DEVELOPMENT OF AN EFFECTIVE FEEDING REGIMEN USING DRY CHICORY (*CICHORIUM INTYBUS*) ROOTS TO ERADICATE ZOONOTIC HELMINTHS IN PIGS

By

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I, Ifeoma Chinyelu Nwafor, student number , declare that this thesis: Development of an effective feeding regimen using dry chicory (*Cichorium intybus*) roots to eradicate zoonotic helminths in pigs, submitted to the Central University of Technology, Free State for the degree of Doctor of Technology: Agriculture is my own independent work and that all sources used and quoted have been duly acknowledged by means of complete references; and complies with the code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology; and has not been submitted before to any institution by myself or any other person in fulfillment (or partial fulfillment) of the requirements for the attainment of any qualification. I also disclaim this thesis in favor of the Central University of Technology, Free State.

15-08-2018

Ifeoma C. Nwafor **Date**

DEDICATION

This study is dedicated to my redeemer, the Almighty God. Also to my family for their unmatched love, help, encouragement and support throughout the course of this study.

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ABSTRACT

The overall purpose of this study was to evaluate the efficacy of dry chicory (*Cichorium intybus)* roots in eradicating zoonotic helminths of pigs which have been identified as a public health issue and an animal welfare concern. The study was divided into five objectives. Firstly, a concise review of available literature on the anti-parasitic use of chicory in livestock was evaluated to ascertain its suitability for use in this study. It was concluded that chicory roots possess anthelmintic (AH) properties and should therefore be investigated. Secondly, information was obtained with the help of questionnaires from smallholder pig farmers operating in the central Free State Province to determine their level of practical knowledge in issues pertaining to porcine helminthiasis, zoonosis, AH resistance, pre-and post-slaughter practices. Results show that 65 % of farmers acknowledged the problem of intestinal helminths on their farms even though majority were not aware of porcine zoonosis. Seventy eight percent (78 %) of respondents were unaware of AH resistance in some porcine helminth species, while most respondents did not know about the withdrawal periods of some AH before slaughter. Seventy one percent (71 %) practiced the semi-intensive farming system, while 87 % were engaged in continuous flow-barn management practice. These practices aid the proliferation of intestinal parasites. Seventy four percent do not make use of the abattoirs because of affordability. Half of the farmers noted that their piggery businesses were not profitable and it was concluded that smallholder pig farmers need more animal health information from the experts. Thirdly, fecal samples were collected from pigs owned by smallholder pig farmers in the sample areas to determine the pre-mortem prevalence of intestinal helminths in pigs. Parasitology results reveal that three species of intestinal helminths [*Ascaris suum (*44.5 %), *Trichuris suis (*50.6 %) and *Oesophagostomum dentatum* (26 %)] and Coccidia (72.7 %) were identified. Semi-intensive farms, piglets, females and non-dewormed pigs recorded a higher prevalence of helminths than their counterparts. It was concluded that out-door pigs were more susceptible to infections. The risk factors are age, sex, management system and/or geographical location. The fourth objective focused on the post-mortem prevalence of intestinal helminths in pigs. Three abattoirs in the sample area were visited once a month for three months and the faecal contents of slaughtered pigs were analyzed. Results reveal the prevalence of *A. suum* (16.7 %), *T. suis* (11.1 %), *O. dentatum* (11.1 %), *Hyostrongylus rubidus* (9.3 %) and *Fasciola spp* (5.6 %)*.* The large intestine recorded the highest prevalence of all the other predilection sites. The study also recorded 46.9 % and 47.1 % prevalence for single and mixed infections respectively. It was concluded that low to moderate intensity of helminth infection occurred in this study even though some species of helminths persisted despite AH administration. These parasites were observed more in pigs that had access to out-door foraging facilities. Lastly, the farm experiment consisted of a 28-day feed trial which was conducted using 20 mixed breed grower pigs to evaluate the efficacy of dry chicory roots in eliminating intestinal helminths (*in vivo*) from naturally parasitized pigs. Pigs were randomly assigned to four experimental units in a completely randomized design which was semi-intensively managed. Group A pigs were used as control and were fed with the conventional pig grower feed, while groups B, C and D were the experimental groups which had 5 %, 10 % and 15 % chicory inclusion levels in their diets respectively. Faecal samples were collected from all pigs at intervals for parasitological analysis and growth parameters were also measured. Results indicate a 76.2 % reduction in FEC (fecal egg count) of experimental pigs which were plagued with both single and mixed infections of *A. suum* (89.3 %) and *T. suis* (82.1 %). There were significant differences (P<0.05) in FEC between groups on the first and last days of the trial. Feed intake recorded significant differences (P<0.05) across all groups in the 1st week with group A having the highest intake, while group D had the lowest rate probably due to the bulk in the chicory diet. Group C had the best Feed Conversion Ratio of 1.8, while group A had the least (2.1). It is concluded that dry chicory roots contributed extensively to faecal egg count reduction and relative growth performance in the experimental pigs. The overall best level of chicory inclusion in this study was recorded at 10 % (group C).

CHAPTER 1

BACKGROUND AND OVERVIEW OF THE STUDY

1.1 GENERAL INTRODUCTION

Pork and its products are vital to the global economy as it is the most widely consumed meat worldwide (FAO, 2012). In South Africa, pig farming and the production of pork is an important part of people's livelihood (SAPPO, 2009) because, statistically, it is the third highest produced meat in the country (LDA, 2011). Since pork is an important food for humans, the pig breed, management system, health status, slaughter, sale, welfare and consumption have become a major public health concerns. Pork production and consumption have safety implications for both the producer and consumer alike due to the potential health consequences resulting from endo-parasitic infestions of pigs and the resultant consumption of unwholesome pork or edible pig products (Petersen, 2002; Spencer, 2010). Research has shown that zoonotic diseases caused by pigs can affect farm workers, pig handlers, abattoir workers and pork consumers, thus affecting large portions of the public (FAO, 2008; Spencer, 2010; Holt *et al*., 2016; Humphrey and Jude, 2017).

Helminthiasis in livestock is considered a major disease which influences different farming systems globally. This results in production losses due to ill-thrift and inefficient feed utilization in all farming sectors. The presence of cysts, larvae or oocytes of intestinal helminths, residues of antimicrobials, anthelmintics, certain hormones, chemical pesticides and heavy metals in pig carcasses poses potential health consequences and risks for consumers (Fenwick, 2012). In addition, the development of anthelmintic resistance among zoonotic worm populations due to the indiscriminate and unprofessional use of pharmaceutical anthelmintic drugs resulted in a significant decline in their efficacy (Henrioud, 2011). Likewise, the presence of anthelmintic drug residues in meat products (Rahmann *et al*., 2002) also compounds consumer health risks. Although some of these hazards may be sub-clinical or asymptomatic in the live animal, it can increase host susceptibility to serious pathogens (Aumaitre, 1999; Spencer, 2010). However, several food-borne pathogens which are not unique to the pig meat industry have become the subject of regular scientific and media reporting. When the presence of parasites in meat products becomes the centre of media reports, it could undermine consumer confidence in these products (Oyewumi and Jooste, 2006; Fernandez and Anderson, 2016). The recent media frenzy caused by the Listeria outbreak in polony products in South Africa is a case in point (eNCA.com, 2018). The wholesomeness of pork and its products is thus of significant importance to man, not only because of the provision of variety to the nutritional quality of human diets, but also because many meat-borne illnesses (e.g., Trichinellosis, Cysticercosis, Ascariasis, Taeniasis and Trichuriasis) may compromise public health. These infections are caused by helminths, which are mostly zoonotic (Mkhize-Kwitshana and Mabaso, 2012). Humans are at the top of the biological food chain and are at risk of contracting intestinal helminths from the consumption of animal products. Wholesomeness that is characterized by consistency in safety, quality and value of products presented to the public is thus the most important goal of the animal food production industry in any country (FAO, 2008).

Generally, helminths derive nourishment and protection from hosts and are usually transmitted from host to host through the consumption of contaminated food, soil and water, thereby causing food, soil or waterborne illnesses. They differ in size from tiny single-celled organisms to clearly visible worms (Eckert, 2005). While some worms use a permanent host, others go through a series of developmental phases using different animal or human hosts. These organisms live and reproduce within the tissues and organs of infected humans and animal hosts and are often excreted in faeces. They may be transmitted from animals to humans, from humans to humans, or from humans to animals, hence the term zoonosis. According to various authors such as Zoli *et al*. (2003), Assana *et al*. (2010) and Humphrey and Jude (2017), helminths are likely to cause a range of illnesses from mild discomfort to debilitating illnesses and possibly death. Additionally, they cause economic losses to the farmer, unthriftiness, poor animal welfare, poor quality products, ill health and increased cost of treatment (Knecht *et al.,* 2012).

Anthelmintic (AH) medications are administered to animals either for prevention of infection or for treatment of infected animals (Jackson and Coop, 2000; Forbes, 2017). Usually, the control of helminths is based mainly on mass treatment of farm animals with synthetic pharmaceutical anthelmintics which are not sustainable in the long term due to the development of resistance among worm species. According to Kaplan (2004), Coles *et al.* (2006) and Henrioud (2011), this intensive use of anthelmintic drugs has resulted in treatment failures of most of the anthelmintic drugs that are available today. The evolution of anthelmintic resistance (AR) in worm populations is recognized globally as it threatens the success of pharmaceutical drug treatment programs. Various authors (Van Wyk *et al*., 1999; Vatta *et al.,* 2001; Van Wyk and Bath, 2002; Bakunzi, 2003) have earlier stated that AR is widely disseminated in South Africa, but insufficient information is available on the degree of resistance to commonly used AHs in communally grazed small ruminants in the intensive and semi-intensive management systems in South Africa. Moreover, Williams *et al*. (2014) noted that most subsistence farmers in many developing nations cannot afford expensive AH drugs and that many low-input and organic farmers in developed countries are not able to prophylactically treat animals with synthetic medication.

The increase in public awareness of drug residues in edible tissues of animal products and increased parasitic resistance to modern AHs, combined with the desire for more sustainable farming practices and better animal welfare, have resulted in an intensified effort to find alternative control options for gastro-intestinal parasites (Rahmann *et al*., 2002). The use of AHs as the only remedy for helminth infections in farm animals is no longer considered sustainable and safe. The increasing rates of AR among worm populations, high costs of AH drugs and the issues surrounding chemical drug residues in animal products and the environment have exacerbated this inefficiency. This has triggered the evaluation of the efficacy of a phyto-bioactive plant (chicory) which is purported to possess AH properties with a view to further investigating its anthelmintic capabilities. Nevertheless, there is still insufficient on-farm scientific research in this field, even though several plants are currently used in this regard in third world countries (Hördegen, 2005). These plants do not only deal with helminth infections of livestock, but also have other therapeutic properties which often have successful outcomes (Nfi *et al*., 2001).

Increasing productivity and sustainability in all farming systems is basically the bane of all agricultural developments, especially in rural settings. In reality, the objectives and technological possibilities to implement sustainable parasite control in developed countries are not the same for a resource-poor subsistent livestock producer in remote sub-Saharan Africa (Henrioud, 2011). Therefore, to ensure proper food security and rural economic development, sustainable farming methods and practices are required to help resource-poor farming communities. Henrioud (2011) also stated that in many developing countries, especially amongst smallholder farmers, owning livestock is considered a stock of wealth even though ineffective treatments of their flock for intestinal parasites is usually the case. Therefore, it is crucial to have a theoretical base to better understand the rational practices of parasite control in any given farming region that is aimed at increasing livestock production in a sustainable and safe way.

In this context, the maintenance of the safety of meat products requires control throughout the food chain; this ranges from from the farm of origin, inspection (pre- and post mortem), the handling and storage of meat and the products derived from it, to the time of consumption (i.e., the "farm-to-fork" concept). Improved bio-security and hygienic practices are critical in controlling zoonotic diseases, as this will ensure that pig producers and consumers are protected, as safe and wholesome pork products will reach the market. The responsibility to produce safe and wholesome meat is shared by the industry and the controlling authorities (Smil, 2002; CAC, 2005; FAO, 2018). Food safety comprises both prevention and response aspects, as it requires a continuous program that starts with agricultural production and continues through to the slaughtering, processing, retail marketing, consumer handling and consumption of the products. In a world of constantly evolving and emerging risks, food safety is a journey, not a destination. Therefore, the health of pigs as the origin of the pork food chain will benefit consumers through better quality pork and other products derived from pigs.

1.2 PROBLEM DESCRIPTION

Pork and pig products have been identified as a source of human helminthiasis. Djurković-Djaković *et al*. (2013) reported that, according to the Food and Agriculture Organization (FAO), 10 % of the world's population is estimated to be affected by food-borne zoonoses yearly, of which helminth parasites constitute an important class of aetiological agents. *Trichinella* spp, *Taenia* spp and *Ascaris* spp are among the common pork-borne parasitic helminths mostly transmitted by pigs or their products. These zoonotic helminths are mostly endemic in developing countries and are usually ingested by pigs from their environment during their different stages of development. These helminths have the potential to infect humans and thus provide a reasonable risk for zoonotic transmission, which is an important public health issue of concern. The modern trend of consuming raw meat also favours their re-emergence in the developed world. In as much as the parasites cause considerable health dangers to humans and animals and pose serious public health concerns, they also cause economic losses to the farmer due to unthriftiness or low productivity. These helminth infections cause a major decline in animal wellbeing as well (Simoons, 1995; Ekwuagana, 2004). The decline in the welfare of pigs has become a matter of great concern in developed nations as well. Sadly, such issues have not been prioritized in most developing countries like South Africa, principally due to the lack of education and funding in matters relating to animal welfare (Muchenje and Ndou, 2011).

Preventing zoonotic helminth infections in pigs requires information about the prevailing management practices utilized by farmers, especially smallholders. In addition, the portals of entry of these intestinal parasites and the species of helminths prevalent in pigs that are raised in a particular geographical farm environment should be identified. Thus, an appropriate plan that aims at identifying and possibly eradicating these zoonotic intestinal helminths in pigs by employing a purportedly effective plant anthelmintic, dry chicory (*Cichorium intybus*) roots as a feed additive, can be developed as a baseline comparison for future helminth interventions.

1.3 PROJECT RATIONALE

Pork is an important food product and one of the most consumed meats worldwide (FAO, 2012). Therefore, its safety for human consumption and the quality parameters should not be taken for granted. Pork has a high content of biologically valuable nutrients and it is very versatile in use amongst customary foods in the food chain. The trends in the consumption of different kinds of animal products, mostly meat, are largely influenced by health, breeding and processing factors that affect the criteria of the quality of the meat consumers will desire.

Intestinal parasites of pigs and their potential to infect and harm humans have resulted in food-borne diseases. Additionally, the development of anthelmintic resistance among zoonotic worms due to the indiscriminate use of synthetic drugs and the presence of anthelmintic drug residues in pork have also compounded health risks in consumers. This calls for a critical standpoint by the pork industry and the scientific world involved in safety practices and regulations to continuously seek to improve pork safety and quality, production performance, animal welfare and the safety of the environment to meet consumer and market demands in the production and provision of safe and wholesome meat.

The effective control of these endemic worms has proved to be possible and sustainable through the use of phyto-bioactive ingredients. Plant species such as Birdsfoot, Chicory, Sulla, etc, rich in sesquiterpene lactones, condensed tannins, non-digestible oligosaccharides (prebiotics), etc, have shown a direct anti-parasitic effect against different stages of nematodes in both *in vitro* and *in vivo* investigations. However, none of the various examined compounds have been researched sufficiently in on-farm experiments for any concrete recommendations to be made; thus, scientific evidence of their anti-parasitic effects is still varying. Furthermore, there is a paucity of scientific information on the use of bio-active plants to control zoonotic helminths in monogastrics in South Africa. Therefore, an investigation into the use of dry chicory root that is known to possess some anthelmintic properties that may eradicate these zoonotic helminths in pigs has become imperative. Such an investigation may also go a long way in practices to eliminate the problem of anthelmintic drug residue in pig carcasses, thereby regaining consumer confidence in swine products.

1.4 STUDY OBJECTIVES

1.4.1 Primary objective

The primary objective of the study was to develop an effective feeding regimen using dry chicory (*Cichorium intybus*) roots to eradicate zoonotic helminths in pigs.

1.4.2 Specific objectives

The specific objectives of the study were to:

- Write a concise review of available scientific knowledge to evaluate the *in vivo* and *in vitro* efficacy of phyto-bioactives in controlling zoonotic helminths in livestock.
- Conduct a questionnaire survey to determine the knowledge of smallholder pig farmers regarding porcine helminthiasis and the prevalent farm management operations employed by these farmers in the central Free State Province of South Africa.
- Investigate the pre-mortem prevalence of intestinal parasites in pigs reared on smallholder pig farms in the central Free State Province of South Africa.
- Examine the post-mortem prevalence of helminthiasis in pigs slaughtered in selected abattoirs in the central Free State Province of South Africa.
- Determine the efficacy of combating intestinal helminths in experimental pigs by feeding them graded levels of dry chicory (*Cichorium intybus*) roots.
- Recommend an effective, integrated, safe and sustainable approach to prevent zoonotic helminth infections in pigs and consumers “from farm to fork”.

1.5 HYPOTHESIS

This study hypothesized that the inclusion of graded levels of dry chicory (*Cichorium intybus*) roots in experimental pigs’ diet would enhance the eradication of intestinal helminths in pigs.

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CHAPTER 2

LITERATURE REVIEW

2.1 ZOONOSIS

Zoonosis has been defined by many authors in both ancient and modern literature. According to McGraw-Hill Encyclopedia (2005), zoonosis is "any infection of humans caused by the transmission of disease agents that naturally live in animals". Goldsmid (2005) defines zoonosis as "infections of animals that are naturally transmissible to humans", whereas Webster and Mariger (2008) define it as "an infectious disease transmissible under natural conditions between vertebrate animals and human beings". A more recent definition by MedicineNet (2016) defines zoonosis as "an infectious disease in animals that can be transmitted to people. The natural reservoir for the infectious agent is an animal".

Zoonosis may be derived from wild or domestic animals or from products of animal origin (Encyclopedia of Public Health, 2011). The World Health Organization (WHO) (2011) reported that over 200 zoonotic diseases have been described and known for many centuries. These diseases are caused by all types of agents: bacteria, parasites (including helminths), fungi, viruses and unconventional agents. Because zoonotic diseases are caused by infectious agents that are transmissible under natural circumstances from vertebrate animals to humans, people become infected when they unwittingly intrude into the life cycle of the disease agent and thus become unnatural hosts. Goldsmid (2005) reported that zoonotic infections may be localized in their distribution and that they often reflect particular associations between the natural reservoir hosts and humans. They are thus often influenced by human dietary habits as well as behaviour and relationships with different animal species. To buttress the above point, Spencer (2010) reiterated that a major medical concern is the fact that, due to poor personal hygiene especially among children, these zoonotic infections continue to maintain their cycle of infection between humans and animals. Additionally, Zoli *et al*. (2003) noted that there is undoubtedly many zoonosis lurking in nature that have the potential to cause serious public health consequences if introduced to humans.

According to Chin (2000), WHO (2003, 2011) and Domenico and Eberhard (2011), a partial list of symptoms in man may include some of the following: fever (sometimes hemorrhagic), headache, rash, muscle aches, arthritis, respiratory distress (sometimes pneumonia), abdominal pain, vomiting, blindness, diarrhoea, jaundice, cardiac abnormalities and neurological involvement ranging from stiff neck to meningitis or encephalitis. The course of the diseases varies between different zoonotic pathogens but can be more severe in the very young (Phiri *et al*., 2003) or very old, or in individuals who are immunocompromised (McGraw-Hill Encyclopedia, 2005; Mkhize-Kwitshana *et al*., 2011).

Furthermore, Domenico and Eberhard (2011) stated that the effect of human parasitic diseases that are transmitted by animals is felt globally, especially in developing countries, and that they hamper socio-economic development in these areas. Zoonosis still represent significant public health threats, but many of these threats are neglected and are usually not prioritized by health systems at national and international levels. Even though most of these diseases can be prevented, they affect hundreds of thousands of people, especially in developing countries (WHO, 2011).

2.2 ZOONOTIC HELMINTHS

Zoonotic helminths are multicellular eukaryotic invertebrate parasites that live inside their host (Goldsmid, 2005; John and William, 2006). These worms are protected and nourished by their living hosts while they, in turn, cause diseases and lethargy by obtaining nutrients from and disrupting the normal metabolic function in their hosts. They can live inside humans as well as animals (WHO, 2002; Zanga *et al*., 2003; Maizels and Yazdanbakhsh, 2003; John and William, 2006).

It has been ascertained that, throughout history, humans have been exposed to helminth parasites originating from various animal species. McCarthy and Moore (2000) reported that zoonotic helminth diseases caused by parasitic worms involve many species of helminths. Helminth parasites may be contracted from domestic animals, edible animals or meat products originating from farm animals, sea food, and from wild animals (or game) (Moreno-Ancillo *et al.*, 1997; Anderson and Jaenike, 1997; DeGiorgio *et al*., 2004; McGraw-Hill Encyclopedia, 2005; Sahelian, 2010).

Pigs often suffer from intestinal parasitic worms which live in their gastro-intestinal tract. The process by which these worms obtain nourishment from their hosts damages some internal organs such as the lungs and muscles. This could cause anaemia, poor growth and low productivity in pigs (Gehrke, 1997; Brown and Silverman, 1999; Zanga *et al*., 2003; Campbell *et al*., 2003). Sahelian (2010) noted that parasites found in pigs can also grow in the meat of different animal species.

According to Goldsmid *et al.* (2003), humans can be infected with these zoonotic helminths by ingesting foods containing the parasite(s). In Table 2.1, some examples of important zoonotic helminths transmitted by human food sources are listed and their resultant diseases include: Taeniasis; Trichinosis, Ascariasis, Cysticercosis, Diphyllobothriasis, Clonorchiasis, Anisakiasis, e.t.c. (Moreno-Ancillo *et al*, 1997). Ingesting the worm in its infective stage with contaminated soil (Toxocariasis), water or salad plants (Fascioliasis; Fasciolopsiasis, Toxocariasis) can also cause diseases (Dorny *et al*., 2009). Additionally, human infections can occur through skin contact with contaminated soil/water that contains active infective larvae that penetrate the skin (i.e., cutaneous larva migrans; cercarial dermatitis) (Goldsmid, 2005); from direct animal contact (Hydatid; Toxocariasis); or through insect vectors/intermediate hosts by ingestion (Dipylidiasis, *Hymenolepis diminuta*) (McCarthy and Moore, 2000).

Reporting on the state of emerging food parasites, Dorny *et al*. (2009) posited that, in the past, the risk of human infection with parasites was considered to be limited to distinct geographic regions because of parasites' adaptations to specific definitive hosts, select intermediate hosts and particular environmental conditions. Unfortunately, these barriers are slowly being breached − first by international travel developing into a major industry, and secondly by rapid, refrigerated food transport which has become available at an unprecedented degree since the end of the 20th century (Orlandi *et al*., 2002). Other factors that may explain the emergence of some zoonotic parasitic diseases are the increased population of highly susceptible persons because of ageing; malnutrition; HIV infection (Krecek *et al*., 2004; Adams *et al.,* 2006); underlying medical conditions; and changes in lifestyle such as the increasing number of people eating meals prepared in restaurants, canteens and fast food outlets and street food vendors who do not always respect food safety. Escalation in the quantities of raw or undercooked meats that are eaten is also a factor to consider (WHO, 2002).

Table 2.1: Some important zoonotic helminths transmitted by human food sources

Infection	Organism	Natural definitive hosts	Intermediate hosts	Distribution
Nematodes				
Trichinellosis	*Trichinella spiralis*	pigs	carrion	worldwide
Anisakiasis	*Anisakis pseudoterranova*	tortoise, whale, seal, walrus	herring, cod, mackerel, salmon	worldwide
Cestodes				
Cysticercosis	*Taenia solium*	humans	pigs	worldwide
Echinococcosis	*Echinococcus granulosus*, *Echinococcus multilocularis*	Carnivores: dogs, foxes, wolves, dingoes	Herbivores, especially sheep	South America, Mediterranean area, Asia, Australia, New Zealand
Trematodes				
Schistosomiasis	*Schistosoma japonicum*	sheep, cattle, horses	freshwater snails	Asia-Pacific
Clonorchiasis	*Clonorchis sinensis*	dog, pig, cat, mouse, camel	snails, carp	Asia-Pacific
Opisthorchiasis	*Opisthorchis viverrini*	dog, cat, pig	freshwater fish, snails	Eastern Europe, Asia-Pacific
Paragonimiasis	*Paragonimus westermani*	wild, domestic cats	freshwater snails, crabs	Asia-Pacific
Fasciolosis	*Fasciola hepatica*, *Fasciola gigantica*	herbivores: sheep, cattle	freshwater snails; vegetation	Worldwide, especially Africa, Asia

Source: Adapted from McCarthy and Moore, 2000

2.2.1 MORPHOLOGY AND DEVELOPMENT OF ZOONOTIC HELMINTHS

Parasitic worms are categorized into three groups: cestodes (tapeworms), nematodes (roundworms) and trematodes (flukes) (John and William, 2006). The clinically relevant groups are separated according to their general external shape, body cavity, body covering, attachment organs and the host organ they inhabit. There are both hermaphroditic and bisexual species, and some have digestive tubes that are absent in others. The definitive classification is based on the external and internal morphology of egg, larval and adult stages (Baron, 1996; Edward and Kremer, 2004). Dorny *et al*. (2009) stated that many helminths are free-living organisms in aquatic and terrestrial environments, whereas others occur as parasites in most animals and some plants. Adult worms infect definitive hosts (those in whom sexual development occurs) whereas larval stages may be free-living or parasitize invertebrate vectors, or intermediate or paratenic hosts where the parasites undergo an arrested development on infection. Larval forms will accumulate in these hosts until they have an opportunity to infect the definitive host (McCarthy and Moore, 2000; Edward and Kremer, 2004).

Adult tapeworms (cestodes) are flattened, elongated and consist of segments called proglottids. Tapeworms vary in length from 2 mm to 10 m and may have three to several thousand segments (Baron, 1996; Boreham and Stenzel, 1998; NIAID, 2007). Anatomically, cestodes are divided into a scolex, or head, which bears the organs of attachment, a neck that is the region of segment proliferation, and a chain of proglottids called the strobila. The tapeworm is a hermaphrodite because each piece of the proglottid contains a complete reproductive component (Pawlowski and Prabhakar, 2002; Carter and Bogitsh, 2013). The segments nearest the neck are immature (i.e., the sex organs are not fully developed) and those more posterior are mature. The terminal segments are gravid, with the egg-filled uterus as the most prominent feature. The intermediate hosts ingest the hexacanth oncospheres which have been embryonated and released from gravid segments. They therefore inhabit the intestinal lumen in the host. These ingested oncospheres pierce the internal tissues of their host and metamorphose to metacestodes (encysted larvae). They excyst and form adult tapeworms when ingested by definitive hosts. Larval forms, which are cystic or solid, inhabit extra-intestinal tissues (McCarthy and Moore, 2000). Common cestodes include: beef tapeworm (*Taenia saginata*), pork tapeworm (*Taenia solium*), fish tapeworm (*Diphyllobothrium latum*), and dog tapeworm (*Dipylidium caninum*) (Weintraub, 1998; Saxion, 2003).

Nematodes are cylindrical rather than flattened, hence the common name roundworm. The body wall is composed of an outer cuticle and musculature. They vary in length from 0.3 mm to over 8 m (NIAID, 2007). The alimentary canal of roundworms is complete with both mouth and anus. Lips, teeth, filariform extremities and dentary plates are the organs of attachment to their hosts. Adult and larval roundworms are bisexual and copulation is necessary for fertilization (Baron, 1996). Most nematodes that are parasitic in humans lay eggs that, when voided, contain either an uncleaved zygote, a group of blastomeres, or a completely formed larva. Some nematodes, such as the filariae and *Trichinella spiralis*, produce larvae that are deposited in host tissues and they inhabit intestinal and extra-intestinal sites (Castro, 1996; Boreham and Stenzel, 1998). The developmental process in nematodes involves egg, larval (four stages) and adult stages which are all completed in a single host. Each of the four larval stages is followed by a molt in which the cuticle is shed. The nematode formed at the fifth stage is the adult. The unusual life cycle restricts transmission to animals with cannibalistic and scavenger habits (Boreham and Stenzel, 1998; Hoyt, 2007). Common nematodes include: roundworm (*Ascaris spps, Toxocara spps*), hookworm (*Necator americanus, Ancylostoma duodenal*), pinworm (*Enterobius vermicularis*), heartworm (*Dirofilaria immitis*)*, Strongyloides* (*Stronglyoides stercoralis*), *Trichinella* (*Trichinella spiralis*), Filaria (*Wuchereria bancrofti, Brugia malayi, Onchocerca volvulus, Loa loa, Mansonella streptocerca, Mansonella perstans, Mansonella ozzardi*), and Anisakine larvae (Weintraub, 1998; Corwin and Tubbs, 2015).

A dorso-ventrally flattened body, bilateral symmetry and a definite anterior end are features of trematodes in general. Trematodes are leaf-shaped flatworms that range in length from a few millimeters to 7−8 cm (Maizels and Yazdanbakhsh, 2003; NIAID, 2007). The tegument which is the body covering is morphologically and physiologically complex. Flukes possess an oral sucker around the mouth and a ventral sucker or acetabulum that can be used to adhere to host tissues. A body cavity is lacking. Organs are embedded in specialized connective tissue or parenchyma. Flukes are hermaphroditic, except for blood flukes which are bisexual. The life-cycle of a trematode is rather complex. The larval stage infects the snail (its intermediate host) where it undergoes asexual development. Free swimming miracidia are released in the host when the eggs hatch and they in turn infect the intermediate host, where they multiply to produce numerous rediae. The matured stage (carcariae) when released from the host may encyst on aquatic plants or infect new definitive hosts (Castro, 1996; John and William, 2006). Common trematodes include: intestinal fluke (*Fasciolopsis buski*), blood fluke (*Schistosoma japonicum, Schistosoma mansoni, Schistosoma haematobium*), oriental lung fluke (*Paragonimus westermani*), and sheep liver fluke (*Fasciola hepatica*) (Gittleman, 2001).

Pozio and Murell (2006) observed that most helminth eggs have tough resistant walls to protect the embryo while it develops. Mature eggs hatch to release larvae either within a host or into the external environment. The four main modes of transmission by which the larvae infect new hosts are faecal-oral, transdermal, vector-borne and predator-prey transmissions (Zoli *et al.*, 2003).

2.2.2 PORK TAPEWORM (*TAENIA SOLIUM*)

The pork tapeworm (*Taenia solium*) is a member of the cyclophyllid cetode in the Taeniidae family. This parasite is zoonotic in nature and occurs globally, especially in regions where pork is consumed raw or only slightly cooked (Garcia, 2001; Pawlowski and Prabhakar, 2002). Human infections can also occur through unhygienic practices and contact with contaminated meat or cross-contamination with contaminated objects. The highest rates of infection are found in areas of Latin America, Asia and Africa that have poor sanitation and free-ranging pigs that have access to human faeces. Willms (2008) reported that *T. solium* has an indirect life cycle which is depicted in figure 2.1. From pigs (intermediate host), it is transferred to its definitive host (humans) and the eggs are excreted by humans into the environment. These eggs are further ingested by another host.

When ingested by pigs, the morula (embryonated eggs) develop into oncospheres (larvae) that mature to the L_3 larval stage (cysticerci). Humans are infected by this larval stage through the consumption of measly pork (Gutierrez, 2000; Willms, 2008; Carter and Bogitsh, 2013). Inside the small intestine, the larva (cysticercus) breaks out from its sheath. The host's digestive enzymes and bile juices aid in stimulating this process known as evagination. The larva attaches itself to the walls of the intestine using its scolex from where it and gets its nourishment for growth. From 10 – 12 weeks after ingestion, it grows to the adult stage and new proglottids are formed. Each proglottid can contain more than 50,000 embryonated eggs. The adult worm can reproduce at this stage through self- or cross-fertilization. In the fertilization duct, the zygotes are produced by the fusion of spermatozoa and the ova. Three cell types are formed (small micromeres, medium mesomeres and large megameres) by the zygote after undergoing a holoblastic and an unequal cleavage. The megameres further develop into their embryonic membrane (syncytial layer), the mesomeres develop into embryophore, while micromeres form the morula which is a six-hook embryo (oncosphere). Eggs occur in faeces due to the rupture of gravid proglottids in the intestine. These are in turn excreted from the host through the action of peristalsis. The eggs are hardy and can survive up to 2 months in the environment (Mayta, 2009; Carter and Bogitsh, 2013).

Garcia and Del Brutto (2014) observed that pigs are usually infected with these worm eggs from human faeces when they ingest contaminated vegetation or feed. The embryonated eggs hatch to motile oncospheres in the intestine. The host's digestive enzymes remove both the embryonic and basement membranes surrounding the oncopheres which then allows them to attach to the intestinal wall using hooks. These oncopheres enter the blood and lymphatic vessels by penetrating the intestinal mucosa through the help of their digestive enzymes from their penetration glands. From here, they travel all through the circulatory system and internal organs and most are usually destroyed in the liver. The oncopheres that survive the liver clearance will most likely migrate to their predilection sites which include striated muscles, the brain, liver and other soft tissues, where they form cysts known as cysticerci. As reported by Garcia and Del Brutto (2014), cysticerci are usually formed within 70 days and may sometimes continue to grow for about a year. As secondary hosts, humans can be infected by ingesting foods contaminated with these embryonated eggs. When the larvae migrate to the brain, they can cause a condition known as neurocysticercosis (NCC). NCC has been identified as a major cause of sudden onset of seizures and epilepsy in adults (Junghanss *et al*., 2013).

Junghanss *et al*. (2013) further reported that taeniasis is often asymptomatic in the host, although conditions like inappetence, anaemia, indigestion and subsequent emaciation can be noticed in extreme cases. On the other hand, the parasitic larval cyst infection (cysticercosis) is clinically pathogenic (Flisser *et al*., 2010) and symptoms can present as dizziness, headaches, seizures, dementia or hypertension in severe cases. Brain malfunctions, sensory deficits and involuntary movements are other symptoms of this infection. Junghanss *et al*. (2013) also noted that in children, cysts are more likely to occur in the eyes than in other body tissues. Factors that would affect the severity of cysticercosis in a host include: the number of parasitic larvae in predilection sites, the location of infection, the size of the parasites, and the integrity of the host's immunity.

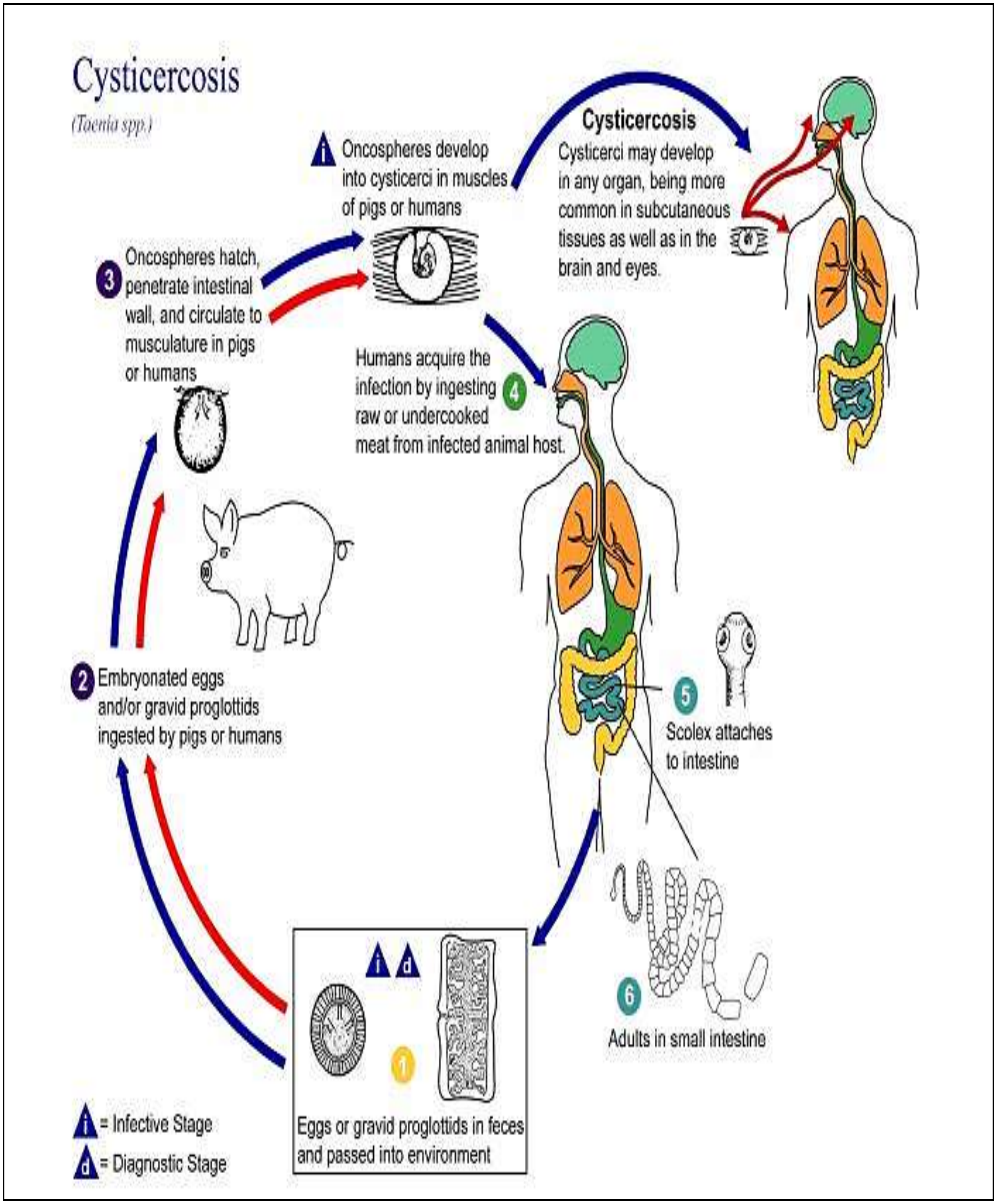

Figure 2.1: The lifecycle of *Taenia solium*

(Source: Centre for Disease Control, 2014)

2.2.3 LABORATORY DIAGNOSES OF ZOONOTIC HELMINTHS

Specific helminths can be identified through microscopic examination of their eggs (ova) found in faecal samples. The unit for measuring the number of eggs observed is eggs per gram (EPG) (Crompton and Savioli, 2007). However, this process does not quantify mixed infections and is inaccurate for quantifying the eggs of schistosomes and soil-transmitted helmiths (Krauth, *et al*., 2012). Sophisticated tests such as serological assays [sero-diagnostic ELISA (SERASCA® test)] (Vlaminck *et al.,* 2015), antigen tests, molecular techniques, and epidemiological investigations (Dupouy-Camet and Bruschi, 2007) are also available (Crompton and Savioli, 2007; Lustigman *et al.,* 2012). However, these methods have been found to be time-consuming, expensive and not always reliable (Hunt and Lello, 2012).

Helminths in the pig are relatively easy to identify if one is aware of their size, gross morphology and the tissues and organs in which they are normally located (TMVM, 2015). Macroscopically, visible lesions typical for some species may provide supportive information. Identification of the parasites may be based on post-mortem examination at slaughter or when animals have died from the disease. Clinical symptoms will rarely be sufficiently specific to point to a single responsible specie.

2.3 PREVALENCE OF ZOONOTIC HELMINTHS IN ANIMALS AND HUMANS IN THE SOUTH AFRICAN CONTEXT

The divergent distribution of the Human Immunodeficiency Virus (HIV) and helminth infections has been widely associated with the notion that persistent infection with helminths exacerbates the HIV epidemic in developing countries (Malhotra *et al*., 1999; Gopinath *et al*., 2000; Lawn *et al*., 2001; Secor *et al*., 2003; Borkow and Bentwich, 2004; Mkhize-Kwitshana and Mabaso, 2014). According to Bradshaw and Steyn (2002) and THSRC (2004), an estimated 57 % of the South African population live in poverty and carry most of the disease burden of HIV and helminthic infections. Earlier reports by Mabaso *et al*. (2004) and Saathoff *et al*. (2005) stated that the national estimates of helminth prevalence in South Africa were not known but, subsequently, Mkhize-Kwitshana *et al*. (2011) reported that helminth prevalence in South Africa ranged between 40 % and 60 %. Data from human surveys in different South African provinces have revealed infestation levels that range between 70 - 100 % mostly in school age children and pre-schoolers (Wolmarans *et al.,* 2005*;* Fincham and Dhannsay, 2006; Appleton *et al*., 2009). Mkhize-Kwitshana *et al*. (2011) suggest that HIV immune responses are impaired by helminth infections in certain susceptible groups of individuals, particularly in individuals who excrete worm eggs and have high parasite IgE in serum. Interestingly, Krecek (2005) reported a bit more than 10 years ago, that the highest prevalence of juvenile neurocysticercosis (NCC) in the world was found in the Eastern Cape Province of South Africa. At the same time, Mafojane *et al*. (2003) also noted that the Xhosa-speaking people of the Eastern Cape Province had the highest prevalence of cysticercosis/taeniosis in South Africa. This was probably due to the common practice of free-range pig farming and the prevailing deficit of basic sanitation practices in these areas. Studies around the same time revealed that non-pork eaters had as great a chance of infection as pork eaters, especially children (Phiri *et al*., 2002). During this period, Burneo and García (2001) also noted that approximately 2.5 million people worldwide carried adult *T. solium.* It was the opinion of these authors at the time that NCC was considered to be the most common parasitic disease of the nervous system globally.

According to the International League Against Epilepsy (ILAE), cysticercosis is probably the single most common cause of acquired epilepsy in the developing world, where the prevalence of active epilepsy is twice that of developed countries (Del Brutto *et al*., 2001). It is also a growing problem in industrialised countries because of the immigration of tapeworm carriers from endemic areas. However, there is little information on the current prevalence of helminths in food animals in South Africa. Only sporadic information is available on the prevalence of Trichinellosis in Africa, and these limited reports suggest that high infection rates occur in pigs in many countries (Pozio, 2007). In 2006, *T. zimbabwensis* larvae were detected in the muscles of fish, reptiles and mammals in the Mpumalanga Province of South Africa (La Grange *et al.,* 2009). The prevalence of Trichinella infection in the Nile crocodiles of this province was 38.5 % at the time (La Grange *et al*., 2009). Moreover, at around the same time, Gwaze *et al*. (2010) observed a high faecal helminth egg load in the indigenous Nguni goats of the Eastern Cape Province of South Africa in the wet season.

2.4 ECONOMIC IMPACT OF ZOONOTIC HELMINTHS

Parasitic worms remain a public health threat to humans and animals worldwide (Murrell, 2006). Zoonotic helminth infections in both pigs and humans could lead to high economic losses in swine production, food safety as well as in high treatment and opportunity costs for people suffering from helminthiasis. In addition, these infections have a high health risk for the general public. In this context, Murrell (2006) noted that the economic impact of these diseases can be divided into three categories:

a) Cost due to the disease in humans;

b) Production losses because of carcass condemnation of diseased animals at the abattoir; and
c) Cost of control programs and education to mitigate or eradicate the diseases.

A scientific study by Pozio (1998) reported that the global cost of detecting Trichinella infection in pigs was roughly estimated to be $3.00 (€2.10) per pig in 1998, which means that the control of Trichinella infection in the 190 million domestic pigs that were slaughtered at that time in the former 15 countries of the European Union had an economic impact of about $570 million (€388 million) per year. However, the true cost of Trichinella inspection by digestion ranged from $0.18 to $3.70 (€0.12 to €2.5) according to the size of the abattoir. For example, in large Danish slaughterhouses where about 10,000 pigs were slaughtered daily, the cost estimate for inspection of pooled sample digestion was $0.22 (€0.15) per pig (Kapel, 2005). In the United States, the herd certification program for Trichinella-free farms carried, according to Pyburn *et al*. (2005), an estimated a cost of $0.25 to $0.70 (€0.16 to €0.48) per pig, which was roughly similar to that of traditional inspection by digestion (Kapel, 2005).

Similarly, annual losses due to porcine cysticercosis (pork tapeworm) were estimated at 25 million Euros in 2002 in ten Western and Central African countries (Zoli *et al.,* 2003), US$5 million in the endemic areas of the Eastern Cape Province of South Africa in 2004 (Carabin *et al*., 2006), US$121 million for 0.2 billion kg of pork meat in China in 2002 (Engels *et al.,* 2003), and US$164 million in all Latin American countries in 1991 (Murrell, 2006).

Blindness caused by larval migration of some helminth species to the eye has profound human and socio-economic consequences with high costs for the individual and society. This condition is also linked to loss of productivity and rehabilitation that was estimated at US$42 billion per year in 2000, and has been predicted to reach as high as US$110 billion per year in 2020 (WHO, 2003; Ryan and Durrand, 2005). Although the actual prevalence and economic impact of zoonotic helminths in Africa (Zoli *et al.,* 2003) and specifically in South Africa (Mafojane *et al*., 2003) are not known, Carabin *et al*. (2006) estimated the overall cost of treating neurocysticercosis (NCC) in South Africa to vary from US$18.6 million to US$34.2 million due to productivity losses.

The most appropriate solution to the problem will depend on the relative costs of developing a control strategy compared to the gains associated with reducing the infection of all parasitic worms in pigs. Perry and Randolph (1999) conclude that farm management decisions are based on financial criteria and that a given control measure can be justified if it improves the farmer's profits.

2.5 PUBLIC HEALTH REGULATORY MEASURES TO ERADICATE HELMINTHS

Intestinal helminth infections cause the greatest burden of disease in poverty-stricken areas in the developing world (Belizario *et al*., 2011). Severe intestinal helminth infection could lead to lung infiltration, appendicitis, obstructive cholecystitis, pancreatitis, peritonitis, volvulus, intestinal obstruction (Zapata *et al*., 2007; Wani *et al*., 2010), dysentery, rectal prolapse, clubbing of fingers, anaemia (Stephenson *et al*., 2000), diarrhea, anaemia, hypoalbuminemia, and pneumonitis (Hall *et al*., 2008). The most vulnerable group and thus the most significant contributors to disease transmission are pre-schoolers, school age children and pregnant and breast-feeding women living in endemic areas (WHO, 2016).

One popular approach to intestinal helminth control/eradication is the school deworming programs (Watkins and Pollitt, 1997). School deworming programs have also been shown to have strong positive externalities. Miguel and Kramer (2004) used a "difference-in-difference" model to show that deworming programs in some schools reduced the burden of disease in neighbouring and untreated schools. Other evidence suggests that deworming children also has strong benefits for adult infection rates, because children are a significant source of transmission to adults, especially to their care-givers (Montresor, 2002). WHO (2016) maintains that the periodic administration of anthelmintic control morbidity from helminthiases by reducing the intensity of infection and the promotion of hand washing and improved sanitation yield positive results.

There is also a need to involve the social science sector to investigate the health seeking behaviour and misconceptions regarding helminthiasis and its diagnosis and treatment. Moreover, the monitoring and evaluation of interventions through identification of success parameter challenges that need to be addressed will contribute to the optimization of school-based helminth control and to strategies towards effective control of intestinal helminth infections as a public health problem (Belizario *et al*., 2011). Existing collaboration among different sectors and local and international agencies should thus be strengthened and untapped agencies and resources should be involved in the research, planning and implementation of helminth control programs.

Legislation and guidelines for food producers improve food safety for consumers (Gottstein, 2009). Meat and food inspections, rodent control, improved hygiene in animal environments, bio-security management practices, education on food safety and public awareness contribute to the eradication of zoonotic helminths (USDA, 2006). According to Ali (2007), further research is underway to produce vaccines for these parasitic worms.

2.6 CURRENT STRATEGIES TO CONTROL ZOONOTIC HELMINTHS IN PIG PRODUCTION

Some of the available tools for endo-parasitic control consist of chemical and non-chemical technologies (Chiba, 2004). Chemical technology relies entirely on treatment with different formulations of anthelmintic products that are used in different control strategies depending on the availability of epidemiological knowledge. This has led to the development of anthelmintic resistance in helminth species (Kaplan, 2004; Coles *et al.*, 2006; Henrioud, 2011). Non-chemical technologies are based on, among other strategies, production systems, breeding management, and nutritional interventions. Basically, the type of pig production system that is practised by farmers is vital when parasite control is considered.

One of the most important production objectives of a pig farmer is to maximise profit, irrespective of the system of production adopted. To ensure maximum profit, the farmer must strive to achieve a high live weight gain while keeping the cost of production comparatively low. These desirable outcomes will be obtained only if the production environment is manipulated to suit the need for optimal returns. In most developed countries, pigs are farmed commercially in factory houses through the intensive system of production, while only a small percentage of pigs are raised outdoors (Edwards, 2003). In intensive pig farming, pigs are kept and raised indoors from farrow to finish or slaughter with a high level of management proficiency resulting in high production levels at low cost, better controlled environments, and protection from predators. Also, because cleaning is more efficient in stalls, it is easier to protect pigs from vectors and parasites. However, as reported by Olsen (2001) and Presto *et al*. (2008), the intensive pig production system is also besieged with limitations such as the high cost of structures, feeding and management, intensive labour requirements, welfare problems and behavioural anomalies which lead to injuries, reduction in growth performance and, consequently, poor carcass quality.

Outdoor pigs on the other hand are not well protected from disease vectors, pathogens and parasites. The possibilities of transmitting zoonotic diseases may be higher in extensively raised pigs, especially where bio-security measures are not applied (Gebreyes *et al*., 2008). In South Africa, extensive and semi-intensive pig production systems are mostly practised amongst smallholder pig farmers due to the advantages associated with improved welfare, large space allowances, reduced feeding and management costs, low infrastructure requirements, and relatively favourable weather conditions (Onkabetswe *et al*., 2012). In organic pig production, pigs are raised under naturally enriched environments which culminate in better animal welfare (Barton Gade, 2002; Hoffman *et al.,* 2003); fewer injuries (Beattie *et al*., 2000 and 2006); no synthetic medicaments (Barton Gade, 2002); and no chemical residues in carcasses, thus improving meat quality (Barton Gade, 2002). However, the organic system of production has its own limitations as pigs are exposed to a wider range of potential endo- and ecto-parasitic infections from the environment − particularly faeces from small mammal vectors, humans and the pigs themselves. Moreover, effective alternative methods for parasite control in pigs are almost completely absent and use of conventional anti-parasitic drugs is not the rule on organic farms (Baumgartner *et al*., 2001).

The sustainability of helminth control will be largely conditioned by the ability to achieve an integrated parasite management strategy which involves combining several solutions (Waller, 2006). According to Burke *et al*. (2005), these sustainable multi-faceted strategies could involve a combination of two or more conventional or non-conventional practices without negative interactions. Some practices include nutritional manipulation, vaccination, genetic selection of livestock for increased resistance and resilience to gastro-intestinal nematodes (GIN), strategic use of bioactive forages and/or their plant secondary metabolite (PSM) extracts, pasture rotation, grazing different or mixed livestock species at intervals, use of copper oxide wire particles (COWP), biological control by using nematode-trapping fungi *(Duddingtonia flagrans)* and, whenever inevitable, the use of pharmaceutical anthelmintics to control zoonotic helminths in livestock.

2.7 PROPOSED STRATEGY TO CONTROL INTESTINAL HELMINTHS IN EXPERIMENTAL PIGS

In South Africa, making land available mostly for agricultural purposes to societies that were previously disadvantaged is a major priority (Onkabetswe *et al*., 2012). Therefore, to ensure sustainable food security, it is essential that the land allocated to these emerging farmers is kept productive, especially where livestock production opportunities are available such as pig farming. An increase in pork production in South Africa is justifiable because the per capita consumption of pork is low and the country has to import pork (Wright, 2006; Mugido and Bonsu, 2017). Also, most smallholder pig farmers in the Central Free State Province of South Africa are mainly engaged in extensive or semi-intensive pig farming. This system of farming affords resource-poor farmers the opportunity to raise pigs without the high cost of infrastructure, feed, labour, management, qualms about animal welfare, and slurry disposal. However, Rivera Ferre *et al*. (2001) noted that although outdoor and semi-outdoor farming systems are cheaper to establish compared to conventional intensive indoor systems, they are not devoid of limitations.

One of the major challenges of a semi-indoor or outdoor pig production system is the potential for helminth contamination of the pigs from the environment. Such infections are mostly zoonotic, hence meat borne helminthiasis is a public health issue of concern. Additionally, the development of anthelmintic resistance among zoonotic worms as a result of the indiscriminate use of synthetic drugs and the presence of anthelmintic drug residues in pork have also compounded health risks for consumers. Since the aim of any livestock producer is to present an acceptable product to the end user at an affordable price, the need to help combat this issue among smallholder pig farmers requires a nutritional intervention plan that will prove effective in eliminating intestinal helminths in pigs. Such a plan may be devised with reference to the findings of this study. One of the measures was to administer various levels of dry chicory (*Cichorium intybus*) root to grower pigs in a semi-intensively managed farm setting. The *in vivo* response of intestinal helminths was subsequently evaluated.

2.7.1 THE CHICORY PLANT

Common chicory (*Cichorium intybus*) is a perennial herbaceous plant that is grown in most geographical regions of the world with various varieties cultivated for salad leaves or for their roots. The roots can be baked, ground and used as a coffee substitute, and they can be used as an additive or as forage crop for livestock (Blair, 2011). Chicory root is popular in many countries and regions such as the Mediterranean region, India, Southeast Asia, South Africa, southern United States, Europe and New Zealand (Wilson, 2004). Kim and Shin (1996) and Madrigal and Sangronis (2007) stated that, among other compounds, inulin, sucrose, cellulose, protein and ash can be found in fresh chicory roots in rates of up to 68 %, 14 %, 5 %, 6 % and 4 % respectively. Dry chicory root extract contains, by dry weight, approximately 98 % inulin and 2 % other compounds, while up to 23 % of inulin by total weight can be found in fresh roots (Wilson, 2004). In support of the above, Soobo (2005) noted that chicory root is high in inulin-type fructan and oligofructose.

As a polysaccharide that is similar to starch and a type of probiotic ideal for monogastric nutrition, inulin has become popular for its nutritive qualities and its uses as a functional food additive (Mejer, 2006; Madrigal and Sangronis, 2007; Roberfroid *et al*., 2007). Various studies have reported that prebiotics stimulate the growth of host-beneficial gut bacteria such as lactobacilli and bifidobacteria for overall beneficial health (Roberfroid, 2001; Kaur and Gupta, 2002). In addition, a prebiotic may stimulate the immune system of the body, decrease the levels of pathogenic bacteria in the intestine (Liu *et al.,* 2012), relieve constipation, decrease the risk of osteoporosis by increasing mineral absorption of especially calcium (Roberfroid *et al*., 2002), reduce the risk of atherosclerosis by lowering the synthesis of triglycerides and fatty acids in the liver, and decrease their level in serum (Kaur and Gupta 2002). Interestingly, probiotic inulin has been indicated to reduce boar taint and odorous compounds in colon and rectal contents when included in male pig diets (Jensen and Hansen, 2006; Van Loo, 2007; Rasmussen, 2012).

The chicory plant has been used for its enthno-veterinary properties as it has been reported to serve as a herbal remedy for ailments and body conditioning in both humans and animals. The roots are also known to contain volatile oils which are effective in eliminating intestinal worms (Athanasiadou *et al*., 2007). The noxious compounds found in the chicory plant are mostly concentrated in its roots, while the volatile oils can be found in all parts of the plant (Wilson, 2004; Van Loo, 2007). Scientific investigations by Milala *et al.* (2009) revealed that the polyphenolic acid of chicory roots express a wide range of health promoting activities such as anti-carcinogenic, anti-inflammatory, anti-viral, anti-bacterial, anti-mutagenic, anti-fungal, immune-stimulating, anti-hepatotoxic activity (Meehye, 2000; Ahmed *et al*., 2003; Ahmed *et al*., 2008), and antioxidant (Peschel *et al*., 2006; Papetti *et al*., 2006) and anthelmintic properties. Likewise, they can act against the HIV virus, protect the alimentary tract and influence the reduction of serum cholesterol (Meehye, 2000; Wang *et al*., 2003; Innocenti *et al.,* 2005; Mares *et al*., 2005). Therefore, preparations rich in prebiotic saccharides and polyphenols that are produced from chicory can be used as supplements to promote the healthy properties of a diet and, at the same time, act as food and herbal medicaments.

As reported by Ivarsson *et al*. (2010), chicory (*Cichorium intybus* L.) is a herb that can be used as a source of fibre in pig diets. According to Tzamaloukas (2005), Heckendorn *et al.* (2006), Van Loo (2007) and Athanasiadou *et al*. (2007), the anti-parasitic property of chicory root that impacts internal parasites is well known. It has been reported that feeding inulin to pigs suppresses parasites such as *Ascaris* (Petkevicius *et al.,* 1997) and *Trichuris* (Thomsen *et al.,* 2005). The lowering of the intestinal pH, which is not favourable for the development of the parasite embryo, has been suggested as a possible mechanism of action. Based on their experiments, Tzamaloukas (2005) and Athanasiadou *et al*. (2007) reported that a reduction in worm burdens were observed in farm animals that had been fed chicory. Consequently, chicory has since been used as an alternative feed supplement with low fiber content for ruminants. It also contains a low quantity of reduced tannins (Wilson, 2004; ASA, 2005; FAO, 2013; Cardina *et al.,* 2013). High tannin levels may affect protein utilization efficiency in ruminants, even though some tannins have been reported to reduce intestinal parasites in animals (Kidane *et al*., 2010). Studies on pigs in Denmark by Roepstorff *et al*. (2005) and Hansen *et al*. (2005) showed that chicory had a positive effect on parasites and Lawsonia bacteria. Chicory is relatively inexpensive but when too much is ingested, it can cause a feeling of congestion in the digestive tract.

The above discourse has shown that, because the merits of dry chicory roots far outweigh the demerits, the use of this "wonder" plant has come to the forefront to be considered as the present and future nutritional strategy against gastro-intestinal parasites. Chicory has been shown to be a cheaper source and a more sustainable measure for helminth eradication. Consequently, in the current study, graded levels of dried chicory root were incorporated in the diet of experimental pigs to investigate if potentially harmful zoonotic helminths could be eliminated from these pigs that were raised semi-intensively. This nutritional intervention also aimed to curb the incidences of synthetic anthelmintic residues in pork which is a health threat to the consumer. It is stressed at this point that research using feeding trials of this nature have been limited in South Africa, especially in the central Free State Province.

Given that no vaccine has been developed thus far for the prevention of zoonotic helminths in pigs, the success of parasitic control is the synergy of several on-farm interventions and prevention is the key to the control of zoonotic diseases.

2.8 ANTHELMINTICS AND THEIR ROLE IN PIG PRODUCTION

2.8.1 SYNTHETIC ANTHELMINTICS

Gastrointestinal helminths are parasites that deprive the pig of nutrients while they also negatively affect pig growth, performance and feed efficiency and decrease carcass value (Jacela *et al*., 2009). Worm infections occur more frequently in pigs raised in outdoor lots than in conventional confinement facilities. Signs of infection are general and not easily apparent. In as much as worm infections rarely cause elevated mortality levels, they may result in significant economic losses to both the farmer and the consumer (Boes *et al.,* 2000, 2010*;* Joachim *et al.*, 2001; Hoste and Torres-Acosta, 2011). Heavy infestation in some cases can lead to condemnation and loss of carcass quality, especially in the case of liver condemnation due to larval migration of *A. suum* which creates white scars in the liver known as "milk spots".

For decades, helminth infections of livestock have been mostly combated with a synthetic anthelmintic (AH) that was administered via feed, water, surface application or through an injectable substance (Myers, 1988; AD-FDA, 2009). AD-FDA (2009) further listed Dichlorvos, Fenbendazole, Ivermectin, Levamisole, Piperazine and Pyrantel tartrate as some of the pharmaceutical anthelmintics available in swine feed. Veterinary AHs have been used successfully in deworming programs until the advent of AH resistance among various worm populations globally (Van Wyk *et al*., 1999; Nansen and Roepstorff, 1999; Mortensen *et al*., 2003; Kaplan, 2004; Coles *et al.*, 2006; Molento, 2009; Henrioud, 2011). According to Jacela *et al*. (2009), AHs vary in efficacy and spectrum of activity and are usually regulated by an appropriate body in any country. An effective control program depends on the specific worm problem, knowledge of their life cycle (especially the pre-patent period), stage of production and type of production system. It is also important to be cognizant of the withdrawal period of administration prior to slaughter to avoid veterinary drug residues in muscles and meat products (Rahmann *et al*., 2002).

Various authors such as Myer and Brendemuhl (2009), Jacela *et al*. (2009) and AD-FDA (2009) have noted that some species of nematodes that affect pigs are roundworm (*Ascaris suum*), nodular worm (*Oesophagostomum* species), intestinal threadworm (*Strongyloides ransomi*), whipworm (*Trichuris suis*), kidney worm (*Stephanurus dentatus*) and lungworm (*Metastrongylus* species). The control of gastrointestinal helminths is an important component of every herd-health program. Therefore, the use of AHs should be practised consciously and conscientiously by considering the type of worm that is targeted, its stage of development, mechanism of AH action, toxicity effect, and withdrawal period. Furthermore, the use of AH in pig production must not be relied on as the sole approach in controlling worms, but must be integrated with other approaches to be successful and sustainable.

2.8.2 NATURAL ANTHELMINTICS

In most parts of the world, several studies have been conducted on the use of both ethno-medical and ethno-veterinary properties of plants to cure ailments in both humans and animals (Kocsis *et al*., 2003; Mares *et al*., 2005; Tzamaloukas *et al*., 2005; Hoste *et al*., 2006; Matchett, 2010). In light of health concerns, research emphasis has shifted to the search for effective and sustainable natural anthelmintic alternatives without toxic side effects and chemical residues in carcasses. Some of these plant remedies (bioactive plants) and organic acids (e.g., formic, citric and sorbic acids) have been reported to exhibit a potpourri of medicinal properties due to the different phyto-bioactives contained in them (Costa *et al.,* 2013).

Bioactive plants (nutraceuticals) contain plant secondary metabolites (PSM) that are considered beneficial for their positive effect on animal health rather than their direct nutritional or reproductive value (Hoste *et al*., 2006). Saponins, alkaloids, non-protein amino acids, condensed tannins (CT) and other polyphenols, lignins, inulin, coumarines, glycosides, flavonoids, etc. are all PSM. Some of them have been considered responsible for the anti-parasitic effect of plants (Mares *et al*., 2005; Kocsis *et al*., 2003; Hoste *et al*., 2006) and the enhanced immune response in animals (Tzamaloukas *et al*., 2005). Scientific reports from New Zealand, parts of Asia and Europe have shown that CT containing plants can reduce faecal egg counts (FEC) and larval development in faeces and can generally reduce worm burdens in animals (Hoste and Torres-Acosta, 2011). Costa *et al*. (2013) examined four backyard remedies (papaya, coffee grounds, worm grass and cotton bush) used for pigs and poultry and reported that extracts from these plants either paralyzed or killed Barber's poleworms (red stomachworms or wireworms) *in vitro*. In as much as the level of their efficacy was below that of standard anthelmintic agents, the study demonstrated that these plants can be used as alternatives to veterinary AHs.

To support the above arguments, it must be mentioned that garlic contains a sulphuric compound that is considered responsible for its AH effect, whereas the walnut contains naphthoquinone, which is an active compound that is effective against worms (Guarrera, 1999). Guarrera (1999) also mentioned that the seeds or foliage of mint, dill and parsley have been used to treat animals that suffer from gastrointestinal parasitism, while cucumber and pumpkin seeds have been associated with the expulsion of tapeworms from the gastrointestinal tract. Another plant, the Kamala tree (*Mallotus philippinensis*), contains glycosides which have been shown to be the active compound against cestodes in goats (Akhtar and Ahmad, 1992). It has been suggested that the AH effects of chicory could be attributable to terpenoids or phenolic compounds such as sesquiterpene lactones and coumarins respectively (Hoskin *et al*., 1999). According to Molento (2009), many scientific studies investigated the PSM extracts of plant species like chicory (*Cichorium intybus*), birdsfoot trefoil (*Lotus corniculatus*), sainfoin (*Onobrychisviciifolia*), sulla (*Hedysarum coronarium*), Sericea lespedeza (*Lespedeza cuneata*) and quebracho (Schinopsis spp.) for experimental purposes. The analyses of the properties of these plants showed that they have some positive dose-dependent anti-parasitic potential, but studies also highlighted individual limitations in their application. However, several studies have emphasized that phyto-chemicals can be applied worldwide for their anti-parasitic, anti-bacterial, anti-fungal and anti-inflammatory effects. Thus, for subsistence and smallholder farmers, it would make economic and infrastructural sense to be able to utilize local flora to treat helminth infections in their livestock in place of synthetic AHs. Most of these investigations referred to above focused on ruminants; thus, there is a strong motivation for similar investigations to be conducted in monogastrics, especially in South African pigs.

2.9 ANTHELMINTIC RESISTANCE

Anthelmintic resistance is defined as "a significant increase in the ability of individuals within a strain of parasites to tolerate doses of a compound which would prove lethal to the majority of individuals in a normal population of the same species" (Coles *et al*., 2006). The evolution of anthelmintic resistance (AR) in worm populations is recognized globally as it threatens the success of pharmaceutical drug treatment programs. Earlier reports by Chaudhri *et al*. (1997), Maingi *et al*. (1998), Le Jambre *et al*. (1999) and Anziani *et al*. (2001) stated that resistance was probably an inevitable consequence of the use of anthelmintics. The history of parasite resistance to AHs started with the first report on phenothiazine resistance in 1957. During this time, there was substantial evidence that when a parasite had developed resistance to one AH from a certain group, it would usually also be resistant to other products from the same group (Nega and Seyum, 2017). A study by Jackson and Coop (2000) revealed that the usual mode of control of these ubiquitous gastro-intestinal parasites (GIP) was based solely on the repeated use of some or a single AH, either for prevention of infection or for treatment of infected animals. However, the intensive use of AHs has resulted in treatment failures of most of the AH drugs available today (Kaplan, 2004; Coles *et al*., 2006; Henrioud, 2011; Nega and Seyum, 2017). Kaplan (2004) further reported that AR was available to all classes of broad-spectrum AHs such as benzimidazoles (BZ), imidothiazoles-tetrahydropyrines and macrocyclic lactones. In parts of South Africa and the United States of America, multi-resistant *Haemonchus contortus* has become a major threat to the entire small ruminant industry (Van Vyk *et al*., 1999; Mortensen *et al*., 2003; Molento, 2009). Van Wyk *et al*. (1999), Vatta *et al.* (2001) and Bakunzi (2003) also stated that anthelmintic resistance was widely disseminated in South Africa and that insufficient information was available on the degree of resistance to frequently used AHs in communally grazed small ruminants and among non-ruminants raised in different management systems in the different geographical regions of South Africa.

According to Kaplan (2004), resistant nematode populations have been detected in all naturally grazing livestock species: sheep, goats, cattle and horses. An earlier report by Jackson and

Coop (2000) posited that the development of AR in worm populations had become a worldwide phenomenon that constantly expanded and was particularly prevalent in goats. More recent investigations by Cedillo *et al*. (2015), Ramos *et al*. (2016) and Zvinorova *et al*. (2016) in different parts of the world and on different farm animals that were raised under different production systems have also buttressed the existence of anthelmintic resistance among nematode species. In pigs, resistance to pyrantel, levamisole and BZ in Oesophagostumum spp was detected by Roepstorff *et al*. (1987), Bjørn *et al*. (1996) and Gerwert *et al*. (2002). In a comprehensive study in the United States on the prevalence of AR in small ruminants, 90 % of all farms investigated had resistance to two of three drug classes, and 30 % of the farms had worms that were resistant to all three drug classes (Stear, 2008).

This constant increase in AR has stimulated the search for alternative solutions, which has also been supported by an enhanced public concern for more sustainable systems of production which are less reliant on chemotherapy (Waller, 1999; Jackson and Coop, 2000). It is argued that efforts to reduce helminth exposure to AHs will slow down further development of resistance but will not reverse the existing resistance in a population (Ihler, 2010). Thus, the most obvious way to reduce exposure is to reduce the use of AH drugs and to look for effective ways other than AH drugs to control GIP.

2.10 VETERINARY DRUG RESIDUES: ANTHELMINTICS

Veterinary anthelmintic drugs are widely used in livestock production against intestinal worms. Anthelmintics are basically classified according to their mode of action and chemical structure. Romero-González *et al*. (2014) reported that some classes of AHs (e.g., avermectins) can be considered safe, while others like benzimidazoles and levamisole are considered toxic to human health when detected in edible animal tissue. Some of these AH chemicals are excreted to some extent in the faeces and/or urine of previously treated animals. It has since been reported that few of the AHs used in livestock production are completely metabolized to inactive moieties within the host and that biologically active chemicals are normally voided through the urine or faeces of treated animals (McKellar, 1997). It has been demonstrated that members of the avermectin/milbemycin group may have a deleterious effect on non-target organisms that utilize the faeces. McKellar (1997) also noted that accessing the environmental impact of these veterinary anti-parasitic agents will depend on the deleterious effect which the chemical or its metabolites have on the organisms in the locus of the faeces, the amount of active agent excreted, the temporal nature of the excretion, the rate of degradation of the dung and the stability of the exotoxic residues.

Food safety and consumer exposure to chemical residues in food are issues of public health concern and there is an ongoing need for new analytical techniques and information on the occurrence of potentially harmful residues of veterinary drugs in our food (O'Keeffe and Kennedy, 1998; Cooper *et al*., 2011). In edible animal tissues, international organizations have established the maximum residue limits (MRLs) in target tissues with regard to the marker residue definition. Also, Le Boulaire *et al*. (1997), Stolker and Brinkman (2005) and Romero-González *et al*. (2014) noted that, because the MRL levels are usually low, advanced analytical methods of detection that are mainly based on liquid chromatography coupled with mass spectrometry are currently used for reliable determination of these compounds at trace levels.

Earlier investigations by Rose *et al*. (1995a, b) on the stability of sulphamethazine and levamisole in tissues found that the drugs were stable in boiling water at 100 °C and that no losses were observed in the cooking liquid/juice. Rose *et al*. (1995a) reported the stability of sulphamethazine in frozen storage over a period of three months, but that it was unstable with a half-life of about two hours at 180 °C in cooking oil. Losses were also observed in cooking oil at 260 °C. There was no evidence of levamisole instability in any of the cooking methods (microwaving, boiling, roasting, grilling and frying) that were investigated by Rose *et al*. (1995b), except during the roasting process where a net loss of levamisole was observed. In support of the above findings, a more recent investigation by Cooper *et al*. (2011) submitted that there were no major losses observed for residues of oxyclozanide, clorsulon, closantel, ivermectin, albendazole, mebendazole or fenbendazole AH drugs during cooking. However, significant losses were observed for nitroxynil (78 % in fried muscle and 96 % in roast muscle), levamisole (11 % in fried muscle and 42 % in fried liver), rafoxanide (17 % in fried muscle and 18 % in roast muscle) and triclabendazole (23 % in fried liver and 47 % in roast muscle). Furthermore, it was noted that the migration of residues from muscle into expressed cooking juices varied between the different drugs. Therefore, conventional cooking cannot be considered a safeguard against ingestion of anthelmintic residues as such action affords the consumer little or no protection against veterinary drug residues.

2.11 MEAT INSPECTION IN SOUTH AFRICA

Meat inspection requires a controlling authority that is adequately resourced and has the legal power to enforce legal requirements which should be independent of the management of the establishment where the meat is produced. This point underscores the need for a vibrant and bold meat inspection system. In South Africa, meat inspection involves the ante-mortem and post-mortem inspection of animals at slaughtering facilities that are either owned or managed by municipalities or by the Abattoir Commission (ABACOR) (DAFF, 2012). The Department of Agriculture and the Veterinary Inspection Department, together with local municipality officers who are also serving as sole service providers of meat inspection services in the country, are the responsible authorities for regulating meat safety at abattoirs (DAFF, 2012; Songabe, 2013). Songabe (2013) stated that modern-day meat inspection in South Africa is done by the inspectorate in the employ of abattoirs, the International Meat Quality Assurance Service (IMQAS), closed corporations, or private individuals. DAFF (2012), Songabe (2013) and DAFF (2017) conclusively submited that in terms of the Abattoir Hygiene Act of 1992 which was replaced by the Meat Safety Act, section 11(1)(b), Act No. 40 of 2000, all meat inspection services must be independent of the abattoir and should thus not be performed by the owner of the facility. Currently, most meat inspectorate personnel are employed by either the state, the South African Meat Industry Company (SAMIC) or the Food Safety Agency to ensure independent inspection services. This implies that the facility management is deemed responsible and accountable for ensuring the delivery of safe products to the consumer, although this does not in any way absolve the government of its responsibility to ensure that the citizens of South Africa have access to safe food in terms of the Constitution (DAFF, 2012, 2017). Furthermore, section 11(1)(d) of the Meat Safety Act of 2000 described meat inspectorate personnel in South Africa as either a veterinarian, a meat inspector, a meat examiner, an animal health technician, or any other duly qualified persons (DAFF, 2017).

Meat inspection is a critical component of ensuring meat safety and the safety of animal products. According to Mckenzie and Hathaway (2006), the objectives of meat inspection programs are to ensure that only healthy, physiologically normal animals are slaughtered for human consumption and that abnormal animals are separated and dealt with accordingly. Other objectives are to ensure that meat for the market is free from disease, wholesome and that it poses no risk to human health. These objectives are achieved by ante-mortem and post-mortem inspection procedures and by hygienic dressing of carcasses with minimum contamination potential. Whenever appropriate, the Hazard Analysis Critical Control Point (HACCP) principles should be used. Regrettably, rural abattoirs in South Africa are generally faced with meat inspection challenges because of their location, initial cost of compliance, low quantities of meat produced, operational costs, as well as the need for meat inspection services. The feasibility of these facilities does not economically justify the employment of a meat inspector (DAFF, 2012).

Food-borne illnesses account for the majority of illnesses reported in most developed countries and create an enormous burden on the economy (WHO, 2005). For example, a WHO report of 2005 stated that there were 1.8 million deaths in this period that were casued by diarrhoeal diseases from contaminated food. It also reported that 30 % of populations in industrialized countries succumbe to food-borne illnesses every year. Reports by Kistiah *et al*. (2012) and Saif *et al*. (2012) are of the opinion that the seroprevalence of *T. gondii* and leptospirosis in a selected sample of the South African population was moderately high. Earlier, Frean *et al*. (2003) confirmed that food-borne disease was a common public health problem worldwide, but argued that it was generally under-reported and poorly investigated in South Africa and southern Africa at large. The prevalence of Bartonellae, a zoonotic disease, was reported at a rate of 22.5 % in South African individuals (Trataris *et al*., 2012). Mogoye *et al*. (2012) conducted a retrospective data analysis on human echinococcosis serology and reported an overall positivity rate in submitted diagnostic samples of 17.0 %, with the highest rates for the Eastern Cape at 30.4 %, North West at 19.0 %, and Northern Cape at 18.0 %. Lately, South Africa has been experiencing the world's most deadly outbreak of Listeriosis which has killed in excess of 180 people and infected many more (DHRSA, 2018). The source of this food-borne pathogen (*Listeria monocytogenes*) was traced to a cold meat processing plant in the Limpopo Province, and the outbreak has brought the issue of meat inspection and safety in the country into question.

In principle, the Meat Safety Act of 2000 (with the application of the related regulations for each specie) addresses the challenges faced by the meat industry and merges traditional inspection practices with internationally acclaimed science-based approaches. It may therefore be concluded that the Act has not abandoned organoleptic approaches to meat inspection, but has endeavoured to also embrace the newly targeted risk- and systems-based approaches of Hazard Analysis Critical Control Point (HACCP), provisions by the International Standards Organization (ISO), good manufacturing practices (GMP), supplier quality assurance (SQA), and a quality management systems (QMS) approach to the promotion of adequate food safety management within South Africa (DAFF, 2012; 2017).

2.12 MEAT QUALITY

Meat is an important foodstuff and one of the most expensive components of human nutrition, therefore the quality parameters are of great importance to consumers in any form, starting from raw meat to processed meat used for culinary purposes (Aumaitre, 1999; Šubrt and Miksik, 2002; Skovgaard, 2003). Due to its high content of biologically valuable nutrients and versatile use, edible animal tissues are among the most desirable foods in the food chain. The trends in the consumption of different kinds of meat are largely influenced by health (Song *et al*., 2004), religion, gender and age (Song *et al*., 2004; Kurotani *et al*., 2013); and type of meat, socio-economic, geographical location, breeding, and processing factors that affect the criteria of meat quality as a prerequisite among consumers (Lawrie, 2001; Campbell *et al*., 2003; Andersen *et al*., 2005; Grunert, 2006).

Generally, meat quality is a term that is used to describe overall meat characteristics such as its physical, chemical, morphological, biochemical, microbial, sensory (organoleptic), technological, hygienic, nutritional and culinary properties (Šubrt and Miksik, 2002; Skovgaard, 2003). Appearance, texture, juiciness, wateriness, firmness, tenderness, odour and flavour are among the most important and perceptible meat features that influence the initial and final quality judgment by consumers before and after purchasing a meat product (Barbut, 1996; Wood *et al*., 2004; Andersen *et al*., 2005). Furthermore, quantifiable properties of meat such as water holding capacity, shear force, drip loss, cooking loss, pH, shelf life, collagen content, protein solubility, cohesiveness, and fat binding capacity are important to processors involved in the manufacture of value added meat products (Allen *et al*.; 1998; Andersen *et al*., 2005). Raw meat like pork that is used in further processed products is required to have excellent functional properties that will ensure a final product of exceptional quality, acceptance and profitability (Meinert *et al*., 2008).

Some of the factors that affect meat quality are pre-slaughter factors such as stress, muscle fibre type, breed, handling, gender and age factors (Lawrie, 2001; Lawrie and Ledward, 2006). Post mortem chilling, conditioning and ageing are among the most important post slaughter factors that affect meat quality (Jarmila *et al*., 2008; Li *et al*., 2012). Miller *et al*. (2000) argue that pork quality is simply determined by visual appearance and overall satisfaction following preparation and consumption. Visual appearance is influenced by myoglobin concentration, water-holding capacity (WHC), pH, and the amount of intramuscular fat present in the meat, while eating satisfaction is a combination of tenderness, juiciness and flavour (Lawrie, 2001; Li *et al*., 2012). According to Skovgaard (2003) and Barbera and Tassone (2006), some of the emerging technologies which show potential for use as indicators of meat quality include ultrasound, nuclear magnetic resonance, image analysis, autoflourescence spectroscopy, near infrared spectroscopy, temperature measurements, immunoassays, determination of metabolites, and use of a tenderness probe. Presently, the use of pH and colour measurement metres, electrical impedance, conductivity and hyperspectral imaging are additional techniques that are employed for analysing meat quality (Skovgaard, 2003; Cheng *et al*., 2015).

The Codex Alimentarius Commission has detailed the Recommended International Code of Hygiene Practice for Fresh Meat (CAC/RCP 11-1994), which is a code that describes the minimum requirements for the hygiene in meat production. The application of this code can be an important step towards ensuring that consumption of the meat will not cause infection or intoxication when properly prepared, and that it will be free from residues (of pesticides, veterinary drugs, feed additives and certain heavy metals in excess of established limits), zoonotic and non-zoonotic diseases, and obvious contaminations. Meat should also be free from defects that may generally be recognized as objectionable, should be processed under adequate hygienic control conditions, and should fulfil the expectation of the consumer for a consumable product (Codex, 1991a, b).

2.13 PORK: A TABOO MEAT

Cultural understanding concerning food, edibility, contamination and related topics exhibit enormous variation across groups (Barer-Stein, 1999; Rozin, 2000; Aunger, 2000). However, despite such evident heterogeneity, investigators have off-handedly suggested that animals and animal products seem especially likely to be the focus of food taboos (Simoons 1995; Haidt *et al*., 1997). Religious restrictions on the consumption of pork was a tradition in the Ancient Near East. Swine were prohibited in ancient Syria and Phoenicia and the pig and its flesh represented a taboo (Meyer-Rochow, 2009) and the consumption of pigs is forbidden to this day among Muslims, Jews and certain Christian denominations (Filipino Cuisine, 2010). Apart from cultural, traditional and religious beliefs, customer choice of meat based on nutritional and organoleptic qualities can also affect pork consumption. In South Africa, tradition, religion, culture, availability and affordability influence pork consumption (Scholtz *et al*., 2001; Oyewumi and Jooste, 2005). These authors also posited that in South Africa, the white population group consumes most pork products, followed by the black and Asian groups. They argue that the low consumption of pork by the Asian population is predominantly linked to religious beliefs as most white and coloured South Africans have no cultural, religious or traditional patterns that prohibit their consumption of pork.

In the 19th century, some people attributed the taboo on pork in the Middle East to the danger of the parasite, Trichina. Contrary to this belief, Harris (1985) posited that pigs are not suited for being kept in the Middle East for ecological and socio-economic reasons. To buttress his point, he argues that pigs are not suited to living in arid climates as they require far more water than other animals to keep them cool; therefore, instead of grazing, they compete with humans for food. For these reasons, raising pigs in these arid areas was regarded as a wasteful and decadent practice. A common explanation for the fact that pigs are widely considered unclean in the Middle East is that they are omnivores, therefore not discerning between meat and vegetation in their natural dietary habits. Their willingness to consume meat thus sets pigs apart from most other domesticated livestock that naturally eat only plants.

Consistent with the attendant risk of parasite transmission, pork has special salience as a stimulus for humans because animal products are stronger elicitors of disgust and aversion than plant products. However, despite the religious or traditional belief that pork meat is taboo, data by the United States Department of Agriculture (2011a) reported that pork is the most widely eaten meat in the world. A national survey by Filipino Cuisine (2010) also reported that, in the Philippines, pork is the most popular meat.

2.14 PUBLIC HEALTH CONCERNS AND THE SAFETY OF PORK CONSUMPTION

The safety of foods obtained from animals for human consumption is an issue of public health concern. Pork production has safety implications for both producers and consumers. Donham (1998) and Evans (2009) reported that there were potential health consequences for producers, their families, their employees and those involved in the transport, slaughter and processing of pigs which arise from zoonotic diseases caused by these animals. Generally, animal food products pose a unique threat to consumers due to the characteristic nature in which they harbour a wide range of bacteria and protozoans, either as parasitized hosts or as symbiots (Atwill *et al*., 1997; Smil, 2002; Ekwuagana, 2004; Sahelian, 2010). Thus, the zoonotic parasites that are hosted and transmitted by pigs have contributed immensely to outbreaks of food-borne parasitic diseases.

Research by Sahelian (2010) indicated that most of these pig parasites could be transmitted to humans through the consumption of raw pork, undercooked pork or pork products. Other scientists have reported various incidences of parasites in pigs. For example, it has been shown that *Giardia duodenalis* causes Giardiasis (Ey *et al*., 1997; Olson *et al*., 1997; Atwill *et al*., 1997; Guselle and Olsen, 1999); *Cryptosporidium pavum* causes Cryptosporidosis (Coop *et al.,* 1998), *Ascaris suum*, (Roepstorff and Murrell, 1997; Guselle and Olson, 1999; Nsoso *et al*., 2000; Tamboura *et al*., 2006; Dey *et al*., 2014; Lassen *et al*., 2017; Zhao *et al*., 2017), *Ascaris lumbricoides* (Anderson and Jaenike, 1997); different species of Trichinella cause Trichinellosis, or Trichiniasis (Gajadhar *et al*., 1997; Pozio and Murrell, 2006; Sahelian, 2010), *Cyclospora cayetanensis* (USDA, 2011), *Trichuris suis* (Roepstorff and Murrell, 1997; Nsoso *et al*., 2000; Tiwari *et al*., 2009); Toxoplasma causes Toxoplasmosis (Gajadhar *et al*., 1998; Davies *et al*., 1998; Dubey, 1998; Gamble *et al*., 1999), *Sacrocystis* (Dubey, 1998), *Taenia solium* (DeGiorgio *et al*., 2004) and porcine cysticercosis (Ngowi *et al*., 2004; Ngowi, 2005; Waiswa *et al*., 2009), among others.

Additionally, these infections in both pigs and humans could lead to high economic losses by pig producers as well as high treatment and opportunity costs for people suffering from parasitic worm infections. Therefore, the pork industry continues to look for ways to improve pork safety and quality, production performance, and animal welfare and a healthy environment. The responsibility of the production of safe and wholesome meat is shared by the industry and its controlling authorities. Evans (2009) noted that the best way to ensure safety is to have a program based on the principles of HACCP (Hazard Analysis and Critical Control Points) system, and this needs to be extended right back to the farm.

Although cooking pork can greatly reduce the risk of parasite transmission, this is only true when it is cooked thoroughly, when hands are properly washed after contact with raw pork and utensils used to prepare uncooked pork are disinfected after use to prevent cross contamination of objects. For most of human history, these hygiene standards have very likely not been met consistently and may not be in the future, hence cooking alone will not eliminate the dangers of eating unwholesome pork.

2.15 PREVENTION AND CONTROL OF HELMINTH INFECTIONS IN PIG PRODUCTION

One of the major objectives in pig production should be to reduce the exposure of pigs and subsequently consumers to parasites, regardless of the type of production system practised. It is evident that the most efficient way to control porcine helminths is to improve the management and hygiene of the herd. First of all, such improvement will eliminate some helminth species, but additionally the worm burdens of the remaining species may be reduced to more acceptable levels (Roepstorff and Nansen, 1998; Perry *et al*., 2002). McMullen (2000) noted that a reduction in the intestinal carriage rate of parasites in finishing pigs will probably lower the cross-contamination pressure at slaughterhouses and abattoirs. In support of the above statement, Altrock and Waldmann (2003) conclude that farm hygiene measures should focus on preventing the proliferation of pathogens and parasites in animal sheds and environments.

Eradication of helminth species is more or less impossible to obtain merely by routine anthelmintic treatment programmes, which is the other major control principle. Yet, it is often practically impossible to improve management sufficiently, and therefore helminth control programmes normally include both management and the use of anthelmintic medications. For example, the prevention of over-stocking of outdoor pigs, effective grazing management (mixed or alternate grazing), maintenance of strict hygiene measures in pens and grazing areas, routine deworming, proper nutrition, and keeping pigs that are genetically resistant to helminths are some of the ways that have been used to reduce worm burdens in pig herds (Roepstorff and Nansen, 1998).

2.16 CONCLUSION

It is unlikely that gastrointestinal nematode control in pig production will rely on one single approach in the future. The sustainability of helminth control will be largely conditioned by the ability to achieve an integrated parasite management strategy which involves combining several solutions (Waller, 2006).These sustainable multi-faceted strategies could involve a combination of two or more conventional or non-conventional practices without negative interactions. Nutritional manipulation (Kidane *et al.*, 2010; Martínez-Ortíz-de-Montellano *et al*., 2010), vaccination, genetic selection of livestock for increased resistance and resilience to gastrointestinal nematodes, strategic use of bioactive forages and/or their PSM extracts (De Montellano *et al*., 2007), pasture rotation, grazing different or mixed livestock species at intervals, use of copper oxide wire particles (COWP) (Burke *et al*., 2005), biological control by using nematode-trapping fungi *(Duddingtonia flagrans)* and, whenever inevitable, the use of pharmaceutical anthelmintics (Perry *et al*., 2002; Hoste and Torres-Acosta, 2011) are methods that have been proposed for the sustainability of helminth control in pigs.

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CHAPTER 3

CONTEXTUALIZING THE EFFICACY OF PHYTO-BIOACTIVES IN ERADICATING ZOONOTIC HELMINTHS IN LIVESTOCK − A CONCISE REVIEW OF AVAILABLE SCIENTIFIC KNOWLEDGE

3.1 INTRODUCTION

Each livestock specie harbours its own type of gastro intestinal parasite (GIP). These parasites are rarely absent in farm animals (Stear, 2008). GIPs pose significant threats to any herd because they can spread rapidly through the herd and lead to considerable loss of productivity, thus directly or indirectly contributing to reduced sustainability that affects food security, especially in subsistence farming systems (Roepstorff *et al*., 2005; Henrioud, 2011). They endanger animal welfare and constitute a major impediment to efficient and profitable livestock production (Boes *et al.,* 2000*;* Joachim *et al.*, 2001; Hoste and Torres-Acosta, 2011). Nsoso *et al.* (2000) and Knecht *et al*. (2012) noted that the key effect on livestock includes loss of appetite, reduction in daily gain, poor feed utilization, potentiation of other pathogens, and the resultant condemnation of affected organs after slaughter.

These zoonotic helminths are also of economic importance to the animal products consumer as they cause considerable damage in infected humans and can be transmitted from animals to humans, from humans to humans, or from humans to animals − hence the term zoonosis (Zoli *et al*., 2003). Epidemiologic studies by Mafojane *et al*. (2003), Phiri *et al*. (2003) and Krecek *et al*. (2004) reported that the highest levels of human neurocysticercosis (NCC), a zoonotic infection caused by porcine *Taenia solium,* was found in the emerging farming areas of the Eastern Cape Province of South Africa. Other researchers such as Phiri *et al*. (2003) further indicated that 28–50 % of African children with epilepsy were positive for cysticercosis or taeniasis.

Currently, helminth control is mainly based on mass treatment of farm animals with synthetic pharmaceutical anthelmintics (AHs) which are not sustainable in the long term because of the development of resistance to these AHs among worm species. Investigations by Williams *et al*. (2014) found that most subsistence farmers in many developing nations cannot afford expensive AH drugs. Moreover, many low-input and organic farmers in developed countries are also not able to prophylactically treat animals with synthetic AH medication.

The increase in public awareness of drug residues in edible tissues of animal products, increased resistance of parasites to modern AHs, and the desire for a more sustainable farming practice have resulted in an intensified effort to find alternative GIP control options (Rahmann *et al*., 2002). This has triggered the evaluation of the efficacy of phyto-bioactives which have been purported to possess AH properties with a view to further elucidating their ethno-veterinary capabilities. However, insufficient on-farm scientific research has been conducted in this area, even though a lot of plants are currently used in this regard in third world countries (Hördegen, 2005). These plants do not only deal with helminth infections of livestock, but also have other therapeutic properties with often successful outcomes (Nfi *et al*., 2001).

In reality, the objectives and technological possibilities to implement sustainable parasite control in developed countries are not the same for a resource-poor subsistent livestock producer in remote sub-Saharan Africa (Henrioud, 2011). Therefore, it is crucial to have a conceptual framework to improve the understanding of the rationale behind the practices of parasite control in any given field that aims to increase livestock production in a sustainable way.

3. 2 ANTHELMINTIC RESISTANCE

The evolution of anthelmintic resistance (AR) in worm populations is recognized globally as this phenomenon threatens the success of pharmaceutical drug treatment programs. Jackson and Coop (2000) revealed that the usual mode of control of these ubiquitous GIPs was based solely on the repeated use of AH, either for prevention of infection or for treatment of infected animals. However, this intensive use of AH has resulted in treatment failures of most of the AH drugs available today (Kaplan, 2004; Coles *et al.*, 2006; Henrioud, 2011; Ramos *et al.,* 2016; Zvinorova *et al.,* 2016). Kaplan (2004) further reported that AR has been identified in all classes of available broad-spectrum AHs, benzimidazoles (BZ), imidothiazoles-tetrahydropyrines and macrocyclic lactones. In parts of South Africa and the United States of America, multi-resistant *Haemonchus contortus* has become a major threat to the whole small ruminant industry (Van Wyk *et al*., 1999; Mortensen *et al*., 2003; Molento, 2009). Additional studies by Van Wyk *et al*. (1999), Vatta *et al.* (2001) and Bakunzi (2003) reported that anthelmintic resistance is widely disseminated in South Africa, yet insufficient information is available on the degree of resistance to commonly used AHs in communally grazed small ruminants in South Africa.

According to Kaplan (2004), resistant nematode populations have been detected in all naturally grazing livestock species, namely sheep, goats, cattle and horses. A similar result by Jackson and Coop (2000) posited that the development of AR in worm populations is now a worldwide phenomenon in constant expansion, and is particularly prevalent in goats. In pigs, resistance to pyrantel, levamisole and BZ in *Oesophagostumum* spp was earlier detected by researchers such as Roepstorff *et al*. (1987), Bjørn *et al*. (1996) and Gerwert *et al*. (2002). In a comprehensive study in the United States on the prevalence of AR in small ruminants, 90 % of the farms investigated had animals that were resistant to two of three drug classes and 30 % of the farms had worms that were resistant to all three drug classes (Stear, 2008).

This constant increase in AR has stimulated the search for alternative solutions, which is also supported by an enhanced public concern for more sustainable systems of production with less reliance on chemotherapy (Waller, 1999; Jackson and Coop, 2000). However, it is argued that efforts to reduce helminth exposure to AH will slow down further development of resistance but will not reverse the existing resistance in a population (Ihler, 2010). The most obvious way to reduce exposure is to reduce the use of AH drugs and to investigate other ways to control GIP beside AH use.

3.3 BIOACTIVE PLANTS

Medicinal plants have been used for centuries to combat parasitism in many parts of the world and are still used for this purpose today (Athanasiadou *et al*., 2007). In ethno-veterinary medicine which draws inspiration from traditional practice, there seem to be a range of plants or plant extracts that are suitable for treating almost every parasitic disease of livestock (IIRR, 1994). Farm animals can graze directly on these plants in the field or the plants are harvested and used as hay.

Hoste *et al*. (2006) reported that secondary metabolites contained in bioactive plants are considered useful due to their anti-parasitic properties and the maintenance of general wellbeing in animals. Plant secondary metabolites (PMSs) have been associated with defensive mechanisms in plants against herbivore grazing and microbial invasion (Mueller-Harvey and McAllan, 1992) as well as the eliciting of pharmacological or toxicological effects in man and animals (Bernhoft, 2010). Saponins, alkaloids, non-protein amino acids, condensed tannins (CTs) and other polyphenols, lignins, inulin, coumarines, glycosides, flavonoids, e.t.c. are all PSMs. Some of them have been considered responsible for the anti-parasitic effect of plants (Mares *et al*., 2005; Kocsis *et al*., 2003; Hoste *et al*., 2006) and an enhanced immune response in animals (Tzamaloukas *et al*., 2005). Scientific studies from New Zealand, parts of Asia and Europe have shown that CTs containing plants can reduce faecal egg counts (FEC), larval development in faeces and that they generally reduce worm burdens in animals (Hoste and Torres-Acosta, 2011).

To buttress the above point, garlic contains a sulphuric compound which has been considered responsible for its AH effect, whereas the walnut contains naphthoquinone, the active compound that is used to combat worms (Guarrera, 1999). The latter scientist also mentioned that the seeds or foliage of mint, dill and parsley have been used to treat animals that suffer from gastrointestinal parasitism, while cucumber and pumpkin seeds have been associated with the expulsion of tapeworms from the gastrointestinal tract. Moreover, the Kamala tree (*Mallotus philippinensis*) contains glycosides, which have been shown to be the active compound against cestodes in goats (Akhtar and Ahmad, 1992). It has been suggested that the AH effects of chicory could be attributable to terpenoids or phenolic compounds such as sesquiterpene lactones and coumarins respectively (Hoskin *et al*., 1999). Molento (2009) investigated the PSM extracts of the following plant species: chicory (*Cichorium intybus*), birdsfoot trefoil (*Lotus corniculatus*), sainfoin (*Onobrychis viciifolia*), sulla (*Hedysarum coronarium*), *Sericea lespedeza* (*Lespedeza cuneata*) and quebracho (*Schinopsis* spp). The results showed that all plants had some positive dose-dependent anti-parasitic potential, but also highlighted individual limitations in application. Several studies (Hoste *et al*., 2006; Athanasiadou *et al*., 2007; Matchett, 2010; Hoste and Torres-Acosta, 2011; Costa *et al.,* 2013) have emphasised that phytochemicals can be applied worldwide for their anti-parasitic, anti-bacterial, anti-fungal and anti-inflammatory effects.

In developing economies, the use of plants or their extracts for ethno-medicinal purposes has some merit, for example most of these plants can thrive in infertile soil that is unsuitable for crop production or high-input forages; a good number of them are adapted to adverse climatic and soil conditions; they can be propagated separately or together with existing pasture; easy integration into traditional cultural practices; low cost; and they are profitable (Stangeland *et al*., 2008; Tanner *et al*., 2011). According to Hoste and Torres-Acosta (2011), Sericea lespedeza (*Lespedeza cuneata*) has been reported to increase profits for rangeland farmers in South Africa by bringing poor, drought-prone, infertile land into useful production for sheep.

3.4 VALIDATION OF PHYTO-BIOACTIVES

Two methodologies have been employed by researchers to validate the anthelmintic properties of phytochemicals. The first experiment involves testing plant extracts and concoctions derived from medicinal plants via *in vitro* systems, while the second approach is through offering plants, plant parts or plant extracts to naturally or experimentally parasitized animals and quantifying the consequences of their consumption in *in vivo* studies.

3.4.1 *IN VITRO* VALIDATION OF PHYTO-BIOACTIVES

Most scientific justification of the anthelmintic activity of phyto-bioactives occurred mainly through *in vitro* experiments (Githiori *et al*., 2006) which found that their efficiencies, in some cases, reached 100% (Satou *et al*., 2002; Molan *et al*., 2003; Ademola and Idowu, 2006). Various studies evaluated the motility and mortality of the parasites following incubation in the presence of the plant extracts (Sangwan and Sangwan, 1998; Iqbal *et al*., 2001; Lateef *et al*., 2003; Raje and Jangde, 2003; Singh *et al*., 2004; O'Grady and Kotze, 2004; Githiori *et al*., 2006). Several parasite models that were used were based on testing the effect of plant extracts on free-living nematodes (Okpekon *et al*., 2004), trematodes and cestodes (Molgaard *et al*., 2001). *In vitro* models like modified egg hatch assay (Coles *et al.,* 2006), larval development assay (LDA) or larval motility assay (LMA) (Alawa *et al*., 2003, Assis *et al.,* 2003, Lateef *et al.,* 2003), adult development test (ADT) (Lateef *et al.,* 2003; Githiori *et al*., 2006), larval arrested morphology assay (LAMA), egg hatch test (EHT), motility and colorimetric assays were adequately used to evaluate the anthelmintic activity of phytochemicals (Jabbar *et al*., 2006; Kopp *et al*., 2008). Based on their studies, a novel cell monitoring device (xCELLigence, Roche Inc.) for AH screening is recommended by Smout *et al*. (2010), Silbereisen *et al*. (2011); Martinez-Serra *et al.* (2014) and Kho *et al*. (2015).

Purified condensed tannins from several plant species were tested *in vitro* against the helminths *Trichostrongylus colubriformis* and *Teladorsagia circumcincta* (Molan *et al*., 2000a, b), and it was found that the viability, motility and migration abilities of the third stage larvae (L_3) of these nematodes were severely affected by the presence of CTs in their environment. Earlier, Ibrahim (1992) reported that *Balanites aegyptiana* and *Sesbania sesban* plant extracts demonstrated high dose related inhibitory activity on the viability of the *C. elegans* nematode. In another study, acetone extracts of the leaf, bark and root of a popular ethno-veterinary plant, *Peltophorum africanum,* were screened for activity against *H. contortus* and *T. colubriformis* in the egg hatch and larval development assays. Bizimenyera *et al*. (2006a, b) demonstrated that at relatively low concentrations of 0.2 mg/ml, the extracts showed considerable activity, which supports the use of the plant for AH purposes. In a similar *in vitro* experiment conducted in South Africa by McGaw *et al*. (2007), extracts of 17 plant species that were employed to treat infectious diseases were prepared using three solvents. More than a third of the extracts displayed anthelmintic activity against the free-living *Caenorhabditis elegans* nematode. Pessoa *et al.* (2002) reported that the extract of *Ocimum gratissimum* plant showed strong *in vitro* anthelmintic activity against the *Haemonchus contortus* nematode*.* Likewise, Eguale *et al*. (2011) tested the anthelmintic properties of five native Ethiopian plants on the eggs and larvae of *Haemonchus contortus* using the *in vitro* egg hatch assay and the larval development tests. They observed that at a concentration of 1 mg/ml or less, there was a complete inhibition of egg hatching when both the aqueous and hydro-alcoholic extracts of all the plants were used.

Similarly, marine sponges have been reported to have significant bioactive components that can be used to formulate natural novel drugs. An investigation by Perdicaris *et al.* (2013) showed that these invertebrates possess a potpourri of beneficial properties such as anti-inflammatory, antimicrobial, anticoagulant, anticancer, antihypertensive, wound healing, immune modulating and other attributes.

Based on *in vitro* test systems, examples of South African plants with promising AH activity include: *Markhamia obtusifolia* (Nchu *et al*., 2011), *Tulbaghia violacea* (McGaw *et al*., 2000), *Combretum molle* (Ademola and Eloff, 2010), *Hypoxis colchicifolia* (Aremu *et al*., 2010), *Cassinopsis ilicifolia*, *Tetradenia riparia*, and *Coddia rudis* (Okem *et al*., 2012). In addition, the *Aloe ferox*, *Leonotis leonurus* and *Elephantorrhiza elephantina* (Maphosa and Masika, 2011) plants were also shown to be effective AH remedies. However, most of the evidence reported in ethno-veterinary sources was found to be in the form of observations rather than based on experiments (Hammond *et al*., 1997). With reference to reported AH evidence in certain plants, controlled studies (i.e., both *in vitro* and *in vivo* experiments) in some cases supported reports of AH efficacy, for example Idris *et al*. (1982), Hördegen *et al*. (2003) and Athanasiadou *et al*. (2007), whereas others rejected this submission, for example Githiori *et al*. (2002), Ketzis *et al.* (2002), Githiori *et al*. (2003a, b) and Githiori *et al*. (2004).

The core advantages of using *in vitro* bioassays include the low cost involved and rapid turnover that allow for large-scale screening of plants, as well as the low quantity of extracts required (Athanasiadou *et al*., 2001; Githiori *et al*., 2006). Moreover, the opportunity to fractionate and test purified compounds also has its merits. However, Githiori *et al*. (2006) further suggested that *in vitro* assays are useful as pre-screen experiments which are mainly performed with the free-living rather than parasitic stages of nematodes and that, in most cases, *in vitro* conditions and concentrations used are not always comparable to those used *in vivo*. This submission is concurrant with an earlier report (Athanasiadou *et al*., 2001) and a later submission (Eguale *et* *al*., 2011) by authors who noted that *in vitro* and *in vivo* assays often differed. This suggests that researchers often extrapolate results from *in vitro* tests to claim *in vivo* activity and/or efficacy without considering vital factors such as absorption and bioavailability of the PSM(s) in the animal.

3.4.2 *IN VIVO* VALIDATION OF PHYTO-BIOACTIVES

The methodologies used for *in vivo* validation include the provision of fresh, conserved or dried plants, or plant parts to naturally or experimentally parasitized animals (Athanasiadou *et al*., 2007). Likewise, supplementing livestock diets with plant extracts was also investigated. For a plant to have a role in parasite control, its consumption should result in certain levels of anthelmintic efficacy (Githiori *et al*., 2006). The latter authors also stated that a reduction of 99 % or higher in FEC is considered to be highly efficacious, whereas an 80 % reduction is just adequate.

In vivo demonstrations by Iqbal *et al*. (2004) found that the consumption of the whole wormwood plant (*Artemisia brevifolia*) resulted in a 62 % reduction in the agg counts of the abomasal nematode *H. contortus* in parasitized sheep. With reference to parasitized goats, Akhtar and Ahmad (1992) and Paolini*et al*. (2003) both reported a positive AH effect when plant extracts containing high levels of PSM were included in their rations. Also, the consumption of fagara leaves (*Zanthoxylum zanthoxyloides*), a native tree from Africa that is believed to have anti-parasitic activity, resulted in reduced egg excretion by the same nematode in sheep when consumed regularly in small amounts (Hounzangbe-Adote *et al*., 2005). Similarly, *Sericea lespedeza*, a grazing perennial legume native to Eastern Asia showed promising anthelmintic activity when offered to goats either fresh (Min *et al.*, 2004) or as hay (Shaik *et al.*, 2004; Lange *et al.*, 2006).

Additionally, studies reported lower faecal egg counts and worm burdens in ruminants parasitized with abomasal and intestinal nematodes when cassava (*Manihot esculenta*), hay (Sokerya and Preston, 2003; Bunyeth and Preston, 2006) and quebracho extract (Athanasiadou *et al.*, 2001; Butter *et al*., 2001) were used to supplement their diets. Satrija *et al*. (1994) almost eliminated intestinal nematodes within 7 days of supplementation of pig diets with papain extract. In another study on pigs, Petkevičius *et al*. (2003) and Mejer (2006) added purified inulin and dried chicory roots respectively to pig diets and observed almost a complete egg reduction of *Oesophagostomum* spp. However, the evidences on the anti-parasitic properties of phyto-bioactives appear to be mostly circumstantial and were not always consistent, and thus lack scientific validity. Currently, there are increasing numbers of controlled *in vitro* and *in vivo* experimental studies that aim to confirm, validate and quantify such plant activities. Jabbar *et al*. (2006) conclude that both test systems and the varieties of organisms in use have various limitations.

3.5 ANTI-NUTRITIONAL EFFECTS AND SAFETY CONCERNS OF PHYTO-BIOACTIVES

The anthelmintic efficacy of phyto-bioactives should not be the only factor to consider before using them against parasites. For example, Githiori *et al*. (2006) suggested that some of these plants may also have detrimental or toxic effects on the growth and performance of livestock once they have exceeded an optimal intake. Alkaloids, terpenes, saponins, lactones, glycosides and phenolic compounds are classes of active PSMs whose excessive consumption can harmfully affect the health of both ruminants and non-ruminants and, in extreme cases, can threaten their survival (Athanasiadou *et al*., 2007). To buttress the above observation, the consumption of tannins and other PSMs at high intake rates has been associated with reduced feed intake and dry matter digestibility, and also with impaired rumen metabolism when included in the diets of ruminants at more than 4–5 % of dry matter (Barry and McNabb, 1999; Min *et al*., 2003). Weight loss, toxicity and the death of animals have also been reported (Milgate and Roberts, 1995; Waghorn and McNabb, 2003). Other studies have shown that saponins and condensed tannins are responsible for mucosal toxicity, reduction in nutrient absorption and, subsequently, growth impairment (Applebaum and Birk, 1979; Reed, 1995; Milgate and Roberts, 1995; Dawson *et al*., 1999). Githiori *et al*. (2006) and Athanasiadou *et al*. (2007) recounted that these PSMs may also be associated with haemolytic action and bloat in ruminants. Earlier reports by Conn (1979) and Mabry and Gill (1979) purported that excessive consumption of alkaloids, glycosides and terpenoids by animals can result in lesions in the nervous system.

Likewise, monogastrics are not immune to the detrimental fallouts of these phytochemicals. In poultry, tannin levels from 0.5 to 2.0 % has been reported to suppress growth and egg production, and it has been suggested that between 3 to 7 % inclusion levels of tannins in their diet may be lethal (Haslam, 1989; Reed, 1995; Giner-Chavez, 1996). Similar harmful effects of CTs and other plant chemicals have also been reported in swine (Reed, 1995). However, despite their anti-nutritional properties, low levels of PSMs have been noted to increase growth and milk yield in sheep and cattle (Applebaum and Birk, 1979; Van Soest, 1994; Reed, 1995; Milgate and Roberts, 1995; Dawson *et al*., 1999). Interestingly, Athanasiadou *et al*. (2000) and Butter *et al*. (2000) posited that a reduction in the level of parasitism in hosts supplemented with plants, plant parts or extracts containing phyto-bioactives is not always accompanied by an improvement in the performance of the host. These findings thus suggest that, if phyto-bioactives should be used to improve the performance of parasitized animals, then the positive anthelmintic effect(s) of the PSMs should outweigh the potential negative anti-nutritional effect(s) on the host.

3.6 THE FUTURE OF SUSTAINABLE HELMINTH CONTROL

Different scientific studies have noted that some phyto-bioactives exhibited anthelmintic properties and other beneficial attributes in both *in vitro* and *in vivo* studies (Satou *et al*., 2002; Ademola and Idowu, 2006; Githiori *et al*., 2006). However, there are still no absolute scientific validity and consistency within and among the submissions of these various researchers. Also, the potentially detrimental effects of these PSMs have not yet received adequate investigation. PSMs can play a role in parasite control only if parasitized animals can obtain a clear advantage on their performance from PSM consumption (Athanasiadou and Kyriazakis, 2004). This advantage can only be achieved if the anti-parasitic effect of these PSMs balances, or better still, outweighs its anti-nutritional consequences in the animal.

Unlike the synthetic anthelmintics, PSMs do not fulfil certain standards which warrant their professional use as AHs. These standards include well-known and scientifically acceptable efficacy, specific modes of action, dosage parameters, direct and indirect toxicity, potential environmental side-effects, and regulation requirements (Aremu *et al*., 2012). However, PSMs can be attributed to other advantages such as affordability, biodegradability, no environmental pollution, no packaging required, potential sustainability, no known reported helminth resistance, positive acceptance by smallholder farmers, and local availability.

In the future, it is unlikely that gastrointestinal nematode control in livestock will rely on a single approach. The sustainability of helminth control will be largely conditioned by the ability to achieve an integrated parasite management strategy which involves combining several solutions (Waller, 2006). These sustainable multi-faceted strategies could involve a combination of two or more conventional or non-conventional practices without negative interactions. These future integrated strategies may include nutritional manipulations, vaccination, genetic selection of livestock for increased resistance and resilience to GIN, strategic use of bioactive forages and/or their PSM extracts, pasture rotation, grazing different or mixed livestock species at intervals, use of copper oxide wire particles (COWP), biological control by using nematode-trapping fungi *(Duddingtonia flagrans)* and, whenever inevitable, the use of pharmaceutical AH to control zoonotic helminths in livestock.

Some researchers are already involved in investigating such integrated control tools. For example, a study by Burke *et al*. (2005) used COWP and *D. flagrans* which were evaluated with good results in sheep. The effects of supplementary feeding and COWP were also evaluated by De Montellano *et al*. (2007) in browsing goats with positive results. Also, nutrient supplementation in conjunction with some PSM nutraceuticals was proved to reduce the peste des petits ruminant (PPR) infection phenomenon in sheep (Kidane *et al.*, 2009) and affected the worm population of growing lambs (Martínez-Ortíz-de-Montellano *et al*., 2010). Although research studies on the above strategies may be cumbersome, the integrated anti-parasitic concept still requires more accurate scientific validations under different farming conditions and with different livestock species. If specific objectives and sustainable measures to curb the proliferation of these harmful parasites in animal production are not explored, it can be assumed that, in future, infections of the gastrointestinal tract with parasitic helminths will remain highly prevalent in both temperate and tropical areas and will represent a major threat for livestock production and health, especially under outdoor breeding systems (Perry *et al*., 2002; Hoste and Torres-Acosta, 2011).

3.7 CONCLUSION

Scientific evidence surrounding the evaluation of the activity and the role of medicinal plants for parasite control is still inconsistent. The results of the review that was presented in this chapter suggest that none of the investigated phyto-bioactives have been studied adequately to produce consistent results in both *in vitro* and *in vivo* experiments using different livestock farming systems and animal species to warrant their endorsement for commercial usage. Granted, the financial implications of such projects could be enormous and will thus require some cushioning and healthier, collaborative partnerships between researchers, the government and pharmaceutical firms. There is indeed an urgent need for more efficient studies aimed at identifying and validating the use of plants as AHs. Parasitologists have recommended that threshold points should be established, below which the efficacy of medicinal plants for parasite control should not be considered. It has been suggested that such threshold points should be like those set for commercial anthelmintics (Vercruysse and Claerebout, 2001). Further research on the anti-parasitic properties of phyto-bioactives, their anti-nutritional effects, effective dosages for inclusion in animal diets, the mechanism of action involved, the biochemical description of the active PSM, availability of the plants, cost of procurement, and propagation are strongly recommended. Also, an ethical review of the legislation concerned with the use of ethno-traditional plant remedies in animal husbandry should be conducted. A positive helminth resistance to PSMs may be demonstrated as undeniable in the future, but at present, it remains theoretical and hence requires vigorous and ongoing investigation.

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CHAPTER 4

PORCINE HELMINTHIASIS AND THE PREVALENT FARM MANAGEMENT OPERATIONS AMONG SMALLHOLDER PIG FARMERS IN THE FREE STATE

4.1 INTRODUCTION

The consumption of pork and pork products plays a vital role in the nutrition and health status of its consumers in most parts of the world as it complements the need for increased consumption of protein, especially in developing countries. Pork has a high content of biologically valuable nutrients and it is very versatile in use amongst customary foods in the food chain. In statistical terms, pork is the third highest produced meat in South Africa (LDA, 2011; DAFF, 2012a) and the domestic demand for pork in South Africa increased by 24 % between 2007 and 2015 (SAG, 2015). In the Southern African region, South Africa raises the largest number of pigs (Phiri *et al*., 2003), with Limpopo and the North West Provinces as the leading producers that account for 44 % of the country's total pig production (DAFF, 2012b; Munzhelele *et al*., 2016).

Because pork is an important part of the human diet, pig breeding practices, their health, management system, slaughter, sale and consumption have become major issues of public health concern. As a matter of fact, porcine helminthiasis can lead to considerable loss of productivity and animal welfare and may directly or indirectly contribute to reduced sustainability in food security, especially if subsistence farming systems collapse. Should this happen, the consequences will culminate in colossal economic losses to these farmers (Roepstorff *et al*., 2005; Henrioud, 2011) and to the meat production industry that feed large numbers of the South African population. The problem may be extensive, as reports from Nsoso *et al.* (2000) and Knecht *et al*. (2012) indicated that the key effects of porcine gastro-intestinal parasites include loss of appetite, reduction in daily gain, poor feed utilization, potentiation of other pathogens, and condemnation of affected pig organs following slaughter. In addition, some of these worms are zoonotic in nature and have the potential to cause significant health threats in infected humans (Zoli *et al*., 2003). Epidemiologic studies by Mafojane *et al*. (2003), Phiri *et al*. (2003), Krecek *et al*. (2004) and Krecek *et al.* (2012) demonstrated that the highest levels of human neurocysticercosis (NCC), which is a zoonotic infection caused by porcine *Taenia solium,* occurred in the smallholder farming areas of the Eastern Cape Province of South Africa. In different parts of the world, pharmaceutical anthelmintics have been intensively used to treat helminth gastro-intestinal infections in pigs and other farm animals, but it has resulted in a substantial anthelmintic failure due to increasing incidences of resistance in some worm species

(Bakunzi, 2003; Coles *et al*., 2006, Leathwick and Besier, 2014; Van den Brom *et al*., 2015; Nisbet *et al*., 2016; EMA/CVMP, 2017). A review of the literature revealed that in the Free State Province of South Africa, insufficient information is available on the predisposing factors, prevention, control and consequences of porcine helminthiasis, zoonosis and anthelmintic administration. It was in this context that a questionnaire which aims to form the baseline information to determine smallholder farmers' knowledge and awareness in relation to the above issues was designed. This study was deemed imperative and was designed to gather information based on open- and closed-ended questions from smallholder pig farmers in selected districts in this province. The study intended to ascertain, inter alia, the number of viable small-scale pig production units, pre- and post-slaughter practices, prevailing on-farm management practices, hygiene standards, vaccination and deworming regimes, knowledge of zoonotic helminths and their attendant infections, anthelmintic administration and withdrawal practices, and anthelmintic drug resistance.

4.2 METHODOLOGY

4.2.1 RESEARCH DESIGN

This study was conducted using a mixed methods questionnaire approach by administering both open- and closed-ended semi-structured design questions to respondents as recommended by Creswell (2003). The questionnaires were randomly issued to forty-six (46) smallholder pig farmers in selected districts (Manguang Metropolitan, Fezile Dabi, Thabo Mofutsanyana and Lejweleputswa) of the Free State Province of South Africa. The experimental sites were chosen because of the large population of viable smallholder pig production units sited in these districts and the number of respondents was based on the number of reachable smallholder pig farmers in the research sites during the study period. Prior to the main study, a pilot study was conducted on ten (10) smallholder pig farmers in Manguang Metropolitan district to ascertain the validity, appropriateness and reliability of the study by piloting the questionnaire. The questions were designed to address the objectives of the study which had been propelled by an intensive literature review.

4.2.2 QUESTIONNAIRE DISTRIBUTION

To facilitate speedy distribution of the questionnaires to smallholder farmers within the four selected districts (Manguang Metropolitan, Fezile Dabi, Thabo Mofutsanyana and Lejweleputswa - Figure 4.1), the Free State piggery database was obtained from the Department of Agriculture, which is situated in Glen. The database contained the names of farmers, their contact numbers, farm locations (town, municipality and district), scale of production and the details of the designated extension officers. The questionnaires were both interviewer-administered and self-administered between the months of September and December in 2015. Extension officers were used as local language interpreters in most cases.

Figure 4.1: Map of the four (4) districts in the Free State Province of South Africa selected for the study; Manguang Metropolitan, Fezile Dabi, Thabo Mofutsanyana and Lejweleputswa districts. (Source: https://www.google.co.za)

4.2.3 STATISTICAL ANALYSES

Responses from the respondents were arranged, summarised, coded and transferred to an IBM® SPSS® 22 statistical workstation. The data from the questionnaires were further statistically analysed to obtain frequencies and percentage values. Graphical representations and simple correlations between variables were also produced.

4.3 RESULTS AND DISCUSSION

The results as presented in Table 4.1 show that Manguang Metropolitan had the highest number of respondents at 58.7 %, while Lejweleputswa district recorded the lowest rate at 6.5 %. Fezile Dabi and Thabo Mofutsanyana districts had an equal respondent rate at 17.4 % of the total sampled population. The highest response frequency was recorded for Manguang Metropolitan district due to the larger number of emerging pig farmers in this region and accessibility logistics. All the respondents were black farmers who were mostly between the ages of 51−60 years (34.8 %, freq. = 16), and males accounted for more than half (69.6 %) of the sample of respondents. The majority (60.9 %) possessed little or no level of formal education, and could therefore hardly read or write properly in English or their local languages. Their arithmetic ability was generally poor, which concurred with the findings of an earlier study by Maphalla and Salman (2002). Similar finding was also reported by a study in Gauteng Province that was conducted by Matabane *et al*. (2015), who recorded a very low percentage of youth participation in pig farming, a male dominated enterprise, and that there was a dearth of basic skills due to lack of education amongst smallholder pig farmers in the region. In the current study, very few (6.5 %) of the respondents had been in the pig farming industry for more than 20 years, with an average of between 10−15 years of farming experience, while 39.1 % of the respondent farmers had not exceeded five years in this industry. It was revealed that 80.4 % of the smallholder pig farmers had exotic breeds of swine and farmed mostly on a full-time basis.

Correlations between farm size (in hectares) and number of pigs per enterprise were highly positive ($P<0.01$, $r = 0.972$), with 54.3 % of participants farming on between 0−5 ha of land. Most of the farmers (45.7 %, freq. = 21) owned 5−10 pigs at the time of the study (Table 4.2). This suggests the potential for increased production as sufficiently large expanses of land area were available to the farmers. Similarly, positive ($P<0.01$, $r = 0.623$) correlations existed between the type of farming methods and the management systems that were practised by the farmers. Approximately 71.1 % of respondents practised a semi-intensive farming system where animals foraged for food outside their stalls, while a very high proportion (87.0 %, freq. = 40) of the farmers in the sample engaged in continuous flow-barn management practices.

Table 4.1: Demographics of the farmers and their farming details

Factor	Variable	Response frequency	Percentage (%)	Total number of respondents
Farm location	MM	27	58.7	
	FD	8	17.4	
	TM	8	17.4	
	LJ	3	6.5	46
Gender	Male	32	69.6	
	Female	14	30.4	46
Age of farmer (years)	21-30	1	2.2	
	31-40	4	8.7	
	41-50	12	26.1	
	51-60	16	34.8	
	61-70	10	21.7	
	71-80	3	6.5	46
Level of Education	Uneducated	6	13.0	
	Below matric	28	60.9	
	Undergraduate	8	17.4	
	Graduate	4	8.7	46
Years of farming experience	0-5	23	50.0	
	6-10	5	10.9	
	11-15	15	32.6	
	16-20	2	4.3	
	21-25	1	2.2	46
Years in pig farming enterprise	0-5	18	39.1	
	6-10	4	8.7	
	11-15	15	32.6	
	16-20	6	13.0	
	21-25	3	6.5	46
Type of pig breed	Exotic	37	80.4	
	Indigenous	5	10.9	
	Exotic X	2	4.3	
	Indigenous	2	4.3	46
	No idea			
		28	60.9	
Farming time	Full time	18	39.1	46
	Part time			

MM: Manguang Metropolitan; FD: Fezile Dabi; TM: Thabo Mofutsanyana; LJ: Lejweleputswa

Earlier, Krecek *et al*. (2004) reported that 25 % of pigs in South Africa were free-ranging and owned by resource-poor farmers. A lower positive (P<0.05, r = 0.342) correlation was demonstrated between farm size and management practice, and between number of pigs and management practice in this study.

Table 4.2: Correlations between independent on-farm practices

Independent variables	Farm size (ha)	Number of pigs	Type of farming method	Type of management system
Farm size (Ha)	1.000	0.972**	0.760**	0.342*
Number of pigs	0.972**	1.000	0.775**	0.370*
Type of farming method	0.760**	0.775**	1.000	0.623**
Type of management system	0.342*	0.370*	0.623**	1.000

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Regarding the health aspects on Table 4.3, more than 85 % of farmers vaccinated and dewormed their pigs and the other animals on their farms. This category was up-to-date with the vaccination schedule for their pigs. This finding was in contrast with the results recorded by Matabane *et al*. (2015), who found that most of the smallholder pig farmers in their study did not vaccinate their pigs. However, almost all (96.7 %) the respondents in this study had never taken faecal or blood samples of their pigs or other livestock on their farms for laboratory analysis. Also, 80.4 % of the participants did not employ the services of veterinarians or trained animal health technicians to assist, assess or treat their herd due to high cost and lack of availability of these professionals and accessibility to their farms.

Figure 4.2 illustrates that 65.2 % of the respondents indicated that there was a problem with intestinal helminths in their pig herd, with parasites (37.0 %, freq. = 17) emerging as the most common herd health problem, followed closely by bacterial diseases (28.3 %, freq. = 13).

Table 4.3: Responses to pig health related questions

Factor	Variable	Response frequency	Percentage (%)	Total number of respondents
Pig vaccination	Yes No	41 5	89.1 10.1	46
Up-to-date vaccination record	Yes No No idea	29 10 7	63.0 21.7 15.2	46
Source of help during vaccination	Self Professional	37 9	80.4 19.6	46
Pig deworming	Yes No	28 2	93.3 6.7	30
Parasitological analyses of faecal/blood samples	Yes No	1 29	3.3 96.7	30

It is noteworthy that 41.3 % believed that the pigs' environment could be a source of infection, although only 17.4 % cleaned their pig stalls daily and the majority did not use disinfectants. Across the board, piglets were penned to have the highest infection and mortality rates, with 53.3 % of mortalities occurring in females. Also, more than half (53.3 %) of the respondents described the cost of anthelmintics as "expensive".

Figure 4.3 illustrates that nearly 78.0 % (freq. = 36) of the respondents were not aware of anthelmintic resistance in some porcine helminth species and other livestock nematodes. Reports on anthelmintic resistance in some livestock nematode species of economic importance have been documented in South Africa and other parts of the world by Van Wyk *et al*. (1999), Vatta *et al.* (2001), Gerwert *et al*. (2002), Bakunzi (2003), Stear (2008), Leathwick and Besier (2014) and Van den Brom *et al*. (2015). Additionally, 17.4 % of farmers indicated that they repeated or increased the dosage of worm expellers mostly because of anthelmintic failure. Most respondents did not know about the withdrawal period of medication before slaughter (Figure 4.5) or the zoonotic nature of porcine helminths (Figure 4.4), but 67.4 % claimed that they knew how to prevent human infections.

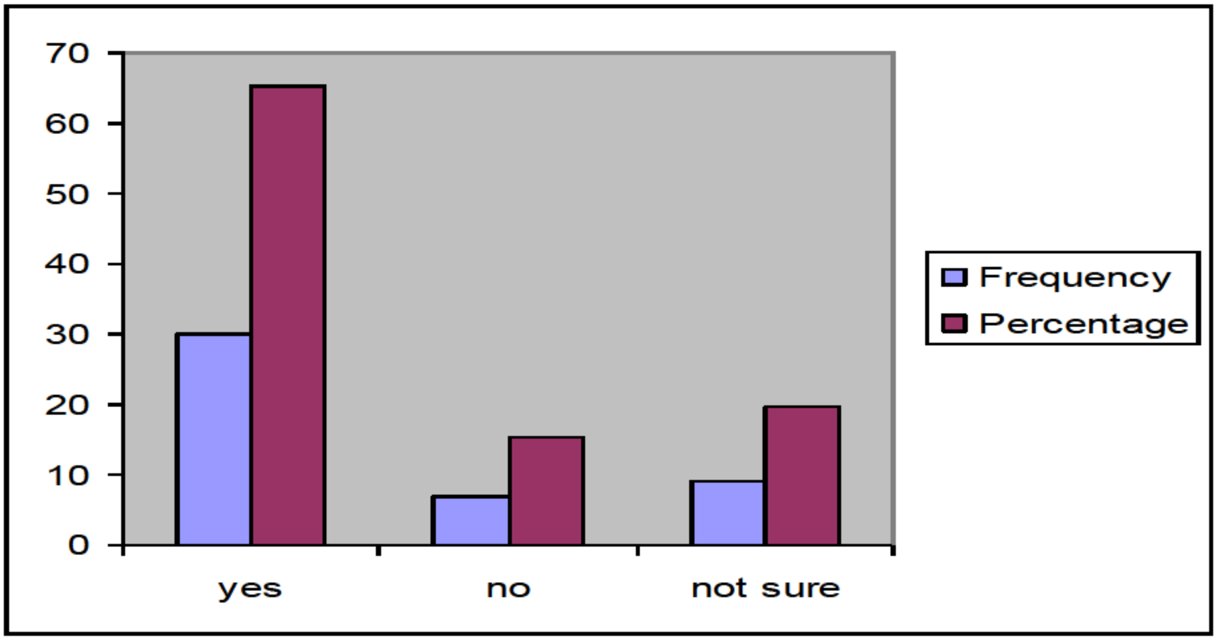

Figure 4.2: Bar graph illustrating awareness of farmers to porcine helminthiasis

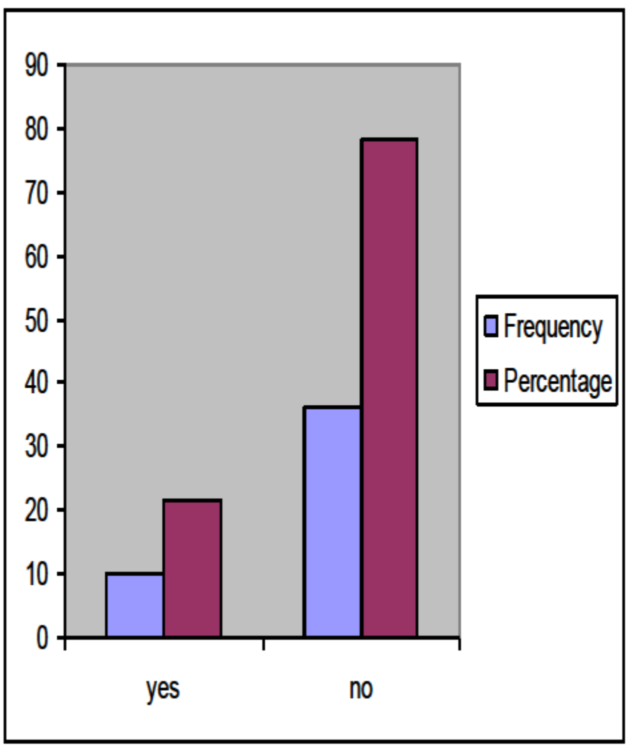

Figure 4.3: Bar graph illustrating awareness of farmers to anthelmintic resistance

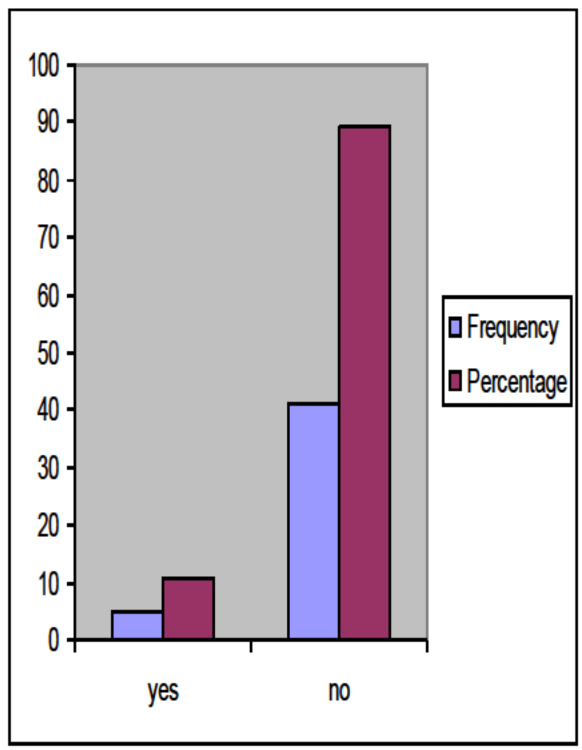

Figure 4.4: Bar graph illustrating awareness of farmes to zoonosis

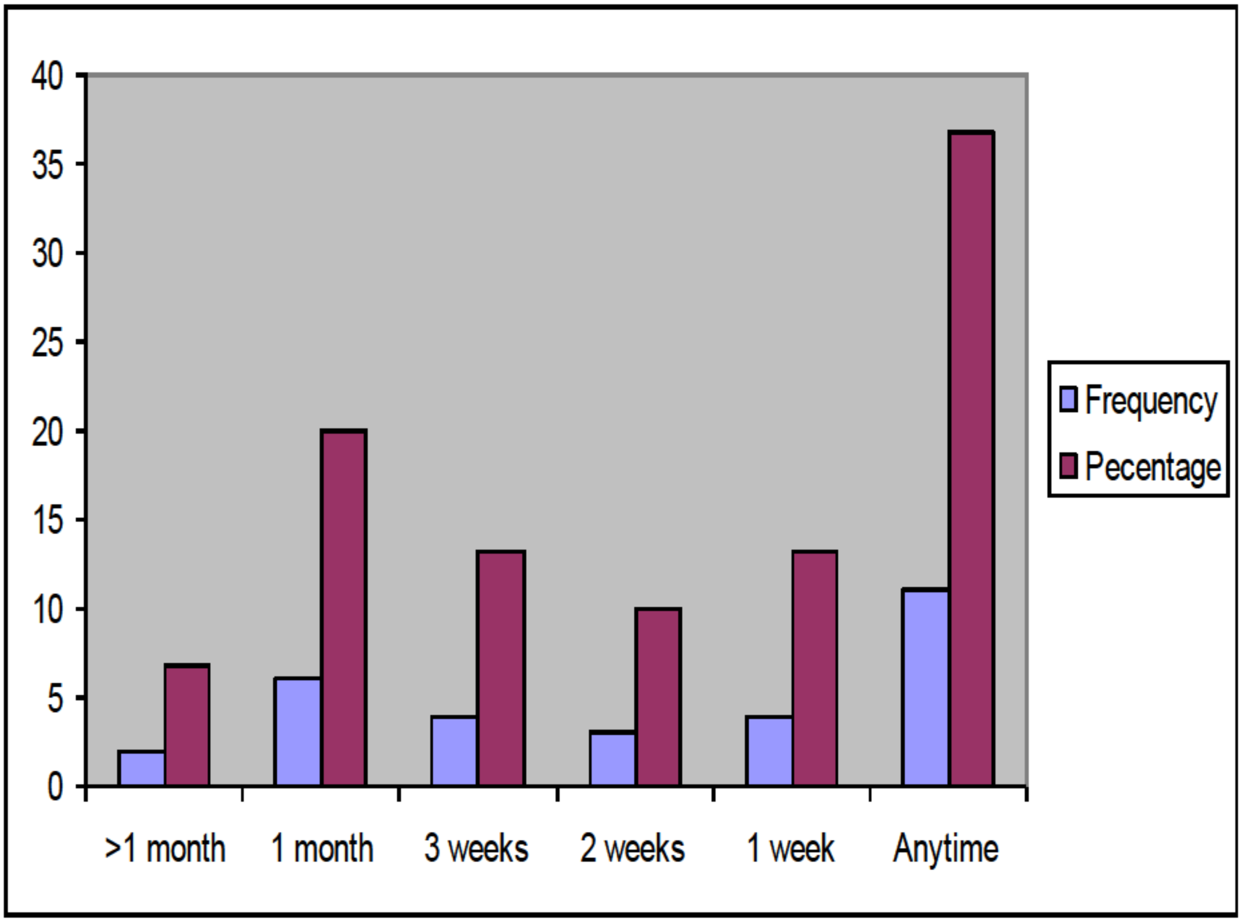

Figure 4.5: Bar graph indicating periods of anthelmintic withdrawal before slaughter

In terms of post-slaughter practices, Table 4.4 shows that 73.9 % of the respondents did not take their pigs to the abattoir to be slaughtered. The respondents provided reasons for this which included high cost of slaughter, high cost of transportation, long distances to the abattoir, small scale of production and very few pigs to slaughter at a given period. All the respondents that made use of the abattoir transported their pigs in bakkies and light delivery vehicles, and they were mostly satisfied with the sanitary conditions at the abattoir. Only 16.7 % (freq. = 2) of the respondents who used abattoirs for slaughtering purposes had had pigs' carcasses condemned due to extensive internal infestation by parasites and subsequent organ damage. Disturbingly, half (50.0 % freq. = 23) of the farmers reported that their pig production enterprise was not profitable and therefore not viable.

Table 4.4: Responses to post-slaughter practices

Factor	Variable	Response frequency	Percentage (%)	Total number of respondents
Abattoir use for pig slaughter	Yes	7	15.2	
	Occasionally	5	10.9	
	No	34	73.9	46
Abattoir sanitary and personnel satisfaction	Always	10	83.3	
	Sometimes	2	16.7	12
Carcass condemnation	Yes	2	16.7	
	No	10	83.3	12
Profitable and viable pig enterprise	Yes	12	26.1	
	Not sure	11	23.9	
	No	23	50.0	46

4.4 CONCLUSION

It was observed that the smallholder pig farmers in the study area were faced with several constraints that militated against improved pig production and viability. Higher levels of education, periodic training, monitoring, organized farmer co-operatives and compliance with relevant guidelines have been demonstrated in the literature to be beneficial to productivity. If these factors are achieved, it will likey make the enterprise attractive to young people. More information and government interventions are still required as matters of urgency to increase farmer awareness of the scourge of porcine helminthiasis and to curb the high rate of failed smallholder pig enterprises in the study area. Veterinarians and animal health technicians should be encouraged and mobilised to constantly visit smallholder pig farmers, especially the resource-poor farmers, in their operation areas. Farm hygiene compliance should also be periodically monitored. Because prevention is better than cure, farmers should be encouraged to buy “clean” pigs from reputable sources, rear pig breeds that are known to have resistance to intestinal parasites, practise good hygiene and biosecurity, and incorporate multiple sustainable measures to exterminate helminths from their farms. Also, there should be a reduction in over-reliance on chemical strategies to control parasitic infestation due to the associated resistance to them in pigs. Periodically, farmers should send faecal samples of their animals to a laboratory for parasitological examination. This will help to detect the presence of parasites in the herd, and the specie(s) and infection intensity will be known. Moreover, the effective method(s) for treating infected animals will therefore be executed. More importantly, zoonotic helminth surveillance on smallholder farms and abattoirs should be prioritised by relevant authorities in endemic regions.

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CHAPTER 5

PRE-MORTEM PREVALENCE OF INTESTINAL HELMINTH PARASITES IN SMALLHOLDER PIGS REARED IN THE CENTRAL FREE STATE

5.1 INTRODUCTION

Globally, pork is the most consumed of all meat products (Phiri *et al*., 2003; Davids *et al*., 2013), and South Africa accounts for the highest pig population in southern Africa even though the pig industry is smaller than its chicken and beef market counterparts. Krecek *et al*. (2004) confirmed that 25 % of pigs produced in South Africa, especially in resource poor rural areas, are free ranging. Also, in these areas pigs are mostly reared because of this industry's contribution to human nutrition, poverty alleviation, food security, enhanced livelihoods and the creation of employment for rural communities (Antwi and Seahlodi 2011). In the central Free State Province, pigs are normally reared intensively, semi-intensively or extensively (free range). The intensive (factory farm) system of production is typically practised by established commercial farmers who account for the bulk of pig production in the province, while the semi-intensive and extensive systems are commonly practised by medium scale, smallholder, emerging or resource poor pig farmers (Van Niekerk *et al.,* 2014).

Considering the high cost of intensive pig production, inadequate managerial skills and other logistical challenges that impact extensively and semi-intensively managed pigs are still common in the rural set-up of many developing countries. In these production systems, pigs are mainly kept as a source of livelihood to generate income and supply protein. However, poor feed conversion and utilisation efficiency, a decline in reproductive performance, land pollution, parasitic contamination, high mobidity and mortality rates, poor carcass quality and the increased rate of zoonotic infections in humans (e.g. Cysticercosis) are some of the prevalent constriants associated with outdoor pig production systems (Lekule and Kyvsgaard, 2003; Krecek *et al*., 2004; Githigia *et al*., 2005; Kagira, 2010). Furthermore, helminthiasis has been reported to be a major set-back to profitable pig production in Africa (Permin *et al* 1999; Lekule and Kyvsgaard 2003; Nissen *et al* 2011). Farmers experience both direct and indirect economic losses due to helminthiasis which also culminates in reduced welfare issues in pigs (Kumsa *et al*., 2010). Reports by Stewart and Hoyt (2006) and Kagira *et al.* (2012) suggested that internal parasitism in pigs can result in loss of appetite, poor growth rate, poor feed conversion efficiency, organ and carcass condemnation, high cost of treatment and potentiation of other pathogens or even death in severe cases.

The prevalence, intensity and helminth species present in any given population of pigs is closely associated with the agroecological zone and type of production system that is practised. The infection levels on farms where pigs are bred intensively are usually lower and manifest with less intensity when compared to the traditional systems where poor hygiene, poor nutrition and inadequate anthemintic intervensions favour the proliferation of intestinal helminths (Nansen and Roepstorff, 1999; Mashatise *et al*., 2005; Tamboura *et al.,* 2006; Nganga *et al*., 2008; Dey *et al.*, 2014). On these farms, the roaming of pigs favour the uptake of the infective stages of these helminths, thus making the pigs more susceptible to a heavy parasitic burden. Additionally, the humid and warm conditions in tropical and sub-tropical agroecological regions where pigs are bred, coupled with the inefficient use of anthelmintics, are conducive for high rates of intestinal parasitism (Mashatise *et al*., 2005; Eijck and Borgsteede, 2005; Marufu *et al.* 2008).

Various prevalence levels of gastro-intestinal parasites of pigs have been reported in epidemiological studies by scientists all over the world. These parasites include, among others, *Ascaris suum, Strongyloides spp., Metastrongylus spp., Oesophagostomum spp., Trichuris suis, Taenia solium, Ancylostoma spp., Hyostrongylus rubidus, Fasciolopsis buski, Dicrocoelium spp., Schistosoma suis, Eimeria spp., Balantidium coli and Isospora suis* (Nsoso *et al*, 2000; Opara *et al*., 2006; Borthakur *et al*., 2007; Marufu *et al*., 2008; Nganga *et al*., 2008; Ismail *et al*., 2010; Sowemimo *et al.*, 2012; Obonyo *et al*., 2012; Dey *et al.*, 2014). In some studies, the multiple infection intensity was recorded to be as high as 96.4 % (Dey *et al.*, 2014) or as low as 1.5 % (Ekong *et al*., 2012) or less for isolated infections (Kumsa and Kifle, 2014). Some parameters such as sex, age, management system, season, geographical location, and level of farmer awareness have been reported to be risk factors that may influence the various levels of parasitism in live or slaughtered pigs.

Due to increasing travel and migration patterns, humans have become more predisposed to zoonotic infections in most regions of the world, including developed countries (Garcia *et al*., 2007). According to Ekong *et al*. (2014), zoonotic helminth infections in humans are among the most common on earth and are responsible for about 60 % of all infectious diseases in humans. Some of these important and well-known human zoonoses are caused by different species of nematodes, cestodes and trematodes (Robinson and Dalton, 2009). Other human gastrointestinal parasites include eosinophilic enteritis, intestinal capillariasis, anisakidosis, oesophagostomiasis and gnathostomiasis (McCarthy and Moore, 2000). Echinococcus infections still account for hepatic and pulmonary pathology while cysticercosis is a major cause of epileptic seizures, whereas fascioliasis causes significant liver pathology (Ekong *et al*., 2012).

There is a dearth of information on the prevalence, intensity and risk factors of pig helminths in the different types of pig management systems in the Free State Province. Therefore, extensive scholarly knowledge of the endemic helminth species in this province can be used as baseline data to help design future effective and sustainable helminth intervention plans. Therefore, the aim of this study was to identify and quantify the major types of intestinal helminths and parasites prevalent in smallholder pigs raised in selected districts in the central Free State Province of South Africa.

5.2 METHODOLOGY

5.2.1 DESCRIPTION OF STUDY AREA

This field study was conducted in four farming communities (Bloemfontein, Botshabelo, Thaba 'Nchu and Manguang) in the Manguang Metropolitan Municipality in the central Free State Province of South Africa (Figure 5.1). This municipality is located within the coordinates 29 ^{0}S and 26 ^{0}E and comprises a geographical area of 4 284 km^2. The area experiences a semi-arid climate with temperatures ranging between 19 ^{0}C to 32 ^{0}C in the summer months and -3 ^{0}C to 14 ^{0}C in the winter months. Annual precipitation varies between 500 to 600 mm. The altitude is 1 395 m (45,776 ft) above sea level (Maphalla and Salman, 2002).

Figure 5.1: Map of Manguang Metropolitan Municipality (Source: https://www.google.co.za)

5.2.2 STUDY ANIMALS

A total of 77 pigs owned by 16 smallholder pig farmers in the survey area were randomly selected to be examined for intestinal helminths irrespective of management system or pig medical status. Already dewormed pigs (n=24) were also included to test the efficacy of the anthelmintics used. The majority of the experimental pigs (n=51) were reared semi-intensively while others were raised intensively (n=26). In the intensive system, the pigs were kept in partially covered stalls and water and feed were placed inside the stalls, while in the semi-intensive system the pigs were allowed to forage for food and water in the open, returning to their stalls at night. The sampled pigs were of foreign breeds – Large White or Large White X Landrace.The pigs' ages were determined by making enquiries from the farmers. Pigs between 0-3 months were tagged as piglets (n=25), 3-7 months were growers (n=36), and the pigs above

7 months were recorded as adults (n=16). Also, both sexes were taken into consideration with males accounting for (n=32) and females (n=45). The number of faecal samples collected depended on the number of pigs available. The inclusion criteria of the the survey farms were accessibility to the farm, the availability of farmers, and the voluntary participation of each of the farmers. The services of extension officers who were designated to these farming areas were also sought and approved.

5.2.3 SAMPLE COLLECTION AND HANDLING

About four grams of faeces were randomly collected per rectum from pigs. Optimum care was taken to avoid additional contamination of the samples. All samples were properly labelled, indicating the date of collection, farm location, farming practice system, medical status, age and sex of the pig. The samples were immediately placed in a cooler box with ice packs to prevent eggs developing and hatching, and they were sent to the laboratory for analysis. Samples were collected between the summer/autumn months of January to March in 2016. Each farm was visited only once during the faecal sampling months due to logistical constraints.

5.2.4 LABORATORY ANALYSES

The faecal samples were analysed in the parasitology section of the provincial veterinary laboratory of the Department of Agriculture, Bloemfontein. Samples were either analysed on the day of collection or stored at 4 ^{0}C in the refrigerator for a maximum of three days before processing. The McMaster counting technique was used to determine the faecal egg count (FEC) per gram of faeces. This technique is used to demonstrate and provide a quantitative estimate of faecal egg output for helminths and coccidia. The identification and quantification procedures were based on the procedures as proposed by Soulsby (1982), the OIE manual of standards for diagnostic test and vaccines, (1996) and the operating procedure of the veterinary laboratory, Bloemfontein as recommended by Wentzel and Vermeulen (2003).

5.2.4.1 LABORATORY PROCEDURE

For the identification and quantification procedure, two grams of each of the faecal samples were weighed and placed in an already marked beaker. Fifty-eight millilitres of floatation fluid made up of 40 % salt solution was added to the beaker and a glass rod was used to break up the faeces to mix the sample properly. The mixture was left to stand for five minutes to allow the eggs to float to the surface. Thereafter, a Pasteur pipette was used to extract aliquots from the faecal mixture to fill the two chambers of the McMaster slide. This was left to settle and stand for about three minutes. Each McMaster slide was examined using a 10 X 10 magnification compound microscope, and the eggs (if present) were identified based on a combination of key structural and morphometric features. All the helminth eggs and coccidia oocytes present within the engraved areas of both McMaster chambers were quantified. This was done by counting all the eggs/oocysts within the engraved area in the two McMaster chambers and the total was multiplied by fifty (50). The FEC (faecal egg count) is usually expressed as EPG (egg per gram). EPG≤100 was grouped as low levels of infection, EPG>100<500 was regarded as moderate infestation, while EPG ≥500 was grouped as significant high levels. For coccidia oocyst, ≤500 OPG (oocyst per gram) was recorded as a low level of infection, while numbers >500 OPG were regarded as a high level of infection.

To further differentiate between the common strongyle type nematode eggs (Hyostrongylus, Globocephalus and Oesophagostomum spps), coproculture was done to obtain the L_3 stage larva using the Baermann technique (Permin *et al*., 1999) and the identification was based on the morphological features of the larvae. In cases where trematode eggs were suspected to be present, the sedimentation technique as described in the operating procedure of the Veterinary Laboratory, Bloemfontein as recommended by Wentzel and Vermeulen (2003) was done. Differentiation between coccidia species was not done. Appropriate hygiene and safety procedures were adhered to.

5.2.5 STATISTICAL ANALYSES

All the data were entered on a Microsoft^R Excel version 2016 spreadsheet and properly coded. Thereafter, they were exported to IBM SPSS, ver.22 statistical package for data analysis. Descriptive analyses of percentages, prevalence and pictorial representations were computed using the statistical package and Excel workstations. Relationships between the rate of the parasitic infections of the experimental pigs and other variables such as farm location, age, sex, farm type and medical status were tested using the chi-square test. The level of significance was set at $P < 0.05$. The prevalence of each specie of intestinal parasite was calculated as the ratio between the number of infected animals (n) and the total number of animals sampled (N). Thus:

$P = n/N \times 100$;

where P = prevalence, n = no. of infected animals, and N = number of animals sampled in that category.

5.3 RESULTS AND DISCUSSION

The results of this study are presented and discussed below.

5.3.1 THE OVERALL PREVALENCE OF INTESTINAL PARASITES IN PIGS

For this phase of the study, 16 smallholder pig farms in selected farming communities in the central Free State were visited. The communities were Bloemfontein, Botshabelo, Thaba Nchu and Manguang. A total of 77 faecal samples were collected from the pigs for parasitological analysis and 61 samples (79.2 %) tested positive for one or more intestinal parasite which was observed as single or mixed infections. Three species of intestinal helminth parasites and intestinal protozoa (Coccidia species) of veterinary importance (Nansen and Roepstorff, 1999) were identified in the faecal samples (Table 5.1), namely *Ascaris suum*, *Trichuris suis, Oesophagostomum dentatum* and *Coccidia spps*. Of all the pigs sampled, 44.5 % was infected with *Ascaris suum,* 50.6 % with *Trichuris suis, and* 26.0 % and 72.7 % were infected with *Oesophagostomum dentatum* and *Coccidia spps* respectively.

Similar overall prevalence of intestinal parasites in pigs had been recorded. In Ibadan, Nigeria, Sowemimo *et al*. (2012) reported an overall prevalence of 80.4 % and 73.4 % was recorded by Ismail *et al*. (2010) in Chungcheongnam-do, Korea. Also, 82 %, 83 % and 84 % prevalence have been reported by Järvis *et al*. (2007), Obonyo *et al.* (2012) and Kagira (2010) in Western Estonia, Homabay district in Kenya and Western Kenya repectively. Higher prevalence of 91 % (Nissen *et al*., 2011), 92.7 % (Tamboura *et al.,* 2006), 94 % (Waiswa *et al*., 2007) and 96.4 % (Dey *et al*., 2014) was also reported in Kabale District, Uganda; East Centre Province, Burkina Faso; South Eastern Uganda and Bangladesh respectively. However, in the current study the prevalence of intestinal parasites in pigs was higher than the results obtained in Jos, Nigeria (66.34 %); Bishofu, Ethiopia (25 %) and in Zimbabwe (58.7 %) by Tidi *et al*. (2011); Jufare *et al*. (2015) and Marufu *et al*. (2008) respectively. Likewise, Nganga *et al*. (2008); Tiwari *et al*. (2009) and Borthakur *et al*. (2007) recorded lower rates in Kenya (67.8 %); Grenada, West Indies (68.8 %) and in Aizawl (37.5 %) respectively. These recorded results probably varied due to geographical and climatic conditions, various pig breeds, farm management practices, the nutritional and medical status of the pigs, method of sample collection and analysis, and differences in the number of samples analyzed.

Table 5.1: Overall prevalence of intestinal parasites in pigs from selected farms in the central Free State

Description	Total no. of samples	No. of infected samples	Prevalence of infection (%)
Faecal samples	77	61	79.2
Parasites			
Ascaris suum	77	35	44.5
Trichuris suis	77	39	50.6
Oesophagostomum dentatum	77	2	26.0
Coccidia spps	77	56	72.7

The overall prevalence (44.5 %) of *Ascaris suum* in this study (Table 5.1) was similar to the prevalence recorded for other studies, namley 40 % byTamboura *et al*. (2006) in Burkina Faso, 50.9 % by Dey *et al*. (2014) in Bangladesh, 54.6 % by Nsoso *et al*. (2000) in Botswana, and 53.1 % by Salifu *et al*. (1990) in Nigeria. Also, Eijck and Borgsteede (2005) reported a similar prevalence of 50 % in free range pigs in the Netherlands, although higher (72.7 %) and lower (11.1 %) rates of infection were recorded in pigs raised in organic and conventional farms respectively. However, varied results for similar studies were recorded across a variety of locations, for example 64.3 % in Sao Paulo, 67.4 % in Nagaland, 88 % in Denmark, 4.9 % in Ethiopia, 5.4 % in Kenya, 28.7 % in Kenya, 68 % in Australia and 36.7 % in China by Kasai *et al*. (1979), Rajkhowa *et al*. (2003), Roepstorff and Jorsal (1989), Jufare *et al*. (2015), Obonyo *et al*. (2012), Nganga (2008), Mercy *et al*. (1989) and Boes *et al*. (2000) respectively. These results show that most non-African countries reported a remarkably higher prevalence of *Ascaris suum* which may have been due to seasonal and geographical variations that favour the proliferation of the helminth. To explain this phenomenon, Kagira (2010) and Obonyo *et al*. (2012) argued that perpetual wet farm conditions, an unhygienic environment and favourable temperatures can lead to high infection rates with *A. suum*.

The whipworm (*Trichuris suis*) was the most prevalent (50.6 %) of all the helminths recovered in this study (Table 5.1), unlike in the West Indies (Tiwari *et al*., 2009) and Botswana (Nsoso *et al*.,

2000) where Oesophagostonum *spp* and *Ascaris suum* were the most prevalent helminths recovered respectively. This result is higher and does not agree with some previous studies for *Trichuris spp* by Jufare *et al*. (2015), Marufu *et al*. (2008), Nsoso *et al*. (2000), Obonyo *et al*. (2012) and Dey *et al*. (2014) who reported 2.9 % in Ethiopia, 4.7 % in Zimbabwe, 6.8 % in Botswana, 7.8 % in Kenya and 9.1 % in Bangladesh respectively. However, the result is slightly similar to the 38 % and 37.5 % prevalence reported respectively in West Indies (Tiwari *et. al.,* 2009) and in outdoor pigs in the Netherlands (Eijck and Borgsteede, 2005). The higher prevalence of *T. suis* in this study might have been due to poor management and husbandry practices as were observed on most of the farms that were visited. Another explanation may be that whipworm eggs are hardy and can therefore withstand adverse environmental conditions for up to four years (Urquhart *et al*. 1996). Heavy infestations are more common in growing and adult pigs raised outdoors and heavy infestation usually presents as bloody diarrhea (Roepstorff and Nansen 1998).

One of the Strongyle-type eggs recovered from coproculture was *Oesophagostonum dentatum* with a 26 % overall prevalence (Table 5.1). Similar to the result of this study, Eijck and Borgsteede (2005) observed 25 %, 27.2 % and 22.2 % of the nodular worm on free range, organic and conventional farms in the Netherlands respectively. Also, infestation was reported at 37 % in Kenya, 27.6 % in India and 27.6 % in Kenya by Kagira *et al*. (2008), Yadav and Tandon (1989) and Kagira *et al.* (2002) respectively, which concur with the result obtained in the current study. However, divergent results were obtained by Obonyo *et al*. (2012), Tiwari *et al.* (2009), Dey *et al*. (2014), Marufu *et al*. (2008) and Tamboura *et al*. (2006) who observed a prevalence of 74 % in Kenya, 44 % in the West Indies, 12.7 % in Bangladesh, 14 % in Zimbabwe and 15.6 % in Burkina Faso respectively. The discrepancies above may have been partly due to seasonal and geographical variations, pig breed, health status, and effective management practices, or the lack thereof.

The most recovered intestinal parasite in this study was Coccidia which recorded a 72.7 % prevalence (Table 5.1). This finding compares well with that of similar investigations in the West Indies where Coccidia spp. was the most recovered intestinal parasite (Tiwari *et al*., 2009). Based on a study in Bangladesh, Dey *et al*. (2014) reported a combined Coccidia spps prevalence of 65.5 % (*Eimeria spp* and *Isospora suis*), and based on studies on organic and conventional farms in the Netherlands, Eijck and Borgsteede (2005) reported a prevalence of 90.9 % and 66.7 % of Coccidia respectively. However, the findings of other studies did not concur with the present study. For example, Obonyo *et al*. (2012), Jufare *et al*. (2015), Abdu and Gashaw (2010), and Weka and Ikeh (2009) recovered Coccidian oocytes at 34.8 % in Homabay district, Kenya; 12 % in Bishoftu, Ethiopia; 5.6 % around Holeta, Ethiopia and 15.6 % in Jos, Nigeria respectively. Also, Eijck and Borgsteede (2005) found 43.8 % infections with Coccidia on free range farms in the Netherlands. These variations may have been due to different husbandry management practices in the various study areas, the season of sample collection, pig breed, general health status of the sampled pigs, sample size, etc.

5.3.2 EFFECT OF DIFFERENT FARM LOCATIONS ON THE PREVALENCE OF INTESTINAL PARASITES

The highest parasitic load per farm location was recovered in Botshabelo (91 %), followed by Bloemfontein (83.8 %), Thaba Nchu (72.7%) and Mangaung (66.7 %) as listed in Table 5.2. *Ascaris suum* was most prevalent in Manguang (61.1 %) and least prevalent in Thaba Nchu (36.4 %), while Botshabelo recorded the highest prevalence for both *Trichuris suis* (72.7 %) and *Oesophagostonum dentatum* (36.4 %).

No *Oesophagostonum dentatum* eggs were recovered from samples in Thaba Nchu, probably because of the small sample size that was obtained and analysed from this area. The prevalence of Coccidia was high in all four farming locations. Ranging from the highest to the lowest rates, Botshabelo, Bloemfontein, Manguang and Thaba Nchu recorded 90.9 %, 73 %, 66.7 % and 63.6 % respectively. Moreover, there was a significant difference (P<0.05) in the prevalence of intestinal parasites among the farming communities, and *T*. *suis* and *Coccidia* also showed significant differences (P<0.05) in prevalence. However, there was no significant difference (P>0.05) in the rate of recovery of *A. suum* and *O. dentatum* eggs from the different farming locations. Because no previously published results could be traced to compare with helminth infection rates in these geographical areas, it is suggested that sample size, distance to laboratory and type of farming practice could be linked to the variations in the rates of intestinal parasitic infections. Also, more samples were collected from semi-intensively managed pigs which recorded high infection rates, which may account for the higher prevalence of intestinal parasites that was observed for this category. There is evidence in the literature to suggest that outdoor swine production systems are more susceptible to intestinal parasite problems than indoor systems (Roepstorff, 1993; Dangolla *et al.*, 1996 and Nansen and Roepstorff, 1999).

Table 5.2: Parasitic load enumeration based on farm location, farm practice, age, sex and medical status of pigs from selected farms in the central Free State

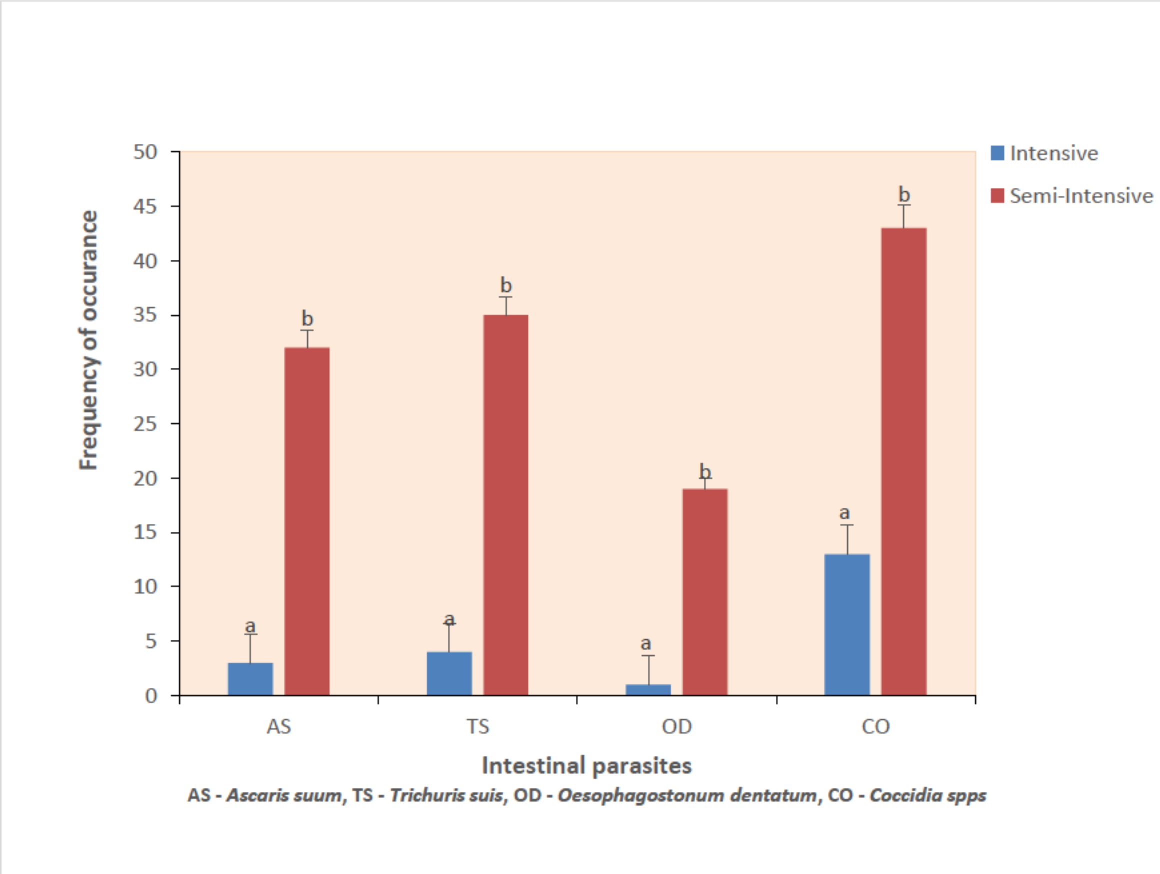
Variable	Category	No of samples (N)	Parasitic load		*Ascaris suum*		*Trichuris suis*		*Oesophagostonum dentatum*		*Coccidia spps*	
			n	%	n	%	n	%	n	%	n	%
Farm location	Bloemfontein	37	31	83.8	14	37.8	20	54.1	10	27.0	27	73.0
	Botshabelo	11	10	91.0	6	54.5	8	72.7	4	36.4	10	90.9
	Thaba Nchu	11	8	72.7	4	36.4	4	36.4	0	0	7	63.6
	Manguang	18	12	66.7	11	61.1	7	38.9	6	33.3	12	66.7
	P-value	-	0.001	-	0.067	-	0.002	-	0.247	-	0.001	-
Farm practice system	Intensive	26	19	73.1	3	11.5	4	15.4	1	3.8	13	50.0
	Semi-intensive	51	42	82.4	32	62.7	35	68.6	19	37.3	43	84.3
	P-value	-	0.003	-	0.001	-	0.001	-	0.001	-	0.001	-
Age	Piglets	25	22	88.0	5	20.0	6	24.0	2	8.0	22	88.0
	Growers	36	28	77.8	23	63.9	23	63.9	11	30.6	27	75.0
	Adults	16	11	68.8	7	43.8	10	62.5	7	43.8	7	43.8
	P-value	-	0.026	-	0.001	-	0.002	-	0.047	-	0.003	-
Sex	Male	32	22	68.8	14	43.8	17	53.1	7	21.9	19	59.4
	Female	45	39	86.7	21	46.7	22	48.9	13	28.9	37	82.2
	P-value	-	0.015	-	0.237	-	0.423	-	0.180	-	0.016	-
Medical status	De-wormed	24	15	62.5	5	20.8	5	20.8	2	8.3	12	50.0
	Not de-wormed	53	46	86.8	30	56.6	34	64.2	18	34.0	44	83.0
	P-value	-	0.001	-	0.001	-	0.001	-	0.001	-	0.001	-

N = number of animals sampled, n = number of infected animals, $p<0.05$.
Piglets (0-3 months), Growers (3-7 months), Adults (7+ months).

5.3.3 EFFECT OF FARM TYPES ON THE PREVALENCE OF INTESTINAL PARASITES

The data revealed that the intensive and semi-intensive management systems recorded divergent prevalence rates for intestinal parasites (Table 5.2). Although the data in this table show that the percentages are close, a significant difference (P<0.05) was found in the rate of parasitic infection between the two farm types, with 73.1 % and a prevalence of 82.4 % for the intensive and semi-intensive systems respectively. This close difference in prevalence could be linked to the poor sanitary and bio-security measures that were observed on both farm types. Also, pigs raised intensively were sometimes allowed to forage outside in times of feed scarcity or to alleviate their hunger during dry seasons. This must have exposed them to almost the same kind of intestinal parasites and the intensity of infection as the free rangers. This may account for the similar results in this category compared with reports from Homabay district, Kenya (Obonyo *et al*., 2012); Busia District, Kenya (Kagira, 2010); Uganda (Nissen *et al*., 2011) and in Ghana (Permin *et al*.,1999), where a prevalence of 83 %, 84.2 %, 91 % and 91 % was obtained respectively for scavenging, free range or extensively raised pigs. Higher rates of 93 %, 95.9 % and 97 % were also reported in Burkina Faso (Tamboura *et al*., 2006), China (Boes *et al*., 2000) and in Nigeria (Ajayi *et al*., 1988) respectively. However, some studies reported lower incidences of intestinal parasites in outdoor pigs such as 52 % in Botswana (Nsoso *et al*., 2000) and 58.7 % in Zimbabwe (Marufu *et al*., 2008).

The semi-intensive farms had a higher incidence of all four intestinal parasites when compared with the intensive type farms as depicted in Figure 5.2. This finding supports previous reports such as the one by Liu and Lu (2002) who stated that the gastrointestinal parasite burden of intensively managed pigs is usually lower. *Coccidia spp* was the most prevalent infection (84.3 %), followed by *Trichuris suis, Ascaris suum* and *Oesophagostomum dentatum* at 68.6 %, 62.7 % and 37.3 % respectively. There were thus significant differences (*P*<0.05) for all parasitic infections. Outdoor pigs generally experience poor sanitary, management and husbandry practices which predispose them more to helminths and other internal/external parasites than their indoor counterparts that are exposed to better husbandry practices (Roepstorff and Nansen, 1998). Eijck and Borgsteede (2005) also agreed that the rate of helminth infections on piggery farms where pigs access the outdoors is higher than in pigs that are raised on conventional farms.



Means with different superscripts [ab] are significantly different (*P*<0.05).

Figure 5.2: Frequency of isolation of intestinal parasites based on farm practice systems

5.3.4 EFFECT OF AGE ON THE PREVALENCE OF INTESTINAL PARASITES

This study detected the highest prevalence of intestinal parasites in piglets (88 %), while adult pigs recorded the lowest prevalence (68.8 %) (Table 5.2). In the Homabay district, Kenya, Obonyo *et al.* (2012) also noted that the lowest prevalence of helminth infections (79 %) occurred in adult pigs, unlike Jufare *et al.* (2015) in Ethiopia, who reported the lowest prevalence of 19.9 % in piglets. Similarly, Bugg *et al.* (1999) in Western Australia; Tiwari *et al.* (2009) in Grenada, West Indies; Lai *et al.* (2011) in Chongqing, China and Sowemimo *et al.* (2012) in Ibadan, Nigeria, reported the highest prevalence in piglets. Other reports disagree with the findings of the current study by observing that the highest prevalence of intestinal helminths occurred among growers and/or adult pigs (Roepstorff *et al.*, 1998; Nsoso *et al.*, 2000; Dutta *et al.*, 2005; Dey *et al.*, 2014) in Nordic countries, Botswana, India and Bangladesh respectively.

The current study found that age had a significant influence (P<0.05) on the prevalence of intestinal parasites.

Coccidia species were the most prevalent (88 %) parasite recovered from piglets, while *Oesophagostonum dentatum* recorded the lowest rate (8 %) also recovered from piglets. Coccidiosis in piglets is one of the major causes of piglet diarrhea and poor performance and predisposes them to opportunistic infections (Stuart *et al*. 1982; Lindsay *et al*., 1992; Koudela and Vítovec 1998). *Ascaris suum* and *Trichuris suis* were the most prevalent helminths identified at 63.9 % in grower pigs. Piglets had the lowest prevalence of *T. suis* infection (24 %) which was similar to a finding by Mercy *et al*. (1989) who reported a 25 % prevalence in Australia, but it was in contrast to a finding by Nsonso *et al*. (2000), who noted a 0 % prevalence in adult pigs for *T. suis* in Botswana. *Trichuris suis* infection is zoonotic (Leman *et al.* 1986) and is therefore a public health concern.

Moderate infections (43.8 %) with *A. suum* were observed in adult pigs. According to Polley and Mostert (1980) and Leman *et al.* (1986), the cause of "milk spot" liver in growing pigs is due to the larval migration of *A. suum*. Polley and Mostert (1980) found that a reduction in weight of up to 40 % occurred in pigs infected with *A. suum* and a reduction of up to 25 % occurred in feed conversion efficiency. The eggs can withstand adverse weather conditions and some chemicals, and may remain viable and infective for extended periods (Roepstorff and Nansen, 1998). In the current study, there were significant differences (*P*<0.05) in the prevalence of the individual parasites identified across all age groups.

The highest rate of infection was observed in Bloemfontein among growers while the lowest prevalence of intestinal parasites among piglets and adults alike were recorded in Thaba Nchu (Figure 5.3). These variations could probably be due to the relatively low number of samples collected, the parasitic life cycle, quality of husbandry practices, and the diverse nature of the health status of the sampled pigs. Production losses, unthriftness, inappetence lethargy, predisposition to diseases and pathogens and death in severe cases are some of the eventual consequences of these parasitic infections (Gibbens *et al*., 1989; Bernardo *et al*., 1990; Stewart and Hoyt, 2006).

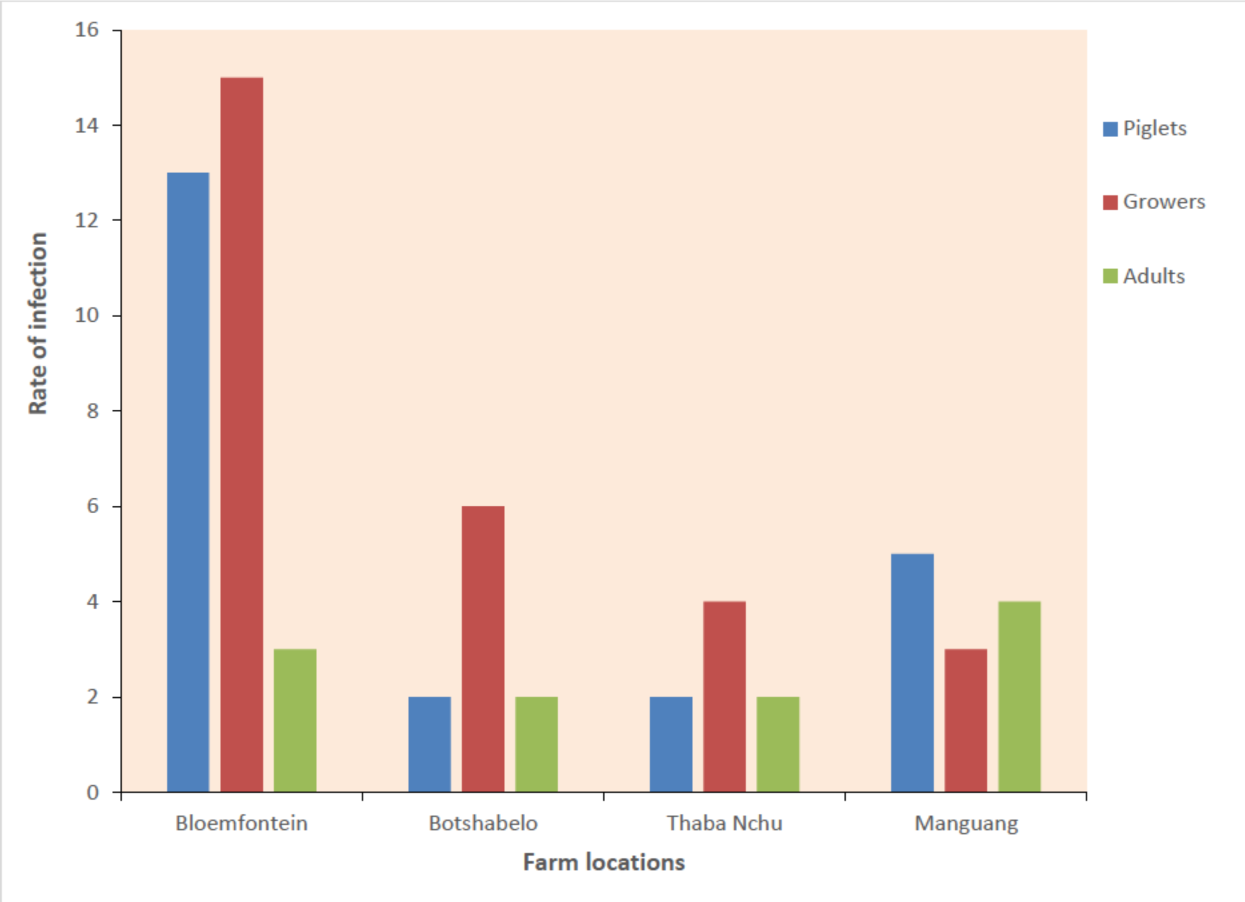


Figure 5.3: Intestinal parasitic infection rates of piglets, growers and adult pigs per farm location

5.3.5 EFFECT OF SEX ON THE PREVALENCE OF INTESTINAL PARASITES

The overall prevalence of intestinal parasites in this study was higher in females (86.7 %) than in males (68.8 %) (Table 5.2). However, both sexes were infected with each of the parasites that were identified in this study. Recent reports by Dey *et al*. (2014) and Jufare *et al*. (2015) respectively confirmed higher parasitic prevalence in female pigs than in male pigs in Bangladesh and Ethiopia. Also, studies in Burkina Faso (Tamboura *et al*. 2006), Nigeria (Opara *et al*., 2006) and Kenya (Obonyo *et al*., 2012) concurred that females shed significantly more helminth eggs than males, but these studies disagreed with Kagira (2010) and Sowemino *et al*. (2012) who reported a higher parasitic prevalence in male pigs in Kenya and Nigeria respectively. Conversely, an earlier report by Yadov and Tandon (1989) observed no significant difference in parasitic infestation between male and female pigs.

The more prevalent trend (Figure 5.4) of higher parasitism in females than in males may be attributed to factors such as hormonal imbalance, gravidity, parturition, lactation, and stress, all of which generally alter the physiologic state of female pigs which leads to supressed immunity and a predisposition to pathogens (Lloyd, 1983; Kusiluka and Kambarage, 1996; Swai *et al.,* 2010). Furthermore, a significant difference (*P*<0.05) was found between the two genders in terms of overall intestinal parasite infection. Conversely, reports by Nsoso *et al*. (2000) and Dey *et al*. (2014) noted no significance in their investigations in Botswana and Bangladesh respectively. *A. suum, T. suis* and *O. dentatum* each recorded no significant differences (*P*>0.05) in prevalence among the sexes. However, there was a significant influence (*P*<0.05) of Coccidia spp on parasitic prevalence.

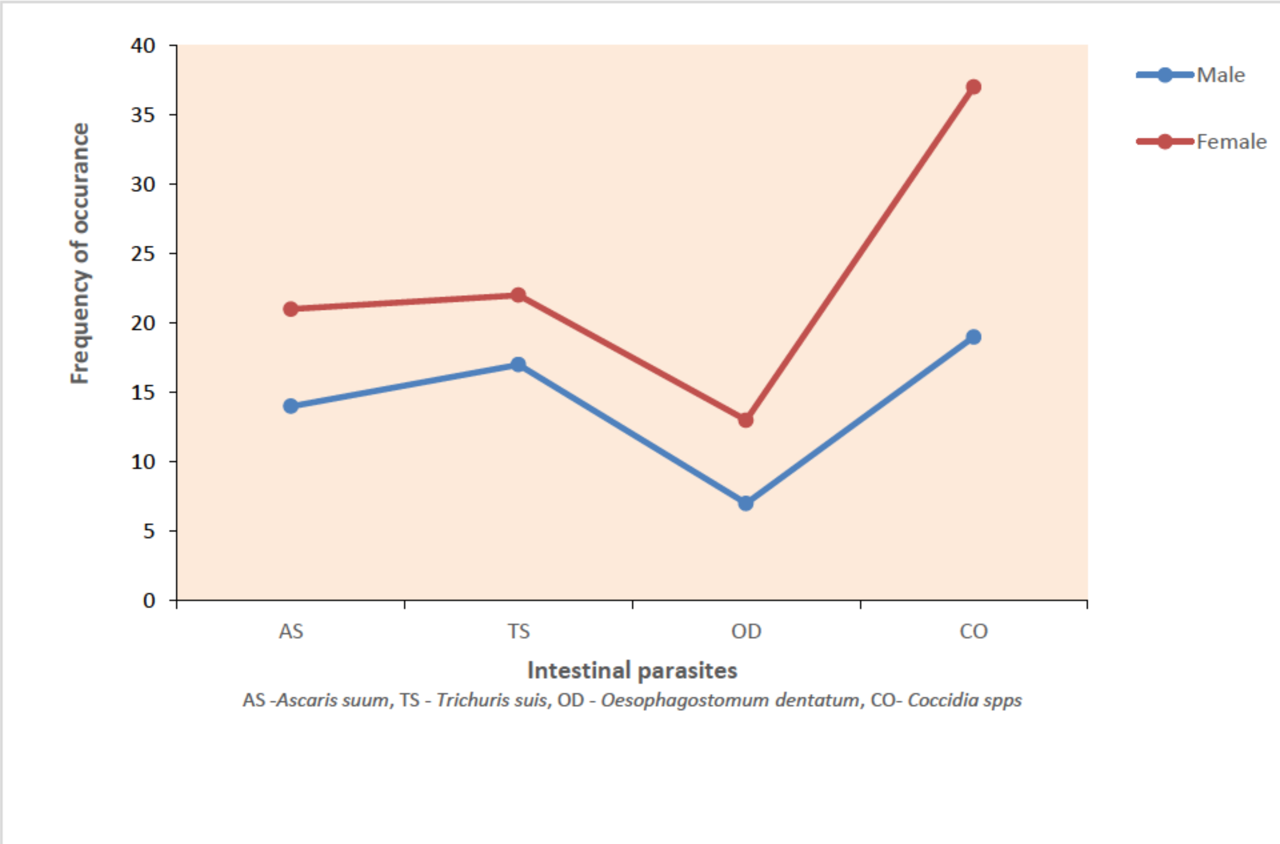
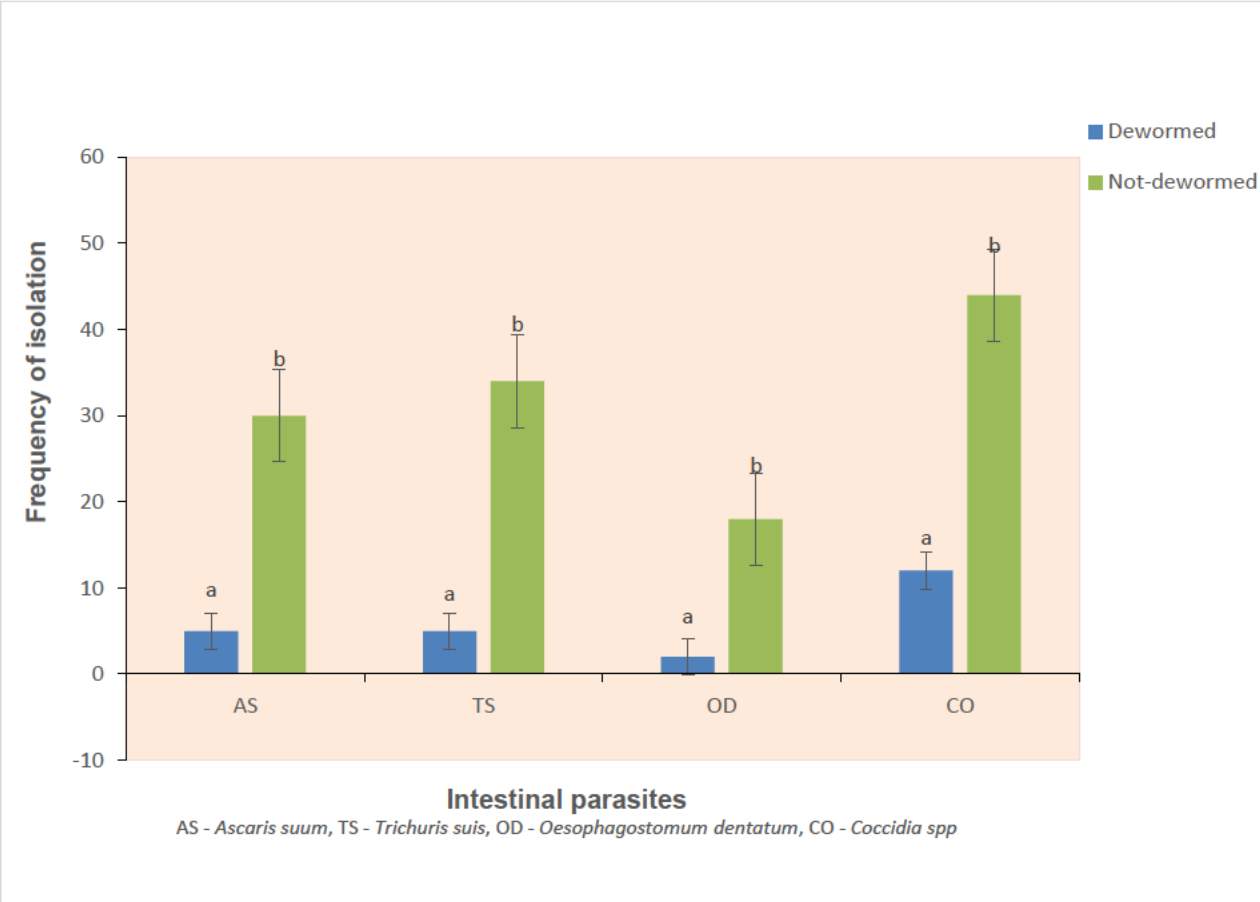


Figure 5.4: Sex related rate of infection of pigs with intestinal parasites

5.3.6 EFFECT OF MEDICAL STATUS ON PREVALENCE OF INTESTINAL PARASITES

For this study, 24 samples were collected from already dewormed pigs, while 53 samples came from pigs that had had no anthelmintic administration. Table 5.2 illustrates a higher prevalence of intestinal parasites amongst the pigs that had not been de-wormed (86.8 %) than for the de-wormed group (62.5 %). There was a significant difference (P<0.05) in the overall prevalence of parasites for both groups of pigs. Coccidia spps were the most prevalent parasite in both categories at 50 % for dewormed and 83 % for pigs that had not been dewormed. Poor management and unsanitary conditions in the pig pens on most of the farms that were visited could account for the high rate of Coccidia infection, especially in already medicated pigs. There was thus a significant difference (P<0.05) in the prevalence of intestinal parasites based on the medical status of the pigs (Figure 5.5). *Oesophagostomum dentatum* had the lowest parasitic prevalence at 8.3 %.



Means with different superscripts [ab] are significantly different (*P*<0.05).

Figure 5.5: Medical status of pigs and infection rate

The farmers who had dewormed their pigs indicated that they had used either single or dual types of dewormers at regular intervals. Earlier questionnaire studies showed high levels of illiteracy among smallholder pig farmers in the study area and the majority admitted that they did not make use of the services of veterinarians or trained animal health technicians. This oversight clearly resulted to maladministration of these anthelmintics. The issue of misuse of anthelmintics plays an important role in the perpetuation of these parasites which results in the eventual resistance of these nematodes to anthelmintics. Earlier studies detected resistance to pyrantel, levamisole and benzimidazoles in Oesophagostumum spp in pigs (Roepstorff *et al.*,1987; Bjørn *et al*., 1996; Gerwert *et al*., 2002). According to an earlier questionnaire-based study, most of the farmers had never taken faecal samples of their sick pigs for laboratory investigation. Van Wyk *et al*. (1999) observed that most resource-poor farmers in their study area had little or no consideration for these parasites, probably due to their internal location in the host and their minute size. Many farmers also appeared to be unaware of the existence of internal parasites and their treatment was therefore given low priority (Vatta and Lindberg, 2006). Also, unhygienic conditions such as those seen on most of the farms will aid the proliferation of internal parasites even among the dewormed pigs. Perry *et al*. (2002) reported that gastrointestinal parasitism emerges as the highest global index for animal health constraint to the poor. Tiwari *et al*. (2009) noted that despite the use of anthelmintics, parasites were still a big problem in Grenada, West Indies. The result of these parasitic infections in pigs may include reduced growth rate due to inefficient feed conversion, inappetence, reduced immunity, and in some severe cases may result in death (Stewart and Hoyt, 2006). Unfortunately, there are no published data on the rate of anthelmintic resistance in pig helminths in South Africa, except for reports of anthelmintic resistance among small ruminants which was described as "the worst globally" (Van Wyk *et al*., 1999; Vatta *et al*., 2001; Bakunzi, 2003). In addition, Prichard (1994) argues that anthelmintic resistance is likely to develop where anthelmintics are frequently used. Some clinical signs of emaciation, diarrhoea, lethargy and inappetence were exhibited by some pigs during this survey.

5.3.7 THE INTENSITY OF PARASITIC EGGS (EPG/OPG) RECOVERED FROM FAECAL SAMPLES

Pigs in this study excreted mostly low (EPG≤100) to moderate (EPG>100<500) levels of helminth eggs in all the farm areas (Table 5.3). However, few samples in Bloemfontein exhibited high levels (EPG≥500) of *Ascaris suum* and *Trichuris suis* eggs. There were no eggs recovered for *Oesophagostomum dentatum* in Thaba Nchu. Coccidia oocytes infected eggs that were recovered were high (OPG>500) in all the farm areas, except in Thaba Nchu where moderate (OPG>100≤500) infection intensity was recorded. This could be because of the unsanitary conditions experienced on most farms in the study area. The result of this study correlated with earlier reports from Ghana by Permin *et al*. (1999) and Burkina Faso by Tamboura *et al*. (2012), who respectively experienced a high overall prevalence of nematode infections without a corresponding high incidence in EPG. However, the experiments by Nsoso *et al*. (2000) in Botswana did not correlate with these results.

Table 5.3: The Intensity of intestinal parasite infection in pigs from selected farms in the central Free State

Farm area	Intensity of Infection (EPG/OPG)			
	Ascaris suum	***Trichuris suis***	***Oesophagostomum dentatum***	***Coccidia spps***
Bloemfontein	+++	+++	+	+++
Botshabelo	+	++	+	+++
Thaba Nchu	+	++	-	++
Manguang	++	+	+	+++

- = No observed infection
+ = Low infestation [EPG (Egg Per Gram) ≤100]
++ = Moderate infestation [EPG>100<500]
+++ = High infestation [EPG≥500]
For Coccidia species, ++ = Moderate infestation [OPG (Oocyte per Gram) >100≤500]
+++ = High infestation [OPG >500]

It is possible that the low to moderate intensity of excreted helminth eggs could indicate false negative results due to pre-patent periods of the immature worms or sub-clinical infections in the sampled pigs. Adebisi (2008) and Marufu *et al*. (2008) argued that sub-clinical infections are the most significant form of infection, as it gives rise to low productivity of livestock and huge economic losses. Low productivity due to poor feed conversion, piglet mortality, unthrifness and unprofitable piggery enterprises due to very low levels of economic returns were experienced in the study region. Hence, helminthiasis could be a contributing factor associated with the above challenges that are faced by smallholding farmers. Some scientists have noted that there is the possibility of developing immunity against helminth infections when pigs have been exposed to these nematodes for an extended period of time, thus an underestimation of the actual prevalence of these infections may occur (Nansen and Roepstorff, 1999; Obonyo *et al.*, 2012). Also, immunity can be passively passed on to the offspring of the sow (Murrell, 1981; Eriksen *et al*.,1992). Due to this acquired host immunity, the fecundity of the female worm is reduced, resulting in lower egg numbers in the faeces. Thienpont *et al.* (1995) further suggested that egg excretion can stop indefinitely in proportion to the increase in host resistance.

Weather conditions could also give rise to this pattern of intensity. There had been very little rain before the samples were collected due to the drought and the resultant low levels of precipitation that South Africa was experiencing at the time of the study. The dry environmental conditions may thus not have favoured the development and proliferation of helminth eggs in the experimental animals, as is posited by Tamboura *et al*. (2012). The number of samples that were analysed and the season of collection may also have contributed to the low to moderate EPG intensities despite the high prevalence of intestinal helminths.

5.3.8 OCCURRENCE OF MIXED PARASITIC INFECTIONS IN PIGS

This survey identified four intestinal parasites of veterinary importance, namely *A. suum, T. suis, O. dentatum,* and *Coccidia spps.* Eleven different associations of these identified parasites were observed, ranging from double to triple parasitic mixed infections (Figure 5.6). This finding was similar to that of an earlier report from Denmark by Roepstorff and Jorsal (1989), and it also corroborated the findings of later studies in Burkina Faso (Tamboura *et al*., 2006), Nigeria (Sowemimo *et al*., 2012) and Ethiopia (Jufare *et al*., 2015). These latter three studies identified multiple (double-quadruple) mixed associations of intestinal parasites, thereby confirming the occurrence of polyparasitism in pigs that are exposed to the outdoors. Bloemfontein recorded the highest association of *T, suis* + *Coccidia* while the mixed infection with *O. dentatum* + *A. suum* + *Coccidia* was recorded only in Botshabelo.

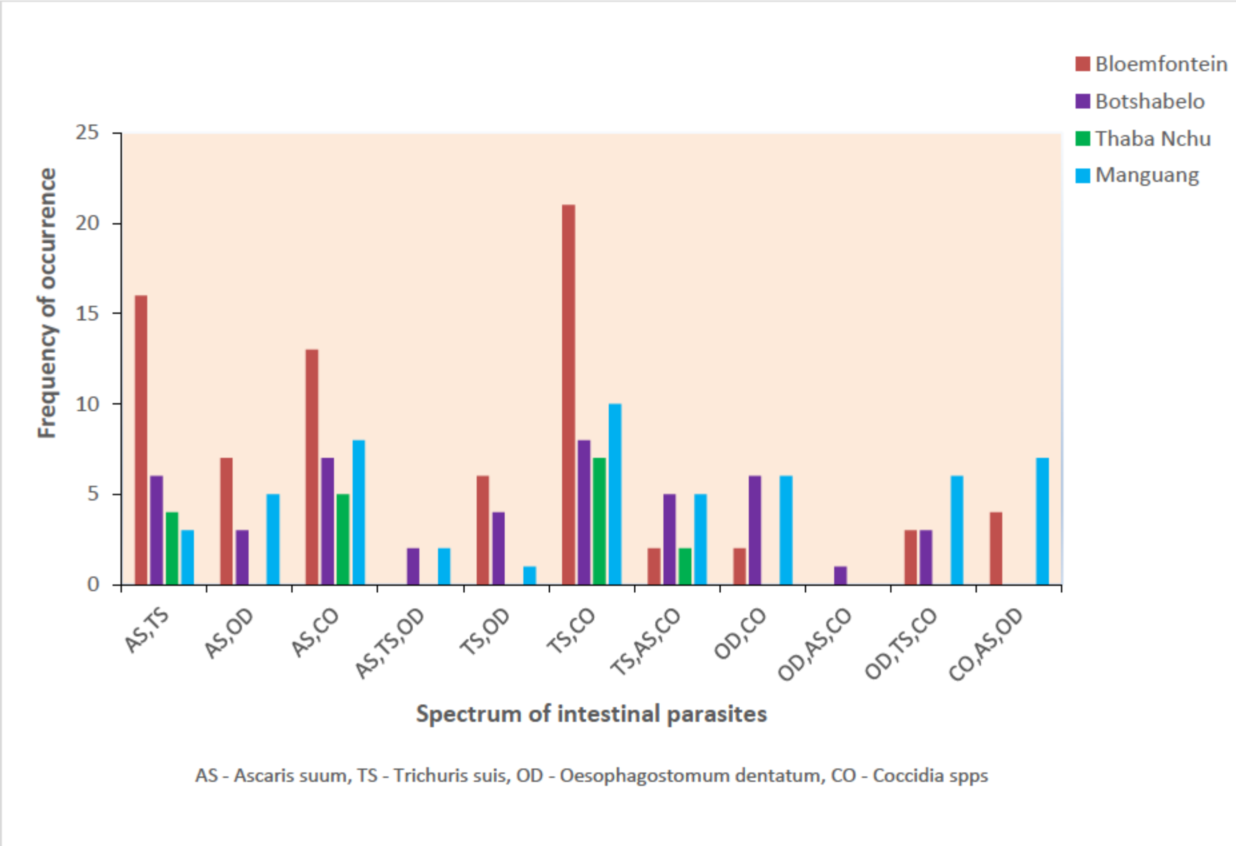


Figure 5.6: Mixed spectrum of intestinal parasites in faecal samples from selected farms in the central Free State

5.4 CONCLUSION

It is now known that different species of internal parasites are present in some pigs reared by smallholder farmers in the study area. Outdoor pigs are more susceptible to these parasites than their indoor counterparts. The risk factors for contracting some of the identified parasites are age, sex, management system, and geographical location. Some of these helminths may be zoonotic, which poses a danger to the farmer, his family, abattoir and farm workers who handle these pigs as well as the public who may consume their meat. It is undeniable that helminthiasis is a public health issue. Problems associated with production, economic losses, a high piglet mortality rate, poor animal welfare and a high rate of collapsed piggery enterprises are issues of concern. The use of anthelmintics should be monitored by trained personnel who should be quick to identify any form of anthemnintic resistance by conducting periodic helminth surveillance on a representative number of pigs on smallholder farms. Farmers should also be taught about and assisted in the administration of these medications because some farmers have low literary levels. The effective use of anthelmintics should be coupled with good farm hygiene, well-balanced nutrition, demarcation of the pig farm area that separates it from other animals on the farm, reduction of traffic on the farm, increasing biosecurity measures, and control of pests and rodents to reduce mechanical transmission of oocytes. Farmers should also adhere to appropriate stocking densities to limit the incidence of body contact infection. Good quality pig stalls and pens that can be easily cleaned should receive attention. Further in-depth studies that will survey parasitic infections during all four seasons using larger sample populations are required to ascertain the levels of helminth contamination on smallholder farms in this province, which will lead to appropriate solutions. Every effort should be made to ensure that smallholder pig farmers get higher returns for production and that the safety and wholesomeness of the pork that they produce are guaranteed for the consumer.

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CHAPTER 6

POST-MORTEM PREVALENCE OF INTESTINAL HELMINTHS IN PIGS FROM SELECTED ABATTOIRS IN THE CENTRAL FREE STATE PROVINCE

6.1 INTRODUCTION

Gastro-intestinal helminths are a major cause of diseases that impact farming systems worldwide. The prevalence of these parasites is known to be influenced by the type of pig management system that the farmer practises. Systems such as free range (Eijck and Borgsteede, 2005; Opara *et al*., 2006), organic (Eijck and Borgsteede, 2005; Kagira *et al*., 2010), extensive (Nansen and Roepstorff, 1999) and semi-extensive (Nwafor *et al*., 2018), coupled with poor environmental hygiene have been some of the identified challenges that contribute to the prevalence of parasitic infections in pigs. Additionally, roaming pigs, warm and humid tropical/sub-tropical conditions favouring the proliferation of parasites (Blood *et al.,* 2007; Aiello and Moses, 2010) and the poor medical attention usually given to local pigs invariably cause them to carry heavy worm burdens (Roepstorff and Nansen, 1998; Mashatise *et al*., 2005). In the tropical and sub-tropical areas of the world, infections in pigs caused by parasites are estimated to be second in severity to African swine fever (ASF) (Permin *et al*., 1999). These infections are a major cause of ill-thrift and production losses in both the commercial and the smallholder farming sector and affect the entire spectre of livestock species (Joachim and Daugschies, 2000; Nsoso *et al.,* 2000; Boes *et al*., 2000; Fenwick, 2012). Intestinal parasites can have a substantial influence on poor output in piggery businesses (Gibbens *et al*., 1989) and cause significant economic losses through reduced weight gain, poor growth rate, decreased litter sizes (Pattison *et al*., 1980; Taylor, 1999), organ condemnation at slaughter (Nsoso *et al*., 2000), carcass rejection during meat inspection, pre-mature slaughter (Gillespie, 1992; Pattison *et al*., 1980) and death (Nsoso *et al*., 2000; Marufu *et al*., 2008). Also, some of these intestinal helminths in pigs are zoonotic and can infect man, thus making helminthiasis a public health threat (Morgan *et al*., 1999; Tomass *et al*., 2013). This problem often stems from situations of inadequate or non-existing meat inspection of slaughtered animals.

Among the helminths that affect domesticated pigs, *Ascaris suum,* Oesophagostomum spp. *Trichuris suis, Hyostrongylus rubidus, Strongyloides ransomi, Metastrongylus* spp., *Stephanurus dentatus* (Nansen and Roepstorff,1999); *Trichinella* and Strongyles spps (Nganga *et al*., 2008) have been identigfied as the most common helminths of veterinary importance. An earlier abattoir investigation by Gibbens *et al*. (1989) identified several helminths in slaughtered pigs in Belize. These included *Oesophagostomum* spp. (most prevalent)*, Hyostrongylus rubidus*, *Physocephalus sexalutus*, *Globocephalus* spp., *Trichostrongylus colubriformis*, *Ascalops strongylina*, *Ascaris suum, Macracanthrynchus hirudinaceus*, *Strongyloides ransomi* and *Trichuris suis.* Also, Polley and Mostert (1980) reported that, of the 2,500 pigs that were sampled in different abattoirs in Canada, 46 % had milk-spot liver lesions and mature or immature *Ascaris suum* were recovered from 37 % of the sampled population. Some later reports concurred with earlier investigations on the prevalence of helminths in slaughtered pigs. Tamboura *et al*. (2006) identified *H. rubidus* infestation in scavenging pigs that had been slaughtered in an abattoir in Burkina Faso. Eyo *et al*. (2014) identified *Strongyloides ransomi* (most prevalent) and *Ascaris suum* in large white pigs in an abattoir in Nigeria. Elsewhere in Nigeria, Okoroafor *et al*. (2014) found *Oesophagostomum dentatum, Trichuris suis* and *Metastrongylus saline* in abattoir pigs. Similarly, Dey *et al*. (2014) recovered *A. suum, T. suis* and *F. buski* from visceral samples of slaughtered pigs in Bangladesh.

In South Africa, consumption of pork has increased over the past decade by 53 % (SAPPO, 2013) and by an annual average of 4.5 % in response to increased demand (BFAP, 2013). Earlier, Krecek *et al*. (2004) reported that 25 % of pigs produced in resource-poor areas in South Africa were free ranging. In general, pigs are reared in these areas mostly because of their contribution to human nutrition, poverty alleviation, food security, enhanced livelihoods and the creation of employment for rural communities (Antwi and Seahlodi, 2011). According to RMAA (2010), abattoirs where pigs are slaughtered in South Africa are usually specialised for this purpose, and of the 485 abattoirs in the country, only 150 slaughter pigs. Earlier, Kirsten *et al*. (2009) stated that 80 % of South African pigs was slaughtered by the 10 largest abattoirs in the country, while Louw *et al*. (2011) later reported that fewer than 20 of these abattoirs slaughtered 98 % of the pigs in South Africa. In 2011, 100,000 to 300,000 pigs were slaughtered in different abattoirs in the Free State (BFAP, 2013), while DAFF (2017) reported that up to 3,009,000 pigs were slaughtered in South Africa between 2015 to 2016 for commercial markets and for own consumption. Grimbeek *et al*. (2016) stated that the average slaughter weight of pigs in South Africa is 78 kg, which is below that of the key pork producers of the world. This suggests that the demand for heavier slaughter pigs is on the increase in the country.

The task to provide wholesome meat products for human consumption from farm-to-fork ends at the slaughterhouses for most food animals (Dupuy *et al*., 2013). This demands appropriate meat inspection (both ante- and post-mortem), periodic disease surveillance in abattoirs, food safety adherence, and control of potential zoonotic infections (Stärk *et al*., 2014; Jaja *et al*., 2016).

There is no available published information detailing the prevalence of gastro-intestinal helminths in abattoirs operating in the Free State Province of South Africa. Therefore, the need to investigate the occurrence of such potential zoonotic helminths in selected abattoirs in this province became imperative. Information generated from this study will form the basis for helminth surveillance and future interventions in pigs reared within the study area and beyond, while promoting food safety and security.

6.2 METHODOLOGY

6.2.1 DESCRIPTION OF STUDY AREA

This study was carried out within Manguang Metropolitan Municipality (MMM) in the central Free State Province (Figure 6.1). This municipality has its capital in Bloemfontein and it is the smallest among other municipalities in the province with an area of 9,886 km^2, a population of 787,803 in 2016 and a population density of 79.7/km^2 (Boundaries, 2016; Community Survey, 2016). It is boardered by Lejweleputswa, Thabo Mofutsanyana and Xhariep district municipalities to the north, northeast and south respectively. The far eastern area is bordered by Lesotho. This municipality is situated within the coordinates 29.1586 ^{0}S and 26.3249 ^{0}E and comprises a geographical area of 6,284 km^2. The area experiences a semi-arid climate with temperatures ranging between 19 ^{0}C to 32 ^{0}C in the summer months and -3 ^{0}C to 14 ^{0}C in the winter months. Annual precipitation varies between 500 to 600 mm. The altitude is 1,395 m (45,776 ft) above sea level (Maphalla and Salman, 2002).

The survey was done in three red meat registered abattoirs located in the study area. The abattoirs were coded BFA, GVA and TNA for confidentiality purposes and ease of reference. One abattoir was high-throughput (Grade B), while the other two were low-throughput abattoirs (Grade D). These abattoirs were selected from the list of operational red meat abattoirs obtained from the Veterinary Laboratory of the Department of Agriculture in Bloemfontein. The selection was based on proximity and ease of accessibility. These abattoirs slaughter pigs and other livestock on specific days of the week. Due to time and financial constraints, each abattoir was visited only three times (once a month) from April to June, 2016 on days designated for pig slaughtering.

Figure 6.1: Map of Manguang Metropolitan Municipality (Source: https://municipalities.co.za)

6.2.2 STUDY ANIMALS

A total of 54 pigs were randomly selected to be examined post mortem at the abattoirs for the presence of intestinal helminths. Every 2nd or 3rd pig (depending on the number of pigs due for slaughter that day) on the slaughter line was selected for sampling. At any given sampling day, the selected pigs were mostly from the same farm, or in situations where there was a small number of pigs from a particular farm, pigs brought for slaughter from other farms were also sampled. Pigs of the Large White, Landrace, Duroc and their crosses, with average live weights of 78 kg and older than 6 months, were sampled. Of the 54 pigs, 35 were males and 19 were female. The majority of pigs (n=47) had been intensively managed, while others (n=7) were from semi-intensive farms. Farm location, breed, age, weight and the medical status of the selected pigs were not cosidered for the purpose of this study. It should be noted that most (46, i.e., 85 %) of the sampled pigs were from already established commercial pig farms or factory farms. Most smallholder pig farmers in this study area do not send their pigs to the abattoirs for slaughter due to high cost, distance to the abattoirs, fear of carcass condemnation and a very small number of pigs ready for slaughter (Earlier investigation by researcher).

6.2.3 SAMPLE COLLECTION AND HANDLING

Pigs were stunned with electric tongs, hoisted on rails and their throats slit and bled according to relevant regulations. Thereafter, the carcasses were washed, immersed in a scalding tank and dehaired. Evisceration was done and the gastro-intestinal tract (GIT) was carefully pulled out from the carcass into a large basin for post mortem inspection. With the help of a veterinary technician, the GIT parts (stomach, small and large intestines) were identified and a pair of scissors was used to severe the portions needed for examination. The parts were cut open and emptied into a sterile plastic bag while being examined for visible worms. If present, the mature and/or immature worms were put in 70 % alcohol and sent to the laboratory to be identified. Three samples of GIT contents were collected from each pig, resulting in a total of 162 samples from 54 pigs. The samples were labelled appropriately, cooled to 4 ^{0}C in a cooler box (to prevent eggs developing and hatching) and sent to the laboratory for analysis. The liver surfaces were examined physically for milk spot lesions and for other morphological irregularities. No incision or laboratory examination was done on the livers.

6.2.4 LABORTORY ANALYSIS

The GIT contents were analysed in the parasitology section of the Provincial Veterinary Laboratory of the Department of Agriculture, Bloemfontein. Samples were either analysed on the day of collection or refrigerated at 4 ^{0}C for up to three days before processing. The McMaster counting technique was used to determine the faecal egg count (FEC) per gram of faeces. This technique is used to demonstrate and provide a quantitative estimate of faecal egg output for helminths and coccidia. The sedimentation technique as described by Wentzel and Vermeulen (2003) for the operating procedure at the Veterinary Laboratory, Bloemfontein was done in suspected cases of trematode eggs. Larvae and adult worms present in the GIT contents were identified based on their morphological structures. The identification and quantification procedures were based on the procedures of Soulsby (1982), the OIE Manual of standards for diagnostic tests and vaccines, (1996) and the operating procedure of the Veterinary Laboratory, Bloemfontein as compiled by Wentzel and Vermeulen (2003).

6.2.4.1 LABORATORY PROCEDURE

For the identification and quantification procedure, each sample was mixed to obtain a homogenous mixture and a quantity of three grams of the GIT digesta was put in an already marked beaker. A quantity of 58 ml of floatation fluid made up of 40 % salt solution was added to the beaker and a glass rod was used to stir and mix the sample properly. The mixture was left to stand for five minutes to allow the eggs to float to the surface. Thereafter, a Pasteur pipette was used to extract aliquots from the faecal mixture to fill the two chambers of the McMaster slide. This was left to settle and stand for about three minutes. The McMaster slide was examined under 10 x 10 magnification compound microscope and if eggs were present, they were identified based on a combination of key structural and morphometric features. The EPG (egg per gram) was quantified by counting all the helminth eggs present within the engraved areas of both McMaster chambers and the total as multiplied by 50. With some modifications, EPG≤100 was grouped as low levels of infection, EPG>100<500 was regarded as moderate infestation, while EPG ≥500 was grouped as significant high levels. The Baermann technique (Permin *et al*., 1999) was used to differentiate between the Strongyle-type nematode eggs. Appropriate hygiene and safety procedures were adhered to at all times.

6.2.5 STATISTICAL ANALYSIS

The collected data were entered into a Microsoft^R Excel version 2016 spreadsheet and coded. Thereafter, the data were exported to IBM SPSS (Statistical Package for Social Sciences) version 22 for statistical analyses. Descriptive analyses and pictorial representations were computed using the statistical package and Excel workstations. Relationships between the helminthic load in slaughtered pigs and other risk factors such as sex and farm type were tested using the chi-square test. The level of significance was set at $P<0.05$. The prevalence of each specie of intestinal helminth was calculated as the ratio between the number of infected animals (n) and the number of animals sampled (N). Thus:

$P = n/N X100$;

where P = prevalence, n = no. of infected animals and N = no. of animals sampled per grouping.

6.3 RESULTS AND DISCUSSION

Below are the results of this phase of the study with the relevant discussions for each section.

6.3.1 OVERALL POST-MORTEM PREVALENCE OF INTESTINAL HELMINTHS RECOVERED FROM PIGS

In total, the contents of 162 samples of gastrointestinal tract were collected from 54 pigs for laboratory analyses from three abattoirs in the central Free State Province. Risk factors such as sex and management system were considered. It was found that there was a 29.6 % prevalence of intestinal helminths, either as single or mixed infections in the slaughtered pigs as detailed in Table 6.1. Four nematode species and a trematode specie were identified. The recovered nematodes were *Ascaris suum*, *Trichuris suis* and two species of the strongylids, namely *Oesophagostomum dentatum* and *Hyostrongylus rubidus*. The trematode identified was a specie of *Fasciola*.

A. suum recorded the highest prevalence at 16.7 %. A lower prevalence of 11.1 % was recorded for *both T. suis* and *O. dentatum*, while much lower prevalences of 9.3 % and 5.6 % were recorded for *H. rubidus* and *Fasciola hepatica* respectively. The overall finding of a 29.6 % prevalence of intestinal helminths obtained in this study was similar to an abattoir survey that was conducted in Nigeria by Okoroafor *et al*. (2014), who reported a 32.7 % prevalence of gastrointestinal parasites in slaughtered pigs. However, higher helminth infection rates of 61.8 %, 79 %, 86.7 % and 91 % were previously recorded for slaughtered pigs in Ethiopia, Tanzania, Kenya and Burkina Faso by Geresu *et al.* (2015), Nonga and Paulo (2015), Obonyo *et al*. (2012) and Tamboura *et al*. (2006) respectively. A slightly higher infection rate of 53 % was also reported by Esrony *et al*. (1997) in Tanzania and a much lower infection rate of 13.2 % was reported in Ethiopia by Marufu *et al*. (2008). Factors that may have contributed to the moderate prevalence of GIT helminths in the latter study could have been effective farm management practices for anthelmintic administration, a small sample size, pig breed, or seasonal and geographical variations.

Table 6.1: Overall prevalence of intestinal helminths in slaughtered pigs

Description	Number of sampled animals	Number of positive samples	Prevalence (%)
Gastro-intestinal Tract	54	16	29.6
Helminths			
Ascaris suum	54	9	16.7
Trichuris suis	54	6	11.1
Oesophagostomum dentatum	54	6	11.1
Hyostrongylus rubidus	54	5	9.3
Fasciola hepatica	54	3	5.6

A. suum was the most prevalent helminth recovered in this study (Table 6.1). Tamboura *et al*. (2006), Ngowi *et al*. (2004) and Kumar *et al.* (2002) reported *A. suum* to be the most recovered helminth in their investigations. The infection rate (16.7 %) of *A. suum* in this study was slightly similar to the 12.6 %, 12.7 %, 17.6 % and 18.5 % reported by Geresu *et al.* (2015), Tiwari *et al*. (2009), Ismail *et al.* (2010) and Agumah *et al*. (2015) in Ethiopia, Ghana, Korea and Nigeria respectively. However, lower rates of *A. suum* were reported in Turkey (3.7 %) and Ethiopia (4.9 %) by Uysal *et al.* (2009) and Jufare *et al*. (2015) respectively. Nsonso *et al*. (2000) also recorded a high rate of *A. suum* infection of 54.6 % in Botswana. The high resistance of *A. suum* eggs to environmental factors and harsh conditions, coupled with farm management practices, could have been responsible for the highest prevalence of helminths recorded in this study. It was noted that Kagira (2010) and Obonyo *et al.* (2012) argued that perpetual wet farm conditions, unhygienic environments and favourable temperatures can lead to high infection rates of *A. suum*.

Trichuris suis and *Oesophagostomum dentatum* both recorded a prevalence of 11.1 % in this study (Table 6.1). Other studies also reported the presence of similar species of intestinal helminths. Gereu *et al*. (2015) reported a slightly similar rate of 6.9 % for *T. suis* in Ethiopia, while much lower rates of 0.3 %, 2.9 % and 4.6 % were reported in Northern Ethiopia (Tomass *et al*., 2013), Bishoftu, Ethiopia (Jufare *et al*., 2015) and Ghana (Pernin *et al*., 1999) respectively. A higher prevalence of 38 % for *T. suis* was also reported in Grenada, West Indies by Tiwari *et al*. (2009). For *O. dentatum*, Okoroafor *et al*. (2014) observed a similarly low prevalence of 9.9 % in slaughter pigs in Nigeria. Lower infection rates at 2.5 % and 3.9 % were recorded in China (Weng *et al*., 2005) and in Ethiopia (Geresu *et al*., 2015) respectively, while investigations in two different locations in Kenya recorded a higher prevalence of 39.1 % (Nganga *et al*., 2008) and 40 % (Kagira *et al*., 2002) for *O. dentatum*. Improved farm hygiene, season of survey, proper use and effectiveness of anthelmintics may have contributed to the lower rates of this strongly type nematode that was observed in this study, despite the high survivability of the eggs in the environment.

The red stomach worm (*Hyostrongylus rubidus*) and the liver fluke (*Fasciola hepatica*) were observed at a prevalence of 9.3 % and 5.6 % respectively in this study (Table 6.1). A higher prevalence of 40 % was reported for *H. rubidus* by Obonyo *et al.* (2012) in an abattoir survey in Kenya. As the only trematode observed in this study, *Fasciola hepatica* was reported at different infection rates of 11.8 %, 9.3 % and 2.8 % in Ethiopia (Geresu *et al.,* 2015), Nigeria (Bernard *et al*., 2015) and Northern Ethiopia (Tomass *et al*., 2013) respectively. Outdoor pigs are more likely to come in contact with the intermediate host of *F. hepatica,* which may contribute to the infection. According to Mas-Coma *et al*. (2005), *F. hepatica* has the ability to adapt and colonise new species, which can also lead to its spread. The aforementioned helminths (*Hyostrongylus rubidus* and *Fasciola hepatica*) were not found in an earlier coprological survey to detect the presence of intestinal parasites in smallholder pigs in the central Free State Province. According to Roepstorff and Nansen (1998), Permin *et al*. (1999) and Nganga *et al*. (2008), the lower sensitivity of faecal examinations when compared to post-mortem investigations may have prevented the detection of these helminths in earlier pre-mortem studies.

6.3.2 PREDILECTION SITES AND THE GIT HELMINTHS RECOVERED

Table 6.2 illustrates a low to very low prevalence of the individual GIT helminths recovered from the different predilection sites in the slaughter pigs examined for this study. The highest total prevalence of helminths was recorded in the large intestine, which is the predilection site for most of the identified helminths at their different stages of development. This finding was in agreement with other post-mortem investigations in Tanzania (Nonga and Paulo, 2015) and Kenya (Obonyo *et al.,* 2012). The higher incidence of helminths recovered in this study may be attributed to the position of the large intestine which is the last part of the GIT and because, by peristalsis, most materials are moved to this part of the tract before voiding. It is also the predilection site for some adult helminths. However, there were low recovery rates of eggs, larvae and adult worms in the stomach as well as in the small and large intestines. The proper use of anthelmintics, coupled with improved farm hygiene for improved conditions as may be observed in some commercial piggeries that make use of the survey abattoirs, may explain this result. Incidentally, no helminth oocytes or larvae were recovered from the stomach and large intestines of the surveyed animals respectively.

Of the 54 animals that were examined, 4(7.4 %) of the livers had faint milk spot lesions that were indicative of *Ascaris suum* larval migration. This result did not concur with a report from a Saskatchewan abattoir in Canada by Polley and Mostert (1980), who observed up to 44 % milk spot livers in 1,102 slaughter pigs. This discrepancy may be due to a smaller sample size that was surveyed in this study. Seasonal, geographical and farm practice differences could also have contrinuted to the diverse finding because all four livers were from semi-intensively managed pigs. The presence of milk spot in the livers could have resulted in liver condemnation during post mortem inspection. However, there were no other identifiable morphological abnormalities in the livers that were suggestive of the presence of the liver fluke trematode.

Table 6.2: Prevalence of GIT helminths in relation to predilection sites and stages of development in slaughtered pigs

Predilection site	Stage of development	Helminth spp	No of infected animals (N=54)	Prevalence (%)
Stomach	Egg	-	-	-
	Larva	*H. rubidus*	4	7.4
		A. suum	3	5.6
	Adult	*H. rubidus*	1	1.9
Small intestine	Egg	*A. suum*	7	12.9
		F. spp	3	5.6
	Larva	*A. suum*	2	3.7
	Adult	*A. suum*	3	5.6
Large intestine	Egg	*A. suum*	4	7.4
		T. suis	5	9.3
		F. spp	1	1.9
		O. dentatum	2	3.7
	Larva	-	-	-
	Adult	*O. dentatum*	3	5.6
		T. suis	3	5.6
Liver	Larval migration	*Milk spots (A. suum)*	4	7.4

6.3.3 POST-MORTEM HELMINTH LOAD ENUMERATION

With reference to the three abattoirs where samples were collected for this study, risk factors such as sex and farm management systems were considered as depicted in Table 6.3 and visually presented in Figure 6.2. TNA had the highest parasitic load at 53.3 %, while GVA recorded the lowest prevalence at 20 %, with BFA having a slightly higher prevalence at 20.7 %. TNA was the only abattoir where samples from semi-intensively managed pigs were collected, which may have accounted fot this output. Pigs under this form of management can forage for food outside their stalls which are areas that are usually characterised by poor hygiene and sanitation. At times, the pigs come in contact with other animals that are kept on the farm. According to Roepstorff and Nansen (1998), outdoor pigs mostly experience poor sanitary, management and husbandry practices which predispose them more readily to helminths and other internal/external parasites than their indoor counterparts with better husbandry practices. Eijck and Borgsteede (2005) agree that the rate of helminth infections on piggery farms where pigs access the outdoors is higher than in pigs on conventional farms.

Sample number and size, prevailing geographical parasites, management practices and season of sampling may also have played a role in the diverse parasitic load observed in samples from the abattoirs.

Table 6.3: Post-mortem helminth load enumeration in slaughtered pigs based on identified variables/risk factors

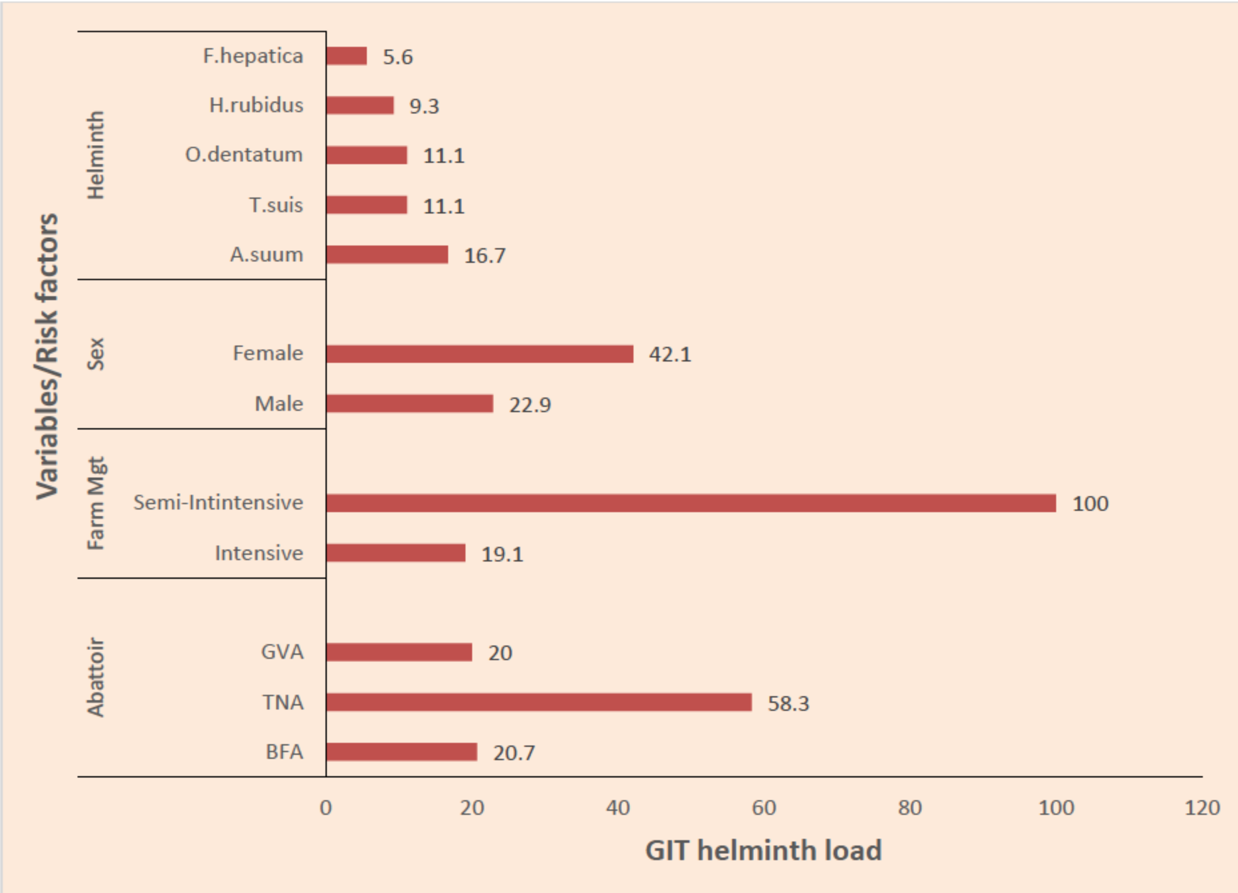
Variable/Risk factor	Category	No of samples (N)	Parasitic load n (%)	χ^2	*P*-value
Abattoir	BFA	29	6(20.7)	3.50	0.174
	TNA	15	8(53.3)		
	GVA	10	2(20.0)		
Farm Management	Intensive	47	9(19.1)	0.25	0.617
	Semi-intensive	7	7(100.0)		
Sex	Male	35	8(22.9)	0.00	1.000
	Female	19	8(42.1)		
Helminths	*Ascaris suum*	54	9(16.7)	3.24	0.518
	Trichuris suis	54	6(11.1)		
	Oesophagostomum dentatum	54	6(11.1)		
	Hyostrongylus rubidus	54	5(9.3)		
	Fasciola hepatica	54	3(5.6)		

N: No. of samples per category
n: No. of infected samples per category

A 100 % helminth prevalence was recorded for the semi-intensive reared pig samples compared to the 19.1 % helminth load that was recorded for intensively reared samples (Figure 6.2). This result compares well with the results from earlier coprologic surveys that were conducted to determine the parasitic load in pigs from smallholder farms. These surveys also reflected a lower parasite burden for intensively managed pigs in comparison to their semi-intensively managed counterparts. Liu and Lu (2002) suggest that the gastrointestinal parasite burden of intensively managed pigs is usually low, and Shima *et al*. (2014) and Eyo *et al*. (2014) concurred that when pigs can roam freely or are raised in unsanitary conditions, helminth build-up and infestation are boosted.

In males, a lower (22.9 %) GIT helminth burden was observed than in females (42.1 %), even though more males were sampled (Figure 6.2). This result is concurrent with a Tanzanian slaughter slab survey, where females were observed to have a higher intestinal helminth prevalence than males (Nonga and Paulo, 2015). Dey *et al*. (2014) and Jufare *et al*. (2015) also observed higher parasitic prevalence in female pigs in Bangladesh and Ethiopia respectively. Likewise, based on their studies in Nigeria (Opara *et al*., 2006), Burkina Faso (Tamboura *et al*., 2006) and Kenya (Obonyo *et al*., 2012), concured that females shed significantly more helminth eggs, but they disagreed with Kagira (2010) and Sowemino *et al*. (2012) who reported a higher parasitic prevalence in male pigs in Kenya and Nigeria respectively. On the other hand, earlier reports by Yadov and Tandon (1989) observed no sex related prevalence of parasites in their investigation. Factors such as hormonal imbalance, gravidity, parturition, lactation, and stress which generally alter the physiologic state of female pigs leading to suppressed immunity and pre-disposition to pathogens (Lloyd, 1983; Kusiluka and Kambarage, 1996; Swai *et al.,* 2010) could explan the higher helminth load that were detected in females.

Amongst the helminths recovered, *Ascaris suum* infection was observed in most of the pigs and had the highest prevalence at 16.7 %, while *Fasciola hepatica* recorded the lowest prevalence at 5.6 % (Figure 6.2). However, there were no statistically significant associations in the number of infected animals across all tested variables/risk factors despite the higher prevalence values recorded in some categories. This result concurs with the results of a similar study that was conducted by Nonga and Paulo (2015) in Arusha, Tanzania, who also found no statistically significant differences among all the tested risk factors. It is thus suggested that a larger sample size, abbatoir sample number and a more extended period of sampling are required to ascertain the exact situation of pig helminth infestations in the province.



Farm Mgt- Farm Management

Figure 6.2: The categorical occurrence of GIT helminths in slaughtered pigs

6.3.4 INTENSITY OF THE RECOVERED GIT HELMINTHS

This study recorded a low to moderate infection intensity of helminth eggs in the slaughter pigs (Table 6.4). However, high rates of *A. suum* eggs were recovered in TNA. In BFA, there were no eggs recovered for *O. dentatum* and *F. hepatica*. Also, *T. suis, H. rubidus* and *F. hepatica* eggs were not recovered in GVA. It is possible that the low to moderate intensity of helminth eggs mostly detected in the slaughter pigs could be because of improved veterinary care and nutrition practised by these commercial pig farmers who have been in this business for a long time and have become more knowledgeable. Also, it could indicate false negative results due to pre-patent periods of the immature worms or sub-clinical infections in the sampled pigs. Adebisi

(2008) and Marufu *et al*. (2008) state that sub-clinical infections are the most significant forms of infection that give rise to low productivity of livestock and huge economic losses. Previous studies indicated that there is a possibility of pigs developing immunity towards helminth infections if they have been exposed to these nematodes for a long period of time. Also, this immunity can passively be passed to the offspring from the sow (Murrell, 1981; Eriksen *et al*., 1992). Due to this acquired host immunity, the fecundity of the female worm is reduced, resulting in lower egg numbers detected. Thienpont *et al.* (1995) also suggested that egg excretion can stop indefinitely in proportion to increased resistence in the host.

Table 6.4: Intensity of GIT helmiths (EPG) observed per abattoir

Helminths	**Abattoir**		
	BFA	**TNA**	**GVA**
Ascaris suum	++	+++	+
Trichuris suis	+	+	-
Oesophagostomum dentatum	-	+	+
Hyostrongylus rubidus	+	++	-
Fasciola hepatica	-	++	-

- No observed infection
\+ Low infestation [EPG (egg per gram) ≤100]
++ Moderate infestation [EPG>100<500]
+++ High infestation [EPG≥500]

6.3.5 PREVALENCE OF MONO-PARASITIC AND POLY-PARASITIC INFECTIONS

This study also recorded an overall 46.9 % prevalence of single (mono-parasitic) helminth infections in the slaughter pigs, while mixed (poly-parasitic) infections were observed at a rate of 47.1 % (Figure 6.3). This result is not concurrent with the findings by Geresu *et al.*, (2015), who reported a higher prevalence of single helminth infections in pigs slaughtered in Addis Ababa, Ethiopia.

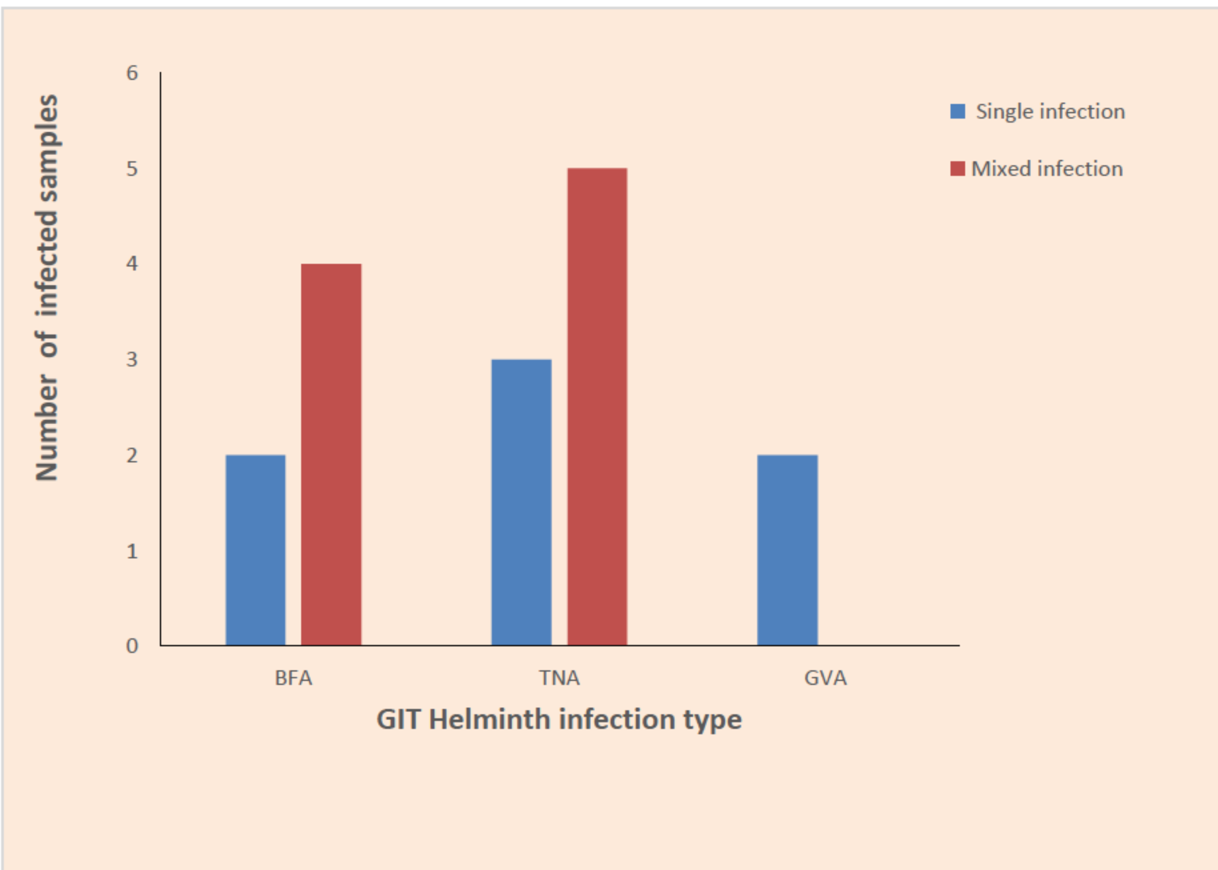


Figure 6.3: Mono- and poly-parasitic infections in slaughtered pigs

6.4 CONCLUSION

Helminthiasis is a public health issue which can pose a threat to the farmer, farm and abattoir workers, consumers of pork and all those who are exposed to the infection. Some species of gastrointestinal tract helminths were observed in slaughter pigs despite anthelmintic administration. These parasites were more prevalent in pigs that had had access to outdoor foraging facilities than those that had been contained in stalls. Production losses due to unthriftiness are of great concern to the piggery enterprise. Farmers should be assisted in the selection and administration of appropriate anthelmintics and be made aware of anthelmintic withdrawal periods before slaughter. Periodic surveillance should be conducted to detect anthelmintic resistance among these nematodes. Proper use of anthelmintics should be coupled with good farm hygiene, well-balanced nutrition, increased bio-security measures, appropriate stocking density, and control of pests and rodents to reduce mechanical transmission of oocytes. Larger sample sizes to survey additional areas will also be required in future studies to extend our knowledge and understanding of the nature and severity of helminthiasis in the province.

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CHAPTER 7

ERADICATION OF INTESTINAL HELMINTHS IN PIGS FED GRADED LEVELS OF DRY CHICORY (*CICHORIUM INTYBUS*) ROOTS

7.1 INTRODUCTION

Pig farming, which forms an integral part of the farming economy, is considered important in many parts of the world due to its production of meat and meat products, industrial raw materials and organic manure. When managed properly, the piggery enterprise can lead to rapid returns on investment. This is because pigs have high feed conversion efficiency and fertility rate, are early maturing with short generation intervals, and can produce significantly within a relatively short period of time (Lekule and Kyvsgaard, 2003). Swine production helps to alleviate the deficiency of animal protein and it has been considered by the Food and Agricultural Organization (2012) as a tool to fight poverty in the tropics. There has been an increase in the demand for pork and pig products in many parts of Africa and in international markets. This is mostly due to an increase in the number of pork consumers and the profits generated from this sector, and this has led to an intensification of pig production over the years (Serres, 2001). Moreover, the International Livestock Research Institute (ILRI) projected that pork consumption in the developing regions of the world for the period 1993 to 2020 are anticipated to double (from 39 to 81 million tonnes) compared to a marginal increase in developed regions (from 38 to 41 million tonnes) (ILRI, 2000).

In South Africa, pig production is smaller than its cattle or poultry counterparts, unlike the global trend where pork is the most consumed meat product (Davids *et al*., 2014). However, according to Basset-Mens and Van der Werf (2005), pork consumption in South Africa has increased by 53 % over the past decade. The Bureau for Food and Agricultural Policy (2014) reported that the increase in pork consumption over the years in the country has led to the rapid expansion of the industry as higher demands are projected for the next decade.

In as much as pig production can be profitable by yielding rapid returns on capital investments, there are still some constraints to economic realizations within this enterprise, especially among smallholder farmers who are faced with many production challenges and who are often compelled to give up on their piggery business. Helminthiasis is one of the limiting factors that impact a profitable piggery enterprise (Nsoso *et al*., 2000). Both Permin *et al*. (1999) and Sangeeta *et al*. (2002) stated that parasitic infections in pigs in tropical and sub-tropical areas are estimated to be the second limiting factor after African swine fever and are a major barrier to efficient pig production of all age groups. According to Eijck and Borgsteede (2005), internal parasites are particularly invasive in tropical and sub-tropical countries where nutrition and sanitation are generally poor. Some researchers have reported that infections with these helminths may result in economic losses to the farmer due to reduced growth rates and weight gain, decreased litter size, inefficient feed conversion and utilization, decreased fecundity, carcass condemnation at slaughter, high cost of treatment, and mortality (Boes *et al*., 2000; Joachim *et al*., 2001; Borthakur *et al*., 2007; Kagira *et al.,* 2012). Also, some of these pig helminths are zoonotic in nature and can infect humans (FAO, 2008; Spencer, 2010).

Various pre- and post-mortem studies have been done in many parts of the world to determine the prevalence of intestinal helminths in pigs. In Africa, many researchers have identified different species of intestinal helminths in pigs that manifest either as mono-parasitic infections and/or poly-parasitic infections. Some of these regions and the researchers that worked there are Ghana (Permin *et al*., 1999), Tanzania (Esrony *et al*., 1997; Ngowi *et al*., 2004; Nonga *et al*., 2015), Botswana (Nsoso *et al*., 2000), Kenya (Nganga *et al*., 2008; Kagira *et al*., 2012; Obonyo *et al*., 2012), Nigeria (Opara *et al*., 2006; Tidi *et al*., 2011; Sowemimo *et al*., 2012; Eyo *et al*., 2014; Gagman *et al.,* 2014), Ethiopia (Seid and Abebaw, 2010; Kumsa and Kifle, 2014; Jufare *et al*., 2015) and Zimbabwe (Zanga *et al*., 2003; Marufu *et al*., 2008). Others include Waiswa *et al*. (2007) and Nissen *et al*. (2011) in Uganda; Tamboura *et al*. (2006) in Burkina-Faso; Zoli *et al*. (2003) in Western and Central Africa; Phiri *et al.* (2003) in Eastern and Southern Africa and NDAD (2001), WHO (2003), Krecek *et al*. (2004), Adams *et al*. (2006), Krecek *et al*. (2008) and Krecek *et al*. (2012) in South Africa*. Ascaris, Taenia, Trichuris, Oesophagostomum and Strongly* are some of the species already identified intestinal helminths that plague pigs in different parts of Africa.

Currently, helminth control is mainly based on the mass treatment of farm animals with synthetic pharmaceutical anthelmintic medications. These are not sustainable in the long term because of the development of resistance to them among worm species. Williams *et al*. (2014) noted that most subsistent farmers in many developing nations cannot afford expensive anthelmintic drugs. On the other hand, many low-input and organic farms in developed countries are not able to prophylactically treat animals with synthetic drugs. Moreover, the increase in public awareness of drug residues in edible tissues of animal products, combined with the desire for a more sustainable farming practice, has resulted in an intensified effort to find alternative helminth control options that are less reliant on chemotherapy (Rahmann *et al*., 2002). This has triggered the evaluation of the efficacy of dry chicory (*Cichorium intybus*) roots that are purported to possess anthelmintic and other beneficial properties. This nutritional intervention regime may be a cheaper alternative and more sustainable than the synthetic anthelmintic drugs used for helminth eradication.

In reality, the objectives and technological possibilities for implementing sustainable parasite control in developed countries are not the same for a resource-poor subsistence livestock producer in remote sub-Saharan Africa (Henrioud, 2011). There is also a paucity of scientific data in South Africa relating to the use of phyto-bioactive plants to combat gastro-intestinal helminths in semi-intensively managed monogastrics like pig. Therefore, this *in vivo* study aimed to explore the possibility of eradicating intestinal helminths in semi-intensively managed pigs by including graded levels of dry chicory roots in their diet.

7.2 MATERIALS AND METHODS

7.2.1 ETHICS STATEMENT

The protocol for this research was evaluated and approved by the Animal Ethics Committee of the University of the Free State before the commencement of the feeding trial. The animal experiment number is NR 24/2013.

7.2.2 EXPERIMENTAL SITE

This study was conducted at Mandla Piggery in Bloemfontein, Manguang Municipality. This municipality is located within the coordinates 29 ^{0}S and 26 ^{0}E and comprises a geographical area of 4,284 km^2. The area experiences a semi-arid climate with temperatures ranging between 19 ^{0}C to 32 ^{0}C in the summer months and -3 ^{0}C to 14 ^{0}C in the winter months. Annual precipitation varies between 500 to 600mm. The altitude is 1,395 m (45,776 ft) above sea level (Maphalla and Salman, 2002). The farm on which the experiment was conducted was owned by a smallholder farmer who farmed pigs and sheep on the same farm and practised the semi-intensive management system with proper demarcation between the pig and sheep sections. The farmer had been involved in the piggery business for three years. The semi-intensive system was used in this trial because it is the most commonly practised system of management among resource-poor smallholder pig farmers in this area. The feed trial took place in the spring months of October and November in 2016.

7.2.3 STUDY ANIMALS

A total of 20 grower pigs (LW x LR - Large White x Landrace breeds) which consist of 12 females and 8 males of an average age of 11 weeks and initial live weight of 21 ± 0.8 kg were randomly selected and used for a 28-day feed trial. Before the commencement of the experiment, the faecal samples of all the grower pigs on the farm were collected and analyzed to determine their helminth load (FEC – faecal egg count) which was measured as the number of eggs per gram (EPG). Thereafter, only pigs with a high FEC (EPG ≥500) were selected for the experiment. According to the farm records, the pigs had been given iron injections earlier but had not been dewormed. No anthelmintic medication, pasture or swill was given to the pigs throughout the duration of the experiment. The age and health statuses of the experimental pigs were provided by the farmer. All the pigs used in this study were farrowed on the farm and were naturally parasitized. A marker was used to identify the selected pigs. No mortalities were recorded during the experiment.

7.2.4 EXPERIMENTAL DESIGN AND HOUSING

Twenty (20) grower pigs having an initial EPG ≥500 (range: 500 – 700) were randomly selected and assigned to four experimental units (Groups A, B, C and D) in a completely randomized design which was semi-intensively managed. Each group comprised five pigs of both genders (3 females, 2 males) even though sex effect was not evaluated. Both genders were used because no particular gender of grower pigs on the farm at the time of the study amounted to 20 in number. Group A pigs were used as control and fed with the conventional pig grower feed, while groups B, C and D were the experimental groups which were fed with 5 %, 10 % and 15 % chicory inclusion levels in their diets respectively. These percentage levels were fixed arbitrarily. On day zero (i.e., before the commencement of the trial), the total FEC for each group was 2,800 epg, 2950 epg, 3000 epg and 3050 epg for groups A, B, C and D respectively. The mean EPG was: Group A (560±29.1), Group B (590±40), Group C (600±35.4) and Group D (610±29.2). The pigs were housed according to their groups in well ventilated stalls with concrete floors, brick walls and zinc roofs. Each stall had an outlet to the field with extended metal fences which ensured that pigs from different groups could not mix while in the field. The stalls were cleaned with water and were disinfected twice weekly. Faeces on the field were manually picked up and disposed of.

7.2.5 FEED INGREDIENTS AND EXPERIMENTAL DIETS

Five hundred kilograms (500 kg) of pig grower ration was compounded at a time on the farm using the different feed ingredients to meet the 18 % CP required for grower pigs. The test ingredient was dry chicory (*Cichorium intybus*) roots purchased from Chicory SA in the Eastern Cape Province, South Africa. The dry chicory roots were milled and a representative sample with the compounded grower feed was taken to ARC Analytical Services, Irene, for proximate analysis (Table 7.1). The three levels (5 %, 10 % and 15 %) of chicory inclusion in the experimental diets are presentend in Table 7.2. Apart from investigating the *in vivo* anthelmintic properties of chicory in pigs, the experimental diets were also formulated for chicory to partially replace soybean meal (SBM) for protein and to reduce the quantity of SBM used, thereby lowering the high cost of purchasing the feed ingredient. Also, chicory partially replaced wheat bran for protein, bulk and soluble fibre content. Dry chicory roots contain some anti nutritional properties and therefore, if it is given in high doses, it could be toxic to the animal. To avoid feed stress due to the sudden change of feed, the experimental pigs were allowed to adapt to their new diets by feeding them 5 % chicory mixed with the grower diet for two days before the trial commenced. All diets were formulated to meet the nutritional requirements of grower pigs. Feed and clean water were provided *ad libitum* in feeding troughs and buckets.

Table 7.1: Proximate analyses of compounded pig grower feed and dry chicory roots

Chemical analysis (%)	Grower feed	Dry chicory roots
Dry matter	92.23	92.36
Moisture	7.77	7.64
Ash	3.19	4.10
Crude protein (N x 6.25)	17.7	6.57
Ether extract	2.63	0.78
Crude fibre	4.54	5.26
Neutral detergent fibre	12.88	9.09
Acid detergent fibre	4.96	5.21
Calcium	0.29	0.25
Phosphorus	0.37	0.13
Gross energy MJ/kg	16.69	15.03
Metabolizable energy MJ/kg	14.50	13.40

Values are means of two determinants
Results were expressed on a wet basis (i.e. as samples were received)
NDF was determined based on extraction of feed with a hot neutral solution of sodium lauryl sulphate (Van Soest & Wine, 1967; Robertson & Van Soest, 1981). ADF was determined using heat treatment of the sample with sulphuric acid containing cetyltrimethyl ammonium bromide (Goering and Van Soest, 1970).

Table 7.2: Ingredient composition of experimental diets for grower pigs per 100 kg, 18 % CP as-fed basis

Ingredients	A	B	C	D
	0% chicory (kg)	5% chicory (kg)	10% chicory (kg)	15% chicory (kg)
Maize	50.00	50.00	50.00	50.00
Soy Bean Meal	18.50	17.58	16.65	15.73
Wheat Bran	28.30	26.89	25.47	24.06
Chicory	0.00	2.34	4.68	7.02
Pig Grower Macro	3.20	3.20	3.20	3.20
Total	100.00	100.00	100.00	100.00

The ingredient composition of each group was calculated based on the 18 % CP requirement for grower pigs. The CP contents of Soy Bean Meal and Dry chicory roots were factored in.

Composition of pig grower macro (Total = 16 kg)

Macro elements

Lysine (min) = 40g/kg

Methionine (min) = 0

Moisture (max) = 100g/kg

Fibre (max) = 0

Calcium (max) = 250g/kg

Phosphorus (min) = 60g/kg

Salt (max) = 225g/kg

Minute elements

Vit A = 0.2ml IU/kg

Vit D_3= 0.03ml IU/kg

Micro elements

Copper (min) = 220mg/kg

Iodine (min) = 15mg/kg

Manganese = 700mg/kg

Iron = 3,000mg/kg

Selenium = 8.5mg/kg

Zinc = 200mg/kg

Vit B_1 = 20mg/kg

Vit B_2 = 50mg/kg

Vit B_6 = 40mg/kg

Folic acid = 10mg/kg

Vit B_{12} = 0.5mg/kg

Vit E = 400mg/kg

Vit K = 40mg/kg

7.2.6 PERFORMANCE MEASUREMENTS

To determine the effect of dry chicory root on the rate of live weight gain, the average weights of the pigs were recorded/group/week. Data on feed intake (FI), average daily gain (ADG), total weight gain (TWG) and feed conversion ratio (FCR) were collected per animal or group per week. The initial and final weights of the individual pigs were also recorded.
Calculations:

FI (g/group/week) = Feed offered – Feed remaining/group/day

ADG (kg/animal/group) = TWG ÷ Number of experimental days

TWG (kg/animal/group) = Final weight – Initial weight

FCR (/group) = Total feed intake ÷ TWG

7.2.7 SAMPLING

Before the experiment commenced, about four grams of feaces were collected par rectum from each grower pig using clean plastic bags and a marker to identify the pig that had been sampled. In situations where faeces could not be collected mid air from the rectum, freshly voided faeces were carefully collected from the ground and the respective pigs were marked. All samples were properly labelled. Optimum care was taken to avoid additional contamination of the samples. The samples were immediately cooled in a cooler box with ice cubes to prevent eggs developing and hatching, and sent to the laboratory for analysis. Midway through and at the end of the trial, faecal samples were also collected par rectum from all the pigs/group for quantification of the helminth eggs present. The samples from each group were pooled to obtain a representative sample of that group. Each representative group sample was halved and the final result was an average of both samples.

7.2.8 LABORATORY PROCEDURE

For the qualitative and quantitative procedures, approximately two grams of each of the faecal samples were weighed and put in an already marked beaker. Fifty-eight ml (58 ml) of floatation fluid made up of 40 % salt solution was added to the beaker and a glass rod was used to mix the sample thoroughly. The mixture was left to stand for five minutes to allow the eggs to float to the surface. Thereafter, a Pasteur pipette was used to extract aliquots from the faecal mixture to fill the two chambers of the McMaster slide. This was left to settle and stand for three minutes. Under a 10 x 10 magnification compound microscope, the McMaster slides were examined for the presence of helminth eggs. All the helminth eggs present within the engraved areas of both McMaster chambers were quantified. This was done by counting all the eggs within the engraved area in the two chambers and the total was multiplied by 50 to obtain the faecal egg count (FEC). The FEC is usually expressed as EPG (egg per gram). EPG≤100 was grouped as low levels of infection, EPG>100<500 was regarded as moderate infestation, while EPG ≥500 was grouped as significant high levels. Identified coccidia oocysts were not recorded for this study. The identification and quantification procedures were based on the standard operating procedure used by the Veterinary Laboratory, Bloemfontein (Wentzel and Vermeulen, 2003). Appropriate hygiene and safety procedures were adhered to.

7.2.9 STATISTICAL ANALYSIS

The data were computed using a Microsoft^{R} Excel version 2016 spreadsheet and properly coded. Descriptive analyses of percentages and graphical representations were computed using the spreadsheet. The group effect of dry chicory roots on faecal egg count, feed intake, average daily feed intake and the average daily gain were compared using one-way analysis of variance (ANOVA) in XLSTAT 2018. The correlations between different parameters were also evaluated. The level of significance was set at *P*<0.05. The prevalence of intestinal helminths was calculated as the ratio between the number of infected animals (n) and the number of animals sampled (N). Thus:

P = n/N X100;

where *P* = prevalence, *n* = no. of infected animals and *N* = no. of animals sampled per grouping.

The faecal egg count reduction (FECR) was calculated using this formula:

$$FECR\ \% = \frac{Initial\ FEC - Final\ FEC}{Initial\ FEC} \times \frac{100}{1}$$

The one-way completely randomised design model used was:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

Where: Y_{ij} = the observed response
μ = the experimental mean
α_i = the treatment effect, and
ε_{ij} = the experimental error

7.3 RESULTS AND DISCUSSION

The results of this study are discussed below with relevant discussions presented in each section.

7.3.1 PREVALENCE OF INTESTINAL HELMINTHS IN GROWER PIGS

In this experiment, two porcine intestinal helminths of both veterinary and economic importance were identified in the grower pigs (Table 7.3). *Ascaris suum* and *Trichuris suis* each recorded a prevalence of 89.3 % and 82.1 % respectively. The presence of at least one of these helminths was reported in earlier experiments by Salifu *et al*. (1990) in Nigeria, Nsoso *et al*. (2000) in Botswana, Boes *et al*. (2000) in China, Eijck and Borgsteede (2005) in the Netherlands, Tamboura *et al*. (2006) in Burkina Faso, Marufu *et al*. (2008) in Zimbabwe, Obonyo *et al*. (2012) in Kenya, Dey *et al*. (2014) in Bangladesh and Jufare *et al*. (2015) in Ethiopia. The high prevalence of *Ascaris suum* in this study was similar to reports of 88 % in Denmark (Roepstorff and Jorsal, 1989), 72.7 % in the Netherlands (Eijck and Borgsteede, 2005), 68 % in Australia (Mercy *et al*., 1989), 67.4 % in Nagaland (Rajkhowa *et al*., 2003) and 64.3 % in Sao Paulo (Kasai *et al*., 1979). Nevertheless, this result did not corrolate with reported lower prevalence records of 4.9 % in Ethiopia, 5.4 % in Kenya, 11.1 % in the Netherlands, 28.7 % in Kenya, 36.7 % in China and 40 % in Burkina Faso by Jufare *et al*. (2015), Obonyo *et al*. (2012), Eijck and

Borgsteede (2005), Nganga *et al*. (2008), Boes *et al*. (2000) and Tamboura *et al*. (2006) respectively. It was noted that non-African countries mostly reported a remarkably higher prevalence for *Ascaris suum* in their studies. This may be due to seasonal and geographical variations which could favour the proliferation of the helminth. Kagira (2010) and Obonyo *et al*. (2012) earlier argued that perpetual wet farm conditions, an unhygienic environment and favourable temperatures could lead to high infection rates with *A. suum*.

Table 7.3: Prevalence of intestinal helminths in grower pigs

Description	No of positive samples (N=28)	Prevalence (%)	EPG Mean±SE	Range Min - Max
Helminth				
Ascaris suum	25	89.3	530±35.6	300 - 900
Trichuris suis	23	82.1	609±36.1	400 - 950
Single infection				
Ascaris suum	4	14.3	325±59.5	250 - 500
Trichuris suis	2	7.1	400±100	300 - 500
Mixed infections				
A.suum + T.suis	21	75	590±17.5	500 - 750

N: Total number of faecal samples

Trichuris suis (whipworm) also recorded a high prevalence of 82.1 % in this study (Table 7.3). This result was both higher and did not agree with some previous studies such as those by Jufare *et al*. (2015), Marufu *et al*. (2008), Nsoso *et al*. (2000), Obonyo *et al*. (2012), Dey *et al*. (2014), Tiwari *et. al.* (2009) and Eijck and Borgsteede (2005) who reported 2.9 % in Ethiopia, 4.7 % in Zimbabwe, 6.8 % in Botswana, 7.8 % in Kenya, 9.1 % in Bangladesh, 38 % in the West Indies and 37.5 % in the Netherlands for Trichuris spp*.* respectively. The high occurrence of *T. suis* in this study may have been due to the poor management and husbandry practices that were observed on this experimental farm. *Trichuris suis* eggs can survive in the environment for up to four years (Urquhart *et al*., 1996). Heavy infestations are more common in growing and adult pigs raised outdoors which is a condition that usually presents with bloody diarrhea (Roepstorff and Nansen, 1998).

Both mono-parasitic infections (single infections) and poly-parasitic infections (mixed infections) were observed in the experiental pigs in this study (Table 7.3). Infection patterns in pigs with lower, similar or higher EPG levels were also recorded in other studies such as those by Geresu *et al*. (2015) in Addis Ababa, Ethiopia; Roepstorff and Jorsal (1989) in Denmark; Tamboura *et al*. (2006) in Burkina Faso; Sowemimo *et al*. (2012) in Nigeria; Gagman *et al*. (2014) in Nigeria; Jufare *et al*. (2015) in Ethiopia; and Seid and Abebaw (2010) in Holetta, Ethiopia. These studies identified single to multiple (double to quadruple) mixed associations of intestinal parasites, thereby confirming the occurrence of poly-parasitism in pigs that access the outdoors. Light helminth loads in pigs may not generally cause clinical symptoms, but the presence of several species at the same time (poly-parasitism) may precipitate disease due to their additive or even synergistic effects. It is therefore important to identify the species present and to assess the numbers of all species.

7.3.2 EFFECT OF DRY CHICORY ROOT ON FAECAL EGG COUNTS AND OTHER MEASURED PARAMETERS

Table 7.4 shows the different parameters that were measured against the effectiveness of dry chicory roots fed to grower pigs in each experimental group. For FEC, there were significant differences ($P<0.05$) between the groups on the first and last days (days 1 and 28) of the trial. On day 14 however, there was no significant difference ($P<0.05$) between groups B and C, although results from group A were significantly different ($P<0.05$) from group D and both groups were significantly different ($P<0.05$) from groups B and C on that sampling day. Prior to the commencement of this study, the grower pigs had varying high levels of intestinal helminth burden. This could possibly explain the significant differences in their FEC for day 1.

Table 7.4: The effect of dry chicory root ingestion on helminth load and growth performance in grower pigs

Parameters	Experimental Groups			
	A	B	C	D
FEC (epg)				
Day 1	560.0[a] ± 29.1	590.0[b] ± 40.0	600.0[c] ± 35.4	610.0[d] ± 29.2
Day 14	575.0[a] ± 25.0	450.0[b] ± 50.0	350.0[b] ± 50.0	175.0[c] ± 25.0
Day 28	500.0[a] ± 0.0	300.0[b] ± 50.0	75.0[c] ± 25.0	50.0[d] ± 50.0
FI (g/group/week)				
1st week	6101.3[a] ± 4.4	6092.7[b] ±14.0	6091.9[c] ± 14.3	5355.1[d] ±166.5
2nd week	6026.0[b] ± 1.7	6025.9[b] ± 1.7	6024.1[b] ± 1.5	6019.1[a] ± 4.5
3rd week	6039.9[b] ± 1.8	6040.0[b] ± 1.7	6039.1[b] ± 1.5	6038.0[a] ± 2.1
4th week	6066.4[b] ± 5.0	6066.1[b] ± 5.0	6058.7[b] ± 5.3	6065.3[a] ± 4.5
TWG (kg/animal/group)				
1	17.9	16.8	19.5	16.0
2	16.8	18.4	17.6	16.1
3	16.9	17.6	18.8	15.9
4	15.5	17.1	19.2	17.7
5	15.5	17.6	19.2	17.0
ADG (kg/animal/group)				
1	0.640	0.600	0.696	0.571
2	0.600	0.660	0.629	0.575
3	0.603	0.623	0.671	0.568
4	0.553	0.611	0.686	0.631
5	0.553	0.629	0.686	0.607
FCR (/group)	2.1:1	1.9:1	1.8:1	2.0:1

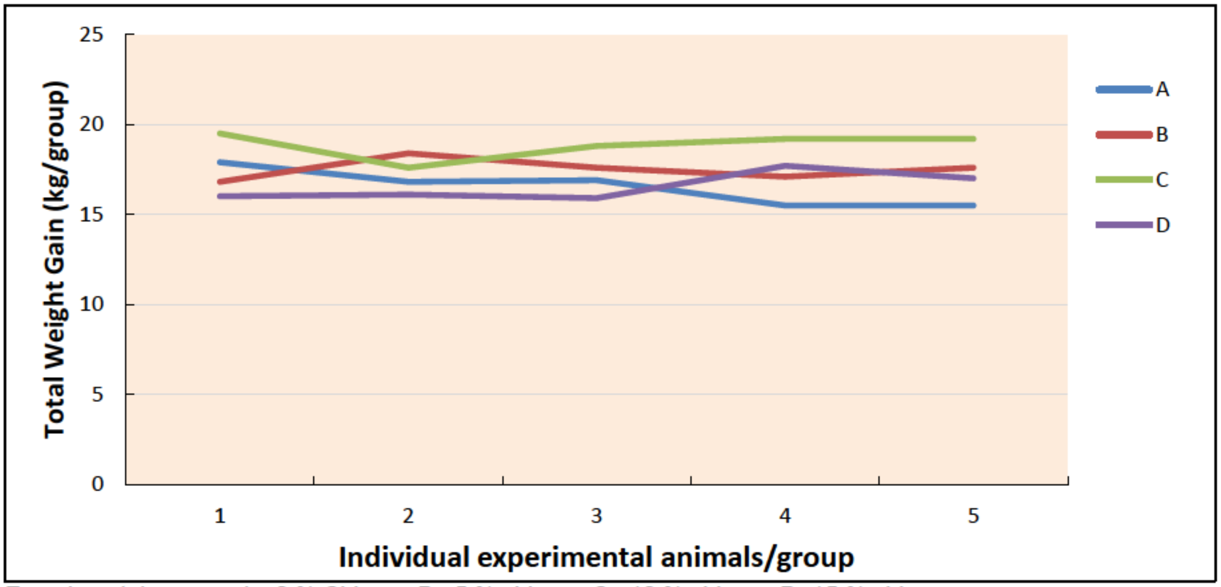
[a,b,c,d] Means within rows with different superscripts are significantly different at (P<0.05).
Experimental groups: A= 0 % Chicory; B= 5 % chicory; C= 10 % chicory; D=15 % chicory.
FEC = Faecal Egg Count; FI = Feed Intake; TWG = Total Weight Gain; ADG = Average Daily Gain; FCR = Feed Conversion Ratio.

Midway into the trial group D, which had the highest chicory inclusion level, recorded the lowest FEC, unlike control group A that maintained a high FEC. The experimental groups recorded a much lower FEC on the last day even though there were significant differences across all groups. The bioactive components of chicory roots that possess anthelminthic properties which reduces worm burdens in farm animals were also reported by Tzamaloukas (2005), Heckendorn *et al.* (2006), Van Loo (2007) and Athanasiadou *et al*. (2007). This may explain the drastic reduction in helminth loads that was observed in groups B to D, especially in group D. This result agrees with earlier submissions by Petkevicius *et al.* (1997) and Thomsen *et al.* (2005) who found that the ingestion of inulin found in chicory roots suppressed parasites such as *Ascaris* and *Trichuris* in pigs.

Significant differences ($P<0.05$) were recorded for feed intake (FI) across all groups in the 1st week of the experiment (Table 7.4). From the 2nd to the 4th weeks, a significant difference ($P<0.05$) was recorded only for group D compared to all the other groups. It was noted that the control group consumed more feed than the experimental groups. Even though the experimental pigs were given a few days to acclimatize to the chicory diet, the bulkiness and the somewhat astringent taste of chicory may have slightly reduced feed consumption in the groups, especially in group D which had the highest chicory inclusion level. According to Barry and McNabb (1999) and Min *et al*. (2003), the consumption of tannins and other plant secondary metabolites at high intake rates is associated with reduced feed intake and dry matter digestibility in farm animals, which were phenomena that were also observed in this study.

There were no statistically significant differences in the total weight gain (TWG) and average daily gain (ADG) of the individual animals within their various groups. However, Group C had a slightly higher TWG (Figure 7.1) and ADG than the other groups. Group D recorded the lowest overall TWG and ADG. This could be connected to the group having the lowest CP level in their diet. The slight percentage differences in chicory dosage among the groups may have resulted in this close uniformity.

Group C had the best feed conversion ratio (FCR) at 1.8 while Group A had the least at 2.1 (Table 7.4). The presence of inulin, a soluble dietary fibre and a prototype prebiotic for monogastrics in chicory roots (Mejer, 2006; Madrigal and Sangronis, 2007; Roberfroid *et al*., 2007) could have been responsible for this result despite the lower CP levels in the experimental diets when compared to the control diet. Various studies have reported that prebiotics stimulate the growth of host-beneficial gut bacteria, such as lactobacilli and bifidobacteria, for overall beneficial health (Roberfroid, 2001; Kaur and Gupta, 2002). In addition, a prebiotic may stimulate the immune system of the body, decrease the levels of pathogenic bacteria in the intestine (Liu *et al.,* 2012) thus relieving constipation, decrease the risk of osteoporosis by increasing mineral absorption (especially of calcium) (Roberfroid *et al*., 2002), and reduce the risk of atherosclerosis by lowering the synthesis of triglycerides and fatty acids in the liver while decreasing their level in serum (Kaur and Gupta, 2002).



Experimental groups: A= 0 % Chicory; B= 5 % chicory; C= 10 % chicory; D=15 % chicory

Figure 7.1: The total weight gain rates of individual pigs in each experimental group

7.3.3 EFFECT OF DRY CHICORY ROOT ON FAECAL EGG COUNT REDUCTION

This study recorded a 76.2 % faecal egg count reduction (FECR) in the experimental pigs in groups B, C and D whose diets were supplemented with varying levels of dry chicory root (Figure 7.2). This rate was lower than the 90 % reduction threshold which is regarded as “highly effective” and the 80 % reduction threshold regarded as “adequate” for plant secondary metabolites (PSMs) by some scientists, for example Githiori *et al*. (2006). The lower rate that was recorded in this study may have been be due to experimental errors that resulted in false negative parasitology results, seasonal variations, the small sample size used in this study, the quality and specie of chicory root used, or it may possibly have been due to helminth resistance to some PSMs. Nevertheless, chicory root contains PSMs that have been reported to reduce FEC, larval development and worm burdens. According to Cabaret and Berrag (2004), faecal egg count reduction (FECR) in faeces is the most widely used method to assess the efficacy of anthelmintic agents against gastrointestinal nematodes. Figure 7.2 illustrates that Group D recorded the highest FEC reduction, followed by Group C. It may be concluded that because these groups (C and D) ingested higher chicory root content than the other groups, higher egg count reduction was the result.

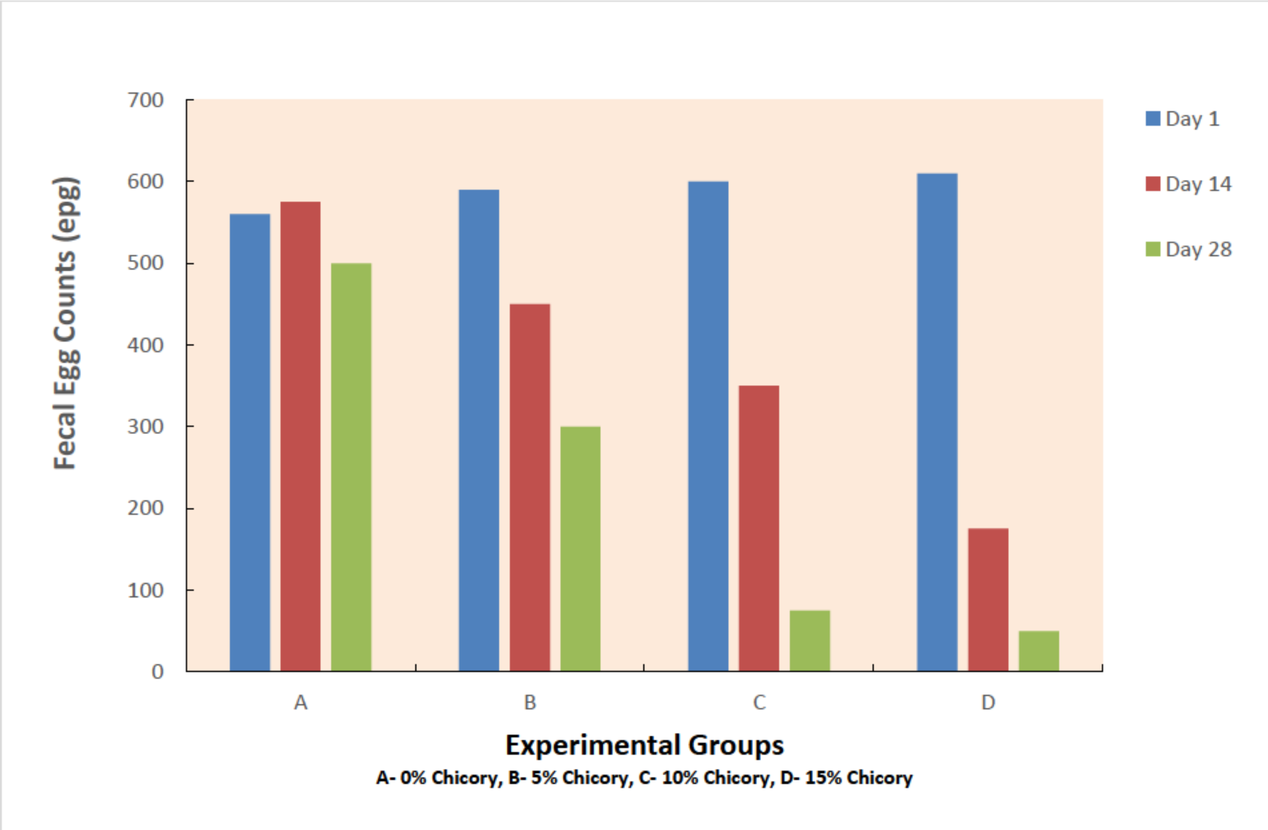


Figure 7.2: Rate of faecal egg count reduction in experimental pigs

7.3.4 CORRELATIONS BETWEEN FAECAL EGG COUNTS AND GROWTH PARAMETERS

Table 7.5 shows the relationships that was found to exist between some of the evaluated parameters. A perfect positive linear correlation (r = 1.000) was exhibited between ADG x TWG. This shows that the rate of daily gain of each pig culminated in the eventual weight that was recorded at the end of the experiment. Likewise, there was a strong positive relationship (r = 0.722) between FEC x ADFI. This explains that the lower the FEC in the experimental pigs, the lower the rate at which the pigs gained weight, especially if chicory was consumed above a volume of 10 % in the feed. This is so because higher quantities of chicory consumed over a longer period resulted in a reduced FEC and a decrease in ADFI. This observation may probably be due to the bulkiness and taste of the dry chicory roots, resulting in reduced FI. There was a negative correlation between FEC x TWG (r = -0265), and FEC x ADG (r = -0.265). This indicates that, as the faecal helminth eggs reduced in number, there was a corresponding increase in the rate of weight gain and the average daily weight gain in the grower pigs. Since a reduction in egg output may not necessarily mean a reduction in adult or larval worm burdens (Nganga *et al.,* 2008), this negative linear correlation supports the fact that gastro-intestinal helminths are a major cause of ill-thrift and life weight gain, resulting in production losses in both the commercial and small-holder farming sectors. Also, lower helminth egg counts have been shown to improve performance in livestock.

Table 7.5: Linear correlations between FEC and growth parameters in experimental pigs

Variables	FEC	ADFI	TWG	ADG
FEC	1	0.722	-0.265	-0.265
ADFI	0.722	1	0.474	0.474
TWG	-0.265	0.474	1	1.000
ADG	-0.265	0.474	1.000	1

Pearson's linear correlation coefficient is significant at $P<0.05$
FEC = Fecal Egg Count; ADFI = Average Daily Feed Intake; TWG = Total Weight Gain; ADG = Average Daily Gain.

7.4 CONCLUSION

The results of this study support the conclusion that dry chicory (*Cichorium intybus*) roots contributed extensively to the *in vivo* faecal egg count reduction in the experimental pigs. The overall best level of chicory ingestion was 10 % in Group C. This group showed the best performance in the majority of the evaluated parameters. It should also be noted that higher levels of dry chicory root ingestion by pigs can reduce feed intake and subsequently limit weight gain. At low levels, dry chicory roots can therefore replace wheat bran for bulk and soybean for protein and can thus reduce feed costs while contributing to the general wellbeing of the animal. For subsistence and smallholder farmers, it would also make economic and infrastructural sense to utilise local flora to treat helminth infections in their livestock in the place of synthetic AH. The sustainability of helminth control will be largely conditioned by the ability to achieve an integrated parasite management strategy which involves a combination of several solutions. Because human health is inevitably linked to the health of animals and to the environment, all farmers, regardless of the size of their enterprise, should be cognizant of the condition of their flocks and give careful attention to the health and wellbeing of their herds.

7.5 RECOMMENDATIONS

With reference to the findings pertaining to the literature review, previous studies and the results of the current study, the following recommendations are offered:

- Extensive research should be done using larger sample sizes and including a post-mortem and sensory evaluation of pig carcasses after their diets have been supplemented with dry chicory roots.

- Because the experimental phase of this study focused on grower pigs, it is recommended that experiments of this nature be carried out on piglets and mature pigs for comparative purposes.

- It is recommended that resource-poor farmers include 10 % of dry chicory roots in the diets of grower pigs to help eliminate intestinal helminths and improve pig welfare.

- There is sufficient scientific evidence to suggest that dry chicory root is a cheap, natural and sustainable alternative for various types of pig feed. It is therefore recommended for use to reduce helminth egg burdens in pigs.

- In order to slow down the rate of pharmaceutical anthelmintic resistance in pigs, farmers should be encouraged to reduce sole reliance on synthetic anthelmintic products and incorporate natural and sustainable measures to combat helminthiasis on their farms. Incorporating dry chicory roots in pig diets is such a solution.

- Management practices that are designed to reduce the exposure of farm animals to parasites and to minimise the frequency of anthelmintic use is recommended.

7.6 THE VALUE OF THIS STUDY

The information and in-depth knowledge that were gained from this study pertaining to the prevalence of intestinal helminths in both live and slaughtered pigs, type of pig parasite and the prevalent farm management practices among smallholder pig farmers may be used as baseline knowledge to help formulate the development of extension programmes for sustainable pig rearing and pork production, especially among smallholder farmers. This may especially be useful if the information is reduced to legible flyers and pamphlets that contain visual illustrations for use by smallholder farmers, with particular focus on upcoming farmers who may not be illiterate, but merely uninformed. In this context, the data that will be released by this study should also inform chicory producers and marketing agents to extend their production and information base to a broad spectrum of farmers. This will render the results of this study far-reaching and effective in pork husbandry and production initiatives.

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