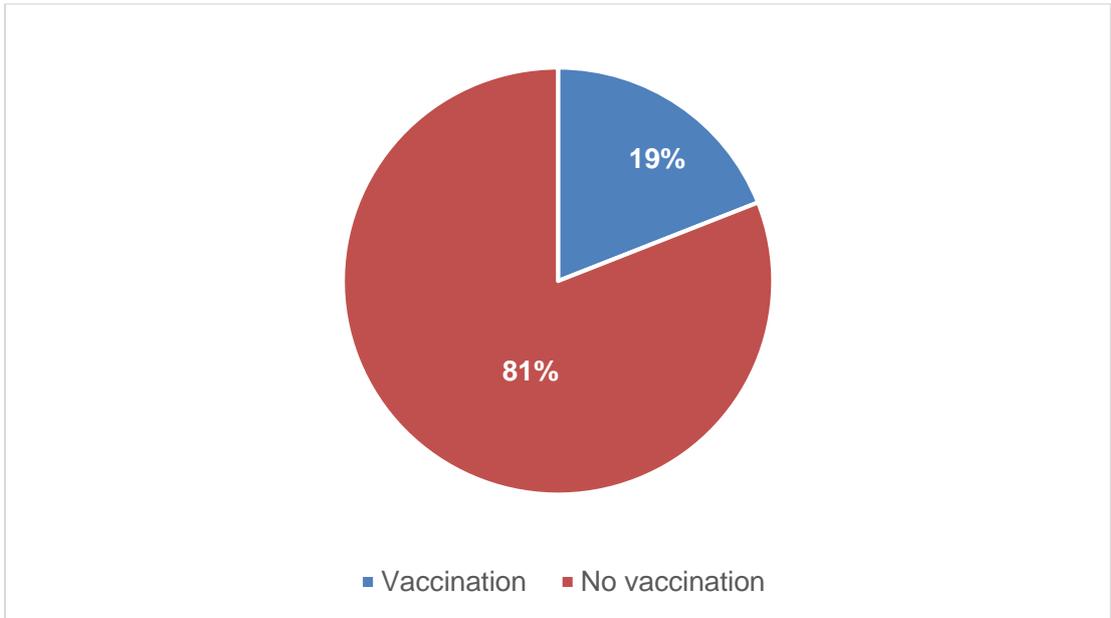
Figure 3.8. Vaccination status at smallholder pig farms within Gauteng Province

The majority of the respondents indicated that they did not have good breeding boars (74%) due to financial constraints (Figure 3.9). The easy availability of boars makes smallholder farmers depend mostly on natural service rather than the use of AI. The drawback of depending on natural service was that the boars that are available were not necessarily genetically superior ones. The limited availability of superior breeding stock and uncontrolled mating were reported as major breeding challenges.
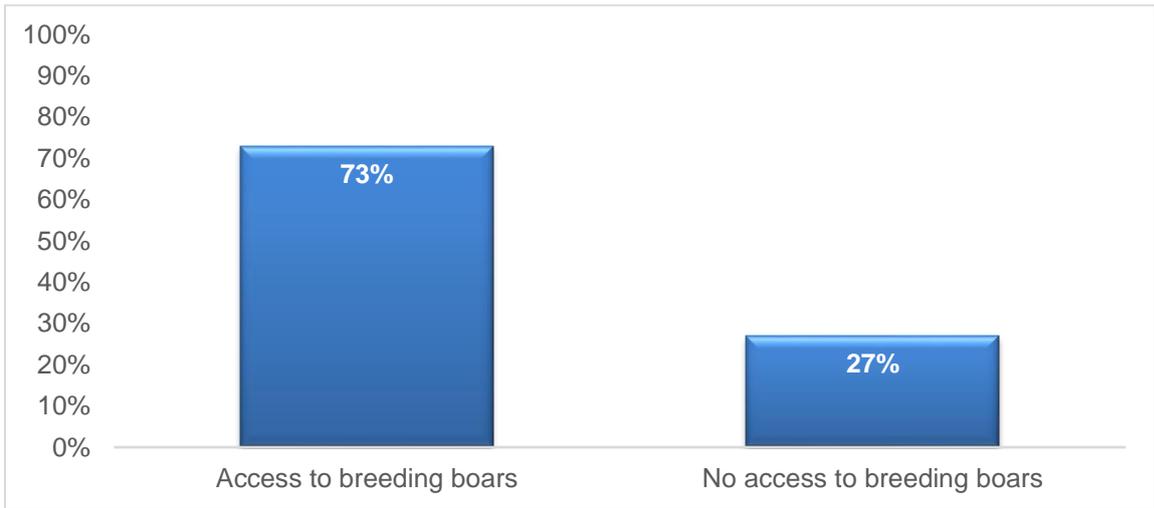
Figure 3.9. Availability of breeding boars at Gauteng Province

The types of breeds kept and source of breeding stock are indicated in Figure 3.10. The types of breeds kept at Gauteng province included none descriptive pig breeds, crossbred pig breeds and exotic pig breeds such as Large White, Landrace and Duroc (Table 3.8). Majority of the respondents kept crossbred pig breeds and bought their breeding stock within local communities.

Figure 3.10. None descriptive pig breed (A) and none descriptive pig breed (B)

Table 3.4. Types of breeds and source of breeding stock at Gauteng Province

Breeds	
Large White	25%
Landrace	3%
Duroc	1%
Cross-breeds	68%
Non-descriptive	3%
Source of breeding stock	
Auctions	16%
Commercial	25%
Local farms	44%
Stud breeders	15%

The respondents indicated that high incidences of pre and post weaning mortalities were a challenge. About 54% of the respondents reported that there were no records kept (Figure 3.11 A and B). Furthermore, 63% of the respondents had means of identification, such as ear tagging, ear notching, mainly for management purposes.
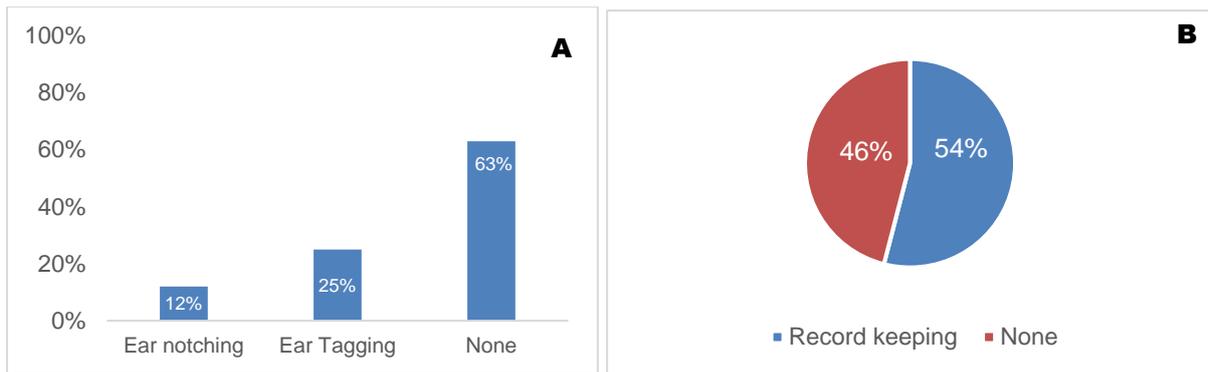
Figure 3.11. Means of animal identification (A) and record keeping (B) at Gauteng Province

Market accessibility by smallholder pig farmers is indicated in Figure 3.12. Majority of the respondents were selling their pigs at auctions (70%) as compared to abattoirs (12%) and informal markets (18%). This may be due to accessibility to sustainable markets. This is attributed to lack of knowledge and skills on price determination prior to the sale of pigs which places these smallholder pig farmers at a disadvantage.
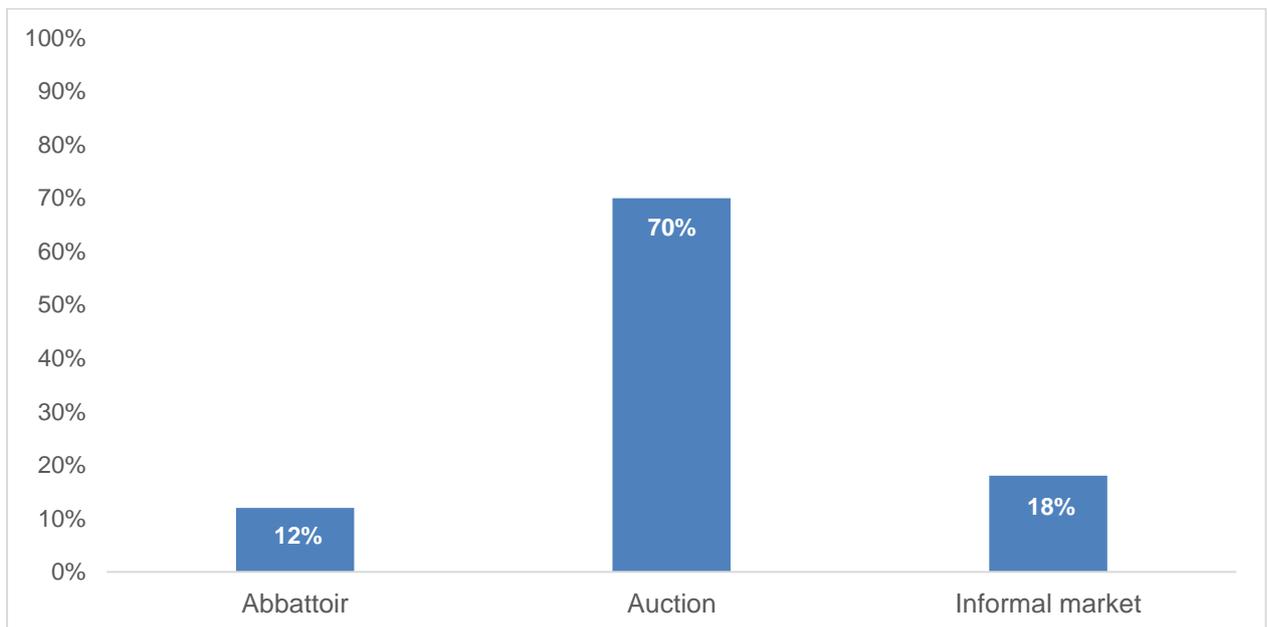
Figure 3.12. Market access for smallholder pig farmers at Gauteng Province

3.4. Discussion

Demographic characteristics such as age, gender, educational level and experience are some of the critical aspects when analysing economic data. These factors may

influence household economic behaviour. The majority of the respondents within Gauteng Province were males. Similarly, it was reported that the majority of the smallholder pig farmers were male at Limpopo Province of South Africa and various regions of Indonesia (Leslie *et al.*, 2015; Mokoele *et al.*, 2014). However, it was reported that the majority of smallholder pig farmers were female in the Eastern Cape Province of South Africa (Madzimure *et al.*, 2013) and Etayi, Namibia (Petrus *et al.*, 2011). The reason for male dominance may be religion and culture, which particularly excludes women from livestock ownership, production and market participation decisions. Thus, marginalising women to an extent of reducing their socio-economic status in society. As a result, this creates their intensive poverty levels and economic inequality with men particularly in the developing countries (IFAD, 2007). Restrictions on access to land or use of land impedes agricultural productivity as well as gaining access to basic assets constrains women's socio-economic empowerment, economic growth and poverty alleviation thus affecting rural women's income. Therefore, transformation of the pig industry is important and creating more opportunities with a critical focus on women and youth from peri-urban areas through training is fundamental.

The majority of the respondents were > 50 years of age, which indicates that there is limited involvement of youth in pig farming. Similarly, Mokoele *et al.* (2014) and Okoli *et al.* (2004) and also indicated that young people were not involved in pig farming or any other type of commercial livestock farming at Limpopo, South Africa and Imo state, Nigeria. As a result, the agricultural sector faces extensive threats in terms of productivity and sustainability due to the aging factor among smallholder pig farmers. This may be attributed to lack of youth participation. Furthermore, aged farmers may struggle to understand and comprehend modern agricultural training approaches, methodologies and content theory requiring adjustments (Mmbengeni & Mokoka, 2002). Hence, policies should be implemented to encourage younger individuals to remain in the rural areas to reduce gross migration to the city, thus enhancing agricultural productivity in the rural areas (Mokoele *et al.*, 2014).

Interestingly, majority of the respondents in the present study had high school education. However, majority of the smallholder pig farmers at Indonesia (Leslie *et al.*,

2015) and Limpopo (Mokoele *et al.*, 2014) had primary to high school education. However, the low levels of education reported in the several studies are bases for great concern. Government interventions are intended to delivering advanced technologies from the commercial farming sector to smallholder farmers, thus education has been demonstrated as an important socio-economic factor that enhances the capability of smallholder farmers to adopt new agricultural innovations and consequently improve productivity (Olaleye *et al.*, 2009; Alene & Manyong, 2007). Conventional and new technologies are primarily targeted at emerging commercial farmers and require new management skills. Furthermore, the education levels of farmers will need to be enhanced, especially as smallholder farmers engage in more sophisticated input and output markets.

The majority of the respondents had less than 5 years' experience in pig farming. It is expected that experienced farmers would have more experience that is technical in pig production in particular more than less experienced farmers. Additionally, older farmers tend to be more productive as their vast experience is anticipated to increase productivity (Matungul, *et al.*, 2002). Similarly, some techniques of farming requires that the farmer possess some degree of experience and hence the lesser the number of years, the higher the probability that the farmer will be technically constrained (Van Schalkwyk *et al.*, 2012). According to Montshwe. (2006), the knowledge or experience gained is crucial as it governs the success of a farmer in terms of improving production and marketing among others. Furthermore, age has been reported to be related to farmer experience (Randela *et al.,* 2000) and agricultural decision-making capacity (Nkhori, 2004). According to Bembridge, (1984), age determines the behavioural patterns of household and community members. However, Mmbengeni & Mokoka. (2002) indicated that older farmers tend to struggle to understand and comprehend modern agricultural training approaches, methodologies and content theory requiring adjustments to suit their old age.

The projected total land size belonging to smallholder farmers in Gauteng was 37 560 ha (GDARD strategic plan, 2010-2014). Approximately 13 190 (35%) was privately owned by smallholder farmers while the remaining land (65%) is being leased (GDARD strategic plan, 2010-2014). In the present study, majority of the respondents

owned the land, while a minority attained the land through both land reform programs such as Land Redistribution for Agricultural Development (LRAD) and Proactive Land Acquisition Strategy (PLAS), respectively. According to the Gauteng Department of Agriculture and Rural Development strategic plan, 2010-2014, nearly 1080 black farmers had acquired land for primary agricultural production since the introduction of land reform programs such as the LRAD and democracy. However, the challenge lies with the advancement of the farms to commercial enterprises and encouragement of farmers to get into agri-business/agro-processing as well as exportation of produce such as secondary and tertiary forms of agriculture, respectively.

Pigs were housed in a wide range of facilities ranging from full earthen floors using low cost housing material to more modern houses made out of cement floors with running water available. It was evident that farm infrastructure still poses a serious challenge due to high capital investment. Extensive production systems may cause disease spread as direct contact between pigs and with other livestock species is not controlled and such systems are characterised by minimal biosecurity (FAO, 2010). Comparable results were found at Limpopo (Manchidi, 2009). In the present study, there were areas with no shade for the pigs, which poses a risk. According to Manchidi (2009), pigs should not be exposed to direct sunlight and winds as this may cause stress. Consequently, when pigs are exposed to high environmental temperatures their libido, fertility and conception rates are compromised. Hence, the presence and condition of pig shelters are important aspects in terms of biosecurity for pigs (FAO, 2010).

In this study, 47% of the respondents feed pigs with feed-swill due to high feed costs. Feed is the most important pig farming input. Grains make up between 55 - 70% of pig rations (Smith, 2006), and is also used for human and other livestock feeds. According to Haynes. (2001), a pig's digestive system is similar to that of humans compared to other animals as they make use of energy and protein from vegetable and animal origins. Thus resulting in pig feed being expensive because there are not enough grains to feed both humans and livestock in many developing countries (Petrus *et al.,* 2011). Subsequently, smallholder pig farmers resort to feeding their pigs feed swill as an inexpensive feed source. As a result, pigs receive inadequate energy,

protein, minerals and vitamins when fed with feed swill. Feeding pigs feed swill is unacceptable at South African abattoirs as Salmonella, Campylobacter, Foot-and-mouth disease and Classical Swine Fever survive in processed meat products (Beltrán-Alcrudo *et al.*, 2008). Some smallholder pig farmers use alternative feedstuff such as bran and brewers grains to mix complete diets with bran as a way of reducing feed costs (Montsho & Moreki, 2012). Moreover, some smallholder pig farmers feed their pigs commercial diets from cooperatives and supplement them with feedstuff like hominy chop and vegetables depending on availability (Mtileni *et al.*, 2006).

Majority of the respondents were found not to vaccinate their pigs. Furthermore, the respondents in Gauteng Province were found not to have biosecurity measures in place. Similarly, biosecurity practices were found to be inadequate at various regions of Indonesia, Limpopo, Mpumalanga and North West Provinces of South Africa (Leslie *et al.*, 2015; Mokoele *et al.*, 2014; Mtileni *et al.*, 2006). In a report by FAO (2010), several measures were recommended to address disease outbreaks in smallholder pig production systems. These measures typically focused on the isolation of animals, including quarantining and controlling pig movement. Furthermore, biosecurity measures such as non-trading of sick animals, avoiding feed swill, disinfecting pens, proper carcass and waste disposal are key factors that should be implemented in the farm health plans (FAO, 2010). According to Mokoele *et al.* (2014), it is recommended that a community specific farm health plan be implemented with the involvement of both state veterinarians and animal health technicians. Vaccinations against diseases in South Africa (Parvovirus, Leptospirosis and Erysepelas, as well as Escherichia Coli) should be incorporated in vaccination programs (Mokoele *et al.*, 2014). According to Perry *et al.* (2002), investing in veterinary services for smallholder pig farmers is crucial.

Reproductive inefficiency is the main limiting factor in enhancing animal production and profitability of an enterprise. In the present study, majority of the farmers did not have access to superior breeding stock. Montsho & Moreki. (2012) also reported that pigs in smallholder systems in Botswana originate from one source and as such inbreeding is common. Inbreeding causes a loss in heterozygocity and increases homozygosity, which results in increased lethal genes that escalates embryonic death,

mummified foetuses and stillbirths. It is thus recommended that smallholder pig farmers should purchase breeding boars from other district municipalities and keep breeding boars for a shorter period in the breeding herd to limit chances of inbreeding. Furthermore, adoption of modern technological approaches in animal breeding such as AI may reduce inbreeding, which are highly characterised by occasional physical deformation in animal offspring, high mortality rates, poor fertility, low farrowing rates and low growth performance.

Some of the exotic breeds in South Africa, such as Landrace, Large White and Duroc, are mainly used in the commercial sector (Swart *et al.,* 2010). In the present study, majority of the respondents had crossbred pig breeds and purchased breeding stock from local communities. These exotic pig breeds were crossbred in the rural areas and smallholder farms, which has influenced several smallholder pig farmers to abandon the indigenous breeds, partly because due to low productivity and high fat deposition apparent in indigenous pig breeds (Halimani *et al.*, 2012; Lekule & Kyvsagaard, 2003; Hossain *et al.*, 2011). The result has been a steady decline in the number of indigenous breeds in the rural areas as seen in the present study.

The respondents in the study area indicated that there were high incidences of pre and post weaning mortalities. According to Phengsavanh *et al.* (2011), diarrhoea and lack of management were the key causes of high losses in piglets. The problem of diarrhoea in piglets was common in many smallholder pig farms and this has led to a significant economic loss to pig farmers (Tuyen *et al.*, 2005). Disease and diarrhoea occurrence in smallholder pig production may have been associated with poor hygiene, and lack of disease preventive measures as well as poor nutrition of sow during gestation and lactation (Phengsavanh *et al.*, 2010). Hong *et al.* (2006) also reported that poor quality of feed and nutrient supply might have been a contributing factor to the high incidence of diarrhoea in piglets.

In the present study, 63% of the respondents did not keep pig records while 46% of the farmers had a means of identification for management purposes. According to Petrus *et al.* (2011), smallholder pig farmers have inadequate skills and resources this resulting in poor management and planning of pig enterprises. According to

Henderson & Gomes (1979), one possible approach to improving smallholder farming is with the use of farm records. This is because a smallholder farmer that maintains an adequate set of farm records can usually solve challenges efficiently (Poggio, 2006; Hansen *et al.*, 1991). Smallholder farmers often consider record keeping a perplexing task, regardless of the importance of keeping farm records to the growth of a farm business (Poggio, 2006). According to Minae *et al.*, (2003), the lack of keeping farm records may be due to high levels of illiteracy and low numeracy levels in resource-poor farming communities. As a result, decisions are often driven by imprecise estimates based on previous experiences (Johl & Kapur, 2001).

In the present study, majority of the respondents sold their pigs at auctions. This may be because of accessibility to sustainable markets. These production constraints may affect improvement to productivity of pigs (Wabacha *et al.* 2004). Mtileni *et al.* (2006) reported that auction prices vary as speculators and butchers are attempting to buy pigs at a cheaper price and the prices are not linked to any classification system. There is also no specific period of selling since sales are dependent on the demand and availability of stock. This may be due to limited knowledge and skills on price determination prior to the selling of pigs thus putting these smallholder pig farmers at a disadvantage.

3.5. Conclusions

In conclusion, the study found that Gauteng Province smallholder pig farming sector is dominated by males, participation of the youth is limited and majority of the smallholder pig farmers have high school education. Hence, it is anticipated that as a result of age, lack of education and lack of basic skills, smallholder pig farmers are faced with increased level of constraints in terms of pig's productivity. The results of the current study also revealed that smallholder pig farmers in the studied area are still faced with nutritional, animal health and marketing constraints. It was also found that farm infrastructure still poses a serious challenge. There was also a general lack of basic pig farming management and husbandry practices in terms of nutrition, animal health, reproduction and market access thus affecting their production and overall profitability.

CHAPTER 4

SEMEN CHARACTERISTICS OF LARGE WHITE BOARS

2

Matabane, M.B., Thomas, R., Netshirovha, T.R., Tsatsimpe, M., Ng'ambi, J.W., Nephawe, K.A. and Nedambale, T.L., 2017. Relationship between sperm plasma membrane integrity and morphology and fertility following artificial insemination. South African Journal of Animal Science 47 (1), 102-106.

Abstract

The objective of the study was to determine semen characteristics of Large White boars. Sixteen ejaculates were collected from three breeding boars using a hand gloved technique. Aliquots of diluted semen were assessed for sperm motility using a computer aided sperm analysis® (CASA®). Sperm viability was evaluated using Synthetic Binding CD-14 (SYBR-14+)/Propidium Iodide (PI-), whereas sperm morphology was evaluated using Eosin Nigrosin staining. Fluorescent microscope was used at 100x magnification to count 200 sperm per each stained slide. The data was analysed using ANOVA. Individual variations existed amongst the boars. The average values for total spermatozoa motility was 95.1%, ranging from 82.7 and 98.5%. Furthermore, there were lower values found for progressive spermatozoa motility, ranging from 13.6 to 39.0%. The spermatozoa were following an irregular path, as the VSL (27.4±3.2 µm / sec) was lower than VAP (43.7±3.4 µm / sec). The average values for ALH and BCF were 3.7±0.1µm and 11.2±0.8Hz, respectively. The mean values for morphologically normal spermatozoa ranged from 47.8-60.9% and live spermatozoa ranged from 71.8-77.7%. In conclusion, the CASA® technology was a useful technique for identifying differences in spermatozoa motion and kinematic characteristics.

4.1. Introduction

There has been increased interest in the use and adoption of assisted reproductive technologies (ARTs). One of the oldest and commonly used ART is artificial insemination (AI) which allows maximum use of the sire' genetic potential (Johnson, 2000). However, it is vital to evaluate spermatozoa quality evaluation which requires the application of precise and reliable laboratory techniques. Spermatozoa motility is considered one of the most important characteristics as a measure of semen quality globally. Standard laboratory semen analysis previously used light microscopy to evaluate spermatozoa motility. However, even though this analysis is inexpensive and rapid, the precision and reliability of the results is dependent on the subjective estimations that are made by individuals (Vyt *et al.*, 2004; Quintero-Moreno *et al.*, 2004). The development of the computer assisted sperm analysis® (CASA®) system provided the most effective way for semen evaluation and further ensures optimal

dilution rate. According to Gloria *et al.* (2013), the CASA® also allows for accurate and comparable estimations of spermatozoa kinetics. These systems are available commercially, but due to high costs, they are seldom used in commercial AI centres (Verstegen *et al.*, 2002).

Traditional spermatozoa evaluations are insufficient to evaluate spermatozoa quality and further evaluate fertilization ability. Therefore, there are various methods including fluorescent techniques, which are exploited for objective and accurate semen quality analysis (Fraser *et al.*, 2011). The plasma membrane is important for preservation of cellular homeostasis thus playing a crucial role in spermatozoa survival in the female reproductive tract and for fertilization capacity (Andrade *et al.*, 2007; Flesch & Gadella, 2000). Fluorochromes such as the SYBR 14, which has the ability to penetrate an undamaged cell membrane and bind with nucleic acids in the nucleus of living cells, and propidium iodide, which has the ability to bind to the DNA of dead cells or those with damaged membranes (Johnson, 2000; Wilhelm *et al.* 1996) are predominantly used. Another reliable technique is the outcome of poor spermatozoa morphology within an ejaculate that has resulted in lower pregnancy rates and reduced litter size following AI (Tsakmakidis *et al.*, 2010; Alm *et al.*, 2006). It is therefore crucial that boar spermatozoa morphology be analysed to identify sub-fertile boars. Eosin Nigrosin stain has been extensively used for boar semen analysis because it is easy, it allows morphological and membrane integrity examination and was correlated with sow fertility (Tsakmakidis *et al.*, 2010; Bjorndahl *et al.*, 2004). Therefore, the objective of the study is to determine semen characteristics evaluated by CASA® as a measure of boar fertility to be used for AI at smallholder farms of Gauteng Province.

4.2. Materials and methods

4.2.1. Study location

Boar semen was collected at the Pig Research Unit and laboratory analysis were done at Germplasm Conservation and Reproductive Biotechnologies unit of the ARC, South Africa. The ARC campus is located at 25° 55" South; 28° 12" East. The institute is located in the Highveld region of South Africa and situated at an altitude of 1525m above sea level.

4.2.2. Experimental boars

Three experimental boars that were available for fertility trials, aged between 18-24 months, were used in the study. The boars were housed individually in pens and the boars were in good health condition throughout the duration of the study. The diets were formulated to meet and exceed the nutritional requirement of breeding boars (National Research Council (NRC), 1998). Water was given *ad libitum* throughout the duration of the study.

Figure 4.1. Boar routinely used for semen collection

4.2.2. Semen collection and processing

Boar semen was collected using the gloved-hand technique and the filtered spermatozoa rich fraction was sealed with a gauze filter inside a pre-warmed (39°C) insulated thermos flask (Figure 4.2). Upon arrival at the laboratory, semen volume was measured by using the graduated falcon tube, pH was measured using the litmus paper and spermatozoa concentration was measured using the spectrophotometer (Jenway 6310 spectrophotometer, Bibby Scientific, England). The readings on the spectrophotometer were recorded and expressed as ($\times 10^9$ sperm/mL).
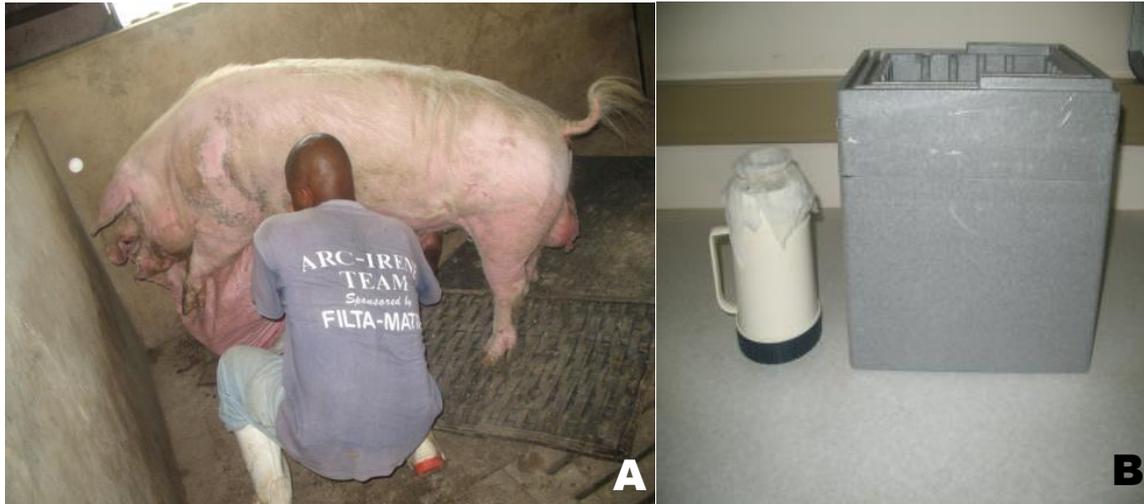
Figure 4.2. Semen collection using gloved hand technique (A) and semen collection flask (B)

4.2.3. Boar spermatozoa motility evaluation

The 10 µl of semen from each boar was placed into 500 µl of Bracket and Olifant wash medium in 15 mL tube. The tube with semen was incubated in 39°C CO_2 incubator for five minutes. Five micro litres of the boar semen placed in a Leja chamber slide (20 µm deep and 5µl volume). The Leja chamber slide (Leja® Products B.V., Nieuw Vennop, Netherlands) then placed on to a temperature controlled stage of the Nikon E50i microscope (IMP, Cape Town, South Africa). A 10X negative phase contrast objective in conjunction with a phase contrast condenser was used by means of a computer aided sperm analysis® (CASA®) and the Sperm Class Analyzer® (Microptic, S.L., Barcelona, Spin, Version 4.2) at a frame rate of 50 frames per second. The spermatozoa motility rates were evaluated by SCA® at the magnification of 10x (Figure 4.3). A minimum of five fields per a chamber will be recorded.

The SCA® recorded the kinematic and velocity characteristics of spermatozoa such as; curvilinear velocity (VCL), straight-line velocity (VSL), average path velocity (VAP), linearity (LIN), straightness (STR), amplitude of lateral head displacement (ALH), beat cross-frequency (BCF). The SCA cut-off values for fast, medium and slow swimming spermatozoa are shown in Table 4.1.

Table 4.1. CASA® settings used to analyse spermatozoa motility and velocity characteristics

Characteristics	Settings
Contrast	169
Brightness	470
Image/second	50
Optic	Ph-
Chamber	Cover slide
Scale	10X
Particle size (μm^2)	10<70
Slow (μm/second)	<40
Medium (μm/second)	<80
Rapid (μm/second)	<120
Progressivity (%)	40 % of straightness
Circular (%)	50 % of linearity
Connectivity	11
Velocity on the average path points	7
Number of images	50
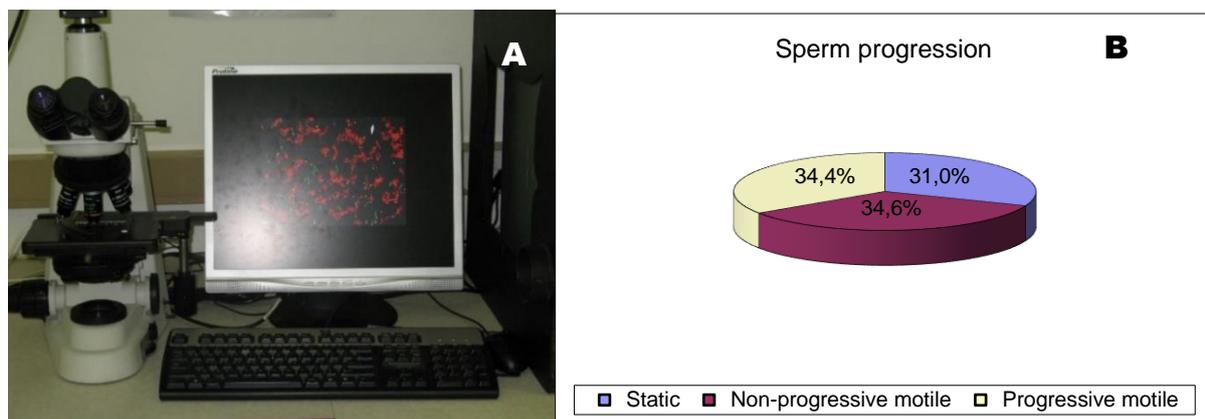
Figure 4.3. CASA® used for spermatozoa motility analysis (A) and boar spermatozoa progressive motility (B).

4.2.4. Evaluation of plasma membrane integrity

Plasma membrane integrity was evaluated using Synthetic binding CD-R 14/Propidium Iodide (SYBR-14/PI) tests (Invitrogen, Molecular Probes, USA) (Garner & Johnson, 1995). Briefly, semen samples were incubated at 38ºC for 10 minutes with SYBR-14$^+$ at a final concentration of 100 µM. The PI$^-$ stain was then added at a final concentration of 10 µM at 38ºC for 5 minutes. A fluorescent microscope (Olympus model, BX-51) was used at 100x magnification to count 200 spermatozoa per each stained slide and results were recorded (Figure 4.4). After this assessment, two spermatozoa populations were identified: (i) viable green-stained spermatozoa (SYBR-14$^+$/PI$^-$) and (ii) non-viable red-stained spermatozoa (SYBR-14$^+$/PI$^-$).

Figure 4.4. Fluorescent microscope used for spermatozoa morphology evaluation

4.2.5. Evaluation of spermatozoa morphology

Spermatozoa morphology was evaluated using Eosin/Nigrosin stain (Tsakmakidis *et al.*, 2010). Briefly, 7µL of boar semen was added to 20µL of Eosin/Nigrosin staining solution in a 0.6mL micro-centrifuge graduated tube and mixed gently. A drop of 5µL boar semen and Eosin/Nigrosin stain was placed on a microscope slide and smeared. Fluorescent microscope (Olympus model, BX-51) was used at 100x magnification to count 200 spermatozoa per each stained slide and results were recorded (Figure 4.4). Morphological defects were recorded and were categorized into major and minor

spermatozoa morphological defects following classification system by Salisbury *et al.* (1978).

4.2.6. Statistical analysis

The PROC UNIVARIATE of the statistical package of SAS (SAS 9.3, Inst. Inc., Cary, NC) was used in the descriptive analyses of the data. The relationships between sperm motility characteristics and fertility were investigated using the PROC CORR procedures of SAS (SAS 9.3, Inst. Inc., Cary, NC). Semen quality values in the tables were expressed as least square means (LSM) and standard error of the mean (SEM). The data were checked for normality using the Kolmogorov-Smirnov (K-S) test with Lilliefors correction. In addition, the Brown-Forsythe test (B-F) determined whether the distributions of the variables have the same variance.

4.3. Results

Macroscopic semen characteristics from Large White boars are shown in Table 4.2. The basic semen analysis included the assessment of physical semen characteristics such as semen volume, pH and spermatozoa concentration. The average semen volume of the ejaculates was 210±21.0mL, ranging from 100 to 300mL. Furthermore, the spermatozoa concentration and semen pH values were 264.8±26.3 x 10^6 spermatozoa/mL and 7.1±0.3, respectively.

Table 4.2. Macroscopic characteristics of Large White boar semen (LSM±SEM)

Macroscopic characteristics	LSM±SEM	Minimum	Maximum
Semen volume (mL)	210.0±21.0	100	300
Spermatozoa concentration (x10^9 spermatozoa/mL)	264.8±26.3	166	356
Semen pH	7.1±0.3	7.0	7.4

[ab] Different superscripts in a row indicate significant differences (P <0.05).

Descriptive statistics of boar spermatozoa motility characteristics using SCA® are indicated in Table 4.3. The average values for total spermatozoa motility was 95.1±0.1%, ranging from 82.7 and 98.5%. However, there were lower values found for

progressive spermatozoa motility, ranging from 13.6 to 39.0%. The spermatozoa were following an irregular path, as the VSL (27.4±3.2 µm / sec) was lower than VAP (43.7±3.4 µm / sec). The average values for ALH and BCF were 3.7±0.1µm and 11.2±0.8Hz, respectively.

Table 4.3. Descriptive statistics of boar spermatozoa motility characteristics using SCA® (LSM±SEM)

Variables	LSM±SEM	Minimum	Maximum
TM (%)	95.1±0.9	82.7	98.5
PM (%)	29.0±1.5	13.6	39.0
RAP (%)	24.6±2.0	7.0	38.3
VCL (µm/sec)	74.4±4.1	54.9	110.3
VSL (µm/sec)	27.4±3.2	15.8	60.1
VAP (µm/sec)	43.7±3.4	29.7	70.8
STR (%)	61.2±2.7	44.5	84.9
LIN (%)	36.1±2.7	24.1	57.7
WOB (%)	58.2±1.9	48.3	73.6
ALH (µm)	3.7±0.1	2.7	4.7
BCF (Hz)	11.2±0.8	8.2	18.2

TM (total motility), PM (progressive motility), RAP (Rapid), MED (medium), SLW (slow), VCL (curvilinear velocity), VSL (velocity on the straight line), VAP (velocity on the average path), LIN (linearity), STR (straightness), WOB (wobble), ALH (Lateral head displacement), BCF (beat cross frequency).

Pearson's rank correlation of boar spermatozoa motility and velocity characteristics are indicated in Table 4.4. A significant correlation ($P<0.05$) was found between total spermatozoa motility and progressive spermatozoa motility ($r= 0.28$) and VSL ($r= 0.27$), although relatively low. Furthermore, a highly significant low correlation ($P>0.01$) existed between total spermatozoa motility and VCL ($r= 0.37$), VAP ($r= 0.31$) and BCF ($r= 0.33$). A highly significant correlation ($P<0.01$) was found between total spermatozoa motility and rapid moving spermatozoa ($r= 0.51$). However, no significant correlations ($P>0.05$) were found between total spermatozoa motility and LIN ($r= 0.13$), STR ($r= 0.15$), WOB ($r= 0.06$) and ALH ($r= -0.11$). There was a highly significant

positive correlation (P<0.01) between progressive spermatozoa motility and rapid moving spermatozoa (r= 0.37), although relatively low. No significant correlation (P>0.05) existed between progressive spermatozoa motility and all the velocity characteristics, except STR (r= 0.38, P>0.01) and ALH (r= -0.34, P<0.01). There was a highly significant correlation (P<0.01) between rapid moving spermatozoa and all the velocity characteristics, VCL (r= 0.54), VSL (r= 0.34) and VAP (r= 0.36). However, no significant correlations (P>0.05) existed between rapid moving spermatozoa with LIN (r= 0.07), STR (r= 0.17), WOB (r= -0.05) and ALH (r= -0.04). A highly significant correlation (P<0.01) existed amongst all the velocity characteristics.

Table 4.4. Pearson's correlation coefficients (r) between spermatozoa motility and velocity characteristics.

Characteristics	TM (%)	PM (%)	RAP (%)	VCL (µm/sec)	VSL (µm/sec)	VAP (µm/sec)	LIN (%)	STR (%)	WOB (%)	ALH (µm)	BCF (Hz)
TM (%)	1.00										
PM (%)	0.28*	1.00									
RAP (%)	0.51**	0.37**	1.00								
VCL (µm/sec)	0.37**	0.08	0.54**	1.00							
VSL (µm/sec)	0.27*	0.18	0.34**	0.72**	1.00						
VAP (µm/sec)	0.31**	0.08	0.36**	0.92**	0.90**	1.00					
LIN (%)	0.13	0.23	0.07	0.33**	0.87**	0.64**	1.00				
STR (%)	0.15	0.38**	0.17	0.18	0.78**	0.45**	0.94**	1.00			
WOB (%)	0.06	0.03	-0.05	0.46**	0.82**	0.76**	0.89**	0.70**	1.00		
ALH (µm)	-0.10	-0.34**	-0.04	-0.47**	-0.75**	-0.67**	-0.73**	-0.63**	-0.72**	1.00	
BCF (Hz)	0.33**	0.14	0.35**	0.82**	0. 84**	0.90**	0.58**	0.45**	0.64	-0.84**	1.00

TM (total motility), PM (progressive motility), RAP (Rapid), VCL (curvilinear velocity), VSL (velocity on the straight line), VAP (velocity on the average path), LIN (linearity), STR (straightness), ALH (Lateral head displacement), BCF (beat cross frequency). *P<0.05, **P<0.01

The summary of boar morphological spermatozoa characteristics are indicated in Table 4.4. The live spermatozoa (Green: SYBR-14) can easily be distinguished from the dead (Red-PI) (Figure 4.5). The average spermatozoa viability of microscopically evaluated SYBR$^+$ stained semen was 73.8±2.7%. The average value for dead spermatozoa (PI$^-$) was 26.2±2.1%, ranging from 9 to 46.5%.
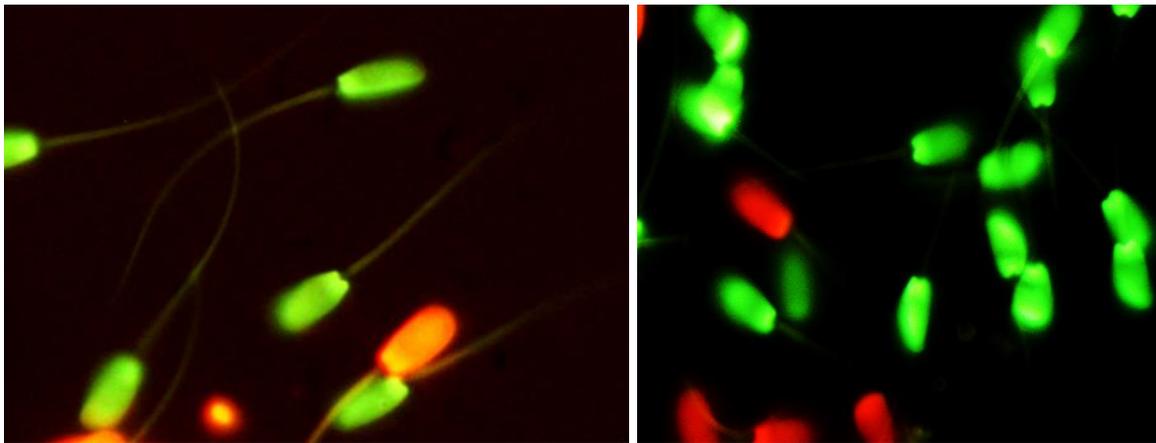
Figure 4.5. Boar spermatozoa stained with SYBR-14 and PI viewed under a fluorescence microscope at 100x magnification.

Analysis of boar spermatozoa morphology with Eosin/Nigrosin staining solution viewed under a fluorescence microscope at 100x magnification is indicated in Figure 4.6. Boar spermatozoa plasma membrane integrity and morphology characteristics are indicated in Table 4.6. The average   morphologically normal spermatozoa was 77.2±0.7%, ranging from 38.5 to 77.5%. As a result, when a higher proportion of morphologically normal boar spermatozoa is used, the higher the chance of conceiving. Of all the morphological sperm defects observed, the most prevalent were proximal (7.5±0.3%) and distal (6.4±0.3%) cytoplasmic droplets. Higher percentages of major and minor morphological spermatozoa defects were found (12.4 and 10.3%, respectively).
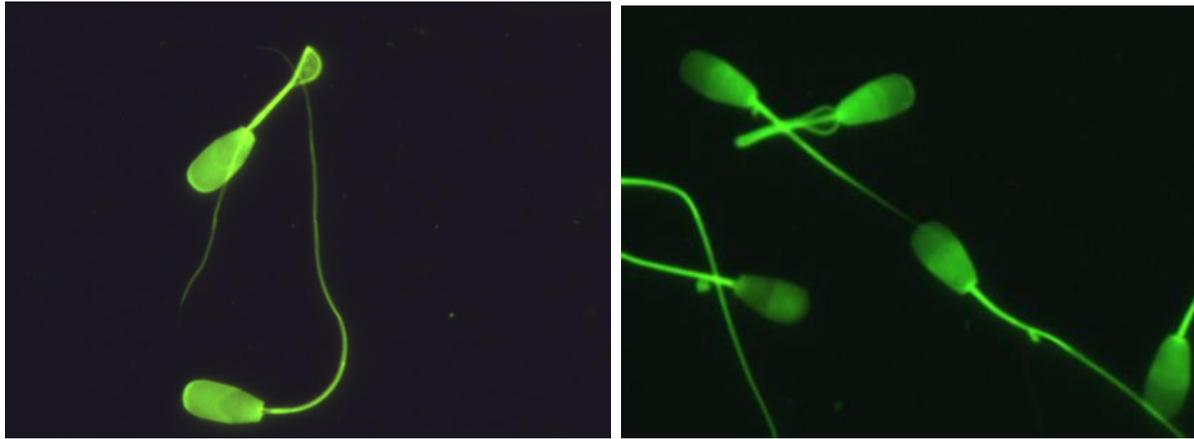
Figure 4.6. Analysis of boar spermatozoa morphology with Eosin/Nigrosin staining solution viewed under a fluorescence microscope at 100x magnification.

Table 4.5. Boar spermatozoa plasma membrane integrity and morphology characteristics (LSM±SEM)

Variables	Average	Minimum	Maximum
Live spermatozoa –SYBR$^+$ (%)	73.8±2.7	53.5	91.0
Dead – PI$^-$ (%)	26.2±2.1	9.0	46.5
Normal spermatozoa (%)	77.2±0.7	38.5	77.5
Head morphological defects (%)	1.9±0.6	0.0	11.0
Midpiece morphological defects (%)	3.0±0.3	0.0	14.0
Tail morphological defects (%)	3.9±0.3	2.0	15.0
Proximal cytoplasmic droplet (%)	7.5±0.3	3.0	25.0
Distal cytoplasmic droplet (%)	6.4±0.3	5.0	41.0
Major morphological defects (%)	12.4±1.5	4.5	22.5
Minor morphological defects (%)	10.3±1.5	2.5	22.5

abc Different superscripts in a row indicate significant differences (P <0.05).

4.4. Discussion

A considerable variation in macroscopic and microscopic semen characteristics was found amongst the experimental boars. There were differences for semen volume and concentration in the present study. It is acceptable that semen quality is subject to considerable variations because of individual characteristics, breed and environmental conditions. Disparities in the number of spermatozoa within an ejaculate has been

reported between different pig breeds (Kommisrud *et al.*, 2002), which is a main factor affecting semen dose production. The semen pH was within the acceptable range. Johnson *et al.* (2000) reported that the semen pH of boar semen may vary between 7.0 and 7.5. Major changes in boar semen pH can result in sperm damage, infertility, or sperm mortality (Purdy, 2006). Furthermore, bacterial contamination may lead to a series of variations including reduced sperm motility, an increased proportion of altered acrosomes and pH lowering to acidic levels (5.7-6.4) (Althouse *et al.*, 2000).

In the present study, spermatozoa motility rate was high (>90%). According to Martin-Rillo *et al.* (1996), boar ejaculates should contain at least 60% motile spermatozoa to ensure fertilization. Progressive motility has been recognised as a fundamental component of spermatozoa's ability to migrate and penetrate the cervical mucus, thereby facilitating oocyte fusion (Mortimer, 1997). In the present study, individual variations existed amongst the boars for progressive spermatozoa motility and rapid moving spermatozoa. This may be due to the biological variability and differences that exists between individual samples. Furthermore, the disparities observed between various studies might be due to initial sampling of the boar semen, processing of semen for evaluation, time elapsing between initial sampling and analysis, settings, accuracy of the specimen chambers used and the number of chambers, fields and spermatozoa evaluated to provide adequate statistical sampling of the material analysed (Farrell *et al.*, 1996). Additionally, spermatozoa kinematics are imperative for spermatozoa transport and fertilization in the female tract and may be used to predict the function of the spermatozoa (Maxwell *et al.*, 2000). Possible fluctuations in spermatozoa quality are related with factors such as breed (Rijsselaere *et al.*, 2007), age (Stone *et al.*, 2013), seasonality (Zhang *et al.*, 2013; Chemineau *et al.*, 2008), temperature (Thonneau *et al.*, 1998) and photoperiod (Kozdrowski & Dubiel, 2004). All of these factors require careful control to for the best semen quality for AI.

A highly significant positive correlation was observed between VCL and VAP (r= 0.92). Similarly, a positive correlation existed between VCL and VAP in rams (Robayo *et al.*, 2008), rabbits (Lavara *et al.*, 2008) and Holstein bulls (Tilley, 2007). Furthermore, a positive correlation existed between VSL and all the velocity characteristics. Similarly, there was a positive correlation between VSL and VAP, BCF and VCL in Holstein bulls

(Tilley, 2007). In contrast, a negative correlation was observed between VSL and LIN in Holstein bulls (Tilley, 2007). Moreover in the present study, there was a negative correlation between ALH and all velocity characteristics (VCL, VSL and VAP), thus indicating that rapid sperm motions are not associated with a greater lateral displacement of the sperm head. In contrast, significant positive correlations were observed between different sperm velocity characteristics and the ALH in rabbits (Lavara *et al.*, 2008).

Spermatozoa defects have been related to infertility (Bonet & Briz, 1991). In a standard semen evaluation, spermatozoa morphology provides information about the effectiveness of spermatogenesis and it can facilitate selection of boars for AI programmes (Waberski *et al.*, 1990). Spermatozoa defects have traditionally been classified by location of the defect (head, midpiece, tail). Blom. (1983) classified spermatozoa defects according to their effect on fertility: major defects include most defects of the head, midpiece and proximal cytoplasmic droplets, whereas minor defects include looped tails and distal cytoplasmic droplets. It has been reported that causes for concern in the differential spermiogram would include less than 30% morphologically normal spermatozoa, more than 30% abnormal spermatozoa heads and/or midpiece defects, or more than 25% spermatozoa with proximal cytoplasmic droplets (Card, 2005) as such levels are usually linked to reduced fertility.

Among the morphological spermatozoa defects found, the most predominant defects were proximal and distal cytoplasmic droplets. It was also reported that spermatozoa with cytoplasmic defects are typically identified in the head of the epididymis (Briz *et al.*, 1995). It was commonly assumed that proximal cytoplasmic spermatozoa defects result from incorrect spermatozoa maturation (Bonet, 1990). During normal spermatogenesis, most of the round spermatid's cytoplasm is phagocytosed as 'residual bodies' by the Sertoli cell at spermiogenesis, and only a minor cytoplasmic residue remains applied to the elongated spermatid after release from the germinal epithelium (Cooper, 2011). Additionally, proximal cytoplasmic droplets may be caused by the shorter time spent by spermatozoa in the epididymal duct (Pruneda *et al.*, 2005) as a result of extremely frequent ejaculation (Bonet *et al.*, 1992). According to Martin-Rillo *et al.* (1996), it is acceptable that an ejaculate contains a maximum of 20%

spermatozoa with a proximal droplet. A higher percentage will translate to compromised male fertility (Soderquist *et al.*, 1991).

In the present study, low percentages of head morphological defects were found. Some defects in the morphology of the sperm head may be related to the condition of the chromatin structure. Even if heads appears to have a normal shape, they can have a disturbed chromatin structure in the nucleus or acrosome defects (Karabinus *et al.*, 1997). Ejaculates containing spermatozoa with head morphological defects may reduce the quality of embryos (De Jarnette *et al.*, 1992) and result in abortions in the first months of pregnancy (Chenoweth, 2005). In the present study, low percentages of tail defects were found. Bent tail defects are near the mid-piece ring and such defects have been reported to negatively affect the fertilization potential of the spermatozoa (Bonet, 1990). According to Morrell *et al.* (2008), it has been reported that bent tails may be due to derangement in the secretion of accessory fluids and may result from pH and osmotic tension of the semen extender used. The number of spermatozoa with bent tail defect was however inconsiderable and below 5%. According to Martin-Rillo *et al.* (1996), boar spermatozoa with a coiled tail, in excess of 5% disqualifies the semen sample. Moreover, tail loops most often arise in the tail of the epididymis and are associated with a persisting distal cytoplasmic droplet (Kondracki *et al.*, 2014). Hence, a bent tail is observed near the mid-piece ring (Bonet *et al.*, 1992).

4.5. Conclusions

In conclusion, there was a considerable variation in both macroscopic and microscopic semen characteristics. Furthermore, the values for boar spermatozoa motility, viability and morphologically normal spermatozoa were within the acceptable threshold. The use of CASA® technology permitted the accuracy and reliability (Am-in, 2005). However; the percentages for major and minor morphological defects were slightly higher than the acceptable values. Proximal and distal cytoplasmic droplets were the most frequent defects in the boar ejaculates. The CASA® technology showed great potential for routine boar evaluation as a measure of boar fertility for AI purposes.

CHAPTER 5
CONCEPTION RATE, FARROWING RATE, LITTER SIZE AND NUMBER OF PIGLETS BORN ALIVE FOLLOWING ART IN SMALLHOLDER FARMS

[3]

Matabane, M.B., Thomas, R., Netshirovha, T.R., Tsatsimpe, M., Ng'ambi, J.W., Nephawe, K.A. and Nedambale, T.L., 2017. Relationship between sperm plasma membrane integrity and morphology and fertility following artificial insemination. South African Journal of Animal Science 47 (1), 102-106.

Abstract

The objective of the study was to determine conception rate, farrowing rate, litter size and number of piglets born alive following AI at smallholder farms. Ejaculates were collected from three Large White boars that are routinely used for semen collection purposes using gloved-hand technique. The semen was extended with a commercial semen extender; Beltsville Thawing Solution, and the AI dose used consisted of 80 mL semen sample (3×10^9 spermatozoa/mL). A total of 73 multiparous sows were synchronized and artificially inseminated. Conception rates, farrowing rates, litter size and number born alive were recorded. The average conception and farrowing rates were 78.1 and 57.5%, respectively. Furthermore, AI resulted in acceptable fecundity (i.e., 11.8 litter size and 10.0 number of piglets born alive). There were significant differences ($P<0.05$) amongst the boars for conception and farrowing rates. In conclusion, satisfactory farrowing conception and farrowing rates with acceptable fecundity were achieved following AI at smallholder farms of Gauteng Province.

5.1. Introduction

High reproductive performance is crucial for optimal economic success in swine production (Gröhn & Rajala-Schultz, 2000). Assisted reproductive technologies such as artificial insemination (AI) offers opportunities for genetic improvements within the herds.This technology permits pig farmers to reduce production costs and rapidly introduce superior genetics (Singleton, 2001)). Currently, AI has largely replaced natural mating in commercial farms because adoption of AI technology into mating management decreases labour costs and improves the efficiency of boar use and space (Vazquez *et al.*, 2005). The proportions of sows that are receiving AI are approximately 82-85% in the USA (National Animal Health Monitoring system, 2007) and 85-90% in European swine industry (Vazquez *et al.*, 2005). South Africa is following a similar global trend of adopting AI with an estimation of 70-75% of mating done through AI (Gerrits *et al.*, 2005; Visser *et al.*, 2014). Kanhym is responsible for the majority of semen production (50%) in South Africa (Kanhym, 2013).

An important and commonly used measure of sow reproductive performance is farrowing rate. Under commercial conditions, it is generally accepted that a farrowing

rate of 85% is appropriate. According to Pig Champ. (2012), the average farrowing rate and litter size were 86.6% and 14, respectively. Furthermore, in the USA, farrowing rate and litter size of 83.6 and 13.4 were attained, respectively. Noteworthy, AI technology has been successfully implemented in smallholder pig farms at Nan province, northern Thailand and it has resulted in higher reproductive performance in terms of farrowing rates and number of piglets born (Am-in 2005, 2010). The objective of the present study was to determine sow fertility following AI at smallholder farms.

5.2. Materials and methods

5.2.1. Semen collection and processing

Three Large White boars, aged 18–24 months, which were genetically different, were used in the study to avoid inbreeding. Sixteen ejaculates were collected from the boars. The boars were housed individually in pens and routinely used for AI purposes. Sperm rich fractions were collected using the gloved-hand technique in a 300 mL glass beaker. The filtered semen fraction was sealed with a gauze filter inside a pre-warmed (39 °C) insulated thermos flask. Ejaculates with 70% sperm motility were extended with a commercial extender, Beltsville Thawing Solution, to 3×10^9 sperm/ml and stored at 17 °C until AI.

5.2.2. Oestrus synchronization and AI

The recipient sows were synchronised through the administration of 400 IU of Equine Chorionic Gonadotropin and 200 IU of Human Chorionic Gonadotropin intramuscular in the neck. Sow were monitored for heat twice a day (Figure 3.6 A). Sows that exhibited standing reflex were considered to be on estrus. Sows were inseminated twice, 12 and 24 hours after standing heat (Figure 3.6 B). Each AI dose consisted of 80 mL of extended semen containing 3×10^9 spermatozoa. Pregnancy diagnosis was done 42 days following AI using ultrasound scanner. Conception rate, farrowing rate, litter size and total born alive were recorded.

Figure 5.1. Heat detection (A) and AI (B)

5.2.3. Statistical analysis

Conception rate was expressed as the ratio of the number of sows that conceived / number of sows that were inseminated. The farrowing rate, expressed as the ratio of number of sows farrowed / number of sows inseminated. Litter size was expressed as the number of total piglets farrowed (live and dead). Data were analysed using SAS (SAS version 9.2, Cary, NC, U.S.A.). Descriptive statistics including the LSM, SEM and ranges of all reproductive performance data were calculated. The conception rate and farrowing rate were analysed by Chi-square tests. The litter size and number of piglets born alive were analysed by one-way ANOVA.

5.3. Results

The conception rate, farrowing rate, litter size and number of piglets born alive following oestrus synchronization and AI at smallholder farms of Gauteng Province are shown in Table 4.8. The average values for conception and farrowing rate were 78.1±0.1 and 57.5±0.1%, respectively. Furthermore, AI resulted in acceptable fecundity (i.e., 11.8 litter size and 10.0 number of piglets born alive).

Table 5.1. Sow fertility following ART at smallholder farms of Gauteng Province (LSM±SEM)

Variables	LSM±SEM	Minimum	Maximum
Conception rate	78.1±0.1	-	-
Farrowing rate	57.5±0.1	-	-
Litter size	11.8±0.8	4	25
Number of piglets born alive	10.0±0.6	3	15

Conception rate, farrowing rate, litter size and number of piglets born alive following ART at smallholder farms of Gauteng Province is shown in Table 5.2. On average, the conception and farrowing rates following oestrus synchronization and AI were 78.1 and 57.5%, respectively. However, conception and farrowing rates differed significantly amongst the boars. No significant differences (P>0.05) were found amongst the boars for litter size and number of piglets born alive

Table 5.2. Conception rate, farrowing rate, litter size and number of piglets born alive following ART at smallholder farms of Gauteng Province.

Variables	Boar 1	Boar 2	Boar 3	P-value
Number of sows inseminated	33	25	15	
Conception rate	63.6±0.3	88.0±0.1	93.3±0.1	<0.0001
Farrowing rate	48.4±0.3	55.3±0.3	80.0±0.3	0.0022
Litter size	11.6±6.2	10.9±5.9	13.0±8.2	0.3270
Number of piglets born alive	10.1±5.5	9.4±5.3	11.0±5.7	0.4888

5.4. Discussion

A commonly used measure of sow herd reproductive performance is farrowing rate (Koketsu *et al*., 1997), which is defined as the proportion of sows/gilts served that farrow (Dial *et al*., 1992). A farrowing rate of 85% is an appropriate target under commercial conditions (Gadea *et al*., 2004). For herds that are trying to achieve 30 pigs/sow/year, it has been recommended that a farrowing rate of 85% to 90% is an appropriate target (Gill, 2007; Knox, 2005). Therefore, in the present study, ejaculates

were catgorized according to the farrowing rate and the threshold value of 85% were selected because it is a common target value for a great number of commercial farms (Gadea *et al.*, 2004).

In the present study, an average conception rate of 78.1% was achieved. Similar results were reported following AI under smallholder production systems at north-eastern India (Kadirvel *et al.*, 2013). On average, the farrowing rates following oestrus synchronization and AI was 57.5%. The farrowing rate reported in the present study was lower compared to the average farrowing rate at commercial pig farms at USA, Europe and Serbia (Young *et al.*, 2010; Stančić *et al.*, 2009; 2013). The AI resulted in an acceptable fecundity (i.e., 11.8 litter size and 10.0 number of piglets born alive). In contrast, lower average litter sizes were achieved at north-eastern India following AI (Kadirvel *et al.*, 2013). Although the conception and farrowing rates following AI with different tested boar sperm varied, the litter size and number of piglets born alive did not differ significantly among boars.

Am-in *et al.* (2010) reported that AI resulted in a significantly improved fertility as compared to natural mating in backyard pig farmers of Thailand. Therefore, the study clearly demonstrated that AI in pigs could be feasible in smallholder pig production systems without negatively affecting the farrowing rate and litter size. It was found in our previous studies that AI provided a higher farrowing rates than natural mating in smallholder pig production systems (Am-in 2005; 2010; Techakumphu *et al.*, 2007, 2008) because in cases of AI, semen was regularly evaluated compared to non-evaluated semen in natural mating (Am-in 2005; 2010; Techakumphu *et al.*, 2005). There were no significant differences observed for litter size and number of piglets born alive. According to Tsakmakidis *et al.* (2010), high farrowing rate does not translate to a high litter size. Furthermore, Tsakmakidis *et al.* (2010) suggested that farrowing rate and litter size are vital indicators' of the herds' productivity. However, these two factors cannot evaluate boar fertility without evaluation of boar spermatozoa quality.

5.5. Conclusions

The AI technology was an effective tool in propagation and dissemination of superior germplasm at smallholder pig farms in Gauteng Province. Furthermore, acceptable fecundity in relation to litter size and the number of piglets born alive were achieved.

CHAPTER 6

RELATIONSHIP BETWEEN SEMEN CHARACTERISTICS AND SOW FERTILITY AT SMALLHOLDER FARMS

4

Matabane, M.B., Nethenzheni, P., Thomas, R., Norris, D, K., Tsatsimpe, M. and Nedambale, T.L. (2016). Relationship between boar sperm traits and fertility rate following artificial insemination under smallholder production systems. Reproduction, Fertility and Development 29(1), 119 (Abstract).

Abstract

The prediction of spermatozoa fertility has a great economic importance to the pig breeding industry. The objective of the study was to determine the relationship between boar spermatozoa quality and field fertility following artificial insemination (AI) under smallholder production systems. Ejaculates were collected from three breeding boars using a hand gloved technique. Aliquots of diluted semen were assessed for sperm motility using a computer aided sperm analysis (CASA®) prior artificial insemination. Spermatozoa viability was evaluated using Synthetic Binding CD-14 (SYBR-14+)/Propidium Iodide (PI-), whereas spermatozoa morphology was evaluated using Eosin Nigrosin staining. Fluorescent microscope was used at 100x magnification to count 200 sperm per each stained slide. The semen was extended with a commercial extender and contained 3×10^9 spermatozoa/dose. A total of 73 multiparous sows were inseminated twice. Fertility was measured by conception rate, farrowing rate, litter size and number of piglets born alive were recorded following AI. A Pearson's correlation was used to examine the relationships between sperm quality traits and fertility using PROC CORR procedures of SAS. Total, progressive and rapid sperm motility differed significantly ($P<0.05$) among the boars. However, no significant differences were found for sperm velocity parameters. The mean values for morphologically normal sperm ranging from 47.8-60.9% and live sperm ranging from 71.8-77.2% did not differ significantly among the boars ($P>0.05$). Conception rate from different boars varied ($P<0.05$) from 63.6 to 93.3%. Of all fertility traits studied, conception rate was significantly related to total sperm motility rate ($r= 0.34$, $P<0.0029$), progressive motility ($r= 0.29$, $P<0.0141$) and rapid motility ($r= 0.34$, $P<0.0032$). There was a low positive relationship between morphologically normal and fertility ($P>0.05$). In conclusion, total, progressive and rapid sperm motility rate were the only sperm traits significantly related to conception rate. Conversely, litter size and number born alive were not correlated with spermatozoa motility, viability and all morphology traits.

6.1. Introduction

Improving the qualitative and quantitative analysis of boar semen samples to estimate fertility potential of males is critical for a successful breeding programme. Although

much progress has been made, the ability to predict the fertility of semen with traditional laboratory tests is still limited, owing mainly to the complexity of spermatozoa morphological damage and their fertilization potential (Brito *et al.*, 2003). In addition, the prediction of sperm fertilizing ability is of great economic importance to breeding of sows as it leads to the selection of boars with better semen fertility, which results in good reproductive performance. Semen fertility trait assessments play a crucial role in the early detection of developmental disorders in male animals (Smital *et al.*, 2004). As well as traditional methods of semen assessment, biochemical tests and morphological analyses of spermatozoa are performed. Disturbances in spermatogenesis give rise to morphological sperm defects (Kavak *et al.*, 2004). Moreover, recent studies have indicated a correlation between normal morphological traits, conception rate, and litter size, which are particularly sensitive to normal head morphology (Gadea, 2005).

Another reliable approach is to use a combination of tests to evaluate various spermatozoa attributes, thereby increasing the accuracy of the prediction (Amann & Hammerstedt, 1993). Assessment of spermatozoa plasma membrane integrity is one of the key parameters in the evaluation of spermatozoa quality in relation to fertility (Pintado *et al.*, 2000). One of the major features discriminating dead cells from live ones is loss in physical integrity of their plasma membranes and loss of motility (Burks & Sailing, 1992). Spermatozoa outer membrane integrity and proper function are vital to sperm metabolism, capacitation, ova binding, and acrosome reaction (Brito *et al.*, 2003). Hence, assessment of spermatozoa morphology and plasma membrane integrity traits may be useful in predicting the fertilizing ability of sperm. The objective of the study was therefore to determine the relationship between boar spermatozoa morphological traits and fertility after AI.

6.2. Materials and methods

6.2.1. Study location

The study was conducted at the Pig Research Unit and Germplasm Conservation and Reproductive Biotechnologies Unit in Agricultural Research Council (ARC), South

Africa. The ARC campus is located at 25° 55" south; 28° 12" east. The institute is located in the Highveld region of South Africa and situated at an altitude of 1525 m above sea level. All procedures in the study that involved animals were performed in accordance with the ethical standards of the Agricultural Research Council (reference APIEC15-046).

6.2.2. Semen collection and processing

Three Large White boars, aged 18–24 months, which were unrelated, were used in the study to avoid inbreeding. A total of 16 ejaculates were collected from the boars. The boars were housed individually in pens and routinely used for AI purposes. Spermatozoa rich fractions were collected using the gloved-hand technique in a 300 mL glass beaker. The filtered semen fraction was sealed with a gauze filter inside a pre-warmed (39 °C) insulated thermos flask. Ejaculates with 70% sperm motility were extended with a commercial extender, Beltsville Thawing Solution, to 3 x 10^9 spermatozoa/dose and stored at 17 °C until AI.

6.2.3. Boar spermatozoa motility evaluation

For boar sperm motility, 10 µl of semen from each boar was placed into 500 µl of Bracket and Olifant wash medium in 15 mL tube. The tube with semen was incubated in 39°C CO_2 incubator for five minutes. Five micro litres of the boar semen placed in a Leja chamber slide (20 µm deep and 5µl volume). The Leja chamber slide (Leja® Products B.V., Nieuw Vennop, Netherlands) then placed on to a temperature-controlled stage of the Nikon E50i microscope (IMP, Cape Town, South Africa). A 10X negative phase contrast objective in conjunction with a phase contrast condenser was used by means of a computer aided sperm analysis® (CASA®) and the Sperm Class Analyzer® (Microptic, S.L., Barcelona, Spin, Version 4.2) at a frame rate of 50 frames per second. The spermatozoa motility rates were evaluated by SCA® at the magnification of 10x. A minimum of five fields per a chamber will be recorded.

6.2.4. Plasma membrane integrity evaluation

Plasma membrane integrity was assessed using synthetic binding CD-R 14/propidium iodide (SYBR-14/PI) tests (Garner & Johnson, 1995). Briefly, semen samples were incubated at 38 °C for 10 minutes with SYBR-14 at a final concentration of 100 µM, and then with PI at a final concentration of 10 µM for 5 minutes at the same temperature. A fluorescent microscope was used at 100 x magnification to count 200 sperm per stained slide and the results were recorded. After this assessment, two sperm populations were identified: live green-stained spermatozoa (SYBR-14+/PI-); and dead red-stained sperm (SYBR-14-/PI+).

6.2.5. Spermatozoa morphology evaluation

Spermatozoa morphology was determined microscopically after staining the semen samples with eosin nigrosin stain on a slide (Tsakmakidis *et al.*, 2010). Briefly, 7µL of boar semen was added to 20µL eosin nigrosin staining solution in a 0.6 mL micro-centrifuge graduated tube and mixed gently. A drop of 5µL boar semen and Eosin Nigrosin stain was placed on a clear end of a microscope slide and smeared. Fluorescent microscope was used at 100 x magnification to count 200 spermatozoa per stained slide and the results were recorded. Morphological defects were recorded and were categorized into major and minor sperm morphological defects according to the classification system by Salisbury *et al.* (1978). Briefly, the major morphological defects included loose head, proximal cytoplasmic droplets, and midpiece reflexes, whereas minor defects included distal cytoplasmic droplets and bent tails.

6.2.6. Oestrus synchronization and AI

A total of 73 Duroc-type, Large White and nondescript multiparous sows from nine smallholder farms in Gauteng were used in the study, these are Winterveldt (17), Cullinan (6), Rooival (8), Zuurbekom (26), Randfontein (5), Midvaal (2), Meyerton (2), Brakpan (5), and Bendaro Park (2). The boar to sow ratio was 1 : 33, 1 : 25 and 1 : 15. Before AI, the recipient sows were synchronised by administering 400 IU equine chorionic gonadotropin and 200 IU human chorionic gonadotropin intramuscularly in the neck. Each sow was checked for estrus twice a day. Sows were further stimulated by back pressure and inseminated twice, 12 and 24 hours after standing heat. Each AI dose consisted of 80 mL semen containing 3×10^9 spermatozoa/dose. Pregnancy

diagnosis was done 42 days after artificial insemination with an ultrasound scanner. Conception rate, farrowing rate, litter size and total of piglets born alive were recorded.

6.2.7. Statistical analysis

First, the boar ejaculates were categorized according to the farrowing rate, the threshold value of 85% was selected as it is a common target value at commercial farms (Gadea *et al.*, 2004). Values at *P*<0.05 were considered significantly different. A Pearson's correlation was used to determine the relationship between spermatozoa quality characteristics and fertility using PROC CORR procedures of SAS version 9.4 (SAS, 2012).

6.3. Results

Statistical analysis of spermatozoa quality characteristics and fertility outcomes following AI are shown in Table 6.1. The boar ejaculated were categorized according to fertility rate (low farrowing rate <85% and high farrowing rate >85%). Semen characteristics were evaluated and the differences between the fertility categories were evaluated. The mean values of conception rate obtained in the two categories of sows were significantly different (93.3% vs 47.5%, P<0.001). No significant differences were found for total spermatozoa motility, progressive motility and rapid moving spermatozoa between both fertility categories. For spermatozoa kinematic characteristics, significant differences were found for VSL between high and low fertility (P<0.0210) and VAP (P<0.0283). Furthermore, there were significant differences between high and low fertility for ALH (P<0.0353) and BCF (P<0.0144). The high fertility group had significantly higher percentages of morphologically normal spermatozoa. Furthermore, major and minor spermatozoa defects were significantly higher in the low fertility group.

Table 6.1. Semen measurements and reproduction results allocated into two groups according to conception rate (LSM±SEM)

Variables	Low fertility (>80% farrowing rate)	High fertility (<80% farrowing rate)	P value
TM (%)	95.1±0.5	95.1±0.9	0.9753
PM (%)	27.8±1.6	29.2±0.8	0.4214
RAP (%)	24.6±1.0	24.6±2.1	0.9935
VCL (µm/sec)	65.3±4.3	76.5±2.1	0.0210
VSL (µm/sec)	28.6±1.6	22.4±3.3	0.0969
VAP (µm/sec)	36.6±3.5	45.4±1.7	0.0283
LIN (%)	36.5±1.4	34.6±2.9	0.5570
STR (%)	61.3±1.4	60.8±2.8	0.8636
WOB (%)	58.7±1.0	56.0±2.0	0.2211
ALH (µm)	3.6±0.1	3.9±0.1	0.0353
BCF (Hz)	11.7±0.4	9.3±0.9	0.0144
SYBR-14+ (%)	76.6±1.4	71.4±2.8	0.0948
Normal spermatozoa (%)	52.1±1.4	62.9±2.3	0.0012
Major defects (%)	13.5±0.8	13.5±1.6	0.0320
Minor defects (%)	12.1±0.7	7.4±1.5	0.0080
Farrowing rate (%)	47.5	80	<0.001
Litter size	11.1±0.8	13.0±1.1	0.1568
Number of piglets born alive	10.0±0.6	9.9±0.8	0.9447

TM (total motility), PM (progressive motility), RAP (Rapid), VCL (curvilinear velocity), VSL (velocity on the straight line), VAP (velocity on the average path), LIN (linearity), STR (straightness), ALH (Lateral head displacement), BCF (beat cross frequency).

Pearson's rank correlation of boar spermatozoa motility and fertility following AI are indicated in Table 6.2. Significant correlations were found between spermatozoa motility characteristics and fertility outcomes. Of all the spermatozoa motility characteristics studied, conception rate was the only fertility characteristic significantly correlated to total spermatozoa motility (r= 0.37, P<0.0012), progressive motility (r=

0.31, *P*<0.0084) and rapid motility (r= 0.40, *P*<0.0005), although relatively low. Furthermore, there was a non-significant correlation between spermatozoa motility characteristics and farrowing rate. There were no significant correlations found between CASA® kinematics characteristics and litter size as well as number of piglets born alive. However, significant correlations were found between WOB and conception rate (r= -0.24). There was a negative correlation between live spermatozoa morphology and conception rate (r= -0.07) and farrowing rate (r= -0.08), although relatively low and not statistically significant. No significant correlation was found between live spermatozoa and litter size (r= 0.12) and number of litter born alive (r= 0.10). There was a relatively low correlation between normal morphological spermatozoa and all the fertility characteristics. Moreover, there was a negative correlation between major morphological defects and fertility characteristics, although relative low and not statistically significant. Furthermore, relatively low negative correlations were found between minor morphological defects and litter size as well as number of piglets born alive.

Table 6.2. Pearson's correlation coefficients (r) between spermatozoa quality and sow fertility characteristics

Variables	TM (%)	PM (%)	RAP (%)	VCL (µm/sec)	VSL (µm/sec)	VAP (µm/sec)	LIN (%)	STR (%)	WOB (%)	ALH (µm)	BCF (Hz)	Live-SYBR+ (%)	Normal (%)	Major defects (%)	Minor defects (%)
Conception rate	0.37**	0.31*	0.40**	0.11	-0.01	-0.01	-0.17	-0.10	-0.24*	-0.01	0.09	-0.07	0.03	0.06	0.02
Farrowing rate	0.07	-0.03	0.20	0.02	-0.13	-0.06	-0.12	-0.15	-0.13	-0.20	-0.09	-0.08	0.12	-0.15	0.00
Litter size	0.15	0.02	0.04	0.21	0.13	-0.20	0.03	0.06	0.13	0.19	0.17	-0.12	0.03	-0.12	-0.02
Number born alive	0.16	0.06	0.10	0.13	0.13	0.17	0.10	0.01	-0.18	0.22	0.14	-0.10	0.03	-0.14	-0.02

TM (total motility), PM (progressive motility), RAP (Rapid), MED (medium), SLW (slow), VCL (curvilinear velocity), VSL (velocity on the straight line), VAP (velocity on the average path), LIN (linearity), STR (straightness), ALH (Lateral head displacement), BCF (beat cross frequency). $^*P < 0.05$, $^*P < 0.01$.

6.4. Discussion

The relationship between laboratory spermatozoa characteristics and fertility has been extensively discussed and studied (Holt *et al.*, 1997; Gadea *et al.*, 1998; Tardif *et al.*, 1999; Januskauskas *et al.*, 2001; Selles *et al.*, 2003; Alm *et al.*, 2006). The differences might have been attributed to differences in experimental conditions and breed effect. Additionally, it has been reported that boar spermatozoa motility evaluation is subject to great intra- and inter-observer variability. However, it has been reported that traditional methods of semen evaluation have low potential in predicting spermatozoa fertility, because only the samples with markedly inferior quality can be detected (Gadea, 2005).

Of all the characteristics studied in the present study, only total spermatozoa motility, progressive and rapid moving spermatozoa motility were significantly correlated with conception rate. Progressive spermatozoa motility has been reported to be a good indicator of spermatozoa fertility and was highly correlated with oocyte penetration rates (Flowers & Turner, 1997; Xu *et al.*, 1996). Significant correlations were reported between progressive spermatozoa motility and farrowing rate (Broekhuijse *et al.*, 2011). However, according to Broekhuijse *et al.* (2012), progressive motility has not been related to fertility. This may be attributed to the fact that progressive motility depends on cut-off values for basic characteristics, which vary for different CASA® systems (Broekhuijse *et al.*, 2012).

A positive correlation was found between total spermatozoa motility and litter size as well as the number of piglets born alive in the present study, although not statistically significant. Similarly, Kwon *et al.* (2015) reported that spermatozoa motility and kinematic motions showed a statistically non-significant correlation with litter size. These findings may be attributed to the sow effect and foetal survivability. In contrast, spermatozoa motility was associated with both litter size and number of piglets born alive (Broekhuijse *et al.*, 2011; Vyt *et al.*, 2008). Several studies have further determined the relationship between spermatozoa motility and litter size by assessing spermatozoa motility visually or under laboratory conditions (Gadea *et al.*, 2004; Tardif *et al.*, 1999). These contradictory findings may be due to individual boar differences causing variability in the association between boar spermatozoa motility and fertility

estimates (Popwell & Flowers, 2004). According to Lima *et al.* (2015), boar semen with high total motility spermatozoa may be expected to produce a higher number of piglets born and a higher rate of live-born piglets per litter. Although boar spermatozoa motility and kinetic characteristics cannot be considered as reliable indicators for the fertilizing potential (Krause, 1995; MacLeod & Irvine, 1995), boar spermatozoa with low or altered movement will be unable to reach the oviduct. Thus, it is realistic to presume that high percentages of progressive spermatozoa will reach the ampulla of the oviduct for fertilization to take place (Muino *et al.*, 2008).

Kinematic motion analyses using CASA$^\circledR$ have shown variable associations between particular motility patterns, such as linearity and field fertility (Bailey *et al.*, 1994; Holt *et al.*, 1997; Hirai *et al.*, 2001; Januskauskas *et al.*, 2001; 2003; Broekhuijse *et al.*, 2012). Although no significant correlations were found between boar spermatozoa velocity characteristics and fertility in the present study, it has been proven that the progressive sperm motility velocities, such as VCL, VSL and VAP correlate with fertilisation rates in African catfish (Rurangwa *et al.*, 2001) and turbot (Dreanno *et al.*, 1999), carp (Linhart *et al.*, 2000) and Rainbow trout (Lahnsteiner, 2000). Furthermore, VSL has been highly correlated with fertility in rats (Moore & Akhondi, 1996) and boars (Holt *et al.*, 1997). In the present study, a low positive correlation was observed between VSL and litter size. Similarly, a relationship between VSL and litter size was shown in other studies (Holt *et al.*, 1997). In contrast, a negative relationship was found between VSL and litter size (Broekhuijse *et al.*, 2012). According to Lui *et al.* (1991), increases in VSL enables the spermatozoa to better fertilize the oocyte.

It has been reported that VAP is a spermatozoa motility parameter that is required in boar semen processed for AI purposes (Broekhuijse *et al.*, 2012). In the study done by Holt *et al.*, 1997, VAP was 47.2 µm/sec, which is slightly higher than that observed in the present study (43.7 µm/sec). The reason may be that CASA$^\circledR$ is dependent on the type of equipment and the settings of the instrument (Holt *et al.*, 1994, 1996). Similarly, the margins or threshold levels used to define spermatozoa subpopulations may vary between laboratories (Hirai *et al.*, 2001). In the present study, a low positive correlation was observed between VAP and litter size. Similarly, a positive correlation

was observed between VAP and litter size (Hirai *et al.*, 2001; Gadea *et al.*, 2004; Broekhuijse *et al.*, 2012).

In the present study, there were no significant correlations between ALH and fertility characteristics. This is in agreement with several studies that showed that ALH is not correlated with farrowing rate (Didion, 2008; Fietsma *et al.*, 2009) and a lack of correlation with litter size (Oh *et al.*, 2010). It is expected that ALH values of refrigerated boar semen be low and it has also been reported previously that ALH was an imperative spermatozoa motility characteristic attained during spermatozoa capacitation and required to accomplish penetration of fertilization barriers surrounding the oocyte (Gadea, 2005; Gil *et al.*, 2009). Hence, ALH may be crucial during penetration thus implying a positive association with fertility, which was shown in the present study. In the present study, a positive relationship was found between ALH and litter size. However, the correlation was relatively low and not statistically significant.

The BCF is a useful spermatozoa characteristic in estimating gross variations in the flagella beat pattern (Selles *et al.*, 2003). In the present study, no significant correlation was found between BCF and fertility. Similarly, it was reported that BCF was not correlated to fertility (Budworth *et al.*, 1988; Lui *et al.*, 1991). In contrast, Broekhuijse *et al.* (2015), reported that a significant but negative relationship existed between BCF and farrowing rate. The negative relationship demonstrated that during spermatozoa motility assessment, spermatozoa do not yet use their beating function. Furthermore, Gil *et al.* (2009) suggested that the beating should be saved until the moment of penetration of the zona pellucida.

The intact nature of the spermatozoa plasma membrane is a requirement for proper spermatozoa metabolism and function. In the present study, negative correlations were found between viable spermatozoa using SYBR-14^{+} staining and fertility. Similarly, it was reported that spermatozoa membrane structure is not closely associated to fertility (Gadea *et al.*, 2004; Gadea, 2005), perhaps due to the fact that it provides information about the viability of the spermatozoa but not about its functionality such as capacitation, acrosome reaction, spermatozoa binding, etc.

Similarly, Januskauskas *et al.* (2003) identified significant correlations between field fertility and plasma membrane integrity. In the present study, a relatively low negative correlation was found between boar spermatozoa viability and litter size as well as number of piglets born alive. Similarly, boar spermatozoa viability was not correlated to fertility when Eosin Nigrosin staining were used to assess spermatozoa viability (Gadea *et al.*, 2004; Lima *et al.*, 2015). In contrast, spermatozoa viability of microscopically assessed Calcein AM and PI stained spermatozoa correlated significantly with litter size (Sutkeviciene *et al.*, 2009).

Previous studies have reported significant relationships between spermatozoa morphology and field fertility (Amann *et al.*, 2000; Johnson, 1997). There was a low negative relationship between conception rate and morphologically normal spermatozoa. Correspondingly, boar spermatozoa morphology has limited predictive value to field fertility (Alm *et al.*, 2006). Although low negative relationships were found between fertility and major morphological defects, Waberski *et al.* (1990) concluded that spermatozoa morphology may assist with boar selection for AI as it provided information on the subject of spermatogenesis.

In the present study, a low positive correlation was found between normal morphological spermatozoa and litter size and number of piglets born alive. In contrast, a significant correlation was found between normal morphological spermatozoa and litter size (Xu *et al.*, 1998; Lima *et al.*, 2015). In the present study, a low negative correlation existed between minor spermatozoa defects and conception rate, litter size and number of piglets born alive. Several articles have reported significant associations between fertility and incidences of specific morphological defects, such as abnormal heads and proximal cytoplasmic droplets, all of which are major spermatozoa defects (Waberski *et al.*, 1994b; Johnson, 1997; Amann *et al.*, 2000).

6.5. Conclusions

Of all spermatozoa motility characteristics studied, total spermatozoa motility, progressive and rapid spermatozoa motility were correlated with conception rate. Conversely, litter size and number born alive were not correlated with CASA®

spermatozoa motility attributes. There was a negative relationship between sperm plasma membrane integrity and fertility following AI. However, there was a relationship between morphologically normal sperm and litter size as well as number of piglets born alive, although relatively low. A negative relationship was observed between major and minor morphological defects with conception rate. Conversely, a positive relationship was found between major and minor defects with litter size and number of piglets born alive, although relatively low. It is thus recommended to further establish a novel method for diagnosing male fertility based on conventional semen analysis prior to and post capacitation.

CHAPTER 7

PRE-WEANING GROWTH PERFORMANCE OF PIGLETS BORN FOLLOWING ARTIFICIAL INSEMINATION (AI) AT SMALLHOLDER FARMS OF GAUTENG PROVINCE

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Matabane, M.B., Thomas, R., Netshirovha, T.R., Tsatsimpe, M., Ng'ambi J.W., Nephawe, K.A. and Nedambale T.L. (2018). Pre-weaning growth performance of piglets at smallholder farms in Gauteng Province. *Journal of Agricultural Science* 10 (4): 18–23.

Abstract

The objective of the study was to determine the pre-weaning growth performance of piglets born following artificial insemination (AI) at smallholder farms of Gauteng province. Data from 496 piglets originating from 73 multiparous crossbred sows were used in the study. Growth performance characteristics were recorded from the litter. Data was analysed using the Proc Univariate procedure of SAS. The average litter size was 11.8 ± 0.2. The average birth weight and weaning weights were 1.9 and 6.2 kg, respectively. No significant differences were found between male and female piglets for all the growth performance characteristics. Piglets born during winter had a significantly higher ($P<0.05$) birth and weaning weight as compared to autumn and summer months. Season had a significant effect on birth and weaning weight ($P<0.01$). However, sex of piglets had no significant effect on all the characteristics recorded ($P>0.05$). The interaction between sex and season was only confirmed on the total number of weaned piglets ($P<0.01$). A highly significant positive correlation was found between litter size and number of piglets born alive ($r= 0.86$) and total number of piglets weaned ($r= 0.50$). A highly significant correlation was found between total number of piglets born alive and total number of piglets weaned ($r= 0.55$). In conclusion, season had an influence on birth to weaning weight. However, sex had no significant influence at birth and weaning weight. Litter size affects the number of piglets born alive and weaned.

7.1. Introduction

The South African pig industry is relatively small in terms of the total South African agricultural sector contributing only 2.05% to the primary agricultural sector (DAFF, 2015). Furthermore, South Africa contributes approximately 0.2% of the world pig population (Muchenje & Ndou, 2010). According to Phiri *et al.* (2003), South Africa has the highest pig populations in southern Africa and 25% are free ranging in the resource-poor areas (Krecek *et al.*, 2004). According to Harvey *et al.* (2014), smallholder farmers depend on agriculture for their livelihoods and have limited resources, hence any decline in agricultural productivity may have a significant impact on their food security, nutrition and income. Pigs are of high economic importance, especially among the resource-poor as they contribute to human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for the

rural community (Antwi & Seahlodi, 2011). However, reproductive performance of pigs in smallholder systems is typically poor due limited access to superior germplasm (Phengsavanh & Ogle, 2010). Therefore, advances in reproductive technologies such as artificial insemination (AI) offers unprecedented opportunities for livestock improvement for smallholder pig farmers (Rege *et al.*, 2011).

One of the major reasons for introducing the improved breeds of pigs through AI is to facilitate the dissemination of superior germplasm (Okwun *et al.*, 1996). Conversely, sow productivity is dependent on the sow's ability to produce piglets that survive to weaning (Fix *et al.*, 2010). Selection for maximum prolificacy has resulted in an increase in litter size at birth and additional piglets weaned per litter. There are different factors that have been shown to be associated such as nutrition, season of birth, diseases, stress, dam's age and parity, social status, levels of different hormones, type and time of insemination, population demography, etc. (Chandler *et al*, 1998; Rorie *et al.*, 1999; James, 2001). However, seasonal infertility remains problematic.

Season is one of the most important environmental factors directly affecting the reproductive performance of pigs (Love *et al.*, 1993). It has a direct impact on litter size and piglet survival after birth (Tummaruk *et al.*, 2010). Additionally, it may affect results in the rearing of piglets due to heat stress and feed intake during lactation. Within the season, temperature variation and photoperiodic reaction are considered the main causes influencing fertility (Knecht *et al.*, 2015), although the resistance of individuals is dependent on the breed (Wysoki´nska & Kondracki, 2013). The sex of the offspring also influences the growth performance of piglets (Peaker & Taylor, 1996). It also plays an integral role in the growth rate of the developing foetus. Alfonso. (2005) reported that at birth male piglets tended to be heavier than female piglets. This may be due to hormonal differences between males and females and subsequent effects of foetal growth. Therefore, the objective of the study was to determine the effect of sex and season on pre-weaning performance of piglets following AI at smallholder farms in Gauteng Province.

7.2. Materials and methods

7.2.1. Location and Study site

The study was conducted at the Pig Research Unit and Germplasm Conservation and Reproductive Biotechnologies Unit in Agricultural Research Council (ARC), South Africa. The ARC campus is located at 25° 55" South; 28° 12" East. The institute is located in the Highveld region of South Africa and situated at an altitude of 1525m above sea level. For oestrus synchronization and AI, the study was conducted at nine smallholder farms of Gauteng Province based on the availability of breeding sows, namely Winterveldt, Cullinan, Rooival, Zuurbekom, Randfontein, Midvaal, Meyerton, Brakpan and Bendaro Park. December to February were grouped as summer months, March to May were grouped as autumn months and June to August were grouped as winter months. All procedures performed in the study involving humans and animals were in accordance with the ethical standards of the University of Limpopo and the ARC (ARC Reference: APIEC15-046).

7.2.2. Pigs and Experimental Design

A total of 73 multiparous sows were synchronised by administering 400 IU of Equine Chorionic Gonadotropin and 200 IU of Human Chorionic Gonadotropin intramuscular in the neck. Each sow was checked for heat twice a day. Sows were further stimulated by back pressure and inseminated twice, 12 and 24 hours after standing heat. Each AI dose consisted of 80 mL of extended semen containing 3×10^9 spermatozoa/dose. Pregnancy diagnosis was done 42 days following artificial insemination using ultrasound scanner. Conception rate, farrowing rate, litter size and total born alive were recorded. The production performance of 73 crossbred sows and their litter were collected for a period of two years from the records maintained at smallholder pig farms. The piglets were weighed with a weighing scale from birth to weaning. The average litter size, number of piglets born alive, sex as well as the birth and weaning weight were recorded. A complete randomized block design to account for potential environmental variations at the different smallholder pig farms was used in the study,

whereby a total of 73 multiparous sows were assigned randomly to the boars and artificially inseminated.

7.2.3. Statistical Analysis

Data were analysed using the PROC UNIVARIATE procedure. Pearson correlation coefficients was used to determine the relationship between litter size, total number of piglets born alive, total number of piglets weaned, birth and weaning weight. Data was presented as least square mean ± standard error. Differences were considered significant at $P<0.05$.

7.3. Results

Descriptive productivity of piglets following AI at smallholder farms are indicated in Table 7.1. The average litter size was 11.8 based on the sample of 496 piglets. Furthermore, the number of piglets born alive was 10.2 and 9.5 for number piglets weaned. The average birth weight was 1.9 kg ranging from 0.8 to 2.4 kg. Moreover, the average weaning weight was 6.2 ranging from 2.9 to 12.2 kg.

Table 7.1. Descriptive productivity of piglets following AI at smallholder farms (LSM±SEM)

Characteristics	Average	Minimum	Maximum
Litter size	11.8±3.5	4	20
Total number of live born piglets	10.2±3.1	3	18
Total number of weaned piglets	9.5±3.1	0	15
Birth weight (kg)	1.9±0.7	0.8	2.4
21-day weight (kg)	3.3±1.0	1.8	6.2
Weaning weight (kg)	6.2±2.2	2.9	12.2

Individual boar fertility and progeny growth performance following AI is indicated in **Table 7.2**. There was no significant difference ($P>0.05$) amongst the boars for litter size, total number of live born piglets as well as total number of weaned piglets.

However, there was a significant difference (P<0.05) amongst the boars for birth and weaning weight.

Table 7.2. Individual boar fertility and progeny growth performance following AI (mean±SD)

Characteristics	Boar 1	Boar 2	Boar 3	P-value
Sex ratio percentage (female: male)	58:42 %	44:56%	63:37%	-
Litter size	11.6±6.2	10.9±5.9	13.0±8.2	0.3270
Total number of live born piglets	10.1±5.5	9.4±5.3	11.0±5.7	0.4888
Total number of weaned piglets	8.6±4.2	9.2±1.8	8.6±3.2	0.1483
Birth weight (kg)	2.1±0.1	1.7±0.1	1.9±0.1	0.0123
Weaning weight (kg)	7.7±0.2	3.5±0.2	4.9±0.2	<0.0001

Detailed results of the growth performance following AI at smallholder farms are indicated in Table 7.3. The sex ratio percentage of piglets born following AI was 52:48% (females: males). No significant differences (P>0.05) were found between males and females for all the growth performance characteristics. The average litter size for males and females was 11.8 and 10.8, respectively. The birth weight for both male and female piglets was 1.9 kg.

Table 7.3. Growth performance of males and female piglets following AI at smallholder farms (LSM±SEM)

Characteristics	Females	Males
Sex ratio percentage (%)	52	48
Litter size	11.8±4.1	10.8±4.1
Total number of live born piglets	10.9±2.7	9.9±4.1
Total number of weaned piglets	9.1±3.9	8.5±2.7
Birth weight (kg)	1.9±0.6	1.9±0.7
Weaning weight (kg)	6.0±2.3	6.3±2.1

Detailed results of the effect of season on litter size, total number of born alive piglets, total number of weaned piglets, birth and weaning mortalities and birth, 21-day and

weaning weights are shown in Table 7.4. Season had no significant effect (P>0.05) on the litter size, total piglets born alive at birth and total number of piglets at weaning. Furthermore, there was no significant difference (P>0.05) between the average number of piglets born and weaned during the different seasons. However, piglets born in winter had a significantly higher (P<0.05) birth, 21-day and weaning weight as compared to autumn and summer.

Table 7.4. The effect of season on subsequent growth performance of piglets following AI at smallholder farms in Gauteng Province (n=496)

Seasons	Litter size	Total number of live born piglets	Total number of weaned piglets	Birth weight (kg)	21-day weight (kg)	Weaning weight (kg)
Autumn	13.3±6.5	11.3±3.8	10.3±3.1	1.7±0.9[b]	3.3±1.0[a]	4.6±0.4[b]
Summer	10.6±3.9	10.5±3.9	8.3±2.0	1.9±0.6[b]	3.1±1.1[a]	4.2±1.2[b]
Winter	11.0±3.2	9.7±3.1	8.4±4.4	2.2±0.4[a]	4.4±1.0[b]	6.2±1.1[a]

[ab]Means with different superscripts in the same column differ significantly, *P*<0.05.

Pearson correlation coefficients between litter size, total number of piglets born alive, total number of piglets weaned, birth, 21-days and weaning weight are shown in Table 7.5. A highly significant positive correlation was found between litter size and number born alive (r= 0.86, P<0.01) and total number of piglets weaned (r= 0.50, P<0.05). However, a relatively low correction (P>0.05) was found between litter size and birth (r= 0.34) and weaning weight (r= 0.22). There was also a significant correlation between total number of piglets born alive and total number of piglets weaned (r= 0.55, P<0.05). A low negative correlation was observed between the total number of piglets weaned and birth weight (r= -0.07) and weaning weight (r= -0.20), although insignificant.

Table 7.5. Pearson correlation coefficients between litter size, total number of piglets born alive, total number of piglets weaned, birth and weaning weight

Characteristics	Litter size	Total number of live born piglets	Total number of weaned piglets	Birth weight (kg)	Weaning weight (kg)
Litter size	1.00				
Total number of live born piglets	0.86 **	1.00			
Total number of weaned piglets	0.50 *	0.55 *	1.00		
Birth weight (kg)	0.34	0.28	-0.07	1.00	
Weaning weight (kg)	0.23	0.11	-0.20	0.50 **	1.00

*P<0.05; **P<0.01.

The significant impact of season and sex for all the evaluated characteristics are shown in Table 7.6. The highest seasonal impact was found for birth, 21-day and weaning weight during winter (P<0.01). Sex had no effect on all the evaluated characteristics recorded (P>0.05). The interaction between the factors studies was only confirmed on the total number of weaned piglets (P<0.01).

Table 7.6. The impact of the season and sex and interaction of these factors on selected productive performance characteristics of the piglets at smallholder farms (n=496)

Factor	Litter size	Total number of live born piglets	Total number of weaned piglets	Birth weight (kg)	21-day weight (kg)	Weaning weight (kg)
Season	NS	NS	NS	**	**	**
Sex	NS	NS	NS	NS	NS	NS
Season x sex	NS	NS	**	NS	NS	NS

*(P<0.05); ** (P<0.01) and NS (Not significant)

7.4. Discussion

There are different factors associated with birth sex ratio percentages in mammals; such as nutrition, season of farrowing, diseases, stress, sow's age and parity, levels of different hormones, type and time of insemination, oestrus synchronisation before insemination, population demography, sex of adjacent embryos in sow's own birth litter (Chandler *et al.,* 1998; Rorie, 1999; James, 2001). Noteworthy, there are contradictory reports in relation to factors that may contribute to altered sex ratio percentage (Rorie, 1999). In the present study, female births (52%) were higher compared to males (48%). In contrast, Khan *et al.* (2012) reported that male births are significantly higher following AI compared to natural service in cattle and buffaloes. Khan *et al.* (2015) reported no significant sex differences in indigenous × Jersey (F1) calves following AI. According to Martinez *et al.* (2004), the percentage of female offspring may be increased through the application of AI technology in the first 18 hours after the onset of estrus in cattle. This may be attributed to the Y chromosome bearing sperm progressing more quickly through the cervical mucus than

those carrying the X chromosome bearing sperm (Rohde *et al.*, 1973). In contrast, Demiral *et al.* (2007) reported that AI performed at different times in the first half of the estrus period did not alter the sex ratio of offspring in dairy cows. Similarly, Foote. (1977) found no effect of the time of insemination on the sex ratio in heifers and cows. Soede *et al.* (2000) reported results similar to those of the present study. The disparities between the results of the studies could be due to the differences in the environment, detection of estrus, the use of different AI protocols and the sire and quality of semen used for inseminations.

In several species, early insemination or mating appeared to favour female offspring, whereas late mating favoured male offspring (Gutierrez-Adan *et al.*, 1999). Artificial insemination is naturally delayed until late estrus whereas natural mating should occur during estrus. If the time of insemination impacts the sex ratio of offspring, then it might be expected that AI would result in a higher percentage of male offspring. Emsen *et al.* (2009) reported that inseminations done within 55 hours of the sponge removal in Romanov and Charollais ewes resulted in 45% of female lambs produced. This is contrary to the previous studies by Gutierrez-Adan *et al.* (1999) whereby timing of insemination had no effect on the sex of lambs born.

Birth weight is considered one of the most important factors that affect piglet survival (Leenhouwers *et al.*, 2001). In the present study, the average birth weight was 1.9 kg ranging from 0.8 to 2.4 kg. Moreover, the average weaning weight was 6.2 ranging from 2.9 to 12.2 kg. Sharma *et al.* (1990) reported a weaning weight of 7.4 kg in Large White Yorkshire (LWY) pigs and Cauveri *et al.* (2009) reported weaning weight of 6.8 kg at 42 days of age in 75% LWY crossbred pigs which were lower compared the results in the present study (6.2 kg). In principle, piglets with low birth weights are particularly at risk of preweaning morbidity and mortality. According to *Lay et al. (2002),* piglets with low birth weight are compromised due to susceptibility to cold temperatures and their inability to compete for milk with larger piglets. Furthermore, this low birth weight was found to increase the likelihood for stillbirth (Le Cozler *et al.*, 2002). In the present study, no significant differences (P>0.05) were found between male and female piglets at birth and weaning. However, Darko & Buadu. (1998) reported that females were heavier at birth than their male counterparts. Contrary to these findings, Rao *et al.* (2004) and Poore & Fowden. (2004), stated that higher weaning weights in males

as opposed to females offspring. Similarly, Milligan *et al.* (2001) reported that on average, males were heavier at birth than females. In the present study, piglets with higher birth weight resulted in higher weaning weight. Similarly, Wolter *et al.*, (2002) reported that heavy birth weight piglets were also subsequently heavier at weaning compared to piglets with light birth weights. It has been reported that lighter piglets at weaning have the inability to accomplish compensatory growth rates during the grow-finish period and thus take longer to reach market weight (Mahan, 1993; Holyoake, 2006). Poor post weaning performance of progeny may be attributed to lighter weaning weight, as weaning weight has been positively related to subsequent growth and survival (Larriestra *et al.*, 2002).

The farrowing season plays a significant role in growth performance through its impact on the dam's nutrition and hence amount of milk available to the unweaned offspring. In the present study, birth and weaning weight was the lowest during autumn and summer seasons. This may be due to their reduced ability to maintain their body temperature, taking more time to reach the udder, subsequently having a lesser colostrum and milk intake (Herpin *et al.*, 1996; Lay *et al.*, 2002). Furthermore, there are several studies regarding the association of low birth weight with a lower survival rate or a lower growth performance (Quiniou *et al.*, 2002; Baxter *et al.*, 2009; Fix *et al.*, 2010). Thermoregulatory capacity, which is directly associated with birth weight, has a great influence on piglet survival. Piglets with a low birth weight have a high body surface relative to their weight, therefore being susceptible to hypothermia (Herpin *et al.*, 2002). It was previously reported that sows produce smaller litters with lower birth weights during hot or warm seasons (Johnson *et al.*, 1999; Quiniou *et al.*, 2002; Tummaruk & Khatiworavage, 2011). Low weaning weights observed during summer may be attributed to the microclimate conditions affecting lactation. Pigs are sensitive to high temperatures, mainly due to the inability to sweat (Nardone *et al.*, 2010). Hence, it is vital to observe the body condition of sows during late pregnancy because of the expected litter performance (Beyga & Rekiel, 2010). Moreover, physiological changes during farrowing and lactation are compounded by a change in diet, postnatal stress and microclimatic factors (Quesnel *et al.*, 2009). Therefore, additional heat stress during summer may contribute to changes in the composition of milk, less milk secretion or decreased food consumption by piglets.

The higher litter size in autumn resulted in lower birth to weaning weights. Similarly, several studies have shown that higher litter size results in decreases in the mean piglet birth weight (Johnson *et al.*, 1999; Quiniou *et al.*, 2002). The increase in litter size may be attributed to increased ovulation rates and lower embryo and foetal mortality (Foxcroft *et al.*, 2006). Thus, leading to overcrowding of the uterus and intrauterine growth retardation of the foetuses, causing lighter foetuses, which may have received fewer nutrients in utero. Furthermore, Quesnel *et al.* (2008) reported that litters with fewer piglets (9 piglets) were 0.5 kg/piglet heavier than a litter with more piglets (≥16 piglets). Sows should farrow a greater number of live piglets to reduce the cost of each piglet at birth, although increasing the litter size has an adverse effect on piglet birth weight and weaning weights (Roehe, 1999; Quiniou *et al.*, 2002; Fix *et al.*, 2010). However, this increase has also resulted in a higher percent mortality of piglets during lactation, which is of high economic loss to swine producers (Roehe & Kalm, 2000). According to Roehe & Kalm. (1997), an increase of litter size from 9 to 14 piglets has been associated with a decrease in their average birth weight from 1.6 to 1.4 kg. However, in the present study, the lowest litter size was 1.7 kg from a litter size of 10.6.

Sex had no significant impact on litter size. Similarly, Soede *et al.* (2000) and Alfonso. (2005) reported that sex ratio is not affected by litter size. Noteworthy, results reported in different species are contradictory (Vangen, 1993; Peaker & Taylor, 1996; Krackow, 1997). In other livestock species such as sheep, litter size showed a significant impact on sex ratio (Skjervold, 1979). Similarly, Jaishankar *et al.* (2015) and Cauveri *et al.* (2009) reported that sex had no significant effect on birth weight of piglets. These authors further indicated that the average birth weight in male piglets was 1.2 kg and in female piglets it was 1.1 kg, which is slightly lower from the results in the present study (1.9 kg). However, Darko & Buadu. (1998) reported that females were heavier at birth than their male counterparts. Contrary to these findings, Rao *et al.* (2004) & Poore & Fowden. (2004), reported higher weaning weights in males as compared to females. Similarly, Milligan *et al.* (2001) reported that on average, males were heavier at birth than females. In general, birth weight, pre- and post-weaning growth performance of piglets decreased with increasing litter size. Similarly, Okai *et al.* (1982) reported that birth weight and pre- weaning growth rate in piglets tended to decrease with increasing litter size. These differences in early postnatal growth of piglets

have largely been attributed to maternal effects such as milk availability, the number of individuals sucking and their vitality and aggressiveness (Le Cozler *et al.*, 1998).

In the present study, there was a low positive correlation between litter size and average birth and weaning weight. In contrast, litter size is negatively correlated to the average birth weight and weaning weight (Raseel *et al.*, 2016). Furthermore, in the present study there was a highly significant positive correlation between birth weight and weaning weight. These findings are in agreement with studies from Raseel *et al.* (2016). This positive correlation of birth weight and weaning weight may indicate that as the birth weight increases the weaning weight also increases.

7.5. Conclusions

In conclusion, there was higher proportion of female piglets than males. season had an impact on birth and weaning weight. The highest birth and weaning weights were recorded during winter. However, sex had no significant impact on the pre-weaning performance of piglets. There was a highly significant relationship was found between litter size and number born alive and total number of piglets weaned. Furthermore, a significant relationship was found between litter size and birth and weaning weight. However, a low negative correlation was found between the total number of piglets weaned and birth weight and weaning weight. Birth weight was the major determining factor for weaning weight. The limiting factor in the present study was the lack of proper records on the parity and other factors such as nutrition and general management on pre-weaning performance. Hence, further research is recommended to determine the impact of season, sex, management, parity and nutrition on pre and post weaning productivity at smallholder farms.

CHAPTER 8

CONCLUSIONS, RECOMMENDATIONS AND POLICY IMPLICATIONS

8. CONCLUSIONS, RECOMMENDATIONS AND POLICY IMPLICATIONS

8.1. Conclusion

The study revealed that majority of the respondents in Gauteng Province were males and involvement of the youth is limited. Moreover, majority of the respondents had acquired high school education. Although majority of the respondents own their farms, farm infrastructure still poses a serious challenge due to high capital investment. It is clear from the present study that smallholder pig farmer demographic factors have proved to be crucial constraints. Among others, age of the smallholder pig farmer plays a critical role in terms of the ability to adopt critical modern pig production technologies and market participation. Additionally, pig production activities in this study area are limited by the lack of youth participation. There is a lack of quality education as the majority of the farmers mostly have high school or no formal school education at all. Hence, it is anticipated that due to age, lack of education and lack of basic skills, smallholder pig farmers are faced with constraints in terms of productivity and mainstream formal market participation.

The study also implied that there is a general lack of information about basic pig farming management and husbandry practices, nutrition, reproduction, animal health and biosecurity as well as market access thus influencing their production and overall profitability. Majority of the smallholder pig farmers do not have access to superior breeding stock thus affecting the overall production. Furthermore, the farmers are not keeping records that may affect decision-making and management of their herds. Hence, the farmers are limited to selling their products at auctions and informal markets. Thus, training on pig production may assist in improving production.

Artificial insemination technique was an effective tool in dissemination of quality germplasm under smallholder conditions in Gauteng Province. The study demonstrated the feasibility and potential benefit of using CASA® and AI technology under smallholder production systems. It is evident that boar spermatozoa motility may be considered an important parameter to validate semen quality, although moderately related to fertility under smallholder pig production systems. Of all spermatozoa motility characteristics studied, total

spermatozoa motility, progressive and rapid spermatozoa motility were the only spermatozoa motility characteristics significantly correlated with conception rate. Conversely, litter size and number born alive were not correlated with CASA® spermatozoa motility attributes. It is thus recommended to further establish a novel method for diagnosing male fertility based on conventional semen analysis prior to and post capacitation. This is imperative because to analyse the accuracy of diagnosis of male fertility, semen analysis under capacitation condition is necessary as only capacitated spermatozoa are capable of fertilizing oocytes both *in vitro* and *in vivo*. It is evident that boar spermatozoa motility may be considered an important parameter to validate semen quality, although moderately related to fertility under smallholder pig production systems. Morphology is one of the factors influencing the quality of spermatozoa. The study demonstrated that the most recurrent defects observed in boars were proximal and distal cytoplasmic droplets. No relationships existed between spermatozoa morphological characteristics and fertility. Moreover, there was no significant relationship between spermatozoa morphological defects and fertility.

There was higher proportion of female piglets than males in the present study. The highest birth and weaning weights were recorded during winter. Season had an impact on birth and weaning weight. However, sex had no significant impact on the growth performance of piglets. Boar and sex interaction was only confirmed on the total number of weaned piglets. Highly significant relationships were found between litter size and number born alive and total number of piglets weaned. There was also a significant correlation between total number of piglets born alive and total number of piglets weaned. A low negative correlation was observed between the total number of piglets weaned and birth weight and weaning weight, although insignificant.

8.2. Recommendations

- Promotion of gender equality and youth in smallholder pig farming is critical thus eliminating discrimination against women and youth.
- There is a need to transform and improve agricultural extension services. Through agricultural extension, smallholder pig farmers will be informed of improved farming practices as well as new technical and economic possibilities that could be beneficial.

- Adoption of assisted reproductive technologies in smallholder production systems.
- It is recommended to evaluate the impact of DNA deterioration in relation to fertility.
- Identification of several biomarkers such as peptides and proteins have been identified in the boar seminal plasma in relation to fertility.
- Establishment of a novel method for diagnosing male fertility based on conventional semen analysis prior to and post capacitation is important. This is imperative because to analyse the accuracy of diagnosis of male fertility, semen analysis under capacitation condition is necessary as only capacitated spermatozoa are capable of fertilizing oocytes both *in vitro* and *in vivo*.

8.3. Policy implications

The current study was conducted to focus on improving pig's smallholder farmers in Gauteng Province. Therefore, livestock production can increase farmers' incomes, and general economic welfare including food security. Agricultural policy in South Africa revolves around the main goals of increasing productivity and income growth, especially for smallholders; enhanced food security and equity, commercialisation and intensification of production especially among small scale farmers; appropriate and participatory policy formulation and environmental sustainability. South Africa has implemented several successful rural poverty relief initiatives yet poverty continues to strain rural development efforts. These programmes have been hampered by the social acceptability of some of the alternative (more appropriate) infrastructure that has been implemented and the lack of suitable education as to technological suitability. The situation is further exacerbated by the high incidence of lack of mentorship in farming and high rates of population growth and urbanization in Gauteng Province.

The current study does link well with several policies and strategies of the South African government such as the National Development Plan (NDP), (National Planning Commission, 2012) of South Africa provides a plan for the reduction of poverty and inequality. The NDP proposes a multifaceted approach to achieve an inclusive and integrated rural economy by 2030. According to the Strategic Plan for the Department of Agriculture, Forestry and Fisheries (2015/16 to 2019/20), the vision for the agricultural,

forestry and fisheries sectors is to improve food security, create one million decent jobs by 2030 and to significantly increase the contribution of these sectors to the GDP. The NDP indicated that agriculture has the potential to create one million jobs by 2030 through:

- Expansion of irrigated agriculture—the 1,5 million ha under irrigation could be expanded by at least another 500 000ha to 2 million ha

- Cultivating underutilised land in communal areas and land-reform projects for commercial production

- Supporting commercial agricultural industries and regions with the highest growth and employment potential

- Supporting upstream and downstream job creation

- Finding creative opportunities for collaboration between commercial farmers, communal farmers and complementary industries

- Developing strategies that give new entrants access to value chains and support.

The NDP is the principle-guiding document, along with the Medium Term Strategic Framework (MTSF, 2014-2019), New Growth Path (NGP, 2011), Industrial Policy Action Plan (IPAP, 2016/17 - 2018/19), Bio-economy Strategy (2014), Gauteng Department of Agriculture and Rural Development (GDARD) strategic plan (2014-2019), Agriparks and other strategies and policies giving articulation to the achievement of the NDP vision. To this end, stakeholders such as the ARC's Strategic Plans are aligned to the broader government policies and priorities. These also form part of the Policy Framework for the government Monitoring and Evaluation System. The NDP indicated agriculture as a priority sector in South Africa to achieve various objectives, including (NDP, 2012):

- Affording rural communities better opportunities to participate fully in the economic, social and political life of the country;

- Ensuring people are well nourished, healthy and increasingly skilled;

- Successful land reform, infrastructure development, job creation and poverty alleviation. South Africa has a priority of reaching food security goal by 2030 with the challenge of its rapidly growing population. The FAO reported that the world population would increase to nine billion by 2050. Consequently, there will be a need to increase the agricultural food production by 70% in order to feed the growing population. The NDP strives for the increased investment in new and improved agricultural technologies, research and development of

adaptation strategies for the protection of rural livelihoods and expansion of commercial agriculture. It is therefore essential for commercial and smallholder famers to increase their productivity to meet this growing demand.

The study implemented alternative methods of technology transfer through training, mentorship and skills transfer. The intervention aligned with the Gauteng 20 Year Food Security Plan document. Moreover, the Gauteng 20 Year Food Security Plan has identified six Provincial Pillars, which contribute to radical socio-economic transformation. In terms of agriculture, the department's focus is to maximise the economic potential of the agricultural sector. Pillar 3 focus on intensifying skills development and training on sustainable food production. In terms of agricultural technical and extension advisory support, 101 smallholder pig farmers were offered non-accredited training on pig reproduction and record keeping. Furthermore, 16 smallholder pig farmers benefited from the project. It is of utmost importance to continue to assist existing smallholder farmers to develop their operations to commercial levels through proper training and good planning.

To augment the above-mentioned interventions, the study recommends that special emphasis should be on women and youth as the participation of women and youth in the present study was a major concern. According to the MTSF (2014-2019) plan, government will continue to broaden the base of black economic empowerment, through the infrastructure investment programme, which provides employment opportunities for women, and youth, promote broad-based black economic empowerment and support local procurement. Furthermore, the NDP recognizes key priorities such as education or rural development strategies that have the biggest impact on woman and youth. Incorporation of women and youth into the agricultural economic sectors may lead to a reduction in poverty and hunger and further improve productivity and economic returns of agriculture. The involvement of women and youth in the agricultural mainstream economy may strengthen their power position and independence (Anarfi & Fayorsey, 1999). It is also important that smallholder farmer acquire formal education in order to be able to access and assess important agricultural information and modern farming practices. There are farmer support programmes by the extension officers from the agricultural extension services at the Department of Agriculture and from the private sector. Agricultural extension services still

plays a key role in disseminating knowledge, technologies and agricultural information, and linking farmers with other stakeholders. However, these farmers are still faced with challenges that impede their growth and ability to contribute towards food security. These challenging areas include inaccessibility to funding, markets and technical skills required to increase productivity. Although knowledge transfer is commonly done through agricultural facilities such as colleges, universities, smallholder farmers do not have access to these facilities.

The current study recommend the establishment of the satellite artificial insemination (AI) centres to service smallholder farmers in Gauteng Province, through the use of current strategy of Agri-Parks (The Rural Economy Transformation Model: One District, One Agri-park/every Municipality a CRDP site, 2015). An Agri-park is a networked innovation system of agro-production, processing, logistics, marketing, training and extension services, located in a District Municipalities of South Africa. As a network it enables a market-driven combination and integration of various agricultural activities and rural transformation services. The Agri-park comprises three distinct but interrelated basic components. (The Rural Economy Transformation Model: One District, One Agri-park/every Municipality a CRDP site, 2015). These satellite AI centres across Gauteng Province will create new knowledge and skills as well as development of pig reproductive expertise. It will further facilitate the propagation and dissemination of superior germplasm to all smallholder pig farmers. The Bio-economy strategy (2014) strategy promotes the initiation of innovative resolutions that are crucial for food security. Innovation does not only focus on developing new and improved products or technologies, but also promotes developing new ways of generating and disseminating knowledge, collaborating, or financing agricultural enterprises including complete value chain. The present study had addressed some of the challenges faced by smallholder pig farmers through education and research, training of smallholder farmers, skills transfer and facilitating the dissemination and propagation of superior germplasm to smallholder pig farmers through the application of advanced reproductive technologies such as AI and oestrus synchronisation of smallholder female pigs. Consequently, health and quality piglets were born using the technology and farmers made extra income following selling of their piglets. It is therefore important to explore possibilities of building facilities and infrastructure, contribute towards skills development of young

graduates, generation of income and increase scientific output of high quality standard. However, fostering partnerships with research centres such as the Agricultural Research Council, industry as well as universities is of paramount importance.

The project contributed towards the Bio-economy strategy (2014). The Bio-economy Strategy's objective for agriculture is to strengthen agricultural biosciences innovation to ensure food security, enhance nutrition and improve health, as well as enable job creation through the expansion and intensification of sustainable agricultural production and processing. The skills and solutions that emerge from biotechnology research need to be effectively transferred to emerging, small-scale and commercial farmers. The project successfully implemented the advanced reproductive technologies at smallholder pig farms in Gauteng Province. It also contributed towards Research & Development as research major findings were published in peer-reviewed journals and delivered at farmers days, national and international conferences.

The study identified underlying challenges that smallholder pig farmers are faced with that impede their ability to grow and contribute towards food security. Reproductive inefficiency was recognized as the main limiting factor. The application of AI technology at smallholder pig farms was an effective tool in dissemination and propagation of superior quality germplasm. Additionally, this study aided in developing a successful model of sustainable development practices that comprised of training, continuous mentorship, technology and skills transfer. It evident that the study aligned well with strategies of the Government of South Africa such as the MTSF (2014-2019), NGP (2011), IPAP (2016/17 - 2018/19), Bio-economy Strategy (2014), Department of Agriculture, Forestry and Fisheries strategic plan (2015/16 to 2019/20), GDARD strategic plan (2014-2019) and Agriparks. Hence, to improve the smallholder pig-farming sector in Gauteng Province, it is imperative to consider establishing satellite AI centres to service farmers within the province. This will in turn increase farmers' incomes, and improve their livelihoods and general economic welfare including food security.

CHAPTER 9

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9. REFERENCES

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CHAPTER 10

APPENDIX

10. APPENDIX

10.1. Questionnaire survey

Respondent Number: ☐ ☐ ☐

QUESTIONAIRE SURVEY
IMPROVEMENT OF REPRODUCTIVE PERFORMANCE IN THE DEVELOPING PIG FARMING SECTOR OF GAUTENG PROVINCE (RSA), THROUGH ARTIFICIAL INSERMINATION

Purpose

Purpose

The purpose of this questionnaire is gather information on the current production and reproduction status in Gauteng Province in order to identify opportunities for growth and possible interventions that would improve the participation of smallholder pig farmers.

Confidentiality

Your answer to the questions and all other information you give will be held in strictest confidentiality

Instructions

Mark the appropriate answer with an X and please feel free to provide your most honest opinion

SECTION 1: DEMOGRAPHICS INFORMATION

1.1. District

1. Tshwane	
2. Sedibeng	
3. Ekurhuleni	
4. West Rand	

1.2. Gender

1. Male	
2. Female	

1.3. Age

1. <35 years	
2. 36-50 years	
3. 51-60 years	
4. >60 years	

1.4. Highest level of formal education

1. Primary school or none	
2. High school	
3. Diploma	
4. University degree	

1.5. Are u farming full time or part-time?

1. Part time	
2. Full time	

1.6. Years of experience

1. > 5 years	
2. 5-10 years	
3. 11-15 years	
4. <16 years	

SECTION 2: FARM PROFILE

2.1. Farm size

1. > 5 ha	
2. 5-50 ha	
3. 50-100 ha	
4. <100 ha	

2.2. Unit size

1. > 5 sows	
2. 5-10 sows	
3. 11-15 sows	
4. <16 sows	

2.3. Production system

1. Intensive	
2. Semi-intensive	
3. Extensive	

2.4. Land tenure

1. Rent	
2. Private	
3. LRAD	
4. PLAS	

If renting or leasing, what is the duration of the contract (years):

_____

SECTION 3: FARM INFRASTRUCTURE

3.1. State of boundary fence

1. Good	
2. Fair	
3. Poor	
4. None	

3.2. Source of water

1. Borehole	
2. Municipal water	
3. Water reservoir	

3.3. Is there enough water

1. Yes	
2. No	

3.4. Condition of access road to the farm

1. Good	
2. Fair	
3. Poor	
4. None	

3.5. Do you have access to the following? (Tick where relevant)

1. Electricity	
2. Cell phone network coverage	
3. Electricity generator	
4. Water pump or engine	

3.6. Condition of pig housing facilities

1. Good	
2. Fair	
3. Poor	
4. None	

3.7. Access to weighing scale

1. Yes	
2. No	

SECTION 4: ANIMAL STATISTICS & PRODUCTION

4.1. Breed type

1. Landrace	
2. Large White	
3. Duroc	
4. Cross breed	
5. Non-descript breed	

4.2. Source of breed stock

1. Stud breeders	
2. Commercial farms	
3. Auctions	
4. Local farms	

4.3. Preferred breeding method

1. Natural mating	
2. Artificial insemination	

Please motivate your answer

_____

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4.4. Method of identification

1. Ear tagging	
2. Tattoo	
3. Ear notching	
4. Other	

4.5. Condition of the pigs

1. Good	
2. Fair	
3. Poor	

SECTION 5: RECORD KEEPING

5.1. Do you keep records?

1. Yes	
2. No	

5.2. If yes, please indicate types of records

1. Production	
2. Reproduction	
3. Financial	
4. Sales	

SECTION 6: HEALTH MANAGEMENT /BIOSECURITY

6.1. Do you have a vaccination programme?

1. Yes	
2. No	

If yes, please indicate which vaccines

_____

_____

_____

_____

6.2. Do you have a biosecurity fence?

1. Yes	
2. No	

6.3. Do you have biosecurity measures?

1. Footbath	
2. Quarantine facilities	

SECTION 7: NUTRITION

7.1. What do you feed your animals?

1. Total mixed ration	
2. Mix own feed	
3. Feed swill	

7.2. Source of feed

1. Local cooperative	
2. Feed manufacturing company	
3. Auction	

SECTION 8: MARKETING

8.1. Where do you market your pigs?

1. Auctions	
2. Informal market	
3. Abattoir	

8.2. Which products do you sell?

1. Weaners	
2. Porkers	
3. Baconers	
4. Breeding sows	

8.3. When do you sell?

1. Annually	
2. Quarterly	
3. Randomly	

SECTION 9: GENERAL COMMENTS

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10.2. Publications

Status of the smallholder pig farming sector in Gauteng Province of South Africa

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Abstract

Pig farming is an important area of pig production among smallholder farmers in Gauteng Province. The objectives of the study were to identify the demographics, farm infrastructure, type of feed, animal health, management and marketing channels within the smallholder pig sector in Gauteng Province. The population was divided into four strata, namely the four district municipalities. A simple random sampling within each strata was done to select the 71 smallholder pig farmers at West Rand, Sedibeng, Tshwane and Ekurhuleni district municipalities. Descriptive statistics was performed using SAS software. The results demonstrated that the majority of the pig farmers were males (67%) and were above 50 years of age (67%), while 56% of the smallholder pig farmers had high school education. Moreover, majority of the pig farmers privately own the farms (62%) and the farm infrastructure had facilities with low cost housing and modern facilities. Moreover, 47% of the farmers feed their pigs with feed swill. A large proportion of the farmers did not vaccinate their pigs (81%). Additionally, majority of farmers were found to not identify their pig herds (63%). Noteworthy, majority of the pig farmers did not have breeding boars (73%) and sold their pigs at auctions (70%). In general, there was lack of information about basic pig management and husbandry.

Introduction

There is a need for increased animal protein especially in developing countries thus leading to animal production coming under pressure to meet the demand from the rapidly increasing human population. Pigs are genetically superior at converting feed to meat when compared to ruminant livestock (Mpofu & Makuza, 2003). Furthermore, pigs contribute towards human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for rural communities (Antwi & Seahlodi 2011; Dietze 2011). Although South Africa has the highest pig population in southern Africa (Phiri *et al*., 2003), 25% are free ranging in the resource poor areas (Krecek *et al*., 2004). Gauteng Province dominated pork exports from 2002 to 2011 followed by Western Cape and Kwa Zulu Natal Provinces. This was due to the fact that these provinces are the main exit points and have requisite infrastructure that facilitate trade (Department of Agriculture, Forestry and Fisheries, 2012).

According to Department of Agriculture, Forestry and Fisheries (2013), South African commercial pig farmers were estimated at 4000 and stud farmers at 19 with the remaining being non-registered, medium scale and smallholder pig farms. Although these smallholder pig farmers contribute towards the national herds, the smallholder pig farming sector is faced with challenges that include inaccessibility to superior breeding stock and markets, low quality feed, insufficient veterinary services and breeding services (Lekule & Kyvsgaard, 2003; Lemke & Zárate, 2008). Hence, the objectives of the study were to identify the demographics, farm infrastructure, type of feed, animal health, management and marketing channels within the smallholder pig sector in Gauteng Province.

Materials and methods

The study was conducted in four district municipalities of the Gauteng Province which were considered to have significant pig production activity, namely: West Rand, Sedibeng, Tshwane and Ekurhuleni district municipalities. A total of 71 smallholder pig farmers as indicated in Table 1 were selected with the assistance of extension officers from Gauteng Department of Agriculture and Rural Development (GDARD). The population was divided into four strata, namely the four district municipalities. A simple random sampling was conducted within each strata. Selection of farmers from each district municipality was not uniform due to the variability of the number of smallholder pig farmers at the different districts. The 50% proportional sample size from each strata was considered representative to provide acceptable results. Face-to-face interviews were conducted using a semi-structured questionnaire composed mainly of closed ended, and few open questions. The survey focused on identifying the demographics, farm infrastructure, type of feed, animal health, management and marketing channels within the smallholder pig sector in Gauteng Province.

Table 1 Number of smallholder pig farmers interviewed at Gauteng Province

District municipalities	Number of smallholder pig farmers	Proportional sample size (50% of the smallholder pig farmers)
West Rand	51	26
Sedibeng	28	14
Tshwane	56	28
Ekurhuleni	5	3
Total	137	68

The data from completed questionnaires was captured and filtered using a Microsoft Excel® (Microsoft, USA) spreadsheet. Descriptive statistics was performed using SAS software. The analyses performed included: proportional percentages; percentiles and graphs of farm characteristics; production parameters; management and health parameters.

Results and Discussion

The results for demographics are illustrated in Figure 1. The smallholder pig farming sector within Gauteng Province was found to be dominated by males (67%) as compared to the females (33%) (Figure 1A). Similarly, the majority of the smallholder pig farmers in Limpopo Province of South Africa and various regions of Indonesia are male farmers (Mokoele *et al.*, 2014; Leslie *et al.*, 2015). In contrast, it was reported that more female farmers rear pigs compared to male farmers in the Eastern Cape Province (Madzimure *et al.*, 2013) and Etayi in Namibia (Petrus *et al.*, 2011). The gender distribution differs from region to region as some regions have higher numbers of female farmers than others. Furthermore, the majority of the farmers were older than 50 years of age (67%), which was an indication that participation of youth is limited (Figure 1B). It was also reported that the majority of smallholder pig farmers in Limpopo Province are older than 50 years of age, which is an indication that the younger generation did not to get involved in agricultural activities (Mokoele *et al.*, 2014). Okoli *et al* (2004) also found that younger people were not actively involved in piggery or any other type of commercial livestock farming in Imo state, Nigeria. Therefore, there is a need to provide more opportunities with a critical focus on women and youth from peri-urban areas through training with a view of increasing their participation in pig farming. Fifty six percent of the smallholder pig farmers had high school education (Figure 1C). In contrast, the majority of the smallholder pig farmers at Indonesia (Leslie *et al.*, 2015) and Limpopo (Mokoele *et al.*, 2014) had primary to high school education. It is of utmost importance for the farmer to have some formal education in order to be able to access and assess important agricultural information and modern farming practices among others. Moreover, the farmers may face challenges regarding adoption of new agricultural innovations and technologies.
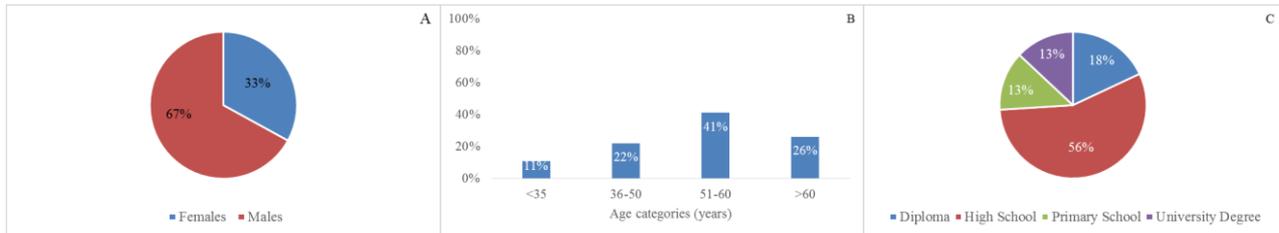
Figure 1 Gender (A), Age (B) and educational level (C) of smallholder pig farmers at Gauteng Province

Results for farm profiles are illustrated in **Table 2**. It was found that 62% of the smallholder pig farmers own land, whereas 18% of the smallholder pig farmers were renting or leasing the farms. Additionally, 10% of the smallholder pig farmers acquired the land through both land reform programs such as Land Redistribution for Agricultural Development (LRAD) and Proactive Land Acquisition Strategy (PLAS), respectively. The estimated total land size in the hands of the smallholder pig farmers in Gauteng Province was 37 560 ha (Gauteng Department of Agriculture and Rural Development strategic plan, 2010-2014). Of this figure, about 13 190 (35%) was privately owned by smallholder farmers while the remaining land (65%) is being leased (Gauteng Department of Agriculture and Rural Development strategic plan, 2010-2014).

**Table 2** Farm profile characteristics for smallholder pig farmers in Gauteng Province

Characteristics	Variables	% of respondents
Production systems	Intensive	88%
	Extensive	3%
	Semi-intensive	9%
Land ownership	Private	62%
	Rent/Lease	18%
	PLAS	10%
	LRAD	10%

It was found that majority of the smallholder pig farmers practise intensive farming system (88%). Intensive production systems consisted of pig houses that are constructed to protect the pigs from the harsh weather conditions. Semi-extensive houses are constructed with fences with roofing, however the climate is not completely controlled. Extensive production systems have no housing and there is free movement of the pigs. In the present study, the pigs were found to be housed in a wide range of facilities from full earthen floors using low cost building material to more modern facilities containing cement floors and running water. The following figures (Figure 2 A-C) show typical housing and management practices and give a good indication of the infrastructure and systems utilized. It was evident in some farms that farm infrastructure still poses a serious challenge due to high capital investment. Similar results were also found at Limpopo (Manchidi, 2009). Moreover it was found that pigs in some areas had no shade. According to Manchidi (2009), pigs should not be exposed to direct sunlight and winds as this may cause stress. Consequently, when pigs are exposed to high environmental temperatures their libido, fertility and conception rates decreases.

Figure 2. Some pigs were housed in wire fenced houses with shade (A), cement floors (A) and outdoor pigs with no shade (C)

Feed is arguably the most important pig farming input. Consequently, smallholder pig farmers feed their pigs feed swill as an affordable feed source. It was found that 53% of smallholder pig farmers use feed-swill as an affordable feed source (Figure 3A). Furthermore, majority of the feed were purchased at feed manufacturing companies (68%) (Figure 3B). Due to high feed costs, smallholder pig farmers use alternative feeds such as bran and brewers spent grains or to mix complete diets with bran as a way of reducing feeding costs (Montsho & Moreki, 2012). Additionally, some smallholder pig farmers feed their pigs commercial diets from agricultural cooperatives and supplement them with feedstuff like hominy chop and vegetables depending on availability (Mtileni *et al.*, 2006). However, feeding pigs feed swill is unacceptable at South African abattoirs as it may lead to Salmonella, Campylobacter, Foot-and-mouth disease (FMD) and Classical Swine Fever (CSF) (Beltrán-Alcrudo *et al.*, 2008).
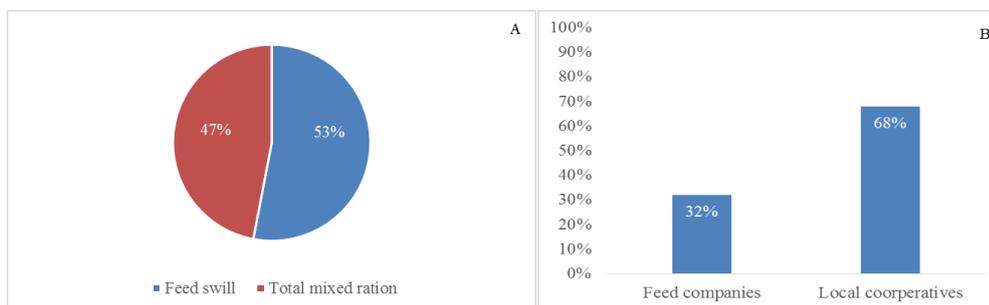

Figure 3 Type of feed used by smallholder pig farmers (A) and source of the feed (B) at Gauteng Province

Majority of the farmers do not vaccinate their pigs (81%) whereas the 19% that did vaccinate only vaccinated their pigs against *E coli* and Parvovirus (Figure 4). It is evident that knowledge regarding vaccination programs and biosecurity was limited amongst the farmers as all the farmers did not have footbaths nor had vaccination programs. Similarly, biosecurity practices were found to be limited at various regions of Indonesia, Limpopo, Mpumalanga and North West Provinces of South Africa (Mtileni *et al.*, 2006; Leslie *et al.*, 2015; Mokoele *et al.*, 2014). In a recent report by FAO. (2010), several measures were suggested to address disease outbreaks in smallholder pig production systems. These measures mostly focused on the segregation of animals, including quarantining and controlling pig movement. Furthermore, biosecurity measures such as not trading sick animals, avoiding feed swill, disinfecting pens, proper carcass and waste disposal are key components that should also be implemented in the farm health plans (FAO 2010). According to Mokoele *et al*. (2014), it is also recommended that a community specific farm health plan be implemented using state veterinarians and animal health technicians. Vaccinations against significant production limiting diseases in South Africa (Parvovirus, Leptospirosis and Erysepelas, as well as Escherichia Coli) should be included in vaccination programs (Mokoele *et al.*, 2014). According to Perry *et al.* (2002), investing in veterinary services for smallholder pig farmers may provide support.
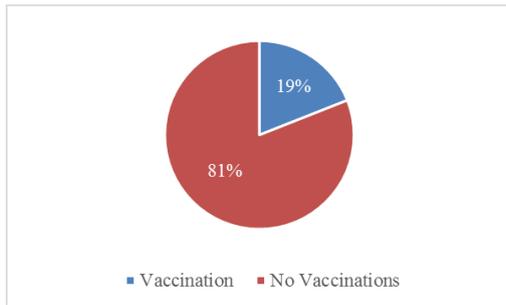
Figure 4 Health status of smallholder pig farmers' pigs within Gauteng Province

Reproductive efficiency is the main limiting factor in maximising animal production and profitability of an enterprise (Figure 5A). In the present study, majority of the farmers do not have good breeding stock (73%) as a result of purchasing breeding materials from local farms and auctions. Montsho & Moreki (2012) also observed that pigs in smallholder systems in Botswana originate from one source and as such inbreeding is common; hence poor quality of stock. Moreover, the smallholder pig farmers reported that there were high incidences of pre and post weaning mortalities. In the present study, 54% did not keep pig records (Figure 5 B and C). According to Phengsavanh *et al.* (2011), diarrhoea and lack of management were the main causes of high losses in piglets. The problem of diarrhoea in piglets was common in many smallholder pig production systems and caused considerable economic loss to pig farmers (Tuyen *et al.*, 2005). Disease and diarrhoea occurrence in smallholder pig production may have been related to the observed poor hygiene, and lack of disease preventive measures as well as poor nutrition of sow during gestation and lactation (Phengsavanh *et al.*, 2010). Hong *et al.* (2006) also reported that poor quality of feed and nutrient supply may have been a contributory factor to the high incidence of diarrhoea in piglets. Furthermore, 63% of the smallholder pig farmers do not use ear tags and notching to identify their pigs for management purposes. In the present study, 63% did not keep pig records. According to Petrus *et al.* (2011), smallholder pig farmers have limited expertise resulting in poor management and planning of pig enterprises.
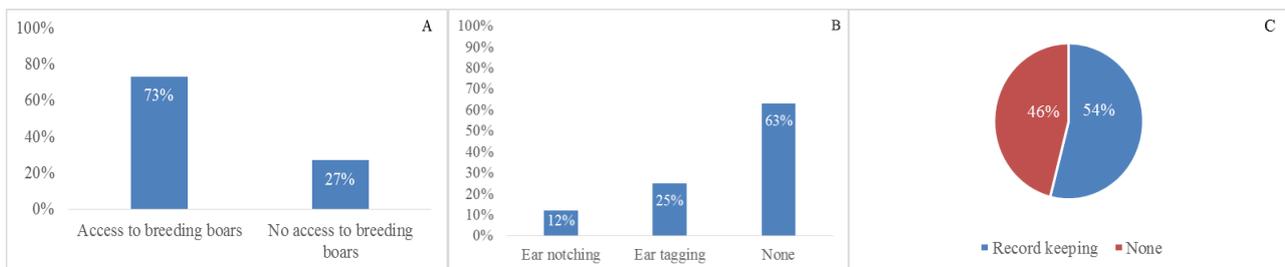
Figure 5 Availability of breeding boars (A), animal identification (B) and record keeping (C) at Gauteng Province

The results for market accessibility are illustrated in **Figure 6**. Majority of the smallholder pig farmers sold their pigs at auctions. This may be because most smallholder pig farmers did not have access to sustainable markets. This could be attributed to lack of knowledge and skills on price determination prior to the selling of pigs which puts these smallholder pig farmers at a disadvantage. This may be because most smallholder pig farmers do not have access to sustainable markets. One other important dynamic is the quality of their products and consistency of production. Mtileni *et al.* (2006) argued that auction prices vary as buyers are most of the time trying to buy pigs at a cheaper price and the prices are not linked to any classification system. There is also no specific period of selling since sales are conducted if there is a demand and availability of stock.
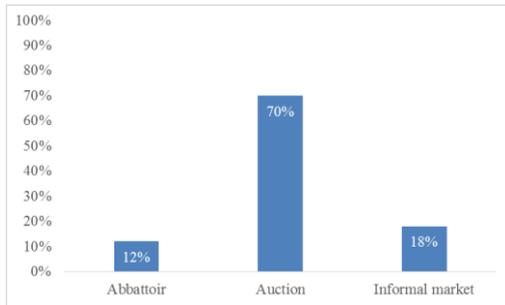
Figure 6 Market access for smallholder pig farmers at Gauteng Province

Conclusions

In conclusion, the study found that Gauteng Province smallholder pig farming sector is dominated by males, participation of the youth is limited and majority of the smallholder pig farmers have high school education. Hence, it is anticipated that as a result of age, lack of education and lack of basic skills, smallholder pig farmers are faced with increased level of constraints in terms of pig's productivity. The results of the current study also revealed that smallholder pig farmers in the studied area are still faced with nutritional, animal health and marketing constraints. It was also found that farm infrastructure still poses a serious challenge. There was also a general lack of basic pig farming management and husbandry practices in terms of nutrition, animal health, reproduction and market access thus affecting their production and overall profitability. It is thus recommended that continuous monitoring and evaluation as well as training will improve the situation of pig farming and reduce the burden of disease in smallholder pig farming sector.

Acknowledgements

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Short communication

Relationship between sperm plasma membrane integrity and morphology and fertility following artificial insemination

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Abstract

Sperm quality plays an important role in determining fertility. The aim of the study was to examine the relationship between sperm plasma membrane integrity and morphology, and fertility following artificial insemination (AI). A total of 16 ejaculates were collected from three Large White boars using the gloved hand technique. The semen was extended with a commercial extender. The AI dose contained 80 mL semen sample (3×10^9 sperm/mL). Aliquots of diluted semen were assessed for sperm plasma membrane integrity (synthetic binding CD-14 (SYBR$^+$)/propidium iodide (PI$^-$) and sperm morphology (eosin nigrosin). A total of 73 Duroc-type, Large White and nondescript multiparous sows from smallholder farms were inseminated with extended semen samples. Boar sperm plasma membrane integrity and morphology were subjected to one-way analysis of variance (ANOVA). The average boar sperm plasma membrane integrity and normal sperm morphology were 78.6% and 77.2%, respectively. The average conception and farrowing rates following artificial insemination (AI) were 78.1 and 57.5%, respectively. A negative correlation was observed between sperm plasma membrane integrity and fertility. There was a weak positive correlation between normal sperm morphology and conception rate (r = 0.11). Additionally, a relationship was observed between normal sperm morphology and litter size (r = 0.37) and total number born alive (r = 0.03), although relatively low. In conclusion, a negative relationship was found between sperm plasma membrane integrity and fertility. Moreover, there was a relationship between morphologically normal sperm and litter size, as well as number of piglets born alive, although relatively low.

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Improving the qualitative and quantitative analysis of boar semen samples to estimate fertility potential of males is critical for a successful breeding programme. Although much progress has been made, the ability to predict the fertility of semen with traditional laboratory tests is still limited, owing mainly to the complexity of sperm morphological damage and their fertilization potential (Brito *et al*., 2003). In addition, the prediction of sperm fertilizing ability is of great economic importance to breeding of sows as it leads to the selection of boars with better semen fertility, which results in good reproductive performance. Semen fertility trait assessments play a crucial role in the early detection of developmental disorders in male animals (Smital *et al*., 2004). As well as traditional methods of semen assessment, biochemical tests and morphological analyses of sperm are performed. Disturbances in spermatogenesis give rise to morphological sperm defects (Kavak *et al*., 2004). Moreover, recent studies have indicated a correlation between normal morphological

traits, conception rate, and litter size, which are particularly sensitive to normal head morphology (Gadea, 2005).

Another reliable approach is to use a combination of tests to evaluate various sperm attributes, thereby increasing the accuracy of the prediction (Amann & Hammerstedt, 1993). Assessment of sperm plasma membrane integrity is one of the key parameters in the evaluation of sperm quality in relation to fertility (Pintado *et al.*, 2000). One of the major features discriminating dead cells from live ones is loss in physical integrity of their plasma membranes and loss of motility (Burks & Sailing, 1992). Sperm outer membrane integrity and proper function are vital to sperm metabolism, capacitation, ova binding, and acrosome reaction (Brito *et al.*, 2003). Hence, assessment of sperm morphology and plasma membrane integrity traits may be useful in predicting the fertilizing ability of sperm. The objective of the study was therefore to determine the relationship between boar sperm morphological traits and fertility after AI.

All procedures in the study that involved animals were performed in accordance with the ethical standards of the Agricultural Research Council (reference APIEC15-046).

The study was conducted at the Pig Research Unit and Germplasm Conservation and Reproductive Biotechnologies Unit in Agricultural Research Council (ARC), South Africa. The ARC campus is located at 25° 55" south; 28° 12" east. The institute is located in the Highveld region of South Africa and situated at an altitude of 1525 m above sea level.

Three Large White boars, aged 18–24 months, which were genetically different, were used in the study to avoid inbreeding. A total of 16 ejaculates were collected from the boars. The boars were housed individually in pens and routinely used for AI purposes. Sperm rich fractions were collected using the gloved-hand technique in a 300 mL glass beaker. The filtered semen fraction was sealed with a gauze filter inside a pre-warmed (39 ºC) insulated thermos flask. Ejaculates with 70% sperm motility were extended with a commercial extender, Beltsville Thawing Solution, to 3×10^9 sperm/ml and stored at 17 ºC until AI.

Plasma membrane integrity was assessed using synthetic binding CD-R 14/propidium iodide (SYBR-14/PI) tests (Garner & Johnson, 1995). Briefly, semen samples were incubated at 38 ºC for 10 minutes with SYBR-14 at a final concentration of 100 µM, and then with PI at a final concentration of 10 µM for 5 minutes at the same temperature. A fluorescent microscope was used at 100 x magnification to count 200 sperm per stained slide and the results were recorded. After this assessment, two sperm populations were identified: live green-stained sperm (SYBR-14$^+$/PI$^-$); and dead red-stained sperm (SYBR-14$^-$/PI$^+$).

Sperm morphology was determined microscopically after staining the semen samples with eosin nigrosin stain on a slide (Tsakmakidis *et al.*, 2010). Briefly, 7µL of boar semen was added to 20µL eosin nigrosin staining solution in a 0.6 mL micro-centrifuge graduated tube and mixed gently. A drop of 5µL boar semen and Eosin Nigrosin stain was placed on a clear end of a microscope slide and smeared. Fluorescent microscope was used at 100 x magnification to count 200 sperm per stained slide and the results were recorded. Morphological defects were recorded and were categorized into major and minor sperm morphological defects according to the classification system by Salisbury *et al.* (1978). Briefly, the major morphological defects included loose head, proximal cytoplasmic droplets, and midpiece reflexes, whereas minor defects included distal cytoplasmic droplets and bent tails.

A total of 73 Duroc-type, Large White and nondescript multiparous sows from nine smallholder farms in Gauteng were used in this study, namely Winterveldt (17), Cullinan (6), Rooival (8), Zuurbekom (26), Randfontein (5), Midvaal (2), Meyerton (2), Brakpan (5), and Bendaro Park (2). The boar to sow ratio was 1 : 33, 1 : 25 and 1 : 15. Before AI, the recipient sows were synchronised by administering 400 IU equine chorionic gonadotropin and 200 IU human chorionic gonadotropin intramuscularly in the neck. Each sow was checked for heat twice a day. Sows were further stimulated by back pressure and inseminated twice, 12 and 24 hours after standing heat. Each AI dose consisted of 80 mL semen containing 3×10^9 sperm/ml. Pregnancy diagnosis was done 42 days after artificial insemination with an ultrasound scanner. Conception rate, farrowing rate, litter size and total of piglets born alive were recorded.

Data were analysed using one-way analysis of variance (ANOVA) using Statistical Analysis System® (SAS®) program. Sperm morphology and plasma membrane integrity values are presented as means ± standard error and were considered statistically significant when $P <0.05$. Pearson correlations were used to examine the relationship between sperm plasma membrane integrity and morphology and fertility.

The summary of boar sperm plasma membrane integrity and morphology with fertility data is illustrated in Table 1. Boar sperm stained with SYBR14 and PI viewed under a fluorescence microscope at 100x magnification is indicated in Figure 1. The live sperm fluoresces green and the red colour indicates dead sperm. There were no differences ($P >0.05$) between the boars for sperm plasma membrane integrity. On average, the sperm plasma membrane integrity was 75.6%. The proportion of normal morphological sperm varied significantly among the boars ($P <0.05$). Furthermore, there was a variation in the prevalence of morphological defects ($P <0.05$). The prevalence of major morphological defects was low in Boar 2 (7.7 ± 2.2) in comparison with Boar 1 (16.4 ± 1.6%) and Boar 3 (13.2 ± 2.1%). It was also found that Boar 2 (9.6 ±

2.3%) and Boar 3 (7.1 ± 4.0%) had the lowest minor morphological defects compared with Boar 1 (14.3 ± 1.2%). As a result, the higher the proportion of morphologically normal boar sperm, the higher the chance of conceiving. Conception rate differed significantly among the boars: Boar 3 yielded the highest conception rate (93.3 ± 0.1%) compared with Boar 1 (63.6 ± 0.1%) and Boar 2 (88.0 ± 0.1%). Farrowing rate was significantly higher in Boar 3 (80.0 ± 0.1%) than in Boar 1 (48.8 ± 0.1%) and Boar 2 (55.3 ± 0.1%). On average, the conception and farrowing rates following oestrus synchronization and AI were 78.1 ± 0.1% and 57.5 ± 0.1%, respectively. The artificial insemination resulted in an acceptable fecundity (i.e., 11.8 ± 0.8 litter size and 10.0 ± 0.6 number of piglets born alive). Similar results were achieved after AI under smallholder production systems in north-eastern India (Kadirvel *et al.*, 2013). An average litter size of 11.7 was achieved in the present study. In contrast, lower average litter sizes were achieved at north-eastern India after AI (Kadirvel *et al.*, 2013).

Table 1 Summary of boar sperm plasma membrane integrity, morphological traits and fertility (mean ± SE)

Variable	Boar 1	Boar 2	Boar 3	Mean ± SE
Number of ejaculates	6	6	4	16
Sperm plasma membrane integrity (%)	77.7 ± 3.7	71.8 ± 4.9	71.8 ± 6.1	75.6 ± 2.7
Normal sperm (%)	69.3[a] ± 3.7	82.7[b] ± 6.1	79.7± 6.1[b]	77.2 ± 2.9
Major morphological defects (%)	16.4[b] ± 1.6	7.7[a] ± 2.2	13.2[b] ± 2.1	12.8 ± 1.5
Minor morphological defects (%)	14.3[b] ± 1.2	9.6[a] ± 2.3	7.1[a] ± 4.0	11.2 ± 1.5
Number of sows inseminated	33	25	15	73
Conception rate (%)	63.6[a] ± 0.1	88.0[b] ± 0.1	93.3[c] ± 0.1	78.1 ± 0.1
Farrowing rate (%)	48.4[a] ± 0.1	55.3[b] ± 0.1	80.0[c] ± 0.1	57.5 ± 0.1
Litter size	11.6 ± 1.1	10.9 ± 1.2	13.0 ± 2.1	11.8 ± 0.8
Number of piglets born alive	10.1 ± 1.0	9.4 ± 1.1	11.0 ± 1.5	10.0 ± 0.6

[abc] Different superscripts in a row indicate significant differences ($P < 0.05$)
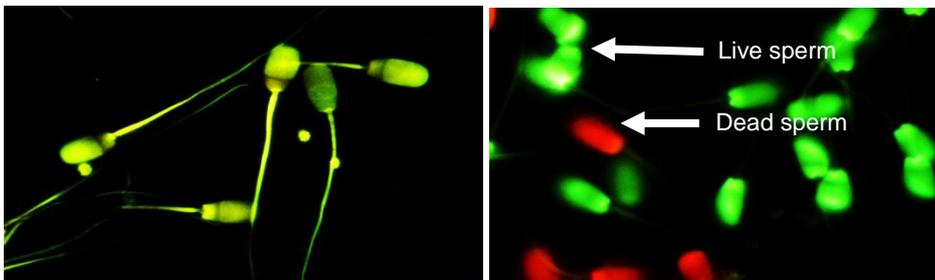
Figure 1 Boar sperm stained with SYBR14 and PI viewed under a fluorescence microscope at 100 x magnification

Pearson's correlation analysis was performed between boar sperm morphological traits and fertility. There was a strong positive correlation ($P < 0.01$) between SYBR-14 (live) sperm plasma membrane integrity and major morphological defects (r = 0.61) and minor morphological defects (r = 0.10). Moreover, negative correlations were found between live sperm using SYBR staining and fertility. Similarly, it was reported that sperm membrane structure is not closely related to fertility (Gadea *et al.*, 2004; Gadea, 2005). This may perhaps be because it provides information about the plasma membrane integrity of the sperm, but not about its functionality, such as the capacitation process, acrosome reaction, sperm binding, etc. In contrast, Januskauskas *et al.* (2003) detected significant correlations between field fertility and plasma membrane integrity. In the present study, a relatively low negative correlation was found between boar sperm plasma membrane integrity and litter size, as well as number of piglets born alive. Similarly, boar sperm plasma membrane integrity was not much related to fertility when eosin nigrosin staining were used to assess it (Gadea *et al.*, 2004; Lima *et al.*, 2015). In contrast, sperm plasma membrane integrity of microscopically assessed Calcein AM and PI stained sperm correlated significantly with litter size (Sutkeviciene *et al.*, 2009).

Several studies have reported significant correlations between fertility and incidence of specific morphological defects (Amann *et al.*, 2000; Johnson, 1997). In the present study, there was a positive correlation (P >0.05) between normal sperm morphology and conception rate (r = 0.11), although relatively low and statistically not significant. Additionally, a relationship (P >0.05) was observed between normal sperm morphology with litter size (r = 0.37) and total number born alive (r = 0.03). However, negative correlations (P >0.05) were observed between conception rate and major sperm defects as well as minor morphological ones. Conversely, boar sperm morphology has been reported to have limited positive predictive value for field fertility (Alm *et al.*, 2006). Although negative correlations were found between fertility and morphological defects, Waberski *et al.* (1990) reported that sperm morphology may assist with boar selection for AI as it provided information about spermatogenesis. In the present study, a weak positive correlation (P >0.05) was found between normal sperm and litter size (r = 0.37). In contrast, a significant correlation was found between normal sperm morphology and litter size (Xu *et al.*, 1998). Moreover, in the present study, a strong positive correlation (P <0.01) was found (r = 0.89) between farrowing rate and litter size. However, the high farrowing rate may not always be relative to high litter size. Moreover, weak correlations between farrowing rate and litter size were found in other studies, indicating that these traits may be affected differently by the semen quality of the boars (Tsakmakidis *et al.*, 2010; Juonala *et al.*, 1998).

In conclusion, there was a negative relationship between sperm plasma membrane integrity and fertility following AI. However, there was a relationship between morphologically normal sperm and litter size as well as number of piglets born alive, although relatively low. A negative relationship was observed between major and minor morphological defects with conception rate. Conversely, a positive relationship was found between major and minor defects with litter size and number of piglets born alive, although relatively low.

Conflict of Interest Declaration
The authors confirm that there is no known conflict of interest associated with the publication of this manuscript. This manuscript has been read and approved by all authors and that the order of authors listed in the manuscript has been approved by all of us.

Authors' Contributions
MBM, TLN, AKN, and JWN were in charge of project design and writing the manuscript. MBM, RT, and TRN were in charge of project implementation. All co-authors participated in results, statistics and interpretation of the study.

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Pre-Weaning Growth Performance of Piglets at Smallholder Farms in Gauteng Province

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Abstract

The objective of the study was to determine pre-weaning performance of piglets born following artificial insemination (AI) at smallholder farms of Gauteng province. Data from 496 piglets originating from 73 multiparous crossbred sows were used in the study. Litter size, number of piglets born alive, number of piglets weaned, birth and weaning weights were recorded. Data was analysed using the Proc Univariate procedure of SAS. The average litter size was 11.8. The average birth weight and weaning weights were 1.9 and 6.2 kg, respectively. No significant differences were found between male and female piglets for all the growth performance characteristics. Piglets born during winter had a significantly higher ($P < 0.05$) birth and weaning weight as compared to autumn and summer months. Season had a significant effect on birth and weaning weight ($P < 0.01$). However, sex of piglets had no significant effect on all the characteristics recorded ($P > 0.05$). The interaction between sex and season was only confirmed on the total number of weaned piglets ($P < 0.01$). A highly significant positive correlation was found between litter size and number of piglets born alive ($r = 0.86$) and total number of piglets weaned ($r = 0.50$). A highly significant correlation was found between total number of piglets born alive and total number of piglets weaned ($r = 0.55$). In conclusion, season of birth had the greatest impact on birth and weaning weight, with the highest birth and weaning weights recorded during winter season. However, sex did not affect the pre-weaning performance of piglets.

Keywords: birth weight, gender, litter size, pigs, weaning weight

1. Introduction

The South African pig industry is small in terms of the total South African agricultural sector contributing around 2.05% to the primary agricultural sector (DAFF, 2015). Furthermore, South Africa contributes about 0.2% of the world pig population (Muchenje & Ndou, 2010). According to Phiri et al. (2003), South Africa has the highest pig populations in southern Africa and 25% are free ranging in rural-poor areas. According to Harvey et al. (2014), smallholder farmers normally depend on farming for their livelihoods with inadequate skills and resources, therefore any decline in productivity may have a significant impact on their food security, nutrition and income. Pigs are of high economic importance, especially among the resource-poor as they contribute towards human nutrition, food security, poverty alleviation, enhanced livelihood and creation of employment for the rural community (Antwi & Seahlodi, 2011). However, according to literature, reproductive performance of pigs in smallholder systems is generally unsatisfactory (Phengsavanh & Ogle, 2010). This may be attributed to limited access to superior germplasm. Therefore, advances in reproductive technologies such as artificial

insemination (AI) offers unique opportunities for livestock improvement for smallholder pig farmers (Rege et al., 2011).

One of the main reasons for introducing the improved pig breeds through AI is to facilitate the dissemination and propagation of superior germplasm (Okwun, Igboeli, Ford, Lunstra, & Johnson, 1996). Furthermore, sow productivity is dependent on the sow's ability to produce piglets that survive from birth to weaning (Fix et al., 2010). Noteworthy, the productive output of pigs depends on several factors. There are different factors that have been shown to be related such as nutrition, season of birth, diseases, stress, dam's age and parity, social status, levels of different hormones, type and timing of the insemination, oestrus synchronisation, environment, population demography, etc. (Chandler, Steinholt-Chenevert, Adkinson, & Moser, 1998). However, seasonal infertility remains a major problem.

Seasonal infertility is one of the most vital environmental factors that influences the reproductive performance of pigs (Janse van Rensberg & Spender, 2014). It has been established that it has a direct influence on litter size and piglet survival following birth (Tummaruk, Tantasuparuk, Techakumphu, & Kunavongkrit 2010). Additionally, it may affect results in the rearing of piglets due to heat stress and feed intake during lactation. Within the season, temperature variation and photoperiodic reaction are considered the main causes influencing fertility (Knecht, Srodon, & Duzinski, 2015), although the resistance of individuals is dependent on the breed (Wysokinska & Kondracki, 2013). The sex of the offspring also influences the growth performance of piglets (Peaker & Taylor, 1996). It also plays an integral role in the growth rate of the developing foetus. Alfonso (2005) reported that at birth male piglets tended to be heavier than female piglets. This may be due to hormonal differences between males and females and subsequent effects of foetal growth. Therefore, the objective of the study was to determine the effect of sex and season on pre-weaning performance of piglets following AI at smallholder farms in Gauteng Province.

2. Materials and Methods

2.1 Location and Experimental Area

The study was conducted at nine smallholder farms of Gauteng Province based on the availability of breeding sows between 2014 and 2015. December to February were grouped as summer months with temperature ranging from 16 to 29 °C, March to May were grouped as autumn months with temperature ranging from 11 to 23 °C and June to August were grouped as winter months with temperatures ranging from 5 to 20 °C with an average rainfall of 1454m. All procedures performed in the study involving humans and animals were in accordance with the ethical standards of the ARC (ARC Reference: APIEC15-046).

2.2 Experimental Design

A factorial design was used in the present study. Sex (males and females) and season of birth (summer, autumn and winter) were the main factors.

2.3 Animals

A total of 73 multiparous sows were synchronised by administering 400 IU of Equine Chorionic Gonadotropin and 200 IU of Human Chorionic Gonadotropin intramuscular in the neck. Each sow was checked for heat twice a day. Sows were further stimulated by back pressure and inseminated twice, 12 and 24 hours after standing heat. Each AI dose consisted of 80 mL of extended semen containing 3×10^9 spermatozoa. Pregnancy diagnosis was done 42 days following artificial insemination using ultrasound scanner. Conception rate, farrowing rate, litter size and total born alive were recorded. The production performance of 73 crossbred sows and its litter were collected for a period of two years from the records maintained at smallholder pig farms in Gauteng Province. Litter size, number of piglets born alive, number of piglets weaned, birth and weaning weights were recorded.

2.4 Statistical Analysis

All of the statistical analyses were performed using SAS software Version 9.2. Data was analyzed using the PROC UNIVARIATE procedure. Pearson correlation coefficients was used to determine the relationship between litter size, total number of piglets born alive, total number of piglets weaned, birth and weaning weight. Data was presented as mean ± standard deviation. Differences were considered significant at $P < 0.05$.

3. Results and Discussion

Descriptive productivity of piglets following AI at smallholder farms is indicated in Table 1. The average litter size was 11.8 based on the sample of 496 piglets. Furthermore, the number of piglets born alive was 10.2 and 9.5 for number piglets weaned. The average birth weight was 1.9 kg ranging from 0.8 to 2.4 kg. Moreover, the average weaning weight was 6.2 ranging from 2.9 to 12.2 kg. Sharma, Dubey, and Singh (1990) reported that a

weaning weight of 7.4 kg in Large White Yorkshire (LWY) pigs and Cauveri, Sivakumar, & Devendran, (2009) reported weaning weight of 6.8 kg at 42 days of age in 75% LWY crossbred pigs which were lower compared the results in the present study (6.2 kg).

Table 1. Descriptive growth performance of piglets following AI at smallholder farms

Characteristics	Average	Minimum	Maximum
Litter size	11.8±3.5	4	20
Total number of live born piglets	10.2±3.1	3	18
Total number of weaned piglets	9.5±3.1	0	15
Birth weight (kg)	1.9±0.7	0.8	2.4
Weaning weight (kg)	6.2±2.2	2.9	12.2

Detailed results of the pre-weaning performance following AI at smallholder farms is indicated in Table 2. No significant differences ($P > 0.05$) were found between males and females for pre-weaning performance. Similarly, Cauveri et al. (2009) reported that sex had no significant impact on birth weight. Jaishankar et al. (2015) further indicated that the average birth weight was higher in male piglets (1.2 kg) compared to female piglets (1.1 kg), which is slightly lower from the results in the present study (1.9 kg). However, Darko and Buadu (1998) indicated that females tended to be heavier at birth than males. Contrary to these findings, Poore and Fowden (2004) found that males have a higher weaning weight compared to females. Similarly, Milligan, Fraser, and Kramer (2001) reported that on average, males were heavier at birth than females. In general, birth weight, pre- and post-weaning growth performance of piglets decreased with an increasing litter size.

Table 2. Growth performance following AI at smallholder farms

Variables	Males			Females			P-value		
	Summer	Autumn	Winter	Summer	Autumn	Winter	Sex	Season	Sex x season
Litter size	10.3±6.7	10.5±1.2	11.7±3.0	11.8±2.4	13.5±4.9	9.5±3.5	0.6623	0.5917	0.1218
Total number of piglets born alive	10.3±6.7	8.0±0.2	10.2±3.2	10.6±2.3	13.5±0.7	9.0±0.2	0.7592	0.8059	0.3023
Total number of piglets weaned	9.3±0.6 [ab]	8.0±0.2 [b]	9.8±2.7 [ab]	9.8±1.3 [ab]	12.0±1.4 [a]	6.2±1.2 [c]	0.7049	0.3547	<0.01
Birth weight (kg)	1.8±0.6 [c]	1.9±0.8 [c]	2.4±0.4 [a]	1.6±0.5 [c]	2.0±0.9 [bc]	2.2±0.4 [ab]	0.2450	<0.01	0.3194
Weaning weight (kg)	5.3±1.2 [b]	5.5±0.4 [b]	8.1±0.9 [a]	5.0±1.2 [b]	5.0±0.1 [b]	8.0±1.3 [a]	0.2756	<0.01	0.6694

Note. [abc] Means with different superscripts in the same row differ significantly ($P < 0.05$).

Season had no significant effect ($P > 0.05$) on the litter size, total piglets born alive at birth and total number of piglets at weaning. However, piglets born in winter had a significantly higher birth and weaning weight as compared to autumn and summer seasons. It is evident that farrowing season plays a significant role in growth performance indirectly through its influence on the dam's nutrition and hence amount of milk available to the unweaned offspring. In the present study, birth and weaning weight were the lowest during autumn and summer seasons. This may be due to their reduced ability to maintain their body temperature and low colostrum and milk intake (Herpin et al., 1996). Furthermore, literature relating to the association between low birth weight and lower survival rate or a lower growth performance is abundant (Fix et al., 2010; Baxter et al., 2009; Quiniou, Dagorn, & Gaudre, 2002). In the present study, sows produced piglets with lower birth weights during summer months. Similarly, it was previously reported that sows tended to produce smaller litters with lower birth weights during hot or warm seasons (Tummaruk & Khatiworavage, 2011; Quiniou et al., 2002). Low weaning weights observed during summer may be attributed to the microclimate conditions affecting lactation. Pigs tend to be sensitive to high ambient temperature because their inability to sweat. Hence, it is of utmost importance to observe the body condition of sows especially during late pregnancy. Moreover, physiological changes that take place during farrowing and lactation may be affected by change in diets, postnatal stress and microclimatic factors (Quesnel et al., 2009). Additional heat stress during summer months contributes greatly to changes in the composition of milk, less milk secretion or decreased food consumption by piglets. Sex had no effect on all the evaluated characteristics recorded ($P > 0.05$). The interaction between the sex and season were only confirmed on the total number of weaned piglets ($P < 0.0001$).

Pearson correlation coefficients between litter size, total number of piglets born alive, total number of piglets weaned, birth and weaning weight are shown in Table 3. A highly significant positive correlation was found between litter size and number born alive (r = 0.86, P < 0.01) and total number of piglets weaned (r = 0.50, P < 0.05). However, a relatively low correlation (P > 0.05) was found between litter size and birth (r = 0.34) and weaning weight (r = 0.22). In contrast, litter size is negatively correlated to the average birth weight and weaning weight (Raseel, Kotresh, & Sunanda, 2016). There was also a significant correlation between total number of piglets born alive and total number of piglets weaned (r = 0.55, P < 0.05). A low negative correlation was observed between the total number of piglets weaned and birth weight (r = -0.07) and weaning weight (r = -0.20), although insignificant. Furthermore, there was a highly significant positive correlation between birth weight and weaning weight (r = 0.5; P < 0.01). These findings are in agreement with studies from Raseel et al. (2016). This positive correlation of birth weight and weaning weight may indicate that as the birth weight increases the weaning weight also increases.

Table 3. Pearson correlation coefficients between litter size, total number of piglets born alive, total number of piglets weaned, birth and weaning weight

Characteristics	Litter size	Total number of live born piglets	Total number of weaned piglets	Birth weight (kg)	Weaning weight (kg)
Litter size	1.00				
Total number of live born piglets	0.86 **	1.00			
Total number of weaned piglets	0.50 *	0.55 *	1.00		
Birth weight (kg)	0.34	0.28	-0.07	1.00	
Weaning weight (kg)	0.23	0.11	-0.20	0.50 **	1.00

Note. *P < 0.05; **P < 0.01.

4. Conclusion

In conclusion, season of birth had the greatest impact on birth and weaning weight, with the highest birth and weaning weights recorded during winter season. Moreover, the interaction between the sex and season was only confirmed on the total number of weaned piglets. However, sex did not affect the pre-weaning performance of piglets. Further research is recommended to determine the impact of season, sex, management, parity and nutrition on pre and post weaning productivity at smallholder farms.

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