INFLUENCE OF NUTRITION AND VALUE CHAIN GOVERNANCE ON ENTERPRISE PERFORMANCE IN SMALLHOLDER PIG PRODUCTION IN KENYA

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A thesis submitted to the Graduate School in partial fulfillment of the requirements for the award of a Doctor of Philosophy Degree in Animal Science of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this or any other university for the award of any degree.

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This thesis has been submitted to the Graduate School for examination with our approval as university supervisors.

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DEDICATION

I dedicate this work to my dear wife Eva, my daughter Lynn and son Mark, my parents Rev. David Muthui and the late Mrs Agnes Muthui and my siblings, Charity, Rachel and Job.

Oh LORD our GOD, how majestic is your NAME in all the earth. Psalms 8:9

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ABSTRACT

Smallholder pig production in Kenya is a popular livelihood strategy but is faced with serious challenges, key among them being high cost and poor quality of feeds and weak value chain governance which result in high enterprise costs. To minimise losses, smallholders use locally available alternative feed resources (AFR) which coud be impacting negatively on performance. This study investigated feeding decisions, bio-economic benefits of using alternative feed resources (AFR), benefits of exogenous dietary enzymes and the influence of value chain governance features on competitiveness of smallholder pig enterprises. A proportionate to size purposive sampling procedure was used to select 144 enterprises in Busia, Nakuru and Kiambu Counties using the snowballing method. Interviews were conducted using pretested structured questionnaires to collect data on enterprises. Feeding experiments were set up at Egerton University Tatton Agricultural Park. Mixed analytical methods including decriptive and inferential statistics and regression analysis were applied using SAS systems, SPSS and STATA statistical software. The study concluded that the daily allowances of dry matter, crude protein and metabolisable energy associated with AFR were significantly lower ($p \leq 0.05$) than the recommended daily allowance. Sows fed on AFR had delayed puberty, lower litter sizes and longer farrowing intervals compared to sows fed on commercially compounded feeds ($p \leq 0.05$). Inclusion of cold pressed canola meal and rice polishing in weaned piglet diets resulted in higher ($p \leq 0.05$) metabolisable energy: average daily gain (ME: ADG) and feed cost: average daily gain (FC:ADG) ratios. Inclusion of rice bran in piglet diets did not offer any bio-economic benefits. Inclusion of a dietary multi-enzyme complex resulted in higher ($p \leq 0.05$) apparent digestibility of Nitrogen, energy and feed cost efficiency. Finisher diets lower in protein (14.9 - 16%) and higher in dietary fibre resulted in higher ($p \leq 0.05$) killing-out percent, loin eye area and villous height. Cold pressed canola diet resulted in higher ($p \leq 0.05$) back fat thickness and larger ($p \leq 0.05$) crypt depth. Value chain governance features including technology adoption product quality and market access had significantly ($p \leq 0.05$) positive influence on enterprise competitiveness. The quality of work in pig enterprises negatively ($p \leq 0.05$) influenced competitiveness of pig enterprises. The study recommend capacity building for farmers and extension staff, animal feed testing and use of biotechnology to improve feeding decisions. Further research into waste conversion technologies, the effects of dietary components such as lipids, phenolics on carcass and digestive tract are recommended.

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LIST OF ACRONYMS AND ABBREVIATIONS

AA	Amino acids
ADC	Agricultural Development Corporation
ADFI	Average daily feed intake
ADG	Average daily gain
AFR	Alternative feed resources
AGRA	Alliance for Green Revolution in Africa
AID	Apparent ileal digestibility
ANOVA	Analysis of variance
APPD	Apparent digestibility
asl	Above sea level
ATTD	Apparent total tract digestibility
BFT	Back fat thickness
CF	Crude fibre
cfu	Colony forming units
CID	Coefficient of ileal digestibility
CP	Crude protein
DAAD	German Academic Exchange Service
DC	Developing Countries
DCe	Digestibility coefficient for energy
DDGS	Dried distillers grains with solubles
DE	Digestible energy
DFID	Department For International Development
DWG	Daily weight gain
EE	Ether extract
EFA	Essential fatty acids
FAO	Food and Agriculture Organization of the United Nations
FCE	Feed conversion efficiency
GIS	Geographical information systems
GIT	Gastrointestinal tract
GOK	Government of Kenya

HACCP	Hazard analysis critical control point
HIV/AIDS	Human Immune- deficiency Virus and Auto- Immune Deficiency syndrome
IC	Industrialized countries
ICDD	International Centre for Development and Decent Work
ILO	International Labour Office
ILRI	International Livestock Research Institute
Kcal	Kilocalories
KENPIFA	Kenya Pig Farmers Association
KES	Kenya Shilling
Kg	Kilogramme
KMDP	Kenya Market-led Dairy Programme
KO	Killing-out percent
LEA	Loin eye area
KNBS	Kenya National Bureau of Statistics
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MDG	Millennium Development Goals
ME	Metabolizable energy
Mj	Mega joules
MOALF	Ministry of Agriculture Livestock and Fisheries
MOLD	Ministry of Livestock Development
NACOSTI	National Commission for Science, Technology and Innovation
NFE	Nitrogen free extract
NPN	Non protein nitrogen
NRC	National Research Council
NSP	Non-starch polysaccharides
PCA	Principal component analysis
ppb	Parts per billion
PSE	Pale Soft Exudative
PUFA	Polyunsaturated fatty acids
SADG	Scaled average daily gain
SCFA	Short chain fatty acids

SFI	Scaled average daily feed intake
SDG	Strategic Development Goals
SNV	Netherlands Development Organisation
SSA	Sub-Saharan Africa
TAP	Tatton Agricultural Park
TDN	Total digestible nutrient
VFA	Volatile fatty acids

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

1.1.1 Trends in pig production and demand for pork and pork products

Pig production and pork consumption in Kenya is on an upward trend with evidence of an increase in the number of pig production enterprises. This has been accompanied by an increase in the number of pork retail outlets in urban centres that trade in fresh and value added (roasted) pork, commonly known as pork joints. In the year 2015 - 2016, pork consumption in Kenya rose by 60% from 15,000 to 24,000 tonnes (Kenya National Bureau of Statistics [KNBS], 2016).

Pig production in Kenya has benefited from increased access to information and creation of producer and trade networks owing to policy changes in the telecommunications sector. Successive governments' policies have also placed emphasis on the development of agribusiness as an avenue for poverty reduction, food security and creation of employment. The Strategy for Revitalising Agriculture in Kenya was initiated in 2004 and was linked to Economic Recovery Strategy for Wealth and Employment creation 3003 - 2007. Such policies have been instrumental in encouraging investment in agriculture through improving access to credit and promoting smallholder participation in value chains.

On the global scene, changing food preferences with increased demand for meat, milk and eggs have been associated with population growth, urbanization and increased incomes (McDermott *et al*., 2010). In Kenya, change in consumer perception owing to improved husbandry systems with improved hygiene has also contributed to increased demand for pork and pork products. The new constitutional dispensation that established County governments has been instrumental in enforcement of laws that relate to disease control, public health and food safety owing to their proximity to value chain actors. This has contributed to improved consumer confidence in the quality of pork offered for sale. Increased demand for pork has therefore served as an incentive to producers through market price signals.

1.1.2 Quality and cost of pig feeds in Kenya

Among the major challenges that threaten sustainability of the pig industry in Kenya are access to quality feeds and socio-economic and political factors attributed to value chain governance. Pigs have a simple (monogastric) digestive tract and therefore require a diet that is well balanced and has sufficient essential amino acid levels and easily digestible energy sources devoid of anti-nutritional factors. Among the most commonly used protein sources in the animal feed industry in Kenya are fish meal, cotton and sunflower seed cakes and soybean meal. Cereal processing by-products constitute the bulk of feedstuffs used in animal feed processing in Kenya.

High costs of feedstuffs coupled with poor quality remain serious challenges to the pig industry. The high cost is attributed to a high demand against low production of feedstuffs in the East African region, that is, a demand of 6 million metric tonnes against a production of 1.7 million metric tonnes (Kilimo Trust, 2017). This deficit is likely to increase as a result of the rapidly growing animal resource sectors in Uganda and Tanzania. Over 70% of the cereal bran and oil seed cakes used in the feed manufacturing industry in Kenya are imported from Uganda and Tanzania. Kenya imported 25,848 tonnes of maize and rice bran and 29, 534 tonnes of sunflower and cotton seed cakes in 2013. An average of 766 tonnes of soybean cake was imported annually into the East African Community (EAC) states from 2011–2015 where Kenya's feed industry consumed about 70% (Kilimo Trust, 2017).

Poor quality of feedstuffs has been as a result of high levels of mycotoxins above recommended levels of 10ppb and adulteration. Afflatoxins are the most important mycotoxins in pigs and are produced mainly by *Aspergillus flavus* and *Aspergillus parasiticus* in maize, soybeans and peanuts. Afflatoxin levels of up to 200ppb in feeds could produce clinical signs in pigs while levels of 300ppb could be fatal. Effects of afflatoxins include reduced growth, liver damage with subsequent hepatic failure and jaundice and reproductive problems such as infertility, abortions and agalactia. Afflatoxins are also immunosuppressive and therefore may increase severity of concurrent diseases. Adulteration of fish (menhaden) with sand is often done by unscrupulous traders to increase weight. This practice has obvious negative impact on processed feed quality, cost of feeds and performance of pigs offered such feeds.

The sunflower and cotton seed cakes are limiting as protein sources for pigs due to their amino acid composition which is deficient in lysine - the 1st limiting amino acid, and the high dietary fibre content thereby decreasing their protein value. Soybean meal is well balanced in amino acids and its use has increased owing to the declining availability and high cost of fishmeal. Milling by-products of wheat, maize, rice and barley commonly used in pig feeding among many smallholders (Katongole *et al.,* 2012; Montsho and Moreki, 2012) are high in crude fibre (CF) and non-starch polysaccharides (NSP) which reduce the digestibility of feeds by increasing viscosity of digesta.

Some of these raw materials may contain anti-nutritional factors that interfere with digestion and utilization of nutrients while others are toxic to livestock. For example, cotton seed cake contains gossypol which is a toxic polyphenol present in seeds. Signs of gossypol toxicity in pigs include laboured breathing and deaths associated with heart failure and resultant oedema, hydrothorax, lung oedema and hydropericardium due to venous stasis (Gagne *et al*., 1968; Smith and Clawson, 1970). Most cereals and their by-products contain phytates which is the storage form of phosphorous. Phosphorous in this form is unavailable for absorption because pigs lack the enzyme phytase. The excess phosphorous is excreted and could be an environmental concern due to eutrophication.

Feeding cost account for up to 80% of the total costs in pig enterprises. As a result, smallholder farmers use alternative feed resources such as home-made feeds, institutional swill, farm residue, food processing and market waste to reduce losses that arise from high cost and poor quality of commercially compounded feeds. These feed resources often lack sufficient nutrients or are imbalanced in their nutrient content which leads to poor growth and reproductive performance. Information on the nutritional values of these feed resources is hardly available. There is need to improve quality by adding value using biotechnologies like exogenous enzymes to overcome challenges associated with the use of alternative feed resources in pig diets.

1.1.3 Value chain governance

Value chain governance also poses a threat to sustainability of smallholder pig production. Governance refers to coordination and linkages between actors in the value chain. It determines who acquires the means of production, market access and how benefits are distributed among actors (Ouma *et al*., 2017). Value chain governance structures are classified depending on the level of integration with spot market governance at the lowest level of integration. Majority of smallholder agricultural enterprises have features of spot market governance owing to the scale of production and erratic production patterns which are dependent on weather patterns. Spot market governance has the disadvantage of increased transaction costs due to opportunistic behaviour of some actors, increased uncertainty and lack of asset specificity. Features of value chain governance include technology adoption, market access, product quality and work quality therefore influence the competitiveness of pig enterprises.

Value chain governance aspects that suppress ease of market access to smallholder pig farmers in Kenya include; market dominance by fully integrated firms such as Farmers Choice Limited, lack of statutory support (lack of a pig production policy in Kenya) (Githigia, 2013), inadequate disease control associated with lack of capacity resulting in losses due to mortalities and lack of meat inspection especially where home slaughter is common owing to lack of or inaccessibility of licensed slaughter slabs. Cultural attributes constitute an important aspect of value chain governance. African societies are generally paternalistic and this plays a major role in access to factors of production to women and youth and may impact on their competitiveness. Pig value chain governance in Kenya lacks coordination and linkages between actors in the value chain. The activities in the value chain are not completely integrated. Spot markets are characterised by many buyers and sellers, little information sharing and price plays a centre role while hierarchical governance is characterised with elaborate contractual arrangements.

This study therefore evaluated daily nutrient allowances associated with feeding decisions, bio-economic gains associated with nutritional interventions and the influence of value chain governance features on enterprise performance.

1.2 Statement of the problem

Smallholder farmers in Kenya are increasingly adopting pig production to gain from expanding market opportunities associated with increased global and local demand for pork and pork products. The performance of these enterprises is constrained by weak feeding management decisions and socio-economic and institutional factors that characterise value chain governance. Growth of the livestock resource industry in the East African Community countries has led to increased local demand and price of animal feedstuffs owing to the fact that Kenya imports about 70% of its animal feed raw materals from the region. Smallholder pig farmers are using locally available alternative feed resources to benefit from lower cost of feed input. Nutrition decisions are however difficult under situations of lack of information on nutritional values, implication on performance and posible biotechnological interventions. There is hardly any information on pig value chain governance and its association with enterprise competitiveness in the Kenyan context. This study focussed on designing interventions that address socio-economic and institutional challenges so as to contribute to improving sustainability of smallholder pig production.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study was to characterise alternative feed resources used in smallholder enterprises in Kenya, evaluate biotechnology that improves their efficiency and to estimate the role of value chain governance in enterprise competitiveness with the aim of contributing to reducing production costs.

1.3.2 Specific objectives

The specific objectives of this study were;

i. To compare the daily nutrient allowances associated with selected alternative feed resources (AFR) used by smallholder farmers in Kenya against the recommended daily allowance and their association with reproductive performance.
ii. To estimate bio-economic values associated with inclusion of selected AFR in diets for weaned pigs.
iii. To estimate the benefits of exogenous multi-enzyme supplementation in selected AFR-based diet offered to weaned pigs.
iv. To determine the effects of selected AFR-based diets on carcass characteristics and gut morphology of finishing pigs.
v. To estimate the effects of value chain governance on the competitiveness of smallholder enterprises.

1.4 Research hypotheses

The study sought to test the following hypotheses;

i. The daily nutrient allowance for dry matter (DM), crude protein (CP) and metabolisable energy (ME) in alternative feed resources (AFR) are not significantly different from the recommended daily allowance (RDA) for DM, CP and ME and have no significant association with reproductive performance.
ii. Inclusion of selected AFR in isocaloric weaned piglet diets has no significant influence on average daily feed intake (ADFI), average daily weight gain (ADG), metabolisable energy: ADG (ME: ADG) ratio and feed cost: ADG (FC: ADG) ratio.

iii. Inclusion of exogenous multi-enzyme complex in selected AFR diet of weaned piglets has no significant influence on feed digestibility, ADFI, ADG, ME: ADG ratio and FC: ADG) ratio.
iv. Inclusion of selected AFR in diets of finisher pigs has no significant association with variation in carcass characteristics and gut morphology.
v. There is no significant relationship between value chain governance features (technology use, quality control, market access and labour conditions, production efficiency) at the production node and competitiveness of smallholder pig enterprises in Kenya.

1.5 Justification of the study

Smallscale pig farming plays an essential role in the livelihoods of many families in the developing world and has great potential to reduce poverty (Lanada *et al*., 2005; Mutua *et al*., 2010). In Kenya, pig production provides an opportunity for value chain development due to the low requirement for land and a quicker return on investment compared to other domestic livestock. This is attributed to pigs ability to farrow at least twice annually with large litters of up to 14 - 16 healthy piglets each. Locally, there has been increased acceptance of pork with an increase in *per capita* consumption.

Trends in increasing competition for available livestock feed resources in the EAC, increasing competition between man and livestock for cereals and some proteins, production of biodiesel from cereals (FAO, 2008), the changing weather patterns with erratic rainfall associated with global warming and Africa's dependence on rain fed agriculture pose serious challenges for sustainability of the animal resource industry due to insufficient animal feed supply. Weak coordination and linkages between value chain actors aggrevates the situation. This calls for research that is geared towards addressing beneficial use of alternative feed resources.

Kenya's increasing population with 35% being between 15 - 35 years of age and a youth unemployment rate of 67% should be of concern to policy makers with the view of attracting them into agriculture. This can only be practical if participation in the value chain offers work opportunities are decent.

The information generated from this study will be beneficial to investors in pig production enterprises, particularly the small and medium scale producers, feed manufacturers, researchers, agricultural extention workers and by extension to other players in the pig value chain.

1.6 Ethical approval and animal welfare issues in research

Requisite authority to conduct the study was obtained from the National Commission for Science, Technology and Innovation (NACOSTI); which issued a research clearance permit number 15393 (Appendix I). Authority to use farm animals for the study as well as the pig unit was obtained from the Egerton University Tatton Agricultural Park farm committee (Appendix II). Authority to use live animals as experimental units was also obtained from the Institute of Primate Research which issued a research proposal approval reference number ISERC/11/2017 (Appendix III).

1.7 Definition of terms

Alternative feed resources: Refers to the range of feeds available to the smallholder, any feed material other than conventional commercially blended feeds provided to pigs as part or whole of their diet. It is also defined relative to a set of commonly used feed resources which vary depending on geography (Saddoris-Clemons *et al*., 2011).

Biotechnological interventions: Refers to the application of biologically active material to an animal so as to influence animal functions such as production and reproduction.

Decent work: Refers to conditions of work that promote opportunities for men and women to obtain decent and productive work in conditions of equity, security and human dignity (Anker *et al*., 2002).

Decent work deficits: The International Labour Office of the United Nations recognizes work characterized by decent work deficits as that which does not promote opportunities for men and women to obtain decent and productive work in conditions of equity, security and human dignity.

Exogenous enzymes: Refers to exogenous compounds that can be included in animal feeds with the intention of enhancing the digestibility of specific feed components. These enzymes are usually not produced in the gut of target animals.

In-vitro microbial degradation: Refers to digestion of feed material by anaerobic bacteria obtained from a section of the gastro-intestinal tract and is conducted in an artificial environment that mimics that of fermentation chambers in the gut.

Smallholder pig farmer: According to FAO (2012), a farmer who has 50 or less pigs in total is recognized as a smallholder pig farmer.

Value chain governance: Value chain governance characterises the linkages between actors in the chain and how these linkages affect the flow of a product from one node of the value chain to the next (Ouma *et al*., 2017). Value chain governance therefore focuses on the product, the process, production environment and market logistics (Dolan and Humphrey, 2000; Geraffi *et al*., 2005).

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CHAPTER TWO

LITERATURE REVIEW

2.1 Intoduction

Trends for demand for animal protein have shown a consistent increase which has been associated with population growth, rapid rise in urban population (FAOSTAT, 2014), changing food preferences associated with a rise in the middle class with higher incomes that is demanding a diet that includes milk, meat and eggs among other nutritious foods (KMDP, 2013). The projected global consumption for meat is expected to increase to 13.3 million metric tonnes by 2025.

The current global consumption of pork is much higher than any of the other terrestrial meats. China is the world's largest producer and consumer of pork. In 2014, the global production of pork stood at 109.9 million metric tonnes with China accounting for about 50% of this production (FAOSTAT, 2014). Other important producers of pork include the European Union countries especially Germany, the United States of America and Brazil.

In Kenya, meat consumption increased from 361,115 tonnes in 1991 to 606,169 tonnes in 2007, representing a per capita increase from 14.9 Kg to 16 Kg. Poultry and pork account for 19% of meat consumed in Kenya with a *per capita* consumption of 1.1kg of which pork constitutes 0.4kg. (Bett *et al*., 2012; MOALF, 2015). In 2012, the estimated demand for pork was 16,200 metric tonnes and was expected to grow by 400 metric tonnes annually. In the year 2013, the country produced 14,000 metric tonnes of pig meat (FAOSTAT, 2014) indicating a deficit in production. Kenya's export for pork and its products has in the last few years exceeded that of mutton, goat and beef combined. Farmers Choice limited exports 2000 metric tonnes to 15 countries in Africa, Asia and the Middle East. Exports include special meat cuts and value added pork products like sausages, ham and bacon.

2.2 Pig production in Kenya

There has also been a significant growth in pig population between 2007 and 2013 relative to cattle and chicken as seen in Figure 1 in response to the growing demand. Among the factors that have contributed to a shift in choice of livestock enterprise in favour of pig production include increasing demand for pork, higher rate of return on investment and higher feed efficiency (Kagira *et al*., 2010a).

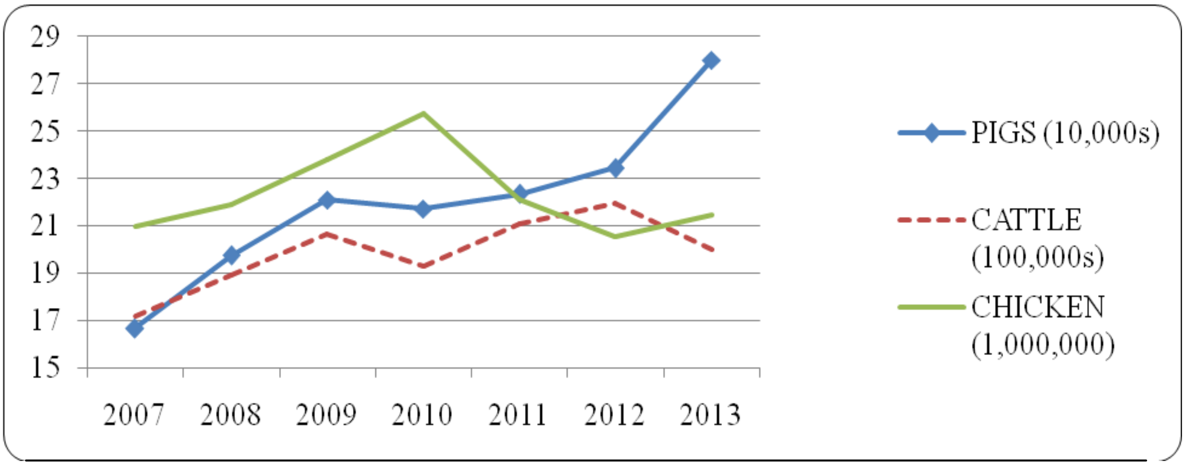

Figure 1: Trend in growth of pig, cattle and chicken population *(Source: FAOSTAT, 2014)*

2.2.1 Contribution of the pig industry to household incomes in Kenya

Pig rearing is an important source of household income for all types of production. In traditional systems, the sale of piglets or finished pigs provides money for immediate needs such as school fees, hospital bills, clothing and building houses, thereby providing income security for these farmers. In many cases, pigs reared in this system constitute an important source of food for these families (Ouma *et al*., 2014). In the small, medium and large scale commercial farms, production is driven by profit either through sale of breeding stock to smaller producers or sale of finished pigs for slaughter.

2.2.2: Pig Production Systems in Kenya

Backyard systems are the main systems of production in Western Kenya and Nyanza regions while commercial systems are predominant in Eastern and Central Kenya regions. The high mortality rates and low reproductive rates that characterize the free range system of production are associated with poor nutritional quality of available feeds. Poor productivity in this system is also related to lack of supplementary feeding, lack of proper health care, poor housing and inbreeding (Kagira *et al*., 2010a).

Smallholder farmers who practice the free range system of pig production in western Kenya (Table 1) own small parcels of land with an average of 3.6 pigs per family. About two thirds of these pigs are tethered and are not housed (Kagira *et al*., 2010a). This study also showed that most of the pig enterprises in the free range system are managed by women, majority of whom receive advice from other farmers. Only 5% of the pigs are supplemented with commercially compounded feeds. Feed resources in this production system consist of a variety of alternative feed resources as shown in Table 2.

Table 1: Distribution of pig holding in Kenya

Province	Pig population	Commercial sector	Traditional/ Backyard
Western	87,838	3,512	84,325
Rift Valley	48,495	14,579	35,654
Nyanza	27,612	900	26,712
North Eastern	68	68	0
Eastern	43,480	35,654	7,826
Coast	5,243	5,243	0
Central	91,977	75,421	16,556
Nairobi	29,976	13,976	16,000
Total	**335,301**	**149,965**	**187,073**

(*Source*: *KNBS 2009 Census; MOLD, Department of livestock Production Estimates, 2010*)

In a study by Doward *et al.* (2001), most of the rural poor households in Mexico keep pigs which they feed on maize thus raising competition for the cereal between man and animals. Most of the poor farmers sell the young piglets to meet domestic demands for income, thereby earning very low incomes. This study concluded that improving the standard measures of performance may not be beneficial to smallholders unless they have the resources to feed the pigs to maturity. Therefore, better management of feeding systems especially using alternative feed resources such as forages would offer the greatest potential for improvement.

Smallholder intensive pig production system is common in Central Kenya, Nairobi and the mid-rift regions with producers keeping a highly variable number of pigs that may vary from less than ten up to one hundred. The major challenge among small scale intensive producers is the high cost and poor quality of feeds. Since majority of these producers are often in close proximity to major urban centres, the use of alternative feed resources from markets, institutions and farms is common. This practice significantly reduced the cost of feeding; however, there is limited information on the effects on overall performance of these enterprises.

Significant numbers of commercial systems are found in Rift valley and Nairobi (Kagira *et al.*, 2010b). Under commercial systems, breeding stock is obtained from established large scale farms such as Farmers Choice Limited and reared under confinement. Large scale commercial establishments keep up to 30,000 pigs. They are involved at all levels of the pig value chain. Some large commercial producers formulate and mix their own feed rations and enjoy the benefit of economies of scale.

Table 2: Types of feed resources among smallholder pig farmers in western Kenya

Types of feed given	Number of households	Percentage in sample
Left over from household	106	58
Ugali (Meal prepared from maize meal flour)	103	57
Vegetables and sweet potato vines from farm	94	52
Market waste and swill from hotels	90	50
Omena fish (*Rastrineobola argentae*)	61	34
Fruits (Pawpaw, Avocado, Guava)	25	14
Cassava peelings and tuber	20	11
Brewers spent grain	12	7
Commercial sow and weaner meal	10	5

(*Table adopted from Kagira et al., 2010a*)

2.2.3 The pig value chain in Kenya

There are about 8000 pig farmers in Kenya, majority of who are small scale farmers (MOALF, 2015). Large scale farms mainly Farmers Choice Limited serves as the source of breeding stock for their own farms, their contract farmers and also many small to medium scale farmers. They also slaughter, grade, process and market pork and pork products from their farms and from their contract farmers.

Most small scale farmers do not produce pigs for breeding, rather for the pork market in local shopping centres and towns. Slaughter is often done at home or in small slaughter slabs owned by other farmers. The market for pork and pork products is well segmented with different pork products for each market segment. These vary from pork cuts in small butcheries in local towns to processed meat product for the local and export market. The pig value chain is supported by other actors such as the relevant government departments for quality assurance, public health inspection and licensing services. The financial service providers are also important players in financing production, processing and marketing functions.

In Kenya, marketing of pigs is unique in that unlike for other livestock, there are no markets for live pigs (Kagira *et al*., 2010a). Mature pigs are sold from the farm and transported to slaughter slabs near urban centres. In the rural setup, pigs are slaughtered and distributed within the locality. Pigs slaughtered in slaughter slabs are usually inspected by the veterinary department while those slaughtered at home are not. Farmers call in butchers or traders when they have mature pigs, who incur the costs of transporting the pigs to the slaughter facility.

2.2.4 Policy and regulatory framework

Among important policies relevant to pig production is the Kenya Vision 2030, the economic blueprint for the countries development up to the year 2030. It identifies agriculture as one of the key pillars of development. The Agricultural Sector Development Strategy institutionalizes Vision 2030 in the Ministry of Agriculture Livestock and Fisheries (MoALF). The national Livestock Policy was developed in 2008 to counter the challenges that arose as a result of the government's implementation of liberalization policies in the 1990s. This policy was also informed by the Economic Recovery Strategy for wealth and employment creation.

The Department of Veterinary services in MoALF enforces a number of acts of parliament that affect the pig industry on behalf of the government. The Animal Diseases Act Chapter 364 of the laws of Kenya empowers the minister to control diseases, gazette diseases as notifiable, control animal movement among other functions. The Meat Control Act Chapter 356 regulates operations in abattoirs, meat inspection and movement. Other relevant laws include the Pig Industry Act Chapter 361 and the Prevention of Cruelty to animals Act Chapter 360 of the laws of Kenya.

There is an increased need for adopting good agricultural practices, proper hygiene, traceability and attention to drug residues in food products for producers to be integrated into global value chains. It is therefore critical that such standards are adhered to with government creating an enabling environment beside regulation.

2.2.5 Constraints along the pig value chain

Though the pig production sector is experiencing positive growth, there are many challenges that may affect its sustainability. Key among these is the availability of good quality feeds and high cost of raw materials (KMDP, 2013). Feeding constitutes the greatest cost in raising pigs and affects the pig's performance and sustainability of the subsector. The poor quality of ingredients as well as concentrates and unavailable local sources of vitamins and amino acids are a significant challenge. Pig farmers resulted to formulating their own pig and poultry feeds as a coping strategy arising from the high cost of commercially blended feeds. Most of these feeds however were reported to be nutritionally inadequate resulting in decreased production efficiency. This has been attributed to use of improper formulae and adulterated feed ingredients (MAAIF, 2005). Quality assurance of raw materials for compounded feeds is a major bottleneck to standardized feeds. The Kenya feed industry does not have adequate standards for ingredients and quality control of the by-product and additives imported for the feed industry (KMDP, 2013). As a result, the feed industry has often carried the blame for substandard feeds arising from adulterated raw materials.

Poor husbandry practices and weak adoption of technology are also a serious constraint to pig production in Kenya. Tuitoek and Kosgey (1999) highlighted shortage of breeding stock as an impediment to improved production leading to undesirable practices such as inbreeding (Wabacha *et al*., 2004; Kagira *et al*., 2010a). The main challenges in pig production in sub-Saharan Africa include high feed prices, inadequate slaughtering facilities, unorganized marketing, poor marketing infrastructure, poor breeding stock, inbreeding, poor hygiene, improper housing, disease outbreaks such as African swine fever, lack of credit and a weak policy framework for pig production and inadequate extension services.

Actors in the pork market including live pig traders, butchers and owners of pork outlets also face similar challenges. Among those reported by Kagira *et al*. (2010b) included; conflict with regulatory authorities, poor mode of transport, competition with meat from other animals, low purchasing power of consumers in the rural set-up, high cost of doing business, high labour cost, losses from condemnation of carcasses and organs and unavailability of government meat inspectors when required.

Despite the challenges discussed, there have been concerted efforts by pig farmers and the government, through relevant ministries to overcome a number of these challenges through formation of an umbrella body of pig producers, The Kenya Pig Farmers Association (KENPIFA). This association has been instrumental in lobbying for the enactment of the National Pig Development Strategy 2013-2018. The objectives of this policy are to increase pig production, promote value addition and market access, create an enabling environment, to facilitate financing of the pig industry and to facilitate mainstreaming of cross-cutting issues such as gender issues and HIV/AIDS so as to promote inclusive job creation.

2.3 Pig nutrition

This section provides background information on dietary nutrient requirements for pigs.

2.3.1 Characteristics of the digestive system of pigs

Pigs are generally omnivorous and have the ability to utilize a wide variety of feedstuffs. Pigs have a simple gastro-intestinal tract and also have the ability to ferment feedstuffs in the caecum and colon and therefore referred to as hind-gut fermenters (Pastorelli *et al*., 2014). At birth, the digestive system of piglets is usually sterile but the environment quickly changes with colonization of the gut by microorganisms from the sows reproductive tract and feaces associated with coprophagia in piglets. The stomach and the anterior small intestines contain a relatively lower number of microorganisms as a result of the unfavourable acidic pH and rapid digesta flow (Bederska-Lojewska and Pieszka, 2011).

Efficient and profitable swine production depends on a proper understanding of concepts of genetics, environment, herd health, management and nutrition. An interaction between these factors determines the level of production and profitability. Broadly, the nutritional requirements of pigs for maintenance, growth reproduction and lactation include energy, amino acids, minerals and vitamins (NRC, 1998).

2.3.2 Dietary energy for pigs

All forms of energy can be converted to heat energy and therefore, it is convenient to express all energy changes in terms of heat. When a substance is completely burnt to its ultimate products of oxidation, carbon dioxide, water and other gases, the heat energy given off is considered as its gross energy (Voet and Voet, 1990; NRC, 1998). Carbohydrates, proteins and fats provide energy through oxidation and have a caloric value of 4.1, 5.7 and 9.4 respectively. Minerals and water however contribute no energy (NRC, 1998). Energy requirements of pigs vary with body weight since basal metabolism and maintenance requirements increase with live weight (Noblet *et al*., 1993; Adesehinwa, 2008). The amount of energy in feed controls the amount of feed consumed *ad libitum* daily since it will compensate for increase or decrease in nutrient density.

Glucose and lactose are the most efficiently utilized sources of energy in piglets below 7 days of age. Fructose and sucrose fed to this group resulted in severe diarrhoea, weight loss and mortality associated with pathogenic microflora (Bederska-Lojewska and Pieszka, 2011). Pigs younger than 3 weeks fed on starch diet performed poorly because they lacked sufficient levels of pancreatic lipase, thereafter they develop the ability to utilize starch efficiently (Cunningham, 1959).

Gross energy is the energy liberated when a substance is combusted in a bomb calorimeter and is dependent on its carbohydrate, protein and fat composition (NRC, 1998). GE of a feedstuff can be accurately estimated if its proximate composition is known. Mavromichalis (2006) estimated this relationship using values for ether extract (EE), crude protein (CP) and ash as follows:

GE = 4143 + (56 X % EE) + (15 X % CP) - (44 X % ash), R^2 = 0.98 -------Equation 1.

Digestible energy (DE) of a feed refers to the GE intake of the feed minus the gross energy of feaces. Faecal metabolic energy is however not considered in DE computation. Noblet *et al*. (1994) reported the following relationships between the chemical components of feed and DE:

DE = 4151 - (122 X % Ash) + (23 X % CP) + (38 X % EE) - (64 X % CF), R^2 = 0.92 --Equation 2**.**

DE = 949 + (0.789 X GE) - (42 X % Ash) - (41 X %NDF), R^2 = 0.96 ---- Equation 3.

The digestibility coefficient of energy (DCe) refers to the DE: GE ratio which is greatly influenced by the presence of dietary fibre (DF) (Noblet, 2006). This is because DF is less digestible than other nutrients. DCe is linearly and negatively related to dietary CF and increases with increasing body weight due to the increasing digestibility of dietary fibre (Gall *et al*., 2009). DE of a feed resource can also be estimated as:

DE = GE X DCe (Noblet, 2006) ---Equation 4.

Metabolizable energy (ME) refers to DE minus the GE of urinary and gaseous loss. The loss of energy in form of gas varies between 0.1 - 3% of DE is therefore often ignored (Shi and Noblet, 1993b). ME can be estimated as follows:

ME = DE x [1.003- (0.0021 x % CP)], R^2 = 0.98 ---------------------------- Equation 5.

Net energy (NE) refers to the difference between ME and heat increment associated with digestive and metabolic processes. NE is therefore the energy that an animal uses for production and maintenance (NRC, 1998).

The estimation of the energy content of pig feed is mainly based on DE and ME though NE is the closest estimate of the true energy value of feed (Noblet *et al*., 1994; Noblet and van Milgen, 2004). Most of the energy lost in gases is due to methane which typically is minimal in growing pigs and therefore commonly ignored in literature. Noblet *et al.* (1994) reported the value of methane loss of approximately 0.4% of digestible energy value of feed. However, this loss is significant in adult pigs (Le Goff and Noblet, 2001) as a result of a longer residence time of ingesta in the digestive tract (Shi and Noblet, 1993). This is explained by extensive fermentation of fibre in the large intestines by a wide spectrum of obligate anaerobic microbiota (Wang *et al*., 2004) which includes *Prevotella ruminocola, Selenomonas ruminantum, Butyrivibrio fibrisolvens, Lactobacillus acidophilus, Peptostreptococcus* species and *Eubacterium aerofaciens*. The microbial population in the large intestines amounts to 10^{11} to 10^{12} colony forming units (cfu) per gram of digesta (Bederska-Lojewska and Pieszka, 2011). The major functions of these microbes include competitive exclusion of pathogens and supply of energy through fermentation which yields volatile fatty acids (VFA) (Wang *et al*., 2004).

Energy loss in urine represents a variable percentage of digestible energy. The amount of urinary nitrogen depends on urinary nitrogen excretion determined by the protein content of the diet (Van Milgen *et al*., 2001).

2.3.3 Dietary protein / amino acid requirements for pigs

Protein generally refers to crude protein (CP) which is determined by obtaining the nitrogen content of a feedstuff and multiplying by 6.25, based on the assumption that proteins contain an average of 16% nitrogen (AOAC, 1990). Proteins are composed of amino acids with varying proportion of amino acids in different protein sources. This means that provision of amino acids to pigs in the correct proportions determines the adequacy of the protein concentrate (NRC, 1998). Formulation of pig feeds should therefore lay emphasis on the amino acid content rather than the crude protein content. This principle is important in meeting pigs' amino acid requirements while at the same time minimizing excess nitrogen excretion (Meisinger, 2010).

The requirements for each of the amino acids follows a concept referred to as ideal protein, where each amino acid is expressed relative to lysine, the first limiting amino acid (Rutherfurd *et al*., 2012; Moore *et al*., 2013). Standard ileal digestible lysine is more often used in place of total lysine because it accounts for the actual amount of lysine that a pig can digest, absorb and deposit as protein. The availability of lysine for protein deposition is subject to available energy. The quality and quantity of protein in the diet affects the relationship between metabolizable energy and digestible energy. Metabolizable energy decreases if protein is of poor quality and with excess protein because the amino acids not used for protein synthesis are catabolised and used as an energy source and nitrogen excreted as urea (Noblet *et al*., 1993).

2.3.4 Dietary fibre in pig diets

Increased demand for high energy cereals for human consumption has availed fibre rich by-products and promoted increased utilization of fibre rich feedstuff for pig nutrition (Le Goff and Noblet, 2001). The ability of pigs to digest more fibrous feeds without compromising performance presents an opportunity to save on feeding cost. In the past, researchers were concerned with the effect of dietary crude fibre on health and performance. However, the development of new analytical methods that determine specific fractions of cell wall components like the van Soest neutral detergent fibre, acid detergent fibre and acid detergent lignin and soluble and insoluble fibre determination has elicited interest in research on fibre fractions in pig nutrition (Dhingra *et al*., 2012).

The digestibility of fibre in pig diets is highly variable and is influenced by the source of fibre, the processing method and concentration in diets (Stanogias and Pearce, 1985; Knudsen and Hansen, 1991). Dietary fibre refers to cellulose, non-cellulosic polysaccharides such as hemicellulose, pectic substances, gums mucilages and a non-carbohydrate component lignin (Dhingra *et al*., 2012). Some fibre types are more digestible than others and though they cannot be broken down by mammalian enzymes, they can be fermented in the hind gut. They are termed as non-starch polysaccharides (NSP) which constitute up to 90% of plant cell walls, mainly cellulose, hemicellulose and pectins. Other less abundant NSP include fructans, glucomannans, galactomannans and β-glucans (Kerr and Shurson, 2013). NSP are partially fermented in the hindgut to produce VFA such as acetate, propionate and butyrate which are rapidly absorbed and supply up to 28% of maintenance energy requirements of pigs (Kerr and Shurson, 2013).

Feeding rations high in dietary fibre increases gut weight with heavier stomach, ceacum, colon and a longer colon (Jorgensen *et al*., 1996). This has been associated with increased proliferation of intestinal epithelial cells leading to increased enterocyte turnover rate (Jin *et al*., 1994). Increase in endogenous fluid secretion such as saliva, gastric juice and pancreatic juice has also been documented by Zebrowska *et al*. (1983) and Wenk (2001). Addition of fibre to pig diet decreases both DE and ME and results in bulky feed (Noblet *et al*., 1993; Gall *et al*., 2009). Gums and pectins increase the viscosity of digesta and water retention. High fibre diets also contribute to earlier satiety as a result of signals from tension receptors on the stomach wall (Kerr and Shurson, 2013). When dietary crude fibre exceeds 10 - 15% of the diet, feed intake in pigs may be depressed as a result of decreased palatability. Increasing dietary fibre was also found to significantly reduce the digestibility of all macronutrients (Gall *et al*., 2009).

2.3.5 Dietary lipids

Linoleic and linolenic acids are essential components of plasma membranes in the brain, nervous system and vascular system making them critical components during rapid tissue formation in gestation and fetal growth (Chen and Chiang, 2005). Cell membranes are made up to a large extent of essential fatty acids (EFA). Hence the formation of new cells during growth requires a constant supply of EFA. Cell growth is not only a function of proteins but equally of EFA availability. Young growing animals and gestating sows are most susceptible to EFA deficiency. Deficiencies of Omega 3 fatty acids and an imbalance in the proportions of these EFA impacts negatively on piglet survival and immune functions (Kim *et al.*, 2007).

In growing-finishing pigs, fat supplementation improves growth rates, reduced feed intake due to higher dietary energy and increased backfat thickness (Coffey *et al*., 1982; Benz *et al*., 2011). The fatty acid composition of dietary fat also results in altered pork fatty acid composition leading to altered pork quality and shelf-life (Wood *et al.*, 2008)

2.4 Evaluation of feed nutrient composition and animal performance

2.4.1 Nutrient composition

Proximate analysis includes the determination in biological material of moisture, ether extract (EE), crude protein (CP), ash, crude fibre (CF) and nitrogen free extract (NFE). The determination of these fractions is frequently the starting point for more detailed analysis of specific nutrients and is the basis for total digestible nutrient (TDN) (AOAC, 1990). TDN is used to express the total energy content of a feed. The Van Soest analysis (Detergent Fibre Technique) (van Soest, 1967) overcomes most limitations of the proximate analysis. It separates the overlap of CF and NFE. The technique divides forage organic matter into two classes; a) Cell contents and b) Cell wall components. Cell contents include lipids, sugars, organic acids, starch, non protein nitrogen (NPN) and soluble proteins (AOAC, 1990). Cell wall components include hemicellulose, fibre bound proteins, lignin, cellulose and lignified nitrogen (Kerr and Shurson, 2013).

2.4.2 *In-vivo* digestibility test

In-vivo digestibility tests are applied to obtain the apparent digestibility (APPD) of a feed resource. A known amount of feed under test is fed to an experimental animal whose feed intake is predetermined. Fecal output is precisely measured. The digestibility of a feed is computed as:

$$\% \text{ Apparent digestibility} = \frac{\text{Feed intake} - \text{Faecal matter}}{\text{Feed intake}} \times 100 \text{ --------------------Equation 6.}$$

The limitation of apparent digestibility is that it does not take into account losses in feces that are of endogenous origin, for example through cell disquamation, bacterial debris and through sweat. To overcome some of these limitations, the indirect method which involves use of dietary markers are used. Such markers must be totally indigestible and unabsorbable, should have no pharmacological action on the gastrointestinal tract, should have uniform passage in gastro-intestinal tract and readily determined chemically and preferably a substance naturally present in feed (Jagger *et al*., 1991). By determining the ratio of the indicator to that of a nutrient under investigation in the feed and in the feaces, then digestibility can be determined without doing feed intake and fecal output determination.

2.4.3 *In vitro* gas production technique

The basic principle of all gas production techniques is that *in-vitro* microbial fermentation of feeds is accompanied by gas production. The rate and extent of fermentation can be measured by the volume of gas produced. The technique was initially used to assess digestibility and ME in ruminant feeds was later used with other animals such as rabbit, horse, ostrich and pigs (Cone *et al*., 2005; Bindelle *et al*., 2007; Bauer *et al*., 2010; Pastorelli *et al*., 2014). The technique requires the creation of an environment that mimics a particular section of the gastro-intestinal tract (GIT) for a given set of parameters. In mono-gastric animals, feaces collected from the animal *per rectum* provide inoculum that is representative of the microbial flora in the caecum and colon (Bauer *et al.*, 2001). This technique has an advantage in that several animals can be used as feacal donors for inoculum preparation at the same time thereby giving statistical significance to the test. It also has an advantage over fistulation associated with its contribution to animal welfare. It is also easier to collect faeces from a pig than adequate quantities of fluid from a fistulated animal (Pastorelli *et al*., 2014).

Mauricio *et al*. (2001) obtained comparable results for organic matter digestibility using rumen liquor and inocula prepared from faeces from fistulated cows. Lawman *et al*. (1996) compared gas production kinetics between inocula from equine faeces and caecal fluid and demonstrated that the results were similar. Bauer *et al*. (2004) also demonstrated similar results in fermentation kinetics using inocula from digesta obtained from 3 different sections of the large intestines of pigs.   Bauer *et al*. (2010) used the technique to evaluate the role of different concentrations of ingredients and antibiotics (Viginiamycin) on fermentation characteristics in pigs. Pastorelli *et al*. (2014) used the technique to compare the efficacy of gas production using fresh and frozen faecal inocula from pigs. Cone *et al*. (2005) used this technique to rank concentrates depending on the degradable CP. *In-vitro* gas production technique therefore provides a better understanding of the site of fermentation, giving an opportunity for gut ecology manipulation and health of pigs through use of feed additives. Bindelle *et al.* (2007) however concluded that though pig feaces are a reliable source of inocula used to characterize fermentation kinetics of feed ingredients, it is important to hydrolyze the substrates with pepsin before gas test. A similar approach was used by Tilley and Terry (1969) in evaluating in-vitro digestibility of forages in ruminants. However, in the case of ruminants, hydrolysis with pepsin was done after 72 hours incubation with rumen liqour.

2.4.4 Feed efficiency

The very basic measure of feed efficiency is daily feed intake. The ratio of daily feed intake to average daily gain is known as the feed conversion ratio (FCR). The concept of residual feed intake was proposed in the 1940s and developed further in the 1980s. The trait represents the amount of feed consumed that is not explained by the requirements for maintenance and production (Arthur *et al*., 2009). This method however requires the determination of body composition for computation of the carcass value.

In an ideal situation, the cost of feeds has major influence on the profitability of the feeding strategy employed. When the feed cost is low, the focus will be on feeds that yield the highest average daily gain (ADG). When feed cost is high, the focus will be on feed with high feed efficiency. Feeding strategies can be evaluated using a number of methods including; Revenue over feed, margin over feeds and facility costs. Evaluating for feed cost per kg live weight gain is a better measure because it allows for comparison of ADG and feed efficiency between feeding strategies.

2.4.5 Pig performance measurements

Measures of performance for pigs are based either on feed efficiency such as the daily feed intake and feed conversion ratio or growth efficiency such as the average daily gain, Kleiber ratio and relative growth rate, against certain target periods (Arthur *et al*., 2009).

The basic measures are the start of test live weight, end of test live weight and the average daily gain (ADG). These live weights are computed from a regression of live weight and time. ADG therefore is the regression coefficient on the regression of weight on time in days. Other growth measures described by Arthur *et al*. (2009) include the metabolic weight and the Kleiber ratio. Metabolic weight is computed as (Average of start and end of test live weight)$^{0.75}$. The Kleiber ratio is defined as live weight gain per unit of metabolic weight.

2.4.6 Evaluation of carcass quality

There are several objectives of pig carcass evaluation which include grading for the market and indications of pale soft exudative (PSE) pork, evaluation for genetic improvement and evaluation of pig productivity based on different nutritional (Tartrakoon *et al*., 2015) and management parameters. Killing-out percent (KO %) is expressed as the weight of the carcass as a fraction of the live weight of the pig immediately before slaughter. Several factors may affect KO% including breed, gender, dietary regime, food withdrawal, transport stress (Gosalvez *et al*., 2006) housing and accuracy during weighing. Dressing percentage on the other hand is expressed as the chilled weight at 24 hours as a fraction of live weight of the carcass. Muscling is estimated by determining the loin eye area of the *longissimus dorsi* muscle that has been cut perpendicularly across the long axis at the junction of the 10th and 11th thoracic vertebrae. The loin eye area is determined by placing a plastic grid over the loin eye area or on acetate paper on which the loin eye has been traced. Back fat thickness is obtained by measuring using a ruler the thickness of fat layer over the 1st, 10th and last ribs at a point 6 inches (approximately 14.6 centimetres) lateral from the dorsal spinous process or along the dorsal midline as per the approach used by Rossi *et al*. (2013).

Determination of carcass pH is performed at 45 minutes and 24 hours post slaughter in the *longissimus dorsi* muscle at the last rib using a portable digital pH meter. Rapid muscle acidification soon after slaughter in PSE pork occurs as a result of rapid glycolysis leading to accumulation of lactic acid in muscle tissue. This acidification leads to partial protein denaturation and reduced water holding capacity and a lighter colour accompanied by a higher drip loss (Tartrakoon *et al*., 2015).

2.5 Alternative feed resources in pig nutrition

The use of AFR significantly reduces the cost of feeding besides a reduction in vitamin deficiencies. Feedstuffs which are locally available constitute a natural asset that smallholders use to achieve their goals. Crop residues constitute a significant proportion of AFR and are characteristically fibrous, of low digestibility, and low in nitrogen. However, there are a variety of AFR that are of high nutritional value such as industrial by-products and excess farm produce. There is a wide variety of these AFR since they are widely spread geographically.

The most widely used tuber as a source of pig feed in Africa is cassava which has been used in studies to assess pig performance. In a study by Aro *et al.* (2013), the cost per kilogram body weight gain and gross profit increased significantly when cassava waste products, that is cassava starch residue and cassava peels were incorporated in pig diet in comparison to diets with maize as the control. Potato peels and rejected tubers are widely used in feeding both ruminants and pigs. In western Kenya, besides the sweet potato vines, rejected sweet potato tubers are also fed to pigs (Kagira *et al*., 2010a). Wadhwa and Bakshi (2013) demonstrated that dried ripe banana peels can be fed to growing pigs up to levels of 20% of the diet without having adverse effects on their performance. In the study, they were found to constitute 30% of the weight of fresh banana and up to 8% crude protein, 6.2% ether extract, 13.8% soluble sugars and rich in trace elements. Dried citrus pulp can be used at a rate of up to 50% of the diet of gestating and lactating sows as a replacement for corn in concentrates due to its high energy content. High crude fibre content in pineapple peels limits its use in pigs but is a valuable feed resource for ruminants (Wadhwa and Bakshi, 2013). Fresh carrots contain 10% crude protein, up to 60% sugars and rich in vitamin C and β-carotene (Wadhwa and Bakshi, 2013). Surplus carrot during a glut or low grade carrots disposed at farm level or in the market can be used as an AFR.

Whey is a by-product of cheese processing and contains proteins such as albumin and globulin and lactose. Whey can be used to replace up to 30% of dietary nutrients for pigs (Alaviuhkola and Harju, 1985). Brewers waste consists of extracted residues of grains from the brewing process. The crude protein content of wet brewers waste is approximately 25.3-28% on a dry matter basis (Sakai *et al*., 2015). Though widely used as livestock feed, there is a limitation in its use in finishing pigs because of high levels of unsaturated fatty acids and the fact that it is bulky (Stein and Lange, 2007). Dried brewers waste had 6.3% crude fat and 2080 Kcal/kg of metabolizable energy and a good source of vitamin B and has been shown to be beneficial as an alternative feed resource in broiler chick (Swain *et al*., 2012).

Slaughter slab waste commonly used by smallholder pig farmers constitutes of blood and offal contents (Kagira *et al*., 2010a; FAO, 2012). Blood meal is a rich source of proteins and lysine but deficient in arginine. It is also imbalanced in isoleucine and leucine and has low digestibility. Commercially, blood meal is processed by heating at high temperatures, a process that reduces the availability of lysine. Steam drying and fermentation however overcomes this challenge (Kingori *et al*., 1998). In the smallholder pig farming set-up in Kenya, pig farmers process blood meal by cooking. Kingori *et al*. (1998) compared the outcome on growth of piglets that were fed on either fermented dried blood meal or cooked dried blood meal with the former yielding better growth rates. In this study, fermentation was done by addition of molasses. The processed fermented blood meal and cooked blood meal were sun-dried and ground using a hammer mill and used to formulate test rations.

Home-made rations constitute a significant proportion of AFR mainly by-products of cereal processing. Most of these feeds have however been reported to be nutritionally inadequate resulting in decreased production efficiencies. This has been attributed to use of improper formulae and adulterated feed ingredients (MAAIF, 2005). Institutional swill and domestic kitchen waste are commonly used AFR however, these feed resources are often delivered to the farm in the wet form therefore making them potential growth media and sources of disease pathogens (Kagira *et al*., 2010a).

2.6 Application of biotechnology in pig nutrition

Among the major challenges that animal nutritionists face in feed formulation is the presence of anti-nutritional factors in feedstuffs. Such anti-nutritional factors include trypsin inhibitors, saponins, tannins, phytates, oxalates and high fibre. Soybean meal is the most widely used protein source for pigs. Processing methods often influence the level of trypsin inhibitor in soybean. Solvent extracted soybean meal has low trypsin inhibitor which is high in pressed raw soybean meal. To reduce trypsin inhibitor activity, pressed raw soybean meal should be sufficiently heated (Woyengo *et al*., 2016). Glucosinolates present in canola and cyanogenic glycosides present in flaxseed meal result in reduced feed intake in pigs (Woyengo *et al*., 2016). Phytates are present in all plants in varying quantities. They are however significant in cereals used in pig diets because of their affinity for phosphorous. Presence of NSP in pig diets constitutes a major challenge in pig nutrition as seen in section 2.3.4.

The use of synthetic dietary enzymes has been widely researched with mixed results on digestibility of nutrients and effects on growth and performance in pigs. Some of these effects are shown in Table 3. Supplementation of pig diets with exogenous enzymes has been hypothesised to improve digestibility of energy, protein and fats by reducing viscosity of digesta by acting on NSP. This increases contact between feed and digestive enzymes as well as with the absorptive surface of the gut. Other forms of biotechnological interventions to

Table 3: **Effects of addition of synthetic dietary enzymes in different diets**

Diet/ Substrate	Enzyme	Effects	Reference
Corn DDGS	Xylanase, Cellulase	Decreased NSP	Jacobsen *et al*. (2015a)
	Xylanase, Glucanase,	Increased ATTD of NSP	Jacobsen *et al*. (2015a)
	Protease	Increased AID of GE	O'shea *et al*. (2014)
	Protease, Xylanase	No effect on growth and performance	O'shea *et al*. (2014)
Rapeseed meal	Protease, Xylanase	No effect on growth and performance	O'shea *et al*. (2014)
Wheat DDGS	B-glucanase, Xylanase, Pectinase	Ambigous overall effect on performance	Jacobsen *et al*. (2015b)
	B-glucanase, Xylanase	Disruption of NSP	Jacobsen *et al*. (2015) Cadogan and Choct (2015)
	Phytase	Almost complete reduction of phytate bound phosphorous	Jacobsen *et al*. (2015b)
	Protease	Increased protein solubility	Jacobsen *et al*. (2015b)
Barley, Wheat, Corn	Xylanase, Mannase Protease	No effect on DE and ME	Park *et al*. (2016)
Wheat, Barley	Pytase, Carbohydrase	Increase CID of energy	Kiarie *et al*. (2010)
	Phytase	Increased CID of AA with decreased endogenous loss	Kiarie *et al*. (2010)
Extruded Corn diet	Amylase, Protease, Xylanase	Improved digestibility	Li *et al*. (2010)
Rough rice diet	Xylanase, Cellulase, β-glucanase,	Increased weight gain, feed efficiency Reduced viscosity of gut contents	Wang *et al*. (2008)

DDGS= Distillers dried grains with solubles, ATTD= Apparent total tract digestibility, NSP= Non starch polysaccharides, AID= Apparent ileal digestibility, GE= Gross energy, CID= Coefficient of ileal digestibility, AA= Amino acids

enhance feed conversion efficiency in pig production include the use of probiotics. Liu *et al*. (2015) demonstrated an increase in average daily gain, average daily feed intake, gain: feed ratio and decreased diarrhoea incidence in piglets when fed diets containing *Lactobacillus* *brevis.* The study also demonstrated an increase in gut lactobacillus population and a decrease in faecal coliforms and concluded that *L. brevis* cultures had beneficial effects on growth and performance, immunity and intestinal microflora balance in piglets.

Prebiotics are non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth or activity of desired micro-organisms that are already resident in the gut (Gibson and Roberfloid, 1995). Among non-digestible oligosaccharides that act as prebiotics include, fructo-oligosaccharide, galacto-oligosaccharide, lactulose, lactitol, gluco-oligosaccharide, isomalto-oligosaccharide and xylose-oligosaccharide (Gibson and Fuller, 2000). The mode of action of mannan oligosaccharides is thought to be through stimulation of the immune system and binding and removal of pathogens from the gastrointestinal tract (Spring *et al*., 2000).

2.7 Value chain governance and decent work agenda in agriculture

Among the major objectives of enterprise development in smallholder agriculture is to help meet the challenges of economic development, equity, poverty alleviation, gender mainstreaming, inclusion of underprivileged communities and climate vulnerability. The expected outcome of commercialization is improved productivity through improved competitiveness in smallholder agricultural enterprises (ILO, 2007). Commercialization is useful in creating productive employment opportunities for the rural poor which is an important link for economic growth to ensure poverty reduction, inclusive rural development and more equitable societies.

Decent work sums up the aspirations of ordinary people in their working lives. It involves opportunities for work that is productive and delivers a fair income for the farmer and his employees, security in the work place and social protection for families, prospects for personal development and social integration, freedom for people to express concerns, organise and participate in decisions that affect their lives and equality of opportunity and treatment for all women and men (ILO, 2007; FAO, 2011). Ten thematic areas of decent work include employment opportunities, adequate earnings and productive work, decent hours, combining work, family and personal life, work that should be abolished (mainly child labour and forced labour), stability and security of work, equal opportunity and treatment in employment, safe environment , social security and social dialogue.

Greater opportunities for sustainable employment for men and women waged agricultural workers as well as sustainable livelihoods for self employed farmers and other workers must be generated to enable people lift themselves out of poverty. On the other hand, success in generating employment opportunities and food security depends directly and indirectly on improving agricultural production.

The value chain concept provides a theoretical understanding of the interactions between value chain actors. A value chain constitutes a range of discrete but inter-related activities from production to consumption. The concept is widely used as a facilitation tool for integrating small micro-enterprises into higher value markets (Reji, 2013). Value chain approach is geared towards identifying constraints to growth in a sector and seeking opportunities for improvement by considering interaction between actors, markets and the business facilitation environment. The approach also focuses on productivity by addressing itself to factors such as access to markets, legal, regulatory and policy framework and access to technical and infrastructural support.

Integration of small enterprises into the value chain enables them to become competitive by increasing their operational efficiency, reduction of transaction costs and self-upgrading along the value chain (Reji, 2013). Integration gives leverage to small enterprises and therefore an important determinant of value chain governance. Value chain governance influences access to markets, leverage for policy interventions, technical support from other value chain actors and knowledge and capacity acquisition. Value chain governance analysis allows one to understand how a chain is controlled and coordinated when certain actors have more power than others. It therefore represents authority and power relations that determine how financial, material and human resources flow within the chain (Gereffi and Fernandez-Stark, 2001). Improving coordination of the different actors reduces transaction costs, helps to ensure the quality and safety of products and stimulates the development of marketing strategies (Adetonah *et al*., 2015). Market integration therefore has a causal relation with incomes, market power and decent work.

The International Labour Office (ILO) in Geneva developed four strategic objectives which were adopted by the United Nations (UN) system as the basis for more just and stable framework for global and rural employment (FAO, 2011). These objectives include:-

1). Employment creation and enterprise development

2). Social protection

3). Standards and rights at work

4). Governance and social dialogue; which can be used as the criteria for measurement of decent work deficits.

2.8 Research on smallholder pig production in Kenya and current research gaps

Several researches have been carried out on the pig production sector in Kenya as shown in Table 4, most of which have concentrated on smallholder free-range production systems common in Western Kenya and Nyanza. These studies have been motivated by the need to address the health risks relating to zoonosis associated with this production system while at the same time looking into the socio-economic aspects of the enterprises. Data on pig population is available from reports in the Ministry of Agriculture, Livestock and Fisheries in the Department of Animal Production. Data on disease incidence is also available both at the Regional Veterinary Investigation Laboratories and the County Director of Veterinary Services.

AFR are an important input in smallholder production, however, studies on the feed resources have mainly concentrated on their identification but have not gone further to assess the bio-economic values, degradability in pig gut and in-vitro gas production kinetics using faecal inocula. There is limited published data on potential incorporation of locally available AFR in pig feeds as well as challenges associated with nutritional values. Literature on the use of enzymes to improve digestibility of AFR is scanty.

Table 4: Research in smallholder pig production in Kenya

Research area	Topics of interest	References
Pig production trends in Kenya	Assessment of socio-economic and policy issues affecting the industry	Tuitoek and Kosgey (1999), FAO (2012), Githigia (2013).
Alternative feed Resources	Characterization of alternative feed resources in smallholder production systems	Kingori *et al.* (1998), Peters (2008), Kagira *et al*. (2010a), FAO (2012).
Pig production systems	Epidemiology of internal parasites of pigs in relation to feeding and management strategies	Wabacha *et al*. (2004), Mutua *et al*. (2010), Kagira *et al*. (2011).

Together with efforts to create employment in agriculture through developing and supporting agricultural value chains, there is need to continually evaluate their sustainability which is to a large extent dependent on decent work status. There is no published work that addresses decent work in the pig value chain in Kenya.

2.8 Conceptual framework of the study

The conceptual framework shown in Figure 2 is developed from the sustainable livelihoods approach which is founded on the notion that interventions must be based on factors that underpin livelihoods (Morse and McNamara, 2013). This framework places livelihood strategies at the centre and by establishing partnerships with other players, makes use of available capital assets within certain constraints to achieve projected livelihood outcomes. The intervening variables play a regulatory and support role in the production process. To improve their competitiveness, it is important that producers conform to laid down regulation that govern the industry.

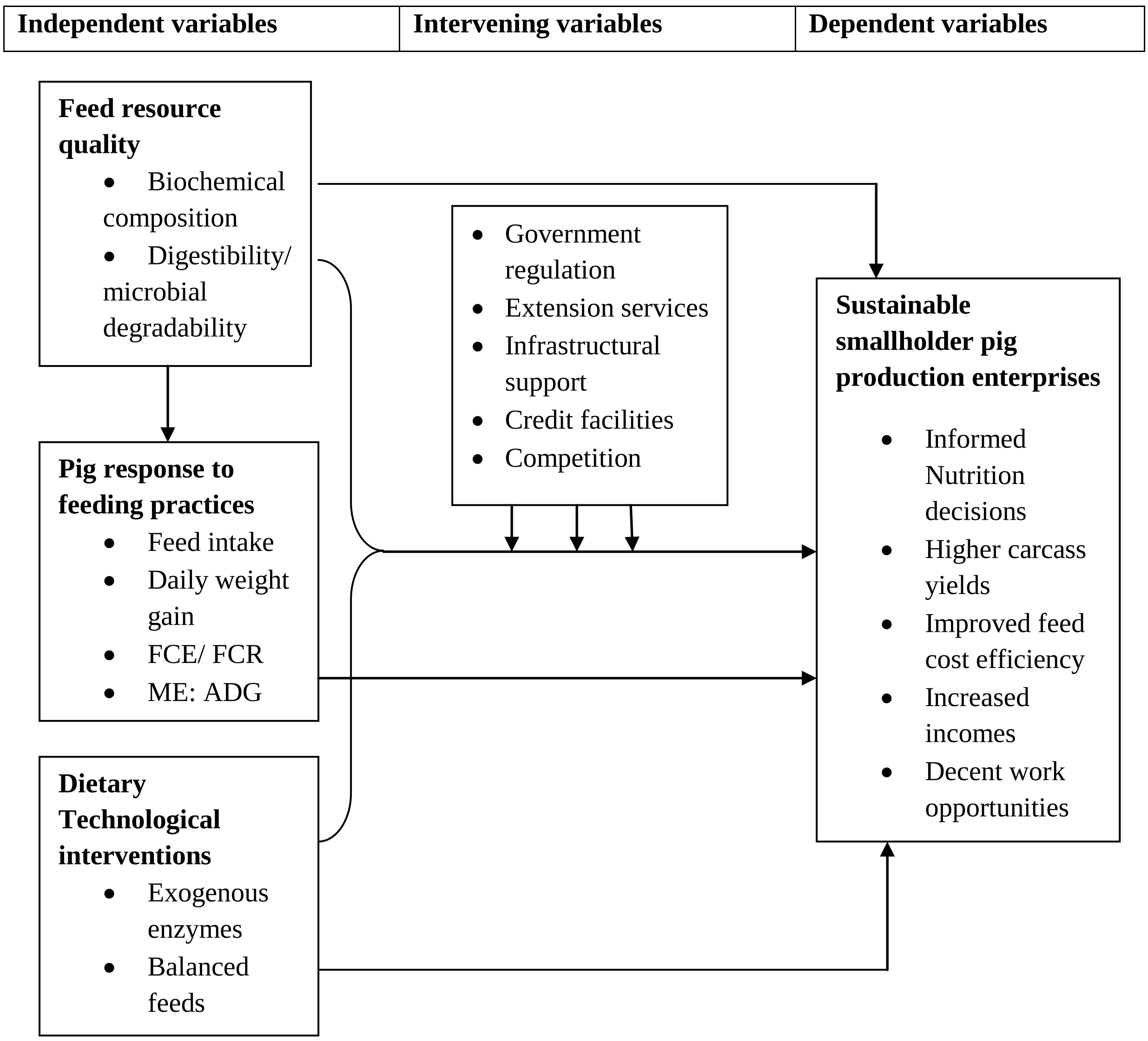

Figure 2: Conceptual framework of the study

determining productivity while competition determines the ease of entry and exit in the industry. Overall, these factors contribute immensely in addressing decent work deficits along agricultural value chains through improved productivity and better market positioning of produce. A typical example in this study would be a situation where pigs are slaughtered at home and sold to neighbours, a practice common in Western Kenya, verses slaughter in a licensed abattoir. In the former case, meat slaughtered from home is unlikely to be inspected by an authorised public health officer and therefore, the consumer is uncertain about the safety of such pork. It is also likely that the neighbours may buy the pork on credit and fail to pay. This implies that market risk in such a situation is high. In the latter case, consumers will be confident about pork from licensed abattoirs because it bears a legal meat inspection stamp while it is also sold in licensed butcheries and other meat outlets. In this case, the pork will fetch better prices whose effect will trickle back to the producer.

Smallholder pig production represents the livelihood strategy, the capital assets represented by feed resource which accounts for up to 80% of total production cost. The intervening variables act either as partners as in the case of government and extension service providers or constraints as with competition. The long term objective of livelihood strategies in agriculture is to achieve sustainability through improved production efficiency, increased incomes, and decent work opportunities.

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CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Introduction

This chapter provides a general overview of the study sites experimental pigs, feeds and protocols with specific details explained in the corresponding chapters.

3.2 The study area

The cross-sectional survey used to provide data for evaluation of alternative feed resources and value chain governance was conducted in Busia, Nakuru and Kiambu Counties as described in section 4.2.1. The Sub-counties involved in the study were selected on *a priori* basis with the assistance of Sub-county livestock officers.

3.3 Experimental pigs

A total of 48 Landrace X Large White piglets weaned at 56 days and consisting of 24 barrows and 24 gilts were obtained from Egerton University Tatton Agricultural Park pig unit. In the first experiment (Chapter 5), 32 weaned piglets were used for analysis while in the second experiment (Chapter 6), 24 piglets were used. However, the two experiments were run concurrently such that only one set of 8 piglets were fed on a basal diet as the control group for the 2 experiments. Data from the 2 experiments was recorded between 62 - 99 days of age. In the third experiment, 16 grower-finisher pigs at 99 days of age were selected from the group used in the previous 2 experiments and data was collected between day 99 - 180 of age.

3.4 Experimental feeds

Experimental feed compounding was done at the Egerton Univertsity Tatton Agricultural Park feed mill. Feed formulation using Evapig® feed formulation software was done following determination of proximate values of feedstuffs. In the first and second experiments, 6 weaner pig diets were formulated and compounded. In the third experiment, 4 finisher pig diets were prepared. The details of the different fractions of feedstuff used in experimental feed formulation are explained in detail in respective chapters.

3.5 Laboratory analysis

Processing and determination of chemical composition of feed and feacal samples was done at the Egerton University Animal Nutrition laboratory. Specimens for preparation of histological slides were preserved in jars containing 10% formaldehyde and dispatched to the University of Nairobi, Department of Veterinary Pathology within 24 hours of slaughter.

CHAPTER FOUR

NUTRIENT CONTENT, DAILY NUTRIENT ALLOWANCE AND SOW PERFORMANCE ASSOCIATED WITH ALTERNATIVE FEED RESOURCES IN SMALLHOLDER PIG ENTERPRISES IN KENYA

Abstract

This study estimated the nutrient content of selected alternative feed resources (AFR), compared the daily nutrient allowances associated with AFR feeding against the recommended daily allowance and compared sow performance indices in a sample of 144 smallholder pig enterprises in Busia, Nakuru and Kiambu Counties. Use of commercially compounded feeds varied between study areas (7.7% in Busia, 53.3% in Nakuru and 45.2% in Kiambu County; $p \leq 0.05$). All pig enterprises in Busia, 86.7% in Nakuru and 77.4% in Kiambu Counties used alternative feed resources as part or whole pig diets ($p \leq 0.05$). The mean crude protein (CP) and neutral detergent fibre (NDF) values of home-made feeds were 176.4 $\pm$ 55.2 and 325.4 $\pm$ 141.2 g/kg respectively. Ether extract values were higher in Busia County than in either Nakuru or Kiambu Counties ($p \leq 0.05$). Swill samples had DM values ranging between 84 - 127 g/kg and CP values of 37.9 - 119 g/kg. The mean DM, CP and NDF values for farm residue and market waste were 197.5 $\pm$ 81.1, 114.1 $\pm$ 47 and 406 $\pm$ 46.8 g/kg respectively. This study concluded that the recommended daily allowance for DM, CP and ME were only achieved in Kiambu County with commercially compounded feeds, agro-industrial by-products of cereals and food processing and home-made feed formulations. Institutional swill, farm residue and market waste did not provide sufficient DM, CP and ME necessary to meet the RDA in all study sites. Use of AFR was associated with smaller litter sizes, delayed age at first farrowing and longer farrowing intervals in sows ($p \leq 0.05$). The study recommended capacity building for farmers and extension agents on feed testing, formulation and proper feeding regimes and research on improving supply of nutrients from viable alternative feed resources through use of technology such as ensiling, dehydrating and compacting and biotechnology.

Key words: By-products, co-products, daily nutrient allowance, farm residue, food waste, performance indices, recommended daily allowance, sustainable pig enterprises.

4.1 Introduction

Feeding decisions constitute one of the most important management aspects in pig production for three main reasons; (i) feeding costs constitute 70 - 80% of the total costs (Carter *et al*.,

2017) in the enterprise (ii) nutrients availed to pigs significantly influence performance indices such as maturity age, fertility, piglet survival and resistance to disease and (iii) nutrition is a determinant of pork quality and by extension, marketability of product.

Farmers' feeding decisions like other agricultural investment decisions are influenced by individual endowment with the factors of production, land, labour and capital and entrepreneurship/ producer knowledge (Alemu *et al.*, 2017). Smallholder farmers often used alternative feed resources so as to reduce the cost of feeding pigs. Other factors that may influence such decisions include accessibility of markets and social- cultural motivations (Lemke *et al.*, 2006). Where such motivations are directed towards auto-consumption, then there is limited effort to adopt technologies that improve production.

Carter *et al*. (2017) showed that decisions to use alternative feed resources may be cost effective if some of the nutrients are in surplus on the farm and also if the piglets achieve sufficient body weight (≥ 11.9 kg) at weaning. Likewise, studies in Burkina Faso and Cameroon showed that under specific conditions, use of forages in pig diets could be more profitable than in industrial systems using commercial diets (Lekule and Kyvsgaard, 2003).

The ability of AFRs to contribute to nutrient supply to pigs for growth and production depends on nutrient intake, their digestibility and relative cost (Kambashi *et al*., 2014; Carter *et al*., 2017). A number of AFRs such as potato peelings, grain by-products and banana peelings are rich energy sources (Regnier *et al*., 2012). Other forages like *Ipomoea batatas* (sweet potato) have high CP (up to 370g/kg DM) and amino acid profiles that match the ideal protein for pigs (Regnier *et al*., 2012; Kambashi *et al*., 2014). Despite the low DM content (12%) of vegetable and fruit waste, Esteban *et al*. (2007) showed that such alternative feedstuffs could still be used to feed pigs.

Sow performance indices have been used in evaluating enterprise performance as well as developing breeding values for genetic improvement. Farrowing intervals are determined to a large extent by the weaning to service period. Abortions, early embryonic deaths and conceptual failure are important determinants of the weaning to service duration (Tummaruk *et al*., 2010). Pig diets have implications on successful fetal implantation, survival and development (Fleming *et al*., 2012). Studies have also shown that sows with higher farrowing interval had lower average daily gain (Cechova and Tvrdon, 2006). Carter *et al*. (2013) associated low average daily gain to malnourishment and recommended the use of locally available feed resources to improve growth rates.

Pre-weaning mortality is a good indicator of overall quality of management as well as adequacy of diets. Nuntapaitoon and Tummaruk (2018) associated high pre-weaning mortality with low birth weights (0.8 - 1.29kg), the incidence of which was higher in large herds. Consequently, pigs were probably fed without due regard to nutritional requirement of individual sows. This could also have explained the higher mortalities in litters with higher (13 - 16) numbers of piglets.

4.2 Materials and methods

4.2.1 The study area

Household survey of smallholder pig enterprises was carried out in Busia, Nakuru and Kiambu Counties where there are numerous smallholders keeping pigs under traditional backyard, intensive and semi-intensive and medium to large scale production systems. These study areas also had a wide variety of alternative feed resources used in pig production and a relatively sizeable market for pork. The study sites were as highlighted in a geographical information system projection map in Figure 3.

Busia County is situated in western Kenya and borders Uganda to the west, Bungoma County to the north, Kakamega County to the east, Lake Victoria and Siaya County to the south. The County has a population of 743,946 (KNBS, 2010) with an urban population of 16.4% and an area of 1628.4 Km^2. Most parts of the county lie within the Lake Victoria basin with altitude gradually rising north-eastwards from 1,130 to 1,500 metres above sea level (asl) in the Teso hills. The average temperature is 22^oC while annual rainfall varies between 750 and 1,800mm. The main economic activities include fishing and subsistence agriculture including livestock, maize, millet, cassava and commercial rice production. Busia County has a pig population of 45,300 (KNBS, 2010), majority of which are kept under the indigenous free-range or tethering systems with an income objective. Between 2002 and 2005, cattle constituted 62% of all animals slaughtered for meat, pigs constituted 27% while goats and sheep comprised only 11%.

Nakuru County is situated in the Rift valley and borders Kiambu, Baringo, Kericho, Laikipia and Nyandarua Counties. The county lies at an average altitude of 1,850 metres asl within agro-ecological zones II, III and IV with an annual rainfall of 650 - 1,200mm. Most of the soils in the county are volcanic. The daily minimum temperatures vary between 11^oC to14^oC while maximum temperatures vary between 23^oC and 29^oC. Nakuru County is the fourth largest county in Kenya with a population of 1,603,325 (KNBS, 2010), 45.8% of which live in urban areas and is cosmopolitan in nature. The county has an area of 7,509.5 Km^2 with 11 administrative sub-counties.

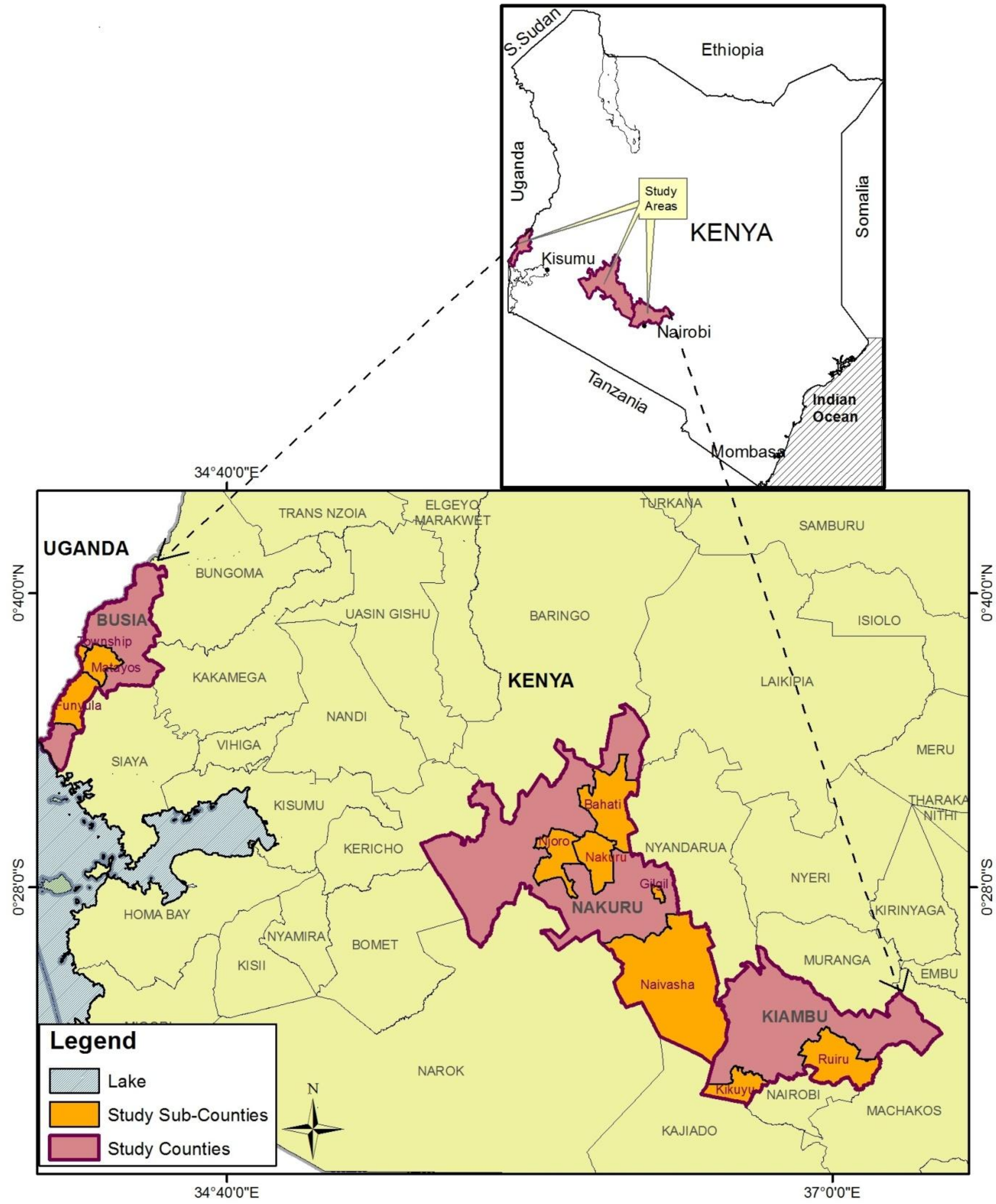

Figure 3: A Geographical information systems projection map of Kenya showing the study sites *(Source: Geography Department, Egerton University)*

The County has among the highest pig populations in the Rift Valley region. According to data available from the National population census of 2009, there were 13,899 pigs in the region covered by present day Nakuru County (KNBS, 2010). The estimate of pig population according to data available from Nakuru County Livestock Production Office (Appendix IV) indicated a 35.9% increase in pig population between the years 2009 and 2014.

Pig production systems in this County are varied and include free range scavenging, semi-intensive and the intensive commercial systems. Small scale farmers under the intensive and semi-intensive commercial systems often source their breeding stock from established large scale farms such as Farmers Choice Limited and government research stations such as the Agricultural Development Corporation (ADC) Station in Lanet, Nakuru. The most common breeds comprise of the Yorkshire Large White and the Dannish Landrace and their crosses.

Kiambu County is located in the central highlands of Kenya adjacent to the northern border of Nairobi County. It has a population of 1,623,282 and an area of 2,449.2 Km^2. As a result of its proximity to Nairobi, the level of urbanization in the County is 60.8% with a poverty level of 28.9%. The County has a population growth rate of 2.81% as a result of influx of people working in the city but prefer to stay in the less congested Kiambu and its environs.

The County has a mean annual rainfall of 1,200mm. The mean temperature in the County is 26^oC with temperatures ranging from 7^oC in the upper highlands to 34^oC in the lower midlands. Agriculture is the predominant economic activity in the County. It is the leading sub- sector in terms of employment, food security, income earnings and overall contribution to the socio-economic well being of the people. Majority of the people in the County depend on the sub- sector for their livelihood with 304,449 directly or indirectly employed in the sector. Coffee and tea are the main cash crops in the county. The main food crops grown in the county are maize, beans, pineapples and Irish potatoes. Livestock farming is mainly done by zero grazing. Animals reared include cattle, sheep and goats, poultry and pigs. Growth in this sub-sector has been encouraged by a ready urban market in Thika, Ruiru, Kiambu, Nairobi and the availability of local food processing factories such as Farmers Choice limited (pork and pork products), Kenchic Limited (broiler) and a number of dairy processing industries.

Kiambu County has the highest pig population in Kenya, majority of which are kept under intensive production systems. Access to good breeding stock by smallholder farmers is less of a challenge as compared to Busia and Nakuru Counties. However, feeding pigs is a challenge to many due to the cost and unavailability of quality feeds. The agro-processing industries provide a possible source of AFR for pig farmers.

4.2.2 Population and characteristics of pig farmers in the survey

The sampling frame included all smallholder pig farmers within in the target sites where majority owned less than 10 pigs and owned less than 5 acres of land. Majority of smallholders in the target study area are often involved in crop production as well as other forms of livestock production. Agricultural production systems in the 3 study site are often influenced by the level of urbanisation and population density such that the pressure on land and the demand for food commodities are high. There are however marked differences in infrastructure between the study sites with respect to licenced slaughter facilities where the number is higher in Kiambu than in Nakuru and Busia Counties. Pig populations shown in Table 1 indicate that pig farming is a popular agro-based income generating activity in the 3 study sites.

Outbreaks of Foot and mouth disease were common in pig enterprises in Busia County while Swine fever affected pigs in all study sites wiping off entire herds in most instances. Challenges associated with thin markets were also common especially in Busia County. As a result, most smallholders kept pigs seasonally when the risks were less.

4.2.3 Sampling procedure and sample size

A proportionate to size purposive sampling procedure was used to sample households that had pigs at the time of the survey. With the help of Sub-county livestock production officers, pig keeping households were identified using a snow-balling procedure. This approach was used to overcome the challenge of using random sampling on a sampling frame that would have identified households without pigs at the time of the survey.

The determination of sample size was based on the statistical concept of the margin of error given as:

$$e = z\sqrt{\frac{p\,(1-p)}{n}}$$ -- Equation 7.

Where e is the desired margin of error, z is the z-score for the desired confidence interval, p is the proportion of a statistic of interest in the universe and n is the sample size (Cochran, 1963). Re-organizing the formula,

$$n = z^2\left[\frac{p\,(1-p)}{e^2}\right]$$ -- Equation 8.

The proportion of small scale pig producers in Kenya was approximately 70% (FAO, 2012). In this case, p = 0.7 and 1-p = 0.3.Assuming a 95% confidence interval, z = 1.96 and 8% margin of error, then the sample size was computed as:

$[1.96^2 \times 0.7 \times 0.3] / 0.08^2 = 126.05$, approximately 130 households. This was distributed between the 3 study areas by pig population ratio for both commercial and backyard production systems based on KNBS (2010). The sample size was increased by a factor of approximately 10% to make up to 144 households, that is, 52 in Busia County, 30 in Nakuru County and 62 in Kiambu County. This was to ensure that more data was collected to replace selected households where it was not possible to collect data.

4.2.4 Pretesting, reliability and validation of instrument

A questionnaire that captured the demographic characteristics of the household heads and enterprise data was developed (Appendix V). With the aid of 2 enumerators, the questionnaire was administered to 6 pig enterprises in Njoro and Nakuru East Sub-Counties. The questionnaire was then rectified for errors and questions that presented difficulty in measurement, visual assessment or difficulty in verifying. The questionnaire template was then prepared using SPSS statistical software Version 22. The reliability of the tool was evaluated by assessing its internal consistency using the Cronbach's coefficient alpha which was computed for groups of related variables. The tool was considered reliable with Cronbach's alpha values that varied between 0.65 and 0.76. Validation of the tool was done by using the construct validity criterion where correlation was done between responses to enquiries on challenges faced by smallholder pig producers while using open ended questions and responses to structured questions on the questionnaire with a correlation coefficient of 0.84.

4.2.5 Data collection

The pretested structured questionnaires were administered to smallholder pig farmers through personal interviews. Precaution was taken to observe research ethics as pertains to obtaining consent from the farmer to collect data and assurance of confidentiality. Information on the demographic characteristics of the smallholders, herd inventory by age and sex, feed resources in use, feeds and feeding regimes, management practices, sow reproduction, disease control, marketing practices, disease incidence and mortalities was captured. By observation, an assessment of pig breeds (either exotic crosses or indigenous) and housing type was done.

During the survey, feed samples were collected immediately before the feeds were supplied to the pigs, weighed, labeled and preserved at 4^oC in sealed water proof containers until analysis was done. Wet feeds were weighed and then frozen. All samples were then desiccated in an oven at 60^{o}C until there was no further loss in weight. Samples were ground using a hammer mill fitted with a 1mm pore size sieve and then stored in water-proof bags. Proximate and detergent fibre analyses of commercially compounded feed and swill samples were done using the procedures described by AOAC (1990) and Abdulrazak and Fujihara (1999) at Egerton University, Department of Animal Science, Nutrition laboratory. Home-made feeds were simulated in Evapig® feed formulation software (INRA *et al*., 2008) after pig farmers were asked to provide details on how they formulate their feeds. Secondary data from published literature was used to compare nutrient values of cereal by-products and other agro-industrial waste products that were used in smallholders pig enterprises.

The study computed four performance indices, that is, age of sows at first farrowing in days, litter size per sow, sow farrowing interval in days and piglet weaning percentage from survey data on sow reproduction. Farrowing interval was obtained by taking the difference between the current farrowing and the previous farrowing dates. Weaning percent (piglet survival rate at weaning) was computed as the total number of weaned piglets as a percentage of the number of piglets farrowed.

4.2.6 Statistical analysis

Analysis of variance (ANOVA) for continuous data with Tukey's test to separate means and chi-squares for categorical data were computed to compare the socio-economic characteristics, production, management and feeding practices of smallholder pig enterprises between study areas using SPSS statistical software (IBM Corp, 2013). To identify and rank barriers to the use of commercially compounded feeds, smallholders' responses were ranked from 1 to 4 where 1= not a serious problem, 2 = a problem sometimes, 3 = a common problem and 4 = most common problem. The barriers that were ranked in this analysis included lack of knowledge on which feed to use, high cost of feeds, lack of stockists, lack of information on where to source feeds, high cost of transport and poor quality of commercially compounded feeds. Rank data analysis of barriers associated with use of commercially compounded feeds was performed to factor in the weight of all responses as illustrated by Ray and Mondal (2011). A Heckman two step model was used to estimate decisions to adopt the use of commercially compounded feeds using STATA statistical software (StataCorp, 2011) using socioeconomic characteristics and production and management practices as the primary regressors. A probit regression for selection was estimated in the first step to estimate the determinants of smallholders' ability to purchase. This was followed by ordinary least squares regression in which a correction factor, the inverse mills ratio (λ) calculated from the probit model was included as a regressor.

Proximate values of feed resources were fitted to the survey data to facilitate computation of daily allowance of nutrients (dry matter, crude protein and metabolisable energy). To establish the normality of this data, the PROC UNIVARIATE NORMAL PLOT command of SAS systems (SAS®, 2002) was applied. Spearman correlation coefficient was computed using "PROC CORR" command of SAS systems (SAS®, 2002) between crude protein and the fibre components of diets. Computation of metabolisable energy (ME) values for commercial feeds was done using the formula;

$$ME = 4194-(9.2 \times Ash)+(1 \times CP)+(4.1 \times EE) -(3.5 \times NDF),\ R^2 = 0.98 \text{----- Equation 9.}$$

(Noblet and Perez, 1993)

Where CP = crude protein in g/kg, EE = ether extract in g/kg and NDF = neutral detergent fibre in g/kg all expressed in DM basis.

Daily allowance for DM, CP and ME were computed by applying the results of proximate analysis and ME computation to feeding regimes obtained from enterprise data from the cross-sectional survey. Comparison of the mean values was done using one-sample T-test with the recommended daily allowance (RDA) as the critical values. The RDA was computed as shown in Table 5 to provide mean values of 40mg/kg bodyweight for DM, 7.38g/kg bodyweight for CP and 144Kcal/kg bodyweight for ME.

Comparison of sow performance indices between study areas was done by computing an ANOVA using SPSS statistical software (IBM Corp, 2013). A comparison of the means of performance indices between feeding decisions (commercially compounded feeds versus AFRs) was done by using independent samples t-test.

4.3 Results

4.3.1 Pig enterprise features

i) Pig farmer and farm characteristics

The number of male headed households was significantly higher than female headed households (77.6% versus 22.4%) in the entire sample. Pig farming household heads in Kiambu County were significantly older ($p \leq 0.05$) than those in Busia County; 50.71 years versus 45.51years.

Table 5: Recommended daily allowance for dry matter, metabolisable energy and crude protein (90% dietary dry matter)

Item	Mean body weight (kg)					RDA
	9	18	37.5	62.5	87.5	
Estimated daily feed intake (g/day)	493	953	1582	2229	2636	
Daily DM intake (g/kg)	49	48	38	32	28	40
Daily ME requirement (kcal/kg)	186.2	177.36	139.22	117.69	99.41	144
Estimated daily CP intake (g/kg)	9.86	9.53	6.83	5.78	4.88	7.38

DM=dry matter, ME=metabolisable energy, CP=crude protein, RDA=estimated recommended daily allowance. *(Information extrapolated from Table 16-1A (NRC, 2012), CP intake was computed based on a CP concentration of 200mg/kg for pigs up to 35kg and 180mg/kg for pigs over 35kg)*

However, pig farmers in Busia County had more ($p \leq 0.05$) years of experience in pig farming (6.77 $\pm$ 7.18 years) compared to either Nakuru County (2.73 $\pm$ 3.27 years or Kiambu County (3.63 $\pm$ 3.97 years). The variance in the mean size of land allocated to livestock between counties was significant; $p \leq 0.05$. Smallholders in Busia County allocated more ($p \leq 0.05$) land to livestock (0.48 $\pm$ 0.56 hectares) compared to farmers in either Kiambu County (0.17 $\pm$ 0.21 hectares) or Nakuru County (0.25 $\pm$ 0.27 hectares). The sizes of land allocated to livestock in Nakuru and Kiambu Counties were comparable.

ii) Pig production and management practices

Pig husbandry systems practiced by smallholders in Busia, Nakuru and Kiambu Counties were significantly different; $\chi^2 = 111.95$, $p \leq 0.05$. Tethering was the predominant husbandry system in Busia County and was the only study area where free-range grazing was encountered. Smallholders in Nakuru County predominantly practiced intensive farming with only 6.7% tethering their pigs. All farmers in Kiambu County practiced intensive pig keeping. A comparison of pig housing practices showed significant ($p \leq 0.05$) differences in all study areas. There were no shelters for pig in 25% of households in Busia County and approximately 60% of those present were temporary. The number of households that had no shelters for pigs in Nakuru and Kiambu Counties were negligible.

Smallholders that were interviewed in Busia and Nakuru Counties had a maximum of 5 sows and 4 sows in Kiambu County. The distribution of sow population in the three study areas showed that on average, 29.5% of smallholders had no sows in their pig enterprises. This comprised of 34.6% of smallholders in Busia County, 23.3% in Nakuru County and 30.6% in Kiambu County. The mean number sows per enterprise in the three study areas was 0.94, 1.37 and 1.47 respectively, $F = 3.08$; $p \leq 0.05$. This difference was significant between Busia and Kiambu Counties, t (112); $p \leq 0.05$. Smallholders in Busia County predominantly kept indigenous sows while those in Kiambu predominantly kept exotic breeds. Smallholders in Nakuru County had preference for both improved crosses and exotic breeds with a bias for improved crosses. Majority (70.9%) of smallholders had no boars in their enterprises. The mean number of boars per enterprise was 0.39 with no significant differences in the means between the study areas. Smallholders in Nakuru and Kiambu Counties did not keep indigenous breeds of boars while in Busia, smallholders predominantly kept indigenous boars.

Majority (89%) of smallholders in all the study areas frequently dewormed their pigs but rarely kept any enterprise records. About 30% of smallholders never used ectoparasiticides. There were significant differences in the frequency of carrying out tooth clipping ($\chi^2 = 46.84$; $p \leq 0.05$), castration of piglets ($\chi^2 = 17.79$; $p \leq 0.05$) as well as administration of iron injections in piglets ($\chi^2 = 73.59$; $p \leq 0.05$). More than half of smallholders in Busia County never carried out these management practices while in Nakuru County, at least 80% of smallholders carried out the practices. In Kiambu County, majority of farmers (over 60%) did iron injections and piglet castration while 56% never practiced teeth clipping. Less than 10% of smallholders in all study areas weighed their pigs.

4.3.2 Pig feeding practices

There was a significant difference in feeding practices with the rate of use of commercially compounded feeds in smallholder enterprises 7.7, 53.3 and 45.2% ($\chi^2 = 14.59$, $p \leq 0.05$) in Busia, Nakuru and Kiambu Counnties respectively. All enterprises in Busia County fed their pigs on alternative feed resources while in Nakuru and Kiambu Counties, 86.7 and 77.42% of enterprises respectively fed pigs on alternative feed resources ($\chi^2 = 26.87$, $p \leq 0.05$). Only 13.3 and 22.58% of the enterprises in Nakuru and Kiambu Counties respectively fed their pigs entirely on commercially compounded feeds.

High cost of commercial feeds was the most serious barrier to their use in all study areas. In Busia County, the second and third most important barriers were high cost of transport and lack of feed stockists respectively. In Nakuru and Kiambu Counties, poor quality of feeds and high cost of transport were the second and third most important barriers to the use of commercially compounded feeds.

4.3.3 Modelling decisions to use commercially compounded feeds

Heckman 2 step regression results showed that the inverse Mills ratio (λ) was significant; 0.024, $p \leq 0.05$, indicating a sample selection bias and therefore justification for the model. Determinants of choice to use commercially compounded feeds that were significant (Appendix VI) included; the level of education of household head (+0.48), number of weaners (+0.11), access to alternative feed resources, that is; home-made feeds (-2.38), agro-industrial by-products (-1.39) and institutional swill (-0.81). Underlying factors that influenced the decision to use commercially compounded feeds as described in the outcome equation included location of enterprise (+.01), gender of household head (+0.19), the level of investment in housing(+0.27) and access to extension services from the public sector (+0.1) all significant at $p \leq 0.05$. Figures in parenthesis indicate the regression coefficients and direction.

4.3.4 Nutrient composition and daily nutrient allowance of commonly used AFR

i) Commercially compounded feeds

Data from the cross-sectional survey showed that there were only two commercial pig diets that were used in smallholder enterprises in all study areas; sow and weaner meal (SWM) and pig finisher meal (PFM). In Busia County, smallholders who used commercially compounded feeds only used SWM. In most cases, there was no clear cut-point that determined at what age or weight the feeding regime changed from a SWM to a PFM.

There were three different brands of commercially compounded SWM that were in use among smallholders sampled in Busia County. All the three brands were sampled for proximate and detergent fibre analysis. There were eight brands of commercially compounded pig feed in use by smallholders in Nakuru County out of which three brands were used in 64.7% of enterprises that used commercial feeds. SWM and PFM from the three brands were sampled for proximate and detergent fibre analysis. There were eight brands of commercial pig feed in use by smallholders in Kiambu County where four brands were used in 74.1% of enterprises that used commercially compounded feeds. These four brands were selected for sampling for laboratory analysis and included SWM and PFM samples. There were three brands of commercially compounded pig feed that were in use in both Nakuru and Kiambu Counties. None of the brands of commercially compounded pig feed in use in enterprises in Busia County was used in either Nakuru or Kiambu Counties. The results for proximate and detergent fibre analysis for sampled commercially compounded feeds are shown in Appendix VII.

A comparison of nutritional composition of the feed samples between research sites showed significant differences in ash, crude protein, ether extract, hemicellulose, cellulose and acid detergent lignin ($p \leq 0.05$). Feed samples from Busia County were significantly higher ($p \leq 0.05$) in ash and lignin compared to feed samples from Nakuru and Kiambu Counties. Feed samples from Nakuru County had higher ($p \leq 0.05$) hemicellulose content than feed samples from Busia and Kiambu Counties. Feed samples from Kiambu County were significantly higher ($p \leq 0.05$) in crude protein and ether extract compared to those from Busia and Nakuru Counties. There was a positive correlation between crude protein and ether extract ($p \leq 0.05$) and a negative correlation between crude protein and hemicellulose ($p \leq 0.05$) and acid detergent lignin ($p \leq 0.05$). Results of comparison of the daily allowance of nutrients per kilogram bodyweight from commercially compounded feeds between study areas were shown in Table 6.

Table 6: Comparison of mean daily allowance of dry matter, crude protein and metabolisable energy associated with commercially compounded feeds with the recommended daily allowance values

Component	RDA	Busia	Nakuru	Kiambu	Mean
DM g/kg	40	11.72(2.46)**	31.36(3.35)**	45.44(2.49)	36.79
CP g/kg	7.38	1.47(0.31)**	4.30(0.46)**	8.25(0.46)	6.09**
ME kcal/kg	144	32.97(6.93)**	94.49(10.1)**	148.57(8.32)	116.73**

DM=dry matter, CP=crude protein, ME=metabolisable energy, RDA=recommended daily allowance derived from NRC (2012) data, values with asterix are significantly lower ($p \leq 0.05$) than the RDA value for corresponding dietary component, numbers in parenthesis are standard errors of the means.

Levene's test of homogeneity of variances indicated that there was no violation of the assumption of non-homogeneity of variances. The daily allowances in g/kg body weight of DM and CP and ME in kilocalories per kilogram body weight ($kcalkg^{-1}$) were significantly higher ($p \leq 0.05$) in pig enterprises in Kiambu County than enterprises in either Nakuru or Busia County which had the lowest values in all cases. The mean values of daily allowance of DM, CP and ME in Busia and Nakuru counties were lower ($p \leq 0.05$) than their RDA values. The mean values of daily allowance for DM, CP and ME in Kiambu county were equal to ($p \leq 0.05$) the recommended daily allowance of these dietary components. The overall mean values of daily allowance for CP and ME were lower ($p \leq 0.05$) than the RDA values for these dietary components.

ii) Alternative feed resources

The most popular alternative feeding practice in Busia County was use of kitchen waste which was practiced in over 75% of smallholder enterprises (Table 7). Feeding crop left-over and farm waste especially, sweet-potato vines (25%) was the second most important alternative pig feed source in Busia County followed by feeding of grain by-products, particularly, maize bran.

In Nakuru County, the use of kitchen waste was the most popular alternative pig feeding practice and was practiced by 49% of smallholder farmers. Market waste mainly comprising cabbage waste was the second most popular alternative feed source in Nakuru County. The third most common feeding practice was the use of home-made feeds which were prepared from feedstuffs that were easily available to smallholder farmers. The formulations varied from enterprise to enterprise. Most respondents indicated that they obtained the feed formulae from other farmers and obtained their raw materials from animal feed millers.

The most popular alternative feed for pigs in Kiambu County was wheat pollard which was used in 59.7% of smallholder enterprises. Use of slaughterhouse waste was recorded in less than 4% of enterprises in Busia and Kiambu Counties. Tomato waste (tomato pomace) was used by 6.7% of smallholders in Nakuru County and comprised of a mixture of tomato peels, pulp and crushed seeds obtained from a vegetable processing factory.

iii) Home-made pig diets

This practice was more common in pig enterprises in Nakuru County as compared to either Busia or Kiambu Counties. Feed preparation was done by hand using spades and in small quantities of up to 300kg. In all cases, there was no inclusion of vitamin and mineral premixes when formulating these diets. The diets were also offered to pigs of all ages on the farm.

Results of analysis of nutritional values are presented in Appendix VIII. Results from the Shapiro-Wilk test indicated that the data for NDF and ME in home-made pig feed in Busia County was not normally distributed while that of CP, EE, ADF and lignin was normally distributed. Data for CP, EE, NDF, ADF, lignin and ME for home-made feed in Kiambu and Nakuru Counties was normally distributed. Results showed that the diets were similar ($p \leq 0.05$) in composition except for EE where the mean value in Busia County (116.9 $\pm$ 64.6g/kg) was higher than either Nakuru (32.3 $\pm$ 2g/kg) or Kiambu (32.6 + 6.3%) Counties. The mean values for CP and NDF for all diets was 176.4 $\pm$ 5.25g/kg and 325.4 $\pm$ 141.2g/kg.

Table 7: A comparison of the percentage rate of use of alternative feed resources in pig enterprises

Feed type	Busia County (N=52)	Nakuru County (N=30)	Kiambu County (N=62)
Home-made formulation	5.8	13.3	6.5
Grain by-products			
Wheat pollard	0	23.3	59.7
Wheat bran	0	3.3	1.6
Maize bran	26.9	0	0
Rice bran	8	0	0
Food processing waste			
Bakery waste	5.8	0	0
Tomato waste	0	6.7	0
Brewer's waste/grain	0	6.7	0
Blood	3.8	0	1.6
Omena	7.7	0	0
Fruit and Vegetable based feed			
Fruits	5.8	3.3	6.5
Cabbage and kales	21.2	36.7	29
Kitchen Waste			
Swill	76.9	16.7	4.8
Peels (potato, peas)	0	13.3	16.1
Crop left-over and farm waste			
Leaves and stems	3.8	0	3.2
Sweet potato vines	25	0	4.8
Grass (cut and carry)	13.5	0	
Weeds	3.8	20	

Omena is the a vernacular name for menhaden (*Rastrineobola argentae)*

Results of comparison of the mean values of daily allowance for DM, CP and ME are shown in Table 8. Levene's test of homogeneity of variances indicated that there was no violation of the assumption of non-homogeneity of variances for DM, CP and ME. There were no significant differences ($p \leq 0.05$) in the daily allowance for DM, and ME for pigs fed on home-made rations in the entire sample. The daily allowance for CP from home-made feed formulations was significantly higher ($p \leq 0.05$) in smallholder pig enterprises in Kiambu County compared to Busia County.

The mean values of daily allowance for DM and CP in Busia, Nakuru and Kiambu Counties associated with home-made feeds were equal ($p \leq 0.05$) to the RDA values. The mean values of daily allowance for ME in Busia and Nakuru Counties were lower ($p \leq 0.05$) than the RDA value for ME. The overall mean values of daily allowance for DM and CP were not different ($p \leq 0.05$) from their RDA values. The overall mean value of daily allowance for ME was lower ($p \leq 0.05$) than the RDA value.

Table 8: Comparison of mean daily allowance of dry matter, crude protein and metabolisable energy associated with home-made feeds with the recommended daily allowance values

Component	RDA	Busia	Nakuru	Kiambu	Mean
DMg/kg	40	32.93(5.07)	43.78(2.9)	50.91(8.55)	38.93
CP g/kg	7.38	5.80(0.89)	7.18(0.48)	10.20(1.71)	7.01
MEkcal/kg	144	98.87(15.2)**	104(6.89) **	163.76(27.5)	113.46**

DM=dry matter, CP=crude protein, ME=metabolisable energy, RDA=recommended daily allowance derived from NRC (2012) data, values with asterix are significantly lower ($p \leq 0.05$) than the RDA value for corresponding dietary component, numbers in parenthesis are standard errors of the means.

iv) Grain by-products and food processing waste

The grain by-product that were used by smallholder pig farmers in Busia County were maize bran (26.9%) and rice bran (8%). Wheat pollard was commonly used in smallholder enterprises in Nakuru (23.3%) and Kiambu Counties (59.7%). Wheat bran was not popular as a pig feed in smallholder enterprises and was used only in Kiambu County (1.6%).

There was limited use of food processing waste which was associated with the proximity of smallholder pig enterprises to food processing industries. Bakery waste, blood meal and fishmeal locally known as *omena* (usually obtained from sieved *Restrineobola argentae*) were used in pig enterprises in Busia County. Waste from the tomato processing plant in Njoro, Nakuru County was also used by smallholders within the vicinity while those near informal settlements used brewers spent grain. The only food processing by-product identified in smallholder enterprises in Kiambu County was blood meal (1.6%) obtained from local slaughterhouses. These products were often fed directly to the pigs without any form of processing. These feed resources were also not available in large quantities and could not be stored easily as a result of their bulkiness and low DM content. For the same reason, it was also difficult to transport these feed resources from the source to the farm. They were therefore used for supplementary feeding in all cases. The nutritional values of grain by-products and food processing waste that were used to feed pigs in smallholder enterprises are presented in Appendix IX and X respectively.

A comparison of the mean values of daily allowance of DM, CP and ME associated with cereal byproducts and food processing waste is shown in Table 9. Results showed that the mean values of daily allowance of DM, CP and ME associated with cereal by-products and food processing waste in Busia County were lower ($p \leq 0.05$) than the mean values for Nakuru and Kiambu Counties. The mean values of daily allowance of DM, CP and ME in Busia County and the mean value of daily allowance of ME in Nakuru County were lower ($p \leq 0.05$) than the RDA values. The mean values of daily allowance for DM, CP and ME in Kiambu County and the mean values daily allowance of DM and CP in Nakuru County were equal to the RDA values. The overall mean values of daily allowance of DM, CP and ME associated with cereal by-products and food processing waste were lower ($p \leq 0.05$) than the RDA values.

Table 9: Comparison of mean daily allowance of dry matter, crude protein and metabolisable energy associated with cereal by-products and food processing waste against the recommended daily allowance

Component	RDA	Busia	Nakuru	Kiambu	Mean
DM g/kg	40	20.23(2.2)**	35.8(4.8)	41.21(2.4)	34.51**
CP g/kg	7.38	2.44(0.3)**	7.62(1.3)	7.79(0.5)	6.31**
MEkcal/kg	144	56.11(7.2)**	94.54(13.7)**	135.06(7.7)	106.10**

DM=dry matter, CP=crude protein, ME=metabolisable energy, RDA=recommended daily allowance derived from NRC (2012) data, values with asterix are significantly lower ($p \leq 0.05$) than the RDA value for corresponding dietary component, numbers in parenthesis are standard errors of the means.

Kitchen waste

The most common types of kitchen waste that were used in smallholder enterprises were swill and potato peels mainly obtained from hotels and schools. In Busia County, the composition of swill was predominantly *ugali* (a thick paste prepared from maize meal) irrespective of whether it was sourced from a hotel (the most popular source) or prepared at home. In Nakuru and Kiambu Counties, swill was predominantly sourced from schools and was mainly composed of a mixture of maize and beans.

Results of proximate analysis for the sample from Busia County (*ugali*) were; 12.7% ± 0.34 DM, 2.36% ash, 5.41% ± 1.14 EE, 8.94% ± 0.31 CP and 5.78% ± 0.88 CF. The second sample from Nakuru County which comprised mainly of maize, beans and vegetables had 11.92 ± 0.54 DM, 1.75% ash, 11.9% ± 0.84 CP, 3.06% ± 1.11 CF and 2.91% ± 0.76 EE content. Adegunloye and Oparinde (2017) reported the following proximate values for potato peels; 8.4% DM, 2.02% crude ash, 4.64% CP, 3.79% CF and 72.6% carbohydrates. Smallholder pig farmers in Busia County did not do any processing on swill. Most of the smallholders in Nakuru County carried out processing of swill by either washing it by adding water or draining it or by boiling, or both. Smallholders in Busia County often stored the swill for up to 4 days. Most of the smallholders in Nakuru and Kiambu Counties often collected enough swill to last a maximum of two days.

Results of comparison of the daily allowance of DM, CP and ME from swill are presented in Table 10. The results showed that the mean value of daily allowance for DM in pigs fed on swill was significantly higher ($p \leq 0.05$) in Busia County than in either Nakuru or Kiambu Counties. The mean values of daily allowance of DM, CP and ME were significantly lower ($p \leq 0.05$) than their mean RDA values in Busia, Nakuru and Kiambu Counties. The overall mean values of daily allowance of DM, CP and ME were significantly lower than the mean RDA values.

Table 10: Comparison of mean daily allowance of dry matter, crude protein and metabolisable energy associated with swill against the recommended daily allowance

Component	RDA	Busia	Nakuru	Kiambu	Mean
DM g/kg	40	10.39(1.1)**	1.11(0.3)**	0.81(0.4)**	31.07**
CPg/kg	7.38	1.06(0.1)**	1.11(0.3)**	0.81(0.4)**	0.26**
MEkcal/kg	144	19.98(2.2)**	36.28(10.1)**	26.41(14.4)**	1.14**

DM=dry matter, CP=crude protein, ME=metabolisable energy, RDA=recommended daily allowance derived from NRC (2012) data, values with asterix are significantly lower ($p \leq 0.05$) than the RDA value for corresponding dietary component, numbers in parenthesis are standard errors of the means.

Feeding of vegetable waste which mainly comprised of cabbage and kale leaves was a popular practice across all regions but was most popular in Nakuru and Kiambu Counties in

36.7 and 29% of enterprises respectively. In Busia County, 25% of smallholder pig enterprises fed their pigs on sweet potato (*Ipomoea batatas*) vines. Harvesting grass as pig feed was only recorded in Busia County in 13% of the enterprises. Feeding of weeds was practiced in 20% of enterprises in Nakuru and 16% of enterprises in Kiambu County. The most popular weed that was fed to pigs was of the *Amaranthus* species commonly referred to as pigweed. An analysis of the nutritive value of the various vegetable and farm residues used as animal feed was done using results from secondary data as shown in Appendix XI.

An evaluation of homogeneity of variances of the means showed that the data did not violate the assumption of non-homogeneity of variances. Results presented on Table 11 showed that the daily allowance for DM in pigs fed on farm residue and market waste in Busia, Nakuru and Kiambu Counties were similar. The daily allowance for CP in pigs fed on farm residue and market waste was higher ($p \leq 0.05$) in Nakuru as compared to either Busia or Kiambu Counties. The mean values of daily allowance of DM and CP in Busia, Nakuru and Kiambu Counties were lower ($p \leq 0.05$) than the mean values of RDA. The overall mean values for DM and CP associated with feedin farm residue and market waste were significantly lower ($p \leq 0.05$) than the mean RDA values.

Table 11: Comparison of mean daily allowance of dry matter, crude protein and metabolisable energy associated with farm residue and market waste against the recommended daily allowance

Component	RDA	Busia	Nakuru	Kiambu	Mean
DM g/kg	40	6.82(1.5)**	10.6(2.8)**	9.52(1.8)**	8.05**
CP g/kg	7.38	1.3(0.2)**	3.36(0.5)**	1.49(0.3)**	1.91**

DM=dry matter, CP=crude protein, ME=metabolisable energy, RDA=recommended daily allowance derived from NRC (2012) data, values with asterix are significantly lower ($p \leq 0.05$) than the RDA value for corresponding dietary component, numbers in parenthesis are standard errors of the means.

4.3.5 Sow performance indices

Results in Table 12 showed that the age at first farrowing for sows in Kiambu County was significantly lower ($p \leq 0.05$) than that of sows in Nakuru and Busia Counties. Mutua *et al*. (2011) reported the age at first farrowing for sows in Western Kenya as 12.1 months (approximately 363 days) which was higher than was reported in this study. Litter sizes were also higher in Kiambu County as compared to either Nakuru or Busia Counties ($p \leq 0.05$).

The mean litter size in Busia County in this study was higher than was reported by Mutua *et al*. (2011), 7.8 ± 2.6 piglets for sows in Western Kenya.

Piglet survival rate was higher ($p \leq 0.05$) in in Busia County as compared to Kiambu County. The piglet survival rate reported in this study for sows in Busia County was similar to the findings of Mutua *et al*. (2011) who reported a piglet survival rate of 87.2% for sows in Western Kenya. This difference was however significant at $p \leq 0.05$. There was no significant difference in mean of farrowing interval between counties. The findings for farrowing interval for sows in Busia County were very similar to those of Mutua *et al*. (2011) who reported a mean farrowing interval of 210 days.

Results showed that the litter size of sows fed on commercially compounded feed had higher ($p \leq 0.05$) litter sizes than those fed on AFR (11 verses 8.6 piglets). Results also indicated that sows that were fed on commercially compounded feeds had an earlier age at 1st farrowing (315 days) compared to those that were fed on farm residue (334 days); $p \leq 0.05$. Sows fed on commercially compounded feeds had a shorter ($p \leq 0.05$) mean farrowing interval (176 days) compared to sows fed on farm residue (210 days).

Table 12: Comparison of means of performance indices between study areas

Index	N	Busia	Nakuru	Kiambu	p-value
Age 1st farrow (Days)	137	329^a (10.8)	353^a(12.2)	307^b (4.4)	0.01
Average litter size	141	8.13^a(0.34)	9.23^a (0.53)	10.97^b (0.35)	0.01
Piglet survival (%)	137	88.74^a (3.05)	88.83^a(4.11)	78.04^b(3.02)	0.03
Farrow interval (Days)	75	209^a (20.8)	202^a (13.7)	181^a (7.17)	0.12

Means on the same row with different superscripts are significantly different.
N= number of sows, numbers in parenthesis are standard errors of the means, critical value was $p \leq 0.05$.

4.4 Discussion

i. Farmer and farm dynamics

The difference in mean age of household head between Kiambu and Busia Counties was an important indicator in this study which implied either low access of land resource to younger individuals in Kiambu County or a higher availability of youthful labour in Busia County. The finding is also indicative of interest among younger people to participate in pig production. There was higher proportion of pig enterprises in Busia County that had housing for pigs in this study compared to previous studies. This shows that there has been increasing interest in pig production. Majority of smallholders were keen on disease control as was indicated by the high percentage of those who frequently sprayed their pigs to control external parasites and also frequently dewormed their pigs.

The proportion of pig enterprises that did not have breeding stock was significantly high with up to 70% for boars and 36% for sows. Owing to the small herd sizes, most smallholders probably felt that it was economical to keep a breeding boar and preferred to hire the services of other farmers who had specialised in offereing breeding services. This could also have been as a result of farmers' preference to by weaners pigs for finishing. Likewise,it could have implied that pig mortality was high either via a ready market for slaughter of mature pigs or as a result of disease. Either way, there is need to educate smallholder farmers on the reproductive cycle of pigs to ensure enterprise continuity.

ii. Feeding decisions

The choice of a Heckman 2 step regression was based on results from Shapiro-Wilk test which showed that the dependent variable was not normally distributed (Shapiro-Wilk statistic = 0.6; 144 degrees of freedom; p= 0.00) and therefore, a probit regression would not have been appropriate. Smallholder pig farmers also had many similarities in terms of their socio-economic characteristics and on-farm practices mainly due to their methods of learning, that is, from social networks. It was therefore likely that this would result in collapse of a logistic regression due to multicollinearity in the regressors. For these reasons, a selection model was selected to estimate adoption of use of commercially compounded feeds.

Smallholder pig farmer feeding decisions were informed by socio-economic as well as production factors. Education was an important determinant of smallholders' choice to use commercially compounded feeds. Smallholder pig farmers who had secondary school level of education and above were more likely to feed their pigs on commercially compounded feeds. This was an expected outcome for two reasons; the frequently positive relationship between education and income implying more purchasing power, and the role of education in providing information that informs decisions to adopt or not to adopt technologies. In this case, commercially compounded feeds were considered as the technology of interest in that it provides nutrients to pigs in precise and adequate quantities and in a concentrated form resulting in earlier achievement of market weight. This finding however is different from that of Ogeto *et al*. (2013) who argued that individuals with higher education are likely to be engaged in off-farm activities and therefore invest less in on-farm technology. Murage and Ilatsia (2011) observed that education creates a favourable mental attitude for acceptance of new practices and that technology complexities have negative effects on its adoption that can be dealt with by education.

Gender was a significant determinant of pig feed choice; there was an increase in likelihood of using commercially compounded feed where the household head was female. An important contributing factor to this decision was the bulky nature of alternative pig feeds making them an undesirable choice for women.

Smallholder pig farmers who had higher number of weaner piglets were more likely to use commercially compounded feeds to feed pigs. This could have been explained by the fact that the bulky nature of AFR made it difficult to transport therefore making it difficult to use where the numbers of pigs was high. Since most AFR cannot be stored for long due to spoilage, this feeding option becomes untenable with increasing herd size becauses it will eventually translate to high cost of feeding as a result of high cost of sourcing and delivery.
Among factors that contribute to high weaning rate are; investment in good breed of sows, proper housing, good hygiene and disease control. It was therefore likely that such farmers would also invest in quality feeds. Pig housing in this regression was used as a dummy for the level of investment. In this case, smallholders who had invested more capital in their piggery (which was an indicator of more disposable income) had a higher probability of using commercially compounded feeds.

Smallholder pig farmers who had access to AFR were less likely to feed their pigs on commercially compounded feeds. This could probably have been the case because, most alternative feed resources were cheaper though not necessarily cost effective, and were available in small quantities. Likewise, the use of alternative feed resources was a practice passed on from farmer to farmer and therefore not easy to unlearn where a cheaper alternative was available. However, it is likely that the target market had an influence on the choice of feed; very few smallholders in Kiambu County used blood meal and brewer's waste despite their abundance. This could have been dictated by market forces especially conditions imposed by large commercial slaughterhouses and also consumer perceptions on hygiene and pork safety. Conversely, in Busia County, market failure could have resulted in low earnings and therefore inability to purchase commercially compounded feeds due to low disposable incomes.

Smallholder pig farmers who frequently received government extension services had a higher likelihood of feeding pigs on commercially compounded feeds. Increased adoption of a technology is often associated with increased access to information on the technology.

iii. Nutrient supply for smallholder pig enterprises

The objective of feeding strategies in commercial pig production systems is to maximize profit by providing indispensable nutrients in such a manner that they just meet and do not exceed pigs' nutritional requirements (Chiba, 2000). These strategies often factor in the pigs genotype, age, sex (Campbell and Taverner, 1988) and environmental factors that affect voluntary feed intake. These strategies are however difficult to implement in smallholder enterprises where alternative feed resources used have large variations in nutrient content. In this study, different feedstuffs were also used simultaneously and in varying quantities. Pigs of different phenotype, age and sex were housed together making it difficult to evaluate these feeding systems based on dietary nutrient content alone. This study applied results of qualitative feed analysis to on-farm feeding practices data to compute daily nutrient allowances associated with feeding alternative feed resources.

The DM intake of pigs is approximately 4% of their body weight when fed *ad libitum,* which implies approximately 40g DM/kg bodyweight. DM intake could however vary as a result of dietary factors such as nutrient concentration and feed palatability (Nyachoti *et al*., 2004). The net requirement for dietary protein refers to the sum of amino acid requirements for maintenance and protein retention (van Milgen *et al*., 2008). Tissue accretion occurs such that the retained tissue is similar in amino acid composition as the proportion of dietary protein retained, known as the ideal protein (Whittemore *et al*., 2001). Protein requirements in growing pigs initially increase linearly where there is adequate supply of energy and then plateau. The upper limit (Pr_{max}) for the linear relationship was modeled by van Milgen *et al*. (2008) using a Gompertz function specified as;

$$Pr_{max} = W.B.\ \ln(A/W) \quad \text{Equation 10}$$

Where A is the mature pig weight, W is the present weight and B is the growth coefficient. The interaction of ME and amimo acids is therefore critical in determining protein requirements for protein retention since limiting energy supply results in lower values of Pr_{max} (Moughan *et al*., 1995; Le Bellego *et al*., 2001).

It was evident that among the various feed resources used in smallholder pig enterprises, only commercially compounded feed, home-made formulations and agro-industrial by-products had the potential to meet the daily DM, CP and ME requirements. The daily DM, CP and ME allowance for pigs fed on commercially compounded feeds in Nakuru and Busia Counties indicated that pigs were not offered sufficient quantities of these feeds. This is because pigs will compensate for a decrease or increase in nutrient supply by adjusting feed intake when fed *ad libitum* (Miller *et al*., 1991). Respondents in the study indicated that the price of commercially compounded feeds were high. In Busia County, respondents identified lack of animal feed outlets and poor infrastructure as major barriers to use of commercial feeds and were left with the option of using locally available alternative feed resources.

Home-made diets using locally available raw materials were a good source of DM, CP and ME in enterprises in Kiambu and Nakuru Counties. Among challenges associated with the practice of home-based feed compounding was lack of technical knowhow as evidenced by improperly balanced diets. Levels of CP of up to $250gkg^{-1}$ in feed sample K086 were observed. High CP levels in pig diets result in decreased efficiency of utilization of ME as a result of increased amino acid catabolism (Noblet and Shi, 1994). High CP levels in weaner pig diets have been associated with increased risk of post-weaning enteric disorder associated with increased proliferation of enterotoxigenic *Eschericia coli* (Wellock *et al*., 2006) leading to scours (Garcia *et al*., 2014) and depressed growth rates (Nyachoti *et al*., 2006; Yue and Qiao, 2008; Gloaguen *et al*., 2014). High levels of dietary CP are also wasteful and contribute to environmental pollution as a result of increased amino acid deamination and excretion of nitrogenous waste with resultant eutrophication (Dourmad and Jondreville, 2007). Low CP level in pig diet as was observed in feed sample N136 would result to a lower Pr_{max} where dietary energy is low (Moughan *et al*., 1995) leading to poor growth and reproductive performance.

Though fats and oils are known to be readily digestible energy sources (Li *et al*., 1990; Jorgensen *et al*., 1996; Rossi *et al*., 2010), high levels of lipids in some home-made diets (feed samples B006 and B035) were undesirable because they predispose feeds to oxidative rancidity which renders feeds unpalatable with subsequent reduced feed intake and average daily gain (Liu *et al*., 2014).

Cereal by-products were the most valuable alternative feed resources, particularly so wheat pollard and rice bran similar to the findings of Kambashi *et al*. (2014). High levels of non-starch polysaccharides (NSP) are however well documented in maize and wheat bran. The most common NSP in cereal by-product are the soluble arabinoxylans (pentosan) and cellulose (Bach-Knudsen, 1997; Choct, 2006). Soluble NSPs have anti- nutritive effects associated with increased viscosity of digesta (I'Anson *et al*., 2014) leading to increased intestinal transit time, altered gut physiology and morphology and alteration of gut ecology (Bedford and Cowieson, 2012) associated with increased transit time (Choct, 2006). Arabinoxylan rich feedstuffs often have detrimental effects on nutrient digestibility when fed to young animals (Pieper *et al*., 2015) and therefore, their use should be limited.

Institutional swill was bulky due to high moisture content with low nutrient density resulting in low daily allowance of DM, CP and ME. This implied that swill could not be used on its own account to supply sufficient daily nutrient allowances for pigs. The high moisture content however limits its use in young pigs because of their limited capacity to feed on bulky feeds. Similarly, market waste and farm residues were bulky and had low nutrient density and could not supply sufficient daily nutrient allowances for pigs. However, the use of sweet potato vines to make silage for pig feeding has been explored with satisfactory results (Ly *et al*., 2010; Figueredo *et al*., 2012; Pedrosa *et al*., 2015) and could provide pig nutrition solutions for smallholder farmers.

iv. Pig performance indices and feeding decisions

The performance of pig enterprises can be assessed based on reproduction indices, age at first farrowing, litter size, weaning rate (piglet survival rate) and farrowing interval. These indices are often used as the parameters that determine sow production efficiency (Britt, 1986). The ideal productivity targets are 2.2 farrows per year (implying a farrowing interval of 166 days) with at least 10 piglets per litter surviving at weaning (Koketsu, 2002). Age at first farrowing and litter size indicated a better performance of sows in Kiambu County compared to either Nakuru or Busia Counties. Dietary energy is an important determinant of sow fertility (Kim *et al*., 2013). As earlier reported in this study, the amount of dietary energy provided to pigs in Kiambu County was higher than in Nakuru and Busia Counties. A lower survival rate of piglets in Kiambu County was associated with crushing by sows as a result of the small floor space allowance provided for nursing sows due to land pressure.

Survival rates of piglets from sows fed on commercially compounded feeds were higher than those that were fed on other feeds. This could be associated with the fact that these feeds were better balanced for macro and micro-nutrient. New born piglets are usually in a negative energy balance since they have limited glycogen stored in liver and muscles, yet the energy demand is high owing to the need for thermoregulation and locomotion. Improved sow nutrition in late gestation is critical in improving energy supply in newborn piglets through increasing glycogen stores in the sow, increasing colostrum yield and composition and increasing production of transient milk (Theil *et al*., 2014). This finding is supported by the findings of Kim *et al*. (1999) who reported that mammary gland growth and subsequent milk production is affected by nutrient intake during lactation. Thodberg and Sorensen (2006) concluded that sows fed on higher energy diets in late gestation had better nursing behaviour associated with reduced feed seeking activity during lactation and hence a reduced incidence of crushing piglets. Smallholders who fed pigs on alternative feed resources never supplemented pig diets with micro-nutrients (vitamins and mineral premixes/ supplements). Macronutrients such as the fat soluble vitamins (A, D and E) and minerals such as copper, manganese, selenium, iron and cobalt are critical for sow fertility. This probably explains in part the negative effect on age at sexual maturity and farrowing intervals.

4.5 Conclusion and Recommendations

4.5.1 Conclusion

This study concluded that the recommended daily allowance for DM, CP and ME were only achieved in Kiambu County with commercially compounded feeds, agro-industrial by-products of cereals and food processing and home-made feed formulations. The daily allowance for DM, CP and ME in the overall sample were however not acheived with either commercially compounded feeds or AFR. Institutional swill, farm residue and market waste did not provide sufficient DM, CP and ME necessary to meet the RDA in all study sites. Use of AFR was associated with smaller litter sizes, delayed age at first farrowing and longer farrowing intervals in sows.

4.5.2 Recommendations

The study recommended capacity building for farmers and extension agents on feed testing and formulation. Training and participatory action research could be beneficial in demonstrating improved reproductive performance of sows through proper feeding. Research should also focus on improving supply of nutrients from viable alternative feed resources through use of technology such as ensiling, dehydrating and compacting and supplementation with crystalline amino acids and exogenous enzymes.

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CHAPTER FIVE

BIO-ECONOMIC VALUES ASSOCIATED WITH INCLUSION OF SELECTED ALTERNATIVE FEED RESOURCES IN DIETS OF WEANED PIGLETS

Abstract

This study estimated the benefits of inclusion of selected alternative feed resources (AFR) in weaned piglet diets. A completely randomised design was used where 32 Landrace X Large White piglets weaned at 56 days consisting of 16 barrows and 16 gilts were randomly assigned to the 4 diets by allotting them to numbered cages such that there were 4 piglets of each sex per diet. The diets consisted of; (i). a basal maize-soybean diet, (ii). a diet containing 15% cold pressed canola meal (CPCM diet), (iii). a diet containing 15% rice polishing (RPL diet) and (iv). a diet containing 15% rice bran (RBN diet). The basal diet was used as the control diet. Results showed that CPCM diet had no effect on average daily feed intake (ADFI), average daily gain (ADG) or metabolisable energy: average daily gain (ME: ADG) ratio but reduced ($p \leq 0.05$) feed cost: ADG (FC: ADG) ratio by 24.44% in feeding weaned piglet. RPL diet did not affect ADFI and ADG but there was a 12.96% increase ($p \leq 0.05$) in ME: ADG ratio and a 22.7% decrease ($p \leq 0.05$) in the cost of feeding per kg increase in body weight (FC: ADG ratio). RBN diet had a 13.32% increase ($p \leq 0.05$) in ADFI without a change in ADG. Rice bran did not provide any advantage on either dietary energy or feed cost efficiency over the basal diet. Rice bran therefore did not offer any benefit when used in weaned piglet diets. The study concluded that inclusion of AFR such as cold pressed canola meal and rice polishing in weaned piglet diets provides bio-economic benefits that reduce the cost of feeding pigs. Inclusion of AFR rich in dietary fibre such as rice bran in weaned piglet diet do not offer bio-economic benefits. This study recommended evaluation of use of bio-technology to improve digestibility of fibrous feedstuff such as rice bran. The study also recommended evaluation of effects of dietary components of AFR on changes in digestive capability and carcass quality in finisher pigs.

Key words: Alternative feed resources, Bio-economic values, *Brassica napus*, Cold pressed, dietary energy efficiency, feed cost efficiency

5.1 Introduction

The objective of this study was to investigate the effects of inclusion of selected alternative feed resources (AFR) in weaned piglet diets on average daily feed intake (ADFI), scaled average daily feed intake (SFI) average daily weight gain (ADG) and scaled average daily gain (SADG). The study also sought to compute and compare feed cost efficiencies and metabolisable energy: ADG ratio (ME:ADG) between test feeds.

Some AFR have been reported to have potential to improve production efficiencies through better growth rates, lower feed conversion ratios and reduced anti-nutritional factors (Angle (2017). Diarra *et al*. (2017) reported that dried and ground cassava leave included in pig feeds at 30% maintains growth and reduces cost of pork production. Kang *et al*. (2010) demonstrated the use of dried and fermented papaya processing by-product as a substrate for yeast (*Saccharomyces cerevisiae*) growth resulting in a product that was rich in CP (45%) and could be used as an alternative to commercial protein ingredients. Sandberg *et al*. (2016) and Ncobela *et al*. (2017) reported that boiling, fermentation, sun drying and ensiling AFR were beneficial processing techniques. Chemical treatment of AFR has also been demonstrated to give positive results. Vadivel *et al*. (2011) demonstrated that treating velvet beans with sodium bicarbonate reduced anti-nutritional factors in the beans and improved performance of chicken.

Efficient utilisation of AFR in pig diets is dependent on several factors; key factors being the effects on palatability, digestibility and nutrient availability for absorption (Regnier *et al*., 2010). These factors have a direct impact on ADFI, ADG, ME:ADG and FC: ADG ratios and therefore, these indices can be used to evaluate the performance of pigs offered different diets.

5.2 Materials and methods

5.2.1 Experimental diets

Experimental diets were formulated using Evapig® feed formulation software such that the four diets had a minimum metabolisable energy 2900 kcal/kg, lysine 1.2% and methionine 0.6%. The diets consisted of; (i) basal maize-soybean diet, (ii) diet containing 15% cold pressed canola meal to replace soybean meal as a protein source (CPCM diet), (iii) diet containing 15% rice polishing to replace maize (RPL diet) and (iv) diet containing 15% rice bran to replace maize (RBN diet) as shown in Table 13. Feed preparation was done at Egerton University, Tatton Agricultural Park feed mill. Energy levels were adjusted accordingly using canola oil so that the diets did not vary in metabolisable energy content. The cost of each diet was computed using the price of each raw material used in its formulation based on purchase receipts as shown in Table 13.

The AFR used were selected on the basis of potential availability in the country, observation from a survey of smallholder pig farms, likelihood of reducing competition for food grain with man and potential to provide an alternative and cheaper protein source. Cold pressed canola cake was obtained from a vegetable oil processing factory in Nakuru County which sources its raw material from Canola (*Brassica napus*) growing regions including Timau and Mau Narok. Hybrid seeds for the crop are distributed locally by Bayer East Africa Limited that distributes *Belinda Bayer*, a variety selected for low uracic acid. Cold pressed canola meal was used in the second diet at the rate of 15% to replace soybean meal as was used in the basal diet. Rice polishing and rice bran were obtained from Sagana Rice Mill in Kirinyaga County which is located in a rice growing region.

5.2.2 Management of experimental piglets

Experimental piglets were obtained from Egerton University Tatton Agricultural Park pig unit. The experiment was set up in a completely randomized design using 32 Landrace X Large White piglets consisting of 16 boars and 16 gilts weaned at 56 days that were assigned to the 4 diets. They were allotted to numbered cages such that there were 4 boars and 4 gilts per diet. The piglets were offered feed and water *ad libitum* throughout the duration of the experimental period (5 weeks). Feeding was done in such a way as to ensure that there was always some feed left in the trough every morning. To achieve this, an additional 100g of feed was provided for any piglet whose trough had less than 50g of left over feed from the previous days ration.

Authority to use Egerton University Tatton Farm animals for the study as well as the pig unit was obtained from the Egerton University Tatton Agricultural Park farm committee. Measures to maintain biosecurity were put in place since the farm is a quarantine area. Authority to use live animals as experimental units was also obtained from the Institute of Primate Research after certifying compliance with international code of animal ethics in research. Constant observation was done to ensure that pigs were free from any kind of distress. Regular observation of pigs for any signs of ill health was done to facilitate prompt treatment.

Piglets were allowed 5 days to acclimatise with the experimantal diet as well as the cages, ensuring that the ambient temperatures which varied between 18^{o} - 22^{o} C were comfortable for the pigs. Care was also taken to minimise unfarmiliar movements to avoid fright. Sufficient clean water was availed to the piglets through out the day.

Table 13: Feed composition and feed cost computation for experimental diets

Feed Component	Price Ksh/kg	Inclusion Rate In Diet (%)				Cost of fraction per 100kg			
		Basal	CPCM	RPL	RBN	Basal	CPCM	RPL	RBN
Maize (White)	27.78	65.60	60.00	53.20	46.45	1822.37	1666.8	1477.9	1290.38
Soybean meal	90	22.80	6.60	20.40	19.35	2052	594	1836	1741.5
Fish meal	120	5.00	5.00	5.00	5.00	600	600	600	600
Canola meal	26	0.00	15.00	0.00	0.00	0	390	0.00	0.00
Rice polishing	9.6	0.00	0.00	15.00	0.00	0.00	0.00	144	0.00
Rice bran	8	0.00	0.00	0.00	15.00	0.00	0.00	0.00	120
Lysine	280	0.50	0.60	0.50	0.50	140	168	140	140
Methionine	740	0.40	0.30	0.40	0.40	296	222	296	296
Limestone	5	2.50	2.50	2.50	2.50	12.5	12.5	12.5	12.5
DCP	140	2.50	2.50	2.50	2.50	350	350	350	350
S/W Premix	280	0.25	0.25	0.25	0.25	70	70	70	70
Salt	60	0.25	0.25	0.25	0.25	15	15	15	15
Vegetable oil (Canola)	128	0.20	2.00	0.00	2.80	25.6	15	0	358.4
		100.00	100.0	100.0	100.0	5383.47	4103.3	4941.4	4993.78
					Cost of feed in Ksh/kg	53.83	41.03	49.41	49.94

Key: CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet, DCP=dicalcium phosphate, S/W=sow and weaner,

Vitamin and mineral premix provided per kilogram of diet: 450 mg Fe; 400 mg Cu; 250 mg Zn; 150 mg Mn; 0.5 mg I; 0.25 mg Se; 8,000 IU vitamin A; 2,000 vitamin D3; 37.5 mg vitamin E; 0.925 mg vitamin K-3; 8.43 mg vitamin B2; 0.04 mg vitamin B12; 34.5 mg nicotinic acid; 26 mg pantothenic acid.

1 US$ = 101.2

5.2.3 Data collection and analysis

Difference in the means of weaning weight of experimental piglets between and sexes were computed using T-test using SPSS statistical software. ANOVA was computed and Tukey's test used to seperate the mean weights of piglets between diets. Proximate and energy values of diets were determined in triplicates and comparison of mean values was done by computing ANOVA using PROC ANOVA procedures of SAS® systems and Tukey's test used to seperate the mean. Dietary gross energy values were determined using bomb calorimeter model number e2K and comparison of mean values done in a similar procedure.

Daily feed intake was calculated as the difference between the total amount of feed offered to each piglet and the residual feed in the trough after 24 hours. Weight of piglets was taken every 7^{th} day using a digital weighing scale with an accuracy of 5g. Feacal samples were collected from 4 piglets randomly selected from the 8 allocated to each diet over a period of 26 days (between day 9 and 35 of the experiment). Faecal weight was determined and recorded by collecting all the feaces on the cage floor. To estimate the percentage moisture content of feaces, a sub-sample of approximately 200 g was weighed, and then dried in an oven at 55^oC until there was no further loss in weight. Dry feaces from pigs on same diet were mixed and milled then stored in air-tight containers until the time of analysis.

The cages were equipped with a drain which allowed for urine to be collected in a container placed under the cage in which 1 ml of 1% H_2SO_4 was added. Urine volume was measured using a measuring cylinder and a sub-sample of 10 ml was collected in corked test tubes, placed in a rack and refrigerated at -4^oC until the time of analysis for urinary nitrogen. Urinary nitrogen concentration was determined using Kjedhal method and multiplied by a standard constant factor 6.25 to estimate the amount of crude protein in urine. Comparison of mean protein values was done by computing ANOVA using PROC ANOVA procedures of SAS® systems and Tukey's test used to seperate the mean.

Computation of apparent digestibility was done using Equation 6 and comparison of means was done using PROC ANOVA procedure. The ADFI was computed by dividing the total amount of feed eaten by each piglet over the test period by the test duration in days. Scaled daily feed intake (SFI) was computed to account for the different individual weight of pigs using the approach of Ncobela *et al*. (2018) and was given as the daily feed intake in grams per kg body weight. The average daily weight gain (ADG) was computed as the regression coefficient (β_1) on the regression of weight in kg against time in days. Scaled average daily gain (SADG) was computed to account for the different individual weight of pigs using the approach of Ncobela *et al*. (2018) and was given as the daily weight gain in grams per kg body weight.

Feed conversion ratio (FCR) was computed as the coefficient of a regression of ADFI against ADG. The metabolisable energy to ADG ratio (ME:ADG) was computed as the regression coefficient (β_1) on the regression of piglets' mean daily ME intake against their ADG. The mean daily ME intake was computed as the product of ADFI and the dietary ME content. The product of ADFI and feed cost per kg was used to compute the feed cost to ADG ratio (FC: ADG). Comparison of the mean values of ADFI, SFI, ADG, SADG, FCR, ME: ADG and FC: ADG was done by computing ANOVA using PROC ANOVA procedures of SAS® systems and Tukey's test used to seperate the mean. Least square means of ADFI, ADWG, ME:ADG ratio and FC: ADG ratio for the experimental diets and between sex of piglets were computed using PROC GLM procedures of SAS® systems and Tukeys test used to seperate the means.

5.3 Results

5.3.1 Piglet weight at start of experiment

The mean weight of piglets at day 62 (start of experiment) was 10.91 $\pm$ 0.39kg. The difference in the mean weights between diets and sex was insignificant ($p \leq 0.05$).

5.3.2 Composition and apparent digestibility of test diets

Results of the proximate, detergent fibre and gross energy values were as shown in Table 14. The EE content in CPCM diet (48.2 $\pm$ 1.2 g/kg) was significantly higher ($p \leq 0.05$) as compared to the EE in the basal diet. The EE content in RPL and RBN diets was also higher ($p \leq 0.05$) compared to the basal diet, (45.7 $\pm$ 0.04 g/ kg, and 20.6 + 0.5 g/kg respectively). The gross energy (GE) value for RPL diet was significantly higher ($p \leq 0.05$) than that of the basal diet (4049 + 19.55 kcal/kg verses 3811.57 kcal/kg). The DM content of RBN diet was higher ($p \leq 0.05$) than in the basal diet, (92.64% versus 91.31%).

Table 14: Proximate, fibre and gross energy fractions of experimental diets on dry matter basis

Diet	DM %	Ash %	CP %	EE %	NDF %	GE %	DE kcal/kg	ME kcal/kg(computed)
Control	91.31(0.14)	9.12(0.04)	19.47(1.15)	1.61(0.01)	25.12(3.02)	3812(0.5)	3361.45	3058.3
CPCM	91.61(0.16)	7.33(0.18)	19.38(0.91)	4.82(0.12)	29.40(1.45)	3718(13.3)	3229.67	3039.3
RPL	91.67(0.38)	9.43(0.06)	18.81(0.81)	4.57(0.00)	32.36(0.32)	4050(19.6)	3491.16	3160.6
RBN	92.64(0.08)	12.76(0.06)	18.03(0.58)	2.06(0.05)	33.80(1.3)	3850(37.1)	3128.97	2944.1

DM=dry matter, CP=crude protein, EE=ether extract, NDF=neutral detergent fibre, GE=gross energy, CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet, Standard errors in parenthesis.

Results of the mean feed intake, feacal weight, dietary and faecal and urinary protein analysis are shown on Appendix XII and XIII. There were no differences in apparent digestibility between the basal diet and the 3 test diets as shown on Table 15.

Table 15: Comparison of apparent digestibility of test diets

Test parameter	Diet				p- value
	Basal	CPCM	RPL	RBN	
Apparent digestibility of diet %	70.1	74	76.66	69.11	0.35
Apparent digestibility of Nitrogen %	78.38	83.75	78.4	79.76	0.32

CPCM=cold pressed canola meal, RPL= rice polishing diet, RBN=rice bran diet

Noblet and Le Goff (2001) reported that the digestibility of fibre varies between 0.4 to 0.6 as compared to fats, sugars and protein whose digestibility is over 0.8. The presence of higher dietary fibre in RBN diet however did not affect crude protein digestibility contrary to the findings of Bindelle *et al*. (2008) and Jha and Berrocoso (2015). These differences can be attributed to the different non starch polysaccharides present in the different feedstuff that also have different digestibility coefficients (Noblet and Le Goff, 2001).

5.3.3 Average daily feed intake

Composite data on ADFI was not normally distributed around the mean (1148.54 $\pm$ 41.99 g/day); Shapiro-Wilk's statistic = 0.93, p =0.05. This data was normally distributed when each diet was considered individually. An evaluation of the distribution of ADFI values between sexes showed that the data was normally distributed. There was no difference in ADFI between the 4 diets; F = 0.51, p = 0.48. There was no difference in the mean ADFI of the test diets compared to basal diet (basal diet = 1095 $\pm$ 86.19, CPCM diet = 1138.89 $\pm$ 88.89, RPL diet = 1153.23 $\pm$ 64.11 and RBN diet = 1206.74 $\pm$ 104.37). There was an initial steep rise in the ADFI of all feeds between the first and second weeks of the experiment after which, the ADFI increased at a decreasing rate. The ADFI for RBN diet remained higher than that of the basal diet throughout the experimental period.

The mean SFI for the basal, CPCM, RBN and RPL diets were 15.17, 15.25, 14.84 and 17.19 g/kg body weight respectively. Results of ANOVA showed that SFI of RBN diet was higher than that of the basal diet as well as RPL diet; F =5.00, p = 0.01. A graphical comparison of SFI for the 4 diets was as shown in Figure 4. This meant that piglets offered RBN diet fed more per kg body weight than piglets fed on any of the other 3 diets.

There was an initial increase in SFI for all diets followed by a gradual decrease from the second week of the experiment onwards.

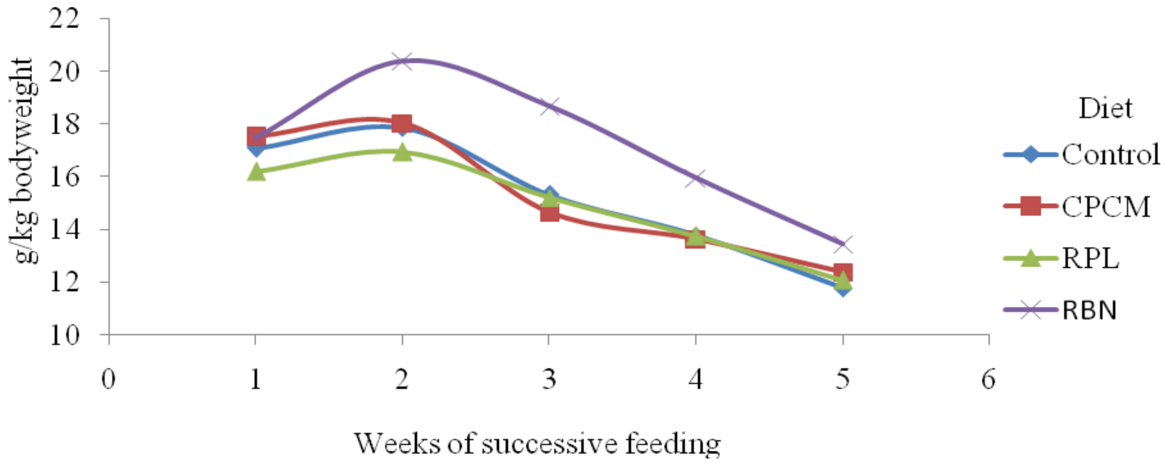

Figure 4: Weekly trend of scaled average daily feed intake of the diets

Key: CPCM=cold pressed canola meal, RPL= rice polishings, RBN=rice bran

5.3.4 Average daily weight gain

Results showed an initial phase of slow growth for all diets between Day 56 (weaning age) and Day 62 which represented the acclimatization period. Regression analysis for the growth curve between 62 and 99 days of age for all diets which showed that linear regression had the highest coefficient of determination; R^2 = 99.8%, p = 0.01.

Results of regression analysis showed that the ADG for the 4 diets were; basal diet = 0.46 $\pm$ 0.01, t = 42.5, p=0.00, R^2 = 99.8%; CPCM diet = 0.47, t = 106.67, p = 0.00; RPL diet = 0.56 $\pm$ 0.02, t = 31.36, p = 0.00 and RBN diet = 0.48 $\pm$ 0.01, t = 35.24, p = 0.00. The mean values for ADG between diets were not different, F = 2.12, p = 0.12. Independent samples T-test showed that there were no differences in ADG between male (0.49 $\pm$ 0.03) and female (0.5 $\pm$ 0.02) piglets over the test period. RPL diet had the lowest mean FCR = 2.04 $\pm$ 0.02, F = 19.20, p =0.00. The mean FCR for CPCM was not different from that of the control diet. The FCR for RBN diet was 2.68 $\pm$ 0.09 which was higher than that of the basal diet (2.42 $\pm$ 0.07).

There was a decrease in SADG followed by a reduction in the rate of decrease from the second week of the experiment onwards. The SADG for the three test diets were similar to the SADG for the control diet; F = 1.92, p = 0.15. The results showed that as piglets grew older, there was s a decrease in weight gain as a proportion of body weight.

5.3.5 Metabolisable energy to ADG ratio

The variances in mean ME:ADG values in kcal/kg for the 4 diets were different; basal diet = 7398.48 ± 230.87, CPCM = 7232.77 ± 62.29, RPL = 6439.59 ± 75.44 and RBN = 7884 ± 273 (Figure 5); F = 24.82, p = 0.01. The mean ME:ADG for male and female piglets were not different (7010.94 ± 123.69 and 7412.28 ± 208.3 respectively); t = -1.629, p = 0.11. A comparison of the mean ME:ADG of each of the 3 test diets with that of the basal diet showed that the mean ME:ADG of RPL diet was significantly lower, t = 3.95, p = 0.00, implying that a lower amount of dietary ME intake (6439.59 kcal) from RPL diet was required for every 1kg increase in body weight compared to 7398.48 kcal from the basal diet.

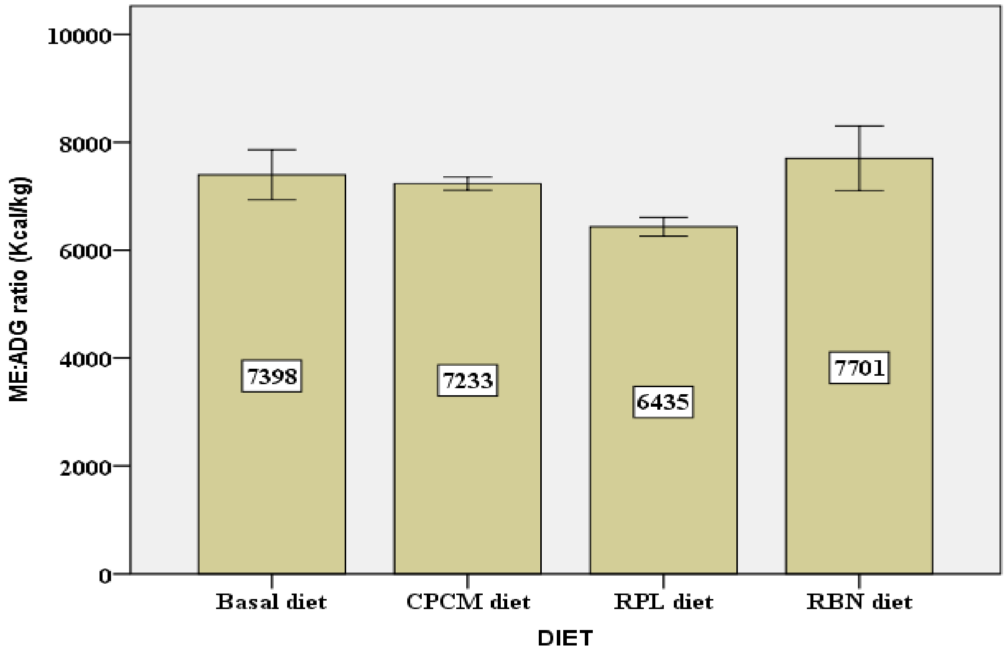

Figure 5: Comparison of mean ME: ADG ratio between research diets

5.3.6 Feed cost to ADG ratio

Results of a comparison of FC: ADG were as shown on Figure 6. Results of independent samples T-test showed that the mean FC: ADG in KES/kg for CPCM diet (97.64 ± 0.86) was lower than that of the basal diet (130.22 ± 4.06); t = 7.09, p = 0.00. The mean FC: ADG for RPL diet (100.67 ± 1.18) was lower than that of the basal diet; t = 6.98, p = 0.01. The mean values of feed cost: ADG ratio for barrows and gilts were comparable at 111.52 ± 3.78 and 117.67 ± 5.09 respectively; t = 0.95, p = 0.35, indicating that the cost of feeding weaned piglet from 56 - 99 days of age was equal between sexes.

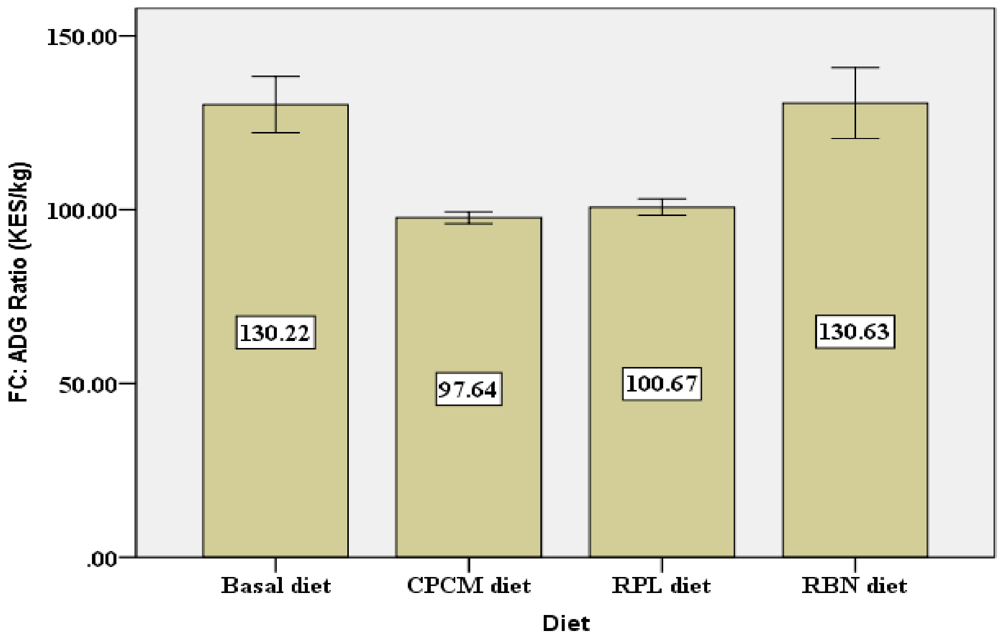

Figure 6: A comparison of FC: ADG ratio between experimental diets

5.4 Empirical estimation

Results of least square means of ADFI, ADWG, ME:ADG ratio and FC: ADG ratio for the experimental diets and between sex of piglets were shown on Table 16. The results showed that the ADFI of the diets were not significantly different. The mean value for ME: ADG for RPL diet was significantly lower ($p \leq 0.05$) than that of the basal, CPCM and RBN diets. The mean value of FC: ADG for CPCM and RPL diets were significantly lower ($p \leq 0.05$) than the mean value for the basal and RBN diets. Both diet and sex were significant ($p \leq 0.05$) in explaining variation in ME: ADG ($R^2 = 0.54$) and FC: ADG ($R^2 = 0.78$) ratios.

5.5 Discussion

Among the major challenges to pig farming in Kenya is high cost and poor quality of feeds. Efforts to reduce feeding costs are often limited by the nutritional value of available alternative feed resources. Though maize is by far the most important energy source for pig feeds in Kenya, its use in pig feed processing is constrained by competition with man because it also is the staple food in the country. There is need to investigate the use of alternative energy sources as well as non-conventional and cheaper protein sources so as to reduce the cost of feeding pigs. This study therefore investigated the bio-economic benefits of inclusion of alternative feed resources in weaned piglet diets while reducing the fractions of maize and soybean as the main energy and protein sources respectively.

Table 16: Effects of diet and sex of pig on daily gain, feed intake and feed efficiency during the grower phase (62 - 99days of age)

Parameter	Diet				Sex		
	Basal	CPCM	RPL	RBN	Male	Female	p-value
ADFI (g)	1079.39[a] (86.01)	1154.81[a] (86.01)	1153.23[a] (85.32)	1206.74[a] (85.32)	1116.28 (56.24)	1181.47 (61.14)	0.15
ADG (g)	454.53[a] (34.94)	480.22[a] (34.94)	566.25[a] (34.66)	456.38[a] (34.66)	478.54 (36.24)	500.15 (38.89)	0.52
ME:ADG (Kcal/kg)	7344.54[a] (182.83)	7286.71[a] (182.83)	6439.59[b] (181.38)	7700.74[a](181.38)	7010.94 (123.64)	7408.40 (209.50)	0.03
FC:ADG (KES/kg)	129.29[a] (3.11)	101.67[b] (3.11)	100.67[b] (3.09)	130.63[a] (3.09)	106.24 (1.18)	124.89 (2.01)	0.02

Means on the same row with different superscripts are significantly different.

CPCM=cold pressed canola meal, RPL=rice polishing diet, RBN=rice bran diet, ADFI=average daily feed intake (g/day), ADG=average daily gain, ME:ADG=metabolisable energy to average daily gain ratio, FC: ADG=feed cost average daily gain ratio.

i. Feed digestibility

Results from this study showed that substituting maize with rice polishing or rice bran at 15% in diets of weaned piglets did not affect the apparent digestibility of the diets. The apparent digestibility of nitrogen was also not affected. Increasing dietary fibre in piglet diets results in reduced digestibility of such diets due to increased bulkiness. However, inclusion of rice polishing and rice bran in weaned piglet diets at the rate of 15% did not increase the dietary fibre to a level that affected feed digestibility and nitrogen digestibility.

Substituting soybean meal with cold pressed canola meal as a protein source did not affect the apparent digestibility of the diet as well as the apparent digestibility of nitrogen. Canola meal is obtained after cold pressing of *Brassica napus* seeds to produce edible oil. Canola meal also has a higher fibre content compared to soybean meal. However, results in this study showed that inclusion of canola meal in weaned piglet diets at the rate of 15% did not affect the apparent digestibility of the diet. Though the difference in NDF fraction between the basal and CPCM diets was insignificant, the mean value in CPCM diet (29.4%) was 4.4 percentage points higher than the recommended maximum of 25% (NRC, 2012) for growing pigs. The effects of dietary fibre on digestibility of diets are attributed to its viscosity and fermentability which are dependent on the solubility and structural characteristics of fibre. Viscous fibre binds water and increases digesta viscosity hence reducing nutrient digestibility in the small intestines (Renteria-Flores *et al*., 2008; Serena *et al*., 2008; Hooda *et al*., 2011. Fermentable fibre passes into the large intestines and is fermented to produce SCFA. It is therefore likely that dietary fibre present in cold pressed canola meal was less of the viscous and more of the fermentable nature.

ii. Average daily feed intake

The starting point for evaluation of animal performance is the evaluation of feed intake (Whittemore *et al*., 2002). Feed intake is influenced by many factors including animal characteristics such as body weight, genetic adaptations, feed factors such as nutrient density, digestibility, presence of anti-nutritional factors (Cadogan and Choct, 2003) particle size, feed form (I'Anson *et al*., 2012), environmental and management factors such as ambient temperature, humidity and housing density. The experiment was done such that there was no variation in the above factors except for experimental diets where the energy and protein sources were varied while maintaining the level of ME and amino acids lysine and methionine constant.

This study showed that ADFI was not changed when rice polishing and rice bran were used as substitutes for maize 15% and canola meal as a substitute for soybean meal at 15% in weaned piglet diets. When individual differences in body weight were considered in the analysis, the results showed that piglets offered RBN diet had a higher feed intake per kg body weight as compared to the piglets fed on the basal diet. RBN diet had a neutral detergent fibre concentration that was 15.06% higher as compared to the basal diet. Though this differences were not statistically significant due to the small samples sizes (in this case 3 replicates for each diet) it could explain the difference in SFI. The difference could also be associated with a higher rate of passage through the gastro-intestinal tract.

Brassica napus seeds are known to contain glycosinolates (Blood and Radostits, 1989) which have astringent properties (Wickramasuriya *et al*., 2015). Since pig tongues are heavily endowed with taste buds, the astringent properties of glycosinolates could have affected feed palatability and feed intake. However, inclusion of canola meal in weaned piglet diet at the rate of 15% in place of soybean meal did not affect either ADFI or SFI of the diet. Feed intake in pigs is affected by dietary factors (energy concentration, protein level and amino acid balance, feed processing), animal factors (breed, body weight, health status) and environmental factors (Li and Patience, 2017). The diets offered to piglets in this experiment were isocaloric while the other factors were held constant, probably explaining lack of difference in mean ADFI and SFI between the basal and CPCM diets.

iii. Average daily weight gain

Results from this study showed that the average daily gain (ADG) of the test diets did not differ from that of the basal diet. Substituting soybean meal with canola meal as a protein source at the rate of 15% did not affect the ADG. A comparison of nutritional values between canola meal and soybean meal from laboratory analysis of samples in this study and different literature is shown on Table 17. Though soybean meal was higher in CP compared to canola meal, the higher EE content in canola meal compensated for energy and therefore the dietary ME remained unchanged. The higher CF in canola meal did not affect the ADG in CPCM diet fed piglets. This finding corroborates the earlier finding that inclusion of cold pressed canola meal in pig diet did not affect feed digestibility, thereby strengthening the arguement that the dietary fibre present is fermentable and probably yielded SCFA which were absorbed to provide energy for pig growth; therefore ADG was not compromised.

Table 17: Comparison of nutritional values of Soybean meal and Canola meal used in diet formulation

Feedstuff	Processing	Nutritional value	Reference
Soybean meal	Solvent	CP=44.52(0.97), NDF=22.14(4.2), EE=2.01(0.52), GE=4199kcal/kg	Current study results
	Solvent	CP=47.73(2.3), CF=3.89(1.6) EE=1.52 (0.91), ME=3294 kcal/kg	NRC, 2012
Canola meal	Expelled	CP=36.32(1.66), NDF=46.64 (8.5), EE=8.31(0.32), GE=4484 kcal/kg	Current study results
	Expelled	CP = 35.19(40.8), C=9.77(2.66) EE=9.97(3.34), ME=3540 kcal/kg	NRC, 2012

CP=crude protein, CF=crude fibre, EE=ether extract, ME=metabolisable energy, NDF=neutral detergent fibre

Substitution of maize for rice polishing and rice bran at the rate of 15% in weaned piglet diets did not affect ADG. As earlier noted, the SFI of RBN diet was higher than that of the basal diets well as CPCM and RPL diets. Therefore, to maintain a similar growth rate with the basal diet, piglets fed *ad libitum* on a diet where maize has been replaced with rice bran at the rate of 15% will increase their feed intake per kg body weight by 13.32%.

iv. Metabolisable energy: Average daily gain ratio (ME:ADG)

ME:ADG was used as a measure of dietary energy efficiency in reference to piglet weight gain. Results in this study showed that substituting maize with rice polishing at 15% in weaned piglet diets resulted in a 12.96% improvement in dietary energy efficiency (basal diet = 7398 $\pm$ 230.87 kcal/kg weight increase, RPL diet = 6439.59 $\pm$ 75.43 kcal/kg weight increase). The two diets were isocaloric and also balanced for lysine and methionine. The RPL diet had an EE content that was 2.8 times higher than the basal diet. This could have resulted in an increased apparent digestibility of RPL diet by 9.4% when compared to the basal diet resulting in a higher ADG. Collins *et al.* (2009) also reported improved performance of pigs fed on diets with increasing fat fractions. The higher EE fractions in RPL diet could have contributed to a lower ME:ADG.

Substituting soybean meal with canola meal in weaned piglet diets at 15% did not alter the energy efficiency of CPCM diet. Replacing maize for rice bran in weaned piglet diets did not alter the energy efficiency of RBN diet. The difference in apparent digestibility between the basal diet and CPCM and RBN diets was 1.4% and 5.5% respectively. From this analysis, feed digestibility appears to be a determinant of ME: ADG. This study would recommend a more robust study on this relationship.

v. Feed cost: Average gain ratio

Substituting soybean meal with canola meal at 15% in weaned piglet diet reduced the cost of feeding for every 1 kg increase in body weight by 24.44%. This was as a result of the relatively big difference in price between soybean meal and canola meal (KES 90 and KES 26 respectively). Use of rice polishing at the rate of 15% to replace maize in weaned piglet diet resulted in a 22.7% reduction in the cost of feeding for every 1 kg increase in body weight. Though rice bran was relatively cheap, it did not reduce the cost of feeding owing to higher feed intake and the cost of increasing dietary ME of RBN diet using vegetable oil to make it isocaloric with the basal diet.

5.6. Conclusion and Recommendations

5.6.1 Conclusion

i. Cold pressed canola meal used in weaned piglet diets at the rate of 15% had no effect on average daily feed intake, weight gain or dietary energy efficiency but increased feed cost efficiency by 24.44% in feeding weaned piglet.

ii. Rice polishing used in weaned piglet diets at the rate of 15% did not affect feed intake and weight gain and there was a 12.96% improvement in dietary energy efficiency and a 22.7% decrease in the cost of feeding per kg increase in body weight.

iii. Rice bran used in weaned piglet diet at 15% increased in feed intake by 13.32% without a change in weight gain. Rice bran did not provide any advantage on either dietary energy or feed cost efficiency over the basal diet. Rice bran therefore did not offer any benefit when used in weaned piglet diets.

5.6.2 Recommendations

This study recommended evaluation of use of bio-technology to improve digestibility of fibrous feedstuff such as rice bran. The study also recommended evaluation of effects of dietary components of AFR on carcass quality and changes in digestive capability in finisher pigs.

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CHAPTER SIX

EFFECTS OF EXOGENOUS ENZYMES ON NUTRIENT DIGESTIBILITY AND PERFORMANCE OF WEANED PIGLETS FED RICE BRAN DIET

Abstract

This study estimated the benefits of inclusion of exogenous enzymes in a low protein, fibre rich diet of weaned piglets. The choice of test diet was informed by the results obtained in Chapter Four which concluded that inclusion of rice bran in weaned piglet diets at the rate of 15% in place of maize did not offer any benefit over basal maize - soybean diet. This study sought to compare the average daily feed intake (ADFI), scaled average daily feed intake (SFI) average daily weight gain (ADG), scaled average daily gain (SADG), metabolisable energy to ADG ratio (ME:ADG) and feed cost to ADG (FC: ADG) ratio between a 20% rice bran diet (RBN), a 20% rice bran diet with exogenous dietary (Natuzyme®) multi-enzyme complex (RBNe) and a basal maize - soybean meal diet. Results showed that inclusion of Natuzyme® multi-enzyme complex in a 20% rice bran diet of weaned piglets had no effect on dry matter digestibility of the diet. Inclusion of exogenous enzymes resulted in increased ($p \leq 0.05$) dietary digestible energy of the diet by 8.7% and a 12.5% increase ($p \leq 0.05$) in apparent digestibility of nitrogen compared to diet without exogenous enzymes. Inclusion of exogenous enzymes in weaned piglet diet reduced ($p \leq 0.05$) the SFI by 13.4% but there was no effect on average daily gain. There was a 12.77% improvement ($p \leq 0.05$) in metabolisable energy: average daily gain ratio and a reduction ($p \leq 0.05$) in the feed cost: average daily gain ratio by 12.25%. The study concluded that though there is no change in growth rate, inclusion of dietary enzymes in weaned piglet diets is beneficial in that it improves the feed conversion ratio and reduces the cost of producing a kilogram of pork. The study recommended further study of individual exogenous enzymes to help understand their mode of action in increasing apparent digestibility of nitrogen.

Key words: Anti-nutritional factors, Apparent digestibility, Dietary fibre, Exogenous dietary enzymes, Rice milling by-product

6.1 Introduction

As a result of current trends with increasing cost feedstuffs used in production of animal feeds, there is increasing interest in improving feed efficiency (Cowieson, 2010; Yegani and Korver, 2013). However, the presence of significant levels of insoluble fibre and anti-nutritional factors (ANFs) in various feedstuffs limits potential benefits in animal feeding. Some of the common ANFs include glucosinolates in mustard and canola meals, trypsin inhibitors and haemagglutinins in legumes, tannins in legumes and cereals, gossypol in cottonseed cakes, and uricogenic nucleic acid bases in yeast by-products (Gilani *et al*., 2012). ANFs have been reported to cause significant decrease in protein and amino acid digestibility. Phytates commonly found in legumes and cereals have been reported to reduce amino acid digestibility and bioavailability of phosphorous.

Dietary fibre (that is, NSP, including pectins, cellulose, hemicellulose, β-glucans, fructans, oligosaccharides, lignin, and resistant starch affects the voluntary feed intake of pigs. Since the apparent digestibility of dietary fibre is low (40 - 50%), dietary fibre lowers the energy value of diets. Pigs consume 100g DM/ kg body weight $^{0.75}$ (Martens *et al*., 2012) and therefore, high dietary fibre levels limit energy intake and reduces performance. To overcome challenges associated with presence of high levels of dietary fibre and phytates, exogenous enzymes have been used in pig diets, however, results have been mixed and inconclusive (Adeola and Cowieson, 2011; Liu *et al*., 2013).

The mode of action of exogenous enzymes is unclear (Bedford and Schulze, 1998 as cited by Walsh *et al*., 2012) but is hypothesised to improve digestibility of energy, protein and fats by reducing viscosity of digesta by acting on NSP. This increases contact between feed and digestive enzymes as well as with the absorptive surface of the gut. NSP hydrolysing enzymes in pigs appear to have a dual role, functioning both to reduce viscosity of the digesta and weakening the cell wall of cereals (Bedford and Schulze, 1998).

Though use of exogenous enzymes has been shown to be beneficial, potential negative effect could result as a result of reduction of the beneficial effects of fermentable dietary fibre; that of reducing ammonia emmision. Inclusion of exogenous enzymes in pig diets has also been shown to reduce the prebiotic effect of β-glucans (Garry *et al*., 2007: Herfel *et al*., 2013).

Rice bran is a by-product of rice milling and constitites about 10% of the total weight of unprocessed rice and comprices of the aleurone, pericarp subaleurone and germ. It is rich in dietary fibre, vitamins and minerals (Sandarodiyan and Salehi, 2016). Dietary fibre present in rice bran comprises mainly comprises of arabinose and xylose (Annison *et al*., 1995; Farrel and Martin, 1998) which could be utilsed more efficiently in pig diets by including exogenous enzymes that enhance their degradation.

6.2 Materials and methods

6.2.1 Experimental diets

Three experimental diets consisted of; (i) a basal maize soybean diet, (ii) a diet in which maize had been substituted with rice bran at 20% (RBN diet) and (iii) a diet similar to RBN diet in which exogenous enzymes had been included (RBNe) as shown in Table 18. The exogenous enzymes used comprised of a multienzyme complex Natuzyme®, manufactured by Bioproton PTY limited, Australia and distributed in Kenya by Cooper Kenya Limited. Natuzyme® is presented in powder form and contains 12,000 units/g of xylanase, 6000 units/g of cellulase, 1500units/g of phytase, 700 units/g of beta-glucanase, 700 units/g of protease and 400 units/g of alpha-amylase. Natuzyme® was included in RBNe diet at the rate of 350mg/kg of feed as per the manufacturer's recommendation. The nutrient composition of RBN and RBNe diets were assumed to be identical since inclusion of Natuzyme® multienzyme complex had negligible effect on composition.

6.2.2 Experimental piglets

The experiment was set up in a completely randomized design using 24 Landrace X Large White piglets consisting of 12 boars and 12 gilts weaned at 56 days that were randomly assigned to the 3 diets. They were randomly allotted to numbered cages such that there were 4 boars and 4 gilts per diet. Piglet management protocols were as described in section 5.2.2 of Chapter Four.

6.2.3 Data collection and analysis

Data collection and analysis was done using procedures described in section 5.2.3 of Chapter Four.

6.3 Results

6.3.1 Comparision of diet composition of experimental diets

Results of proximate and detergent fibre analysis showed that the mean values of EE in RBN and RBNe diets shown in Table 19 were higher ($p \leq 0.05$) than the mean value in the basal diet. The mean DM content of RBN and RBNe diets was higher ($p \leq 0.05$) than the mean value in the basal diet, (92.64% versus 91.31%). The mean CP content of RBN and RBNe diet was lower ($p \leq 0.05$) compared to the mean value the basal diet, (149.3 + 3.3 g/kg versus 197.1 + 11.5 g/kg).

Table 18: Formulation and cost of experimental feeds

Feed component	Price (Ksh/kg)	Inclusion Rate In Diet (%)			Cost of fraction per 100kg		
		Basal	RBN	RBNe	Basal	RBN	RBNe
Maize (White)	27.78	65.60	46.45	46.43	1822.37	1290.38	1290.38
Soybean meal	90	22.80	19.35	19.33	2052	1741.5	1741.5
Fish meal	120	5.00	5.00	5.00	600	600	600
Rice bran	8	0.00	20.00	20.00	0.00	160	160
Lysine	280	0.50	0.50	0.50	140	140	140
Methionine	740	0.40	0.40	0.40	296	296	296
Limestone	5	2.50	2.50	2.50	12.5	12.5	12.5
DCP	140	2.50	2.50	2.50	350	350	350
S/W Premix	280	0.25	0.25	0.25	70	70	70
Salt	60	0.25	0.25	0.25	15	15	15
Vegetable oil (Canola)	128	0.20	2.80	2.80	25.6	358.4	358.4
Natuzyme®	857.14	0	0	0.035	0	0	30
Total		100.00	100.0	100.0	5383.47	5033.78	5063.78
Cost of feed in Ksh/kg					53.83	50.34	50.64

CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet, DCP=dicalcium phosphate, S/W=sow and weaner

Vitamin and mineral premix provided per kilogram of diet: 450 mg Fe; 400 mg Cu; 250 mg Zn; 150 mg Mn; 0.5 mg I; 0.25 mg Se; 8,000 IU vitamin A; 2,000 vitamin D3; 37.5 mg vitamin E; 0.925 mg vitamin K-3; 8.43 mg vitamin B2; 0.04 mg vitamin B12; 34.5 mg nicotinic acid; 26 mg pantothenic acid.

1 US$ = 101.2 KES

Natuzyme® contained 12,000 units/g of xylanase, 6000 units/g of cellulase, 1500 units/g of phytase, 700 units/g of beta-glucanase, 700 units/g of protease and 400 units/g of alpha-amylase.

Table 19: Proximate, fibre and gross energy fractions of experimental diets on a DM basis

Diet	DM%	Ash%	CP%	EE%	NDF%	GE kcal/kg	DEkcal/kg	ME (computed)
Control	91.31(0.14)	9.12(0.04)	19.47(1.15)	1.61(0.01)	33.53(3.02)	3812(0.5)	3361.45	3058.3
RBN	92.64(0.08)	12.76(0.06)	14.93(0.58)	2.06(0.05)	38.58(1.3)	3850(37.1)	3128.97	2944.1
RBNe	92.64(0.08)	12.76(0.06)	14.93(0.58)	2.06(0.05)	38.58(1.3)	3850(37.1)	3360.60	

DM=dry matter, CP=crude protein, EE=ether extract, NDF=neutral detergent fibre, GE=gross energy, CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet, Standard errors in parenthesis.

The mean digestible energy of RBNe diet (3360kcal/kg) was higher ($p \leq 0.05$) than the mean value in RBN diet (3069 kcal/kg). The mean digestible energy of RBNe was however comparable to the mean value of the basal diet.

6.3.2 Apparent digestibility of experimental diets

The mean apparent digestibility of DM of RBNe diet was numerically higher (78%) than that of either the basal diet (70%) and RBN diet (69%), however, this difference was not significant (Table 20). The mean value of apparent digestibility of nitrogen in RBNe diet was significantly higher ($p \leq 0.05$) than that of the basal diet at 90% and 78% respectively, however, there was no difference in the mean value of apparent digestibility for nitrogen between RBN and RBNe diets. The apparent digestibility of NDF in RBNe diet was numerically higher (79%) than that of the basal diet (68%) and RBN diet (70%), however, the difference was insignificant ($p \leq 0.05$).

Table 20: Comparison of apparent digestibility of experimental diets

Parameter	R^2	Diet			p-value
		Basal	RBN	RBNe	
APPD %	0.44	70^a(2.01)	69^a(4.01)	78^a(0.01)	0.24
APPDN %	0.74	78^a(1.0)	80^{ab}(3.21)	90^b(0.01)	0.03
APPDF %	0.56	68^a(2.0)	70^a(4.06)	79^a(1.20)	0.13

Means on the same row with different superscripts are significantly different. APPD=apparent digestibility of DM, APPDN=apparent digestibility of nitrogen, APPDF=apparent digestibility of dietary fibre, RBN=rice bran diet, RBNe=rice bran diet with Natuzyme®, numbers in parenthesis are standard errors.

6.3.3 Average daily feed intake

The weaning weights of piglets between diets were equal, the means for ADFI between barrows (1040 $\pm$ 67.19 g/day) and gilts (1224.37 $\pm$ 57.84 g/day) were different ($p \leq 0.05$). Least square means of the ADFI of experimental diets were equal. Sex of piglets was insignificant in the GLM model while weaning weight was a significant determinant of variation in mean ADFI between experimental diets ($p \leq 0.05$) (Table 21).

Pigs offered RBN diet had a higher SFI throughout the entire period of the experiment. The mean value of SFI for RBN diet (36.45 $\pm$ 1.2 g/kg) was higher ($p \leq 0.05$) than the mean for RBNe diet (31.8 $\pm$ 0.99 g/kg). Both diet and sex of piglets were significant ($p \leq 0.05$) determinants of variation in mean SFI.

Table 21: Effects of experimental diets, sex and weaning weight on growth and performance indicators.

Indicator	Experimental diets			Sex			Weaning weight
	Basal diet 1	RBN diet	RBNe diet	Male	Female	p-value	p-value
ADFI (g)	1143.54[a](54.27)	1210.74[a](52.47)	1065.38[a] (53.89)	1040.1(67.19)	1224.4(57.84)	0.05	0.01
ADG (g)	461.78[a] (20)	456.05[a] (19.34)	468.82[a] (19.86)	450.76(31.61)	484.22(17.65)	0.10	0.01
SFI(g/kg)	33.35[a] (1.2)	36.45[b] (1.2)	31.8[a] (0.99)	32.29(0.88)	35.20(1.22)	0.01	xx
ME:ADG (kcal/kg)	7344.91[a] (256.89)	7727.53[a] (255.99)	6740.35[b] (255.99)	6916.01 (191.41)	7571.3 (258.11)	0.05	xx
FC:ADG (ksh/kg)	129.31[a] (4.41)	131.09[a] (4.39)	115.03[b] (4.39)	118.79(3.41)	130.51(4.41)	0.04	xx

Means on the same row with different superscripts are significantly different.

ADFI=average daily feed intake, ADG=average daily weight gain, SFI=scaled average daily feed intake, ME:ADG=metabolisable energy to average daily weight gain ratio, FC: ADG=feed cost to average daily weight gain ratio. RBN=rice bran diet, RBNe=rice bran diet with multi-enzyme complex, Standard errors in parenthesis, xx=variable omitted due to inefficiency

6.3.4 Average daily gain

Regression analysis showed that the mean values of ADG for the 3 diets were not significantly different ($p \leq 0.05$) ; basal diet = 461.78 $\pm$ 20 g/day, RBN diet = 456.08 $\pm$ 19.34 g/day and RBNe diet = 468.82 + 19.86 g/day. GLM model predicted 66% of the variability in ADG; F = 9.08, $p \leq 0.05$. Weaning weight of piglets was a significant determinant of ADG (F = 31.5, $p \leq 0.05$) while diet and sex of piglets did not significantly explain variation in ADG. Spearman correlation coefficient showed that there was a positive correlation ADG and weaning weight; Pearson's r = 0.84, $p \leq 0.05$ and the results were presented on a graph (Figure 7).

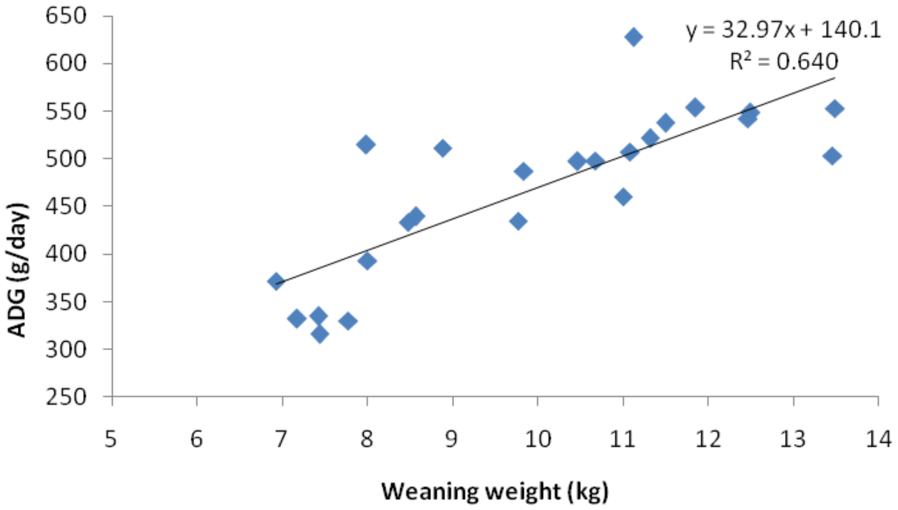

Figure 7: Regression results estimating the relationship between weaning weight of piglets and average daily weight gain between 62 -99 days of age

6.3.5 Metabolisable energy to ADG ratio

Computation of least square means of the ME:ADG ratio of experimental diets showed that the model was significant; F = 4.16, $p \leq 0.05$, and explained 38% of variation in ME:ADG ratio (Table 21). Sex of piglets was significant as a covariate in the model; F = 4.64, $p \leq 0.05$. The mean value of ME:ADG for RBNe diet was significantly lower than the mean values of the Basal diet and RBN diet (F= 4.16, $p \leq 0.05$).

6.3.6 Feed cost to ADG ratio

Computation of feed cost was as shown in Table 18. Computed least square means of the FC: ADG ratio of experimental diets (Table 21) showed that the model was significant; F = 4.45, $p \leq 0.05$, and explained 40% of variation in FC: ADG ratio. Sex of piglets was significant as a covariate in the model; F = 4.62, $p \leq 0.05$. The mean value of FC: ADG ratio of RBNe diet (115.03 ± 4.39 Ksh/kg) was significantly lower than the mean values of either the Basal diet (129.31 ± 4.41 Ksh/kg) or RBN diet (131.09 ± 4.39 Ksh/kg).

6.4 Discussion

This study evaluated the effects of inclusion of exogenous enzymes in high fibre, low protein diet offered to weaned piglets *ad libitum*. The study compared digestibility, feed intake, weight gain, dietary energy efficiency and feed cost efficiency between the basal maize - soybean meal diet and two similar diets where Natuzyme® multi-enzyme complex was included into one.

Results of this study showed that inclusion of Natuzyme® multi-enzyme complex in rice bran diet offered to weaned piglets improved the apparent digestibility for nitrogen. This was associated with the presence of protease in the enzyme complex. Li *et al*. (2010) also reported improved digestibility of nitrogen in extruded corn diets of pigs in which proteases were included. The mode of action of exogenous proteases was through improving the solubility of dietary protein. This study did not find significant improvement in digestibility of NDF. The effects of exogenous enzymes on nutrient and energy digestibility were therefore found to be variable in comparison to other findings in literature. These effects are dependent on a number of factors, key among these being the nature anti-nutritional factors (especially NSPs and phytates) present in the substrate, microbial source of exogenous enzyme and age of experimental animals (Munir and Maqsood, 2013). Jo *et al.* (2012) concluded that the effectiveness of exogenous enzymes can be improved by using a combination of enzymes, particularly carbohydrases, which would effect a broader activity on substrate.

Results of this study showed that inclusion of Natuzyme® multi-enzyme complex in rice bran diet offered to weaned piglets *ad libitum* reduced feed intake per kilogram body weight gained by 13.4%. This was attributed to the increased digestibility of DE. Increasing dietary energy concentration results in a decrease in feed intake in pigs that are fed *ad libitum* (Quiniou and Noblet, 2015).

Results of this study showed that inclusion of Natuzyme® multi-enzyme complex in rice bran diet offered to weaned piglets had no effect on piglets' average daily weight gain, however, there was a 12.77% reduction in metabolisable energy utilisation per kilogram body weight gain. This finding was associated with reduced feed intake of RBNe diet which was attributed to the increased digestibility of DE through reduction of viscosity of digesta thus facilitating more contact of the digesta with intestinal mucosa. Natuzyme® multi-enzyme complex accounted for 0.6% of the total cost of RBNe diet. Though piglets offered RBNe diet had a numerically higher and insignificant mean ADG than the mean values of the basal and RBN diet, the difference was significant when feed cost was considered. As a result, inclusion of Natuzyme® multi-enzyme complex in rice bran diet of weaned piglets reduced the cost of feeds per kilogram weight gain by 12.25%.

6.5 Conclusion and recommendations

6.5.1 Conclusion

This study concluded that inclusion of Natuzyme® multi-enzyme complex in rice bran diet of weaned piglets had no effect on dry matter digestibility of the diet and average daily gain. The beneficial effects included; 8.7% increase in dietary digestible energy, 12.5% increase in apparent digestibility of nitrogen, 13.4% reduction in feed intake per kilogram body weight gained, 12.77% improvement in metabolisable energy: average daily gain ratio and a 12.25% reduction in the feed cost: average daily gain ratio

6.5.2 Recommendations

The study recommended further study of individual exogenous enzymes to help understand their mode of action in increasing apparent digestibility of nitrogen. A comparative study of the efficacies of commercially available exogenous enzymes would be useful.

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CHAPTER SEVEN

EFFECTS OF DIETARY NUTRIENT COMPOSITION ON CARCASS CHARACTERISTICS AND GUT MORPHOLOGY OF BARROWS AND GILTS FED ON SELECTED ALTERNATIVE FEED RESOURCES

Abstract

This study investigated differences in carcass characteristics (killing-out percent, backfat thickness and loin eye area) and ileal mucosal morphology (villous height and crypt depth) in pigs offered 4 grower-finisher diets up to the age of 180 days; upon which barrows were slaughtered. The diets consisted of (i) a basal maize-soybean meal diet, (ii) a standard protein high lipid diet diet containing 20% cold pressed canola meal (iii) a low protein, high lipid diet containing 20% rice polishing (iv) a low protein, low lipid diet containing 20% rice bran. Results showed that Inclusion of rice polishing in finisher pig diets at 20% increased ($p \leq 0.05$) dietary lipids to 45g/kg while reducing dietary protein concentration to 159g/kg and resulted in a higher average daily gain compared to pigs on the basal diet. There was a 12.1% increase in killing-out percent which implied better carcass yield, a 24.5% increase in loin eye area which implied better lean tissue deposition and a 19.3% decrease ($p \leq 0.05$) in villous height. Inclusion of rice bran in finisher pig diets at 20% resulted in a decrease in dietary protein to 149.3g/kg and an increase in NDF resulted in a higher ($p \leq 0.05$) average daily gain compared to pigs on the basal diet (468.07g/day verses 398g/day) and subsequently larger loin eye size (29.21cm^2 verses 20.46cm^2), implying better lean tissue deposition. Ileal villi were significantly longer ($p \leq 0.05$) in rice bran diet pig attributed to higher dietary fibre. Inclusion of cold pressed canola meal in finisher diets at 20% did not change growth rate, however, it increased ($p \leq 0.05$) subcutaneous fat deposition significantly. There was however an increase ($p \leq 0.05$) in ileal crypt depth in pigs fed on CPCM diet though dietary fibre was not high as was the case with rice bran diet. The study concluded that diets that are higher in fibre have beneficial effects of limiting subcutaneous fat deposition and increasing digestive and absorptive gut surface area thereby improving utilisation of dietary fibre. The study recommended further studies on the role of dietary fats of different phyto-origin and anti-nutritional factors in canola meal in altering the morphology of the lower small intestinal mucosa.

Keywords: Backfat thickness, Crypt depth, Killing-out percent, Loin eye, Villous height

7.1 Introduction

This study investigated the effects of using alternative feed resources in pig diets on carcass characteristics and gut morphology. This study was informed by the need to generate information on the effects of the various fractions of pig diets on carcass quality which has implications on market value as well as on the integrity of intestinal epithelia which has an implication on food digestion and assimilation. Pig diets have been shown to induce significant changes in gut weight with obvious effects on killing out percent. Kass *et al*. (1980) and Jin *et al*. (1994) reported that an increase in dietary fibre results in an increase in gut length and weight which would reduce the killing out percentage. Fang *et al*. (2014) reported that pigs fed raw potato starch in place of corn starch over a long period significantly increased the weight of the stomach and large intestines thereby reducing the dressing percentage.

Pig diets have been reported to have significant effects on backfat thickness (BFT). Fang *et al*. (2014) reported a decrease in BFT when pigs were fed on raw potato starch. There was also a decrease in the concentration of short chain fatty acids (SCFA) in the colon. Doti *et al*. (2014) reported that the pattern of gut digestion of starch may affect BFT and growth performance of gilts. Consumption of diets with a high amylose: amylopectin ratio decreased intramuscular fat content and increased loin eye area (LEA) through reduced hepatic lipogenesis (Yang *et al*., 2015). Krecht and Duzinski (2016) reported an inverse relationship between BFT and lean meat content. Resistant starch which escapes digestion in the upper small intestines may act as a potential prebiotic favouring butyrate production with a likelihood of less subcutaneous fat and more lean tissue deposition (Giuberti *et al*., 2015).

Intestinal gut morphology could also be affected by a variety of factors. Raw potato starch was reported to increase intestinal mucosal thickness when compared to corn starch in pig diets (Fang *et al*., 2014). Use of probiotics and prebiotics has also been associated with beneficial effects on intestinal mucosal morphology. Giannenas *et al*. (2016) demonstrated that using *Enterococcus faecium* culture, mannan-oligosaccharides and organic acids in pig diets resulted in increased jejunal villous height. Low concentration of branched-chain fatty acids and lactic acid in the proximal colon was also associated with increased villous height and gut development (Halas *et al*., 2010). It could therefore be suggested that there is a relationship between dietary components, concentration of SCFA in lower gut and fat metabolism which influence fat and protein accretion.

7.2 Materials and methods

7.2.1 Experimental diets

The 4 grower- finisher diets used in this study consisted of; (i) a basal maize-soybean meal diet, (ii) a diet containing 20% cold pressed canola meal to replace soybean meal as a protein source (CPCM diet) (iii) a diet containing 20% rice polishing to replace maize (RPL diet) and (iv) a diet containing 20% rice bran to replace maize (RBN diet).

7.2.2 Management of experimental pigs

Experimental pigs from study 2 (Chapter Five) were selected randomly to participate in this study where 2 barrows and 2 gilts were randomly assigned to each of the 4 diets. The pigs were housed in 4 pens each measuring 5 X 6 metres such that pigs on a similar diet were housed in one pen. The pens were equipped with drinking nozzles which served to provide water throughout the day. Pigs were fed up to the age of 180 days at the rate of 3.5% of their body weight daily in 2 portions at a 6 hourly intervals. At the start of the experiment, water was provided using watering buckets to ensure that pigs that had not learned to drink from drinking nozzles had sufficient drinking water.

7.2.3 Data collection

All barrows (8) were slaughtered at 180 days of age to facilitate measurement of carcass characteristics. The weight of each pig was recorded at the beginning of the experiment. Killing-out percent was computed as the hot carcass weight after evisceration and decapitation as a fraction of the pig live weight immediately before slaughter. Back fat thickness (BFT) was determined by measuring the thickness of the adipose tissue layer at 3 levels; at the first rib, the tenth rib and the first lumbar vertebrae. The measurement was done at a point 6 inches (approximately 14.6 centimetres) lateral from the dorsal spinous process. Measurement was done by first tracing the back fat width on labeled transparent acetate paper using an indelible marker then measuring this width at an accuracy of 0.01mm. The loin eye was identified after making a clean cut perpendicularly across the long axis of the vertebral column at the junction of the 10^{th} and 11^{th} thoracic vertebrae so as to give the view of the transverse section of the *longissimus dorsi* muscle. The loin eye area was determined in triplicates by tracing the loin eye (transverse section of the *longissimus dorsi* muscle) on acetate paper using an indelible marker and placing it on an area grid.

Following evisceration, 3 sections of the ileum measuring approximately 2 cm each were excised at a point approximately 10cm proximal to the ileo-caeco-colic junction and placed in labeled glass jars containing 10% formalin fixative. The samples were then delivered to the University of Nairobi, Veterinary Pathology Laboratory for preparation of histological sections permanently mounted on microscope slides using the procedures described in Appendix XIV. To facilitate examination of morphological features, hematoxylin and eosin dye was used to stain the specimens. Microscopic examination at a magnification of 10 X 10 allowed for measurement of intestinal villous height and crypt depth as illustrated in Appendix XV. One slide with tissue section from each of the slaughtered pigs was selected for examination. On each slide, 2 optical views were randomly examined so that 2 villi with clear lamina propria were selected from each view for estimation of height in triplicates. This resulted in 12 measurements per pig and therefore 24 measurements for each of the 4 diets. The same procedure was followed in measurement of crypt depth.

7.2.4 Data analysis

Data analysis was done by computing T-tests, GLM and ANOVA procedures as described in section 4.2.3.

7.3 Results

7.3.1 Comparison of composition of experimental diets

The EE content in CPCM diet (48.2 $\pm$ 1.2 g/kg) was significantly higher ($p \leq 0.05$) compared to the EE content in the basal diet (16.1 $\pm$ 0.1 g/kg). The EE content in RPL and RBN diets was also higher ($p \leq 0.05$) compared to the EE content of the basal diet with mean values of 45.7 $\pm$ 0.04 g/ kg and 20.6 + 0.5 g/kg respectively. The mean gross energy (GE) value for RPL diet was significantly higher ($p \leq 0.05$) than the mean value of the basal diet (4049 $\pm$ 19.55 kcal/kg verses 3811.57 kcal/kg). The DM content of RBN diet was higher ($p \leq 0.05$) than in the mean value of the basal diet, (92.64% versus 91.31%). The CP content of RBN diet was lower ($p \leq 0.05$) compared to the mean value of the basal diet, (149.3 $\pm$ 3.3 g/kg versus 197.1 $\pm$ 11.5 g/kg). Though the mean NDF values were not significantly different between diets, the mean NDF for RBN diet (367.1 $\pm$ 1.24 g/kg) was 26% higher than the mean for the basal diet (29.06 $\pm$ 3.94 g/kg). The mean NDF of the 4 diets was 311.2g/kg which was significntly higher ($p \leq 0.05$) than the recommended value for the upper limit of 250g/kg in pig diets. When the same comparison was done without the mean NDF of RBN diet, the difference was insignificant. For purposes of this study, CPCM diet was therefore considered as a standard protein ($CP \geq 18\%$) high EE diet, RPL diet was considered as a low protein ($CP \leq 16\%$), high EE diet while RBN diet was considered as low protein, high NDF diet.

7.3.2 Pig weights between ages 99 - 180 days.

The mean initial weight of experimental pigs was 24.52 $\pm$ 1.71 kg. There was no difference in the mean weight of pigs between diets; F =1.89, p = 0.19. A comparison of the mean weight between sex showed that there was no difference in the mean values; t = -0.55, p = 0.59. At 180 days, pigs offered RPL diet were heavier (66.06 $\pm$ 2.11 kg) than pigs offered the basal diet (53.99 $\pm$ 2.02 kg) (Table 22). The mean weights (at 180 days) of pigs offered CPCM diet (57.21 + 2.09 kg) and RBN diet (61.42 $\pm$ 2.09) were not different from the mean weight of pigs offered the basal diet; F = 6.3, p =0.01. Computation of least square means showed that the overall mean ADG was 439.41 g/day. The mean ADG for pigs fed on RPL diet (475.71 $\pm$ 17.35 g/kg) and RBN diet (468.07 + 17.19 g/kg) were significantly higher than the ADG for pigs fed on the basal diet (398.44 + 16.6 g/kg); F =4.77, p =0.01. Sex of pigs was significant in the model, F = 15.21, p = 0.07. The mean ADG for barrows (411.36 $\pm$ 29.62 g/day) was significantly lower than the mean value for gilts (467.47 $\pm$ 15.17 g/day); t = 2.98, p = 0.01.

7.3.3 Killing out percentage (KO %)

Pig diets explained 50.2% of variation in KO%. The overall mean KO% was 68.3%. The mean KO% of pigs offered RPL diet (71.05%) was higher ($p \leq 0.05$) than the mean value for pigs offered the basal diet (66.89%). The mean KO% of pigs offered CPCM (68.2%) and RBN (67.06%) diets were not different from the mean value of pigs offered the basal diet; F = 6.71, p = 0.00 (Table 23).

7.3.4 Back- fat thickness

Pig diet explained 35.2% of variation in BFT. The mean BFT for pigs offered CPCM diet (15.77mm) was significantly higher than the mean value for pigs offered the basal diet (9.48mm) (Table 23). The mean BFT for pigs offered RPL and RBN diets were not significantly different from the mean value for pigs offered the basal diet.

7.3.5 Loin eye area

The analysis of variance model was significant (F = 9.63, p = 0.01) and explained 59% of variation of the LEA. The LEA of pigs offered RBN diet (29.21cm^2) was significantly higher than the mean value for pigs offered the basal diet (20.46cm^2). The LEA of pigs offered CPCM diet (24.11cm^2) and RPL diet (26.46cm^2) were not significantly different from the mean LEA of pigs offered the basal diet (Table 23).

Table 22: Initial and final weights and average daily weight gain of finisher pigs fed on experimental diets between 99 - 180 days

Parameter	N	Diet				Sex		
		Basal	CPCM	RPL	RBN	Male	Female	p-value
Initial weight (kg)	16	22.11[a] (1.98)	23.59[a] (1.98)	28.29[a] (1.98)	24.1[a] (1.98)	23.94 (1.21)	25.11 (1.77)	0.33
Final weight (kg)	16	53.99[a] (2.02)	57.21[ab] (2.09)	66.06[c] (2.11)	61.42[bc] (2.09)	57.12 (1.48)	62.22 (1.51)	0.02
ADG (g/day)	16	398.44[a] (16.6)	418.79[ab] (17.19)	475.71[b] (17.35)	468.07[b] (17.19)	411.36 (29.62)	467.47 (15.17)	0.01

Means on the same row with different superscripts are significantly different.

CPCM=cold pressed canola meal, RPL=rice polishing, RBN=rice bran, ADG=average daily weight gain, numbers in parenthesis indicate standard errors.

Table 23: The effects of experimental diets on killing-out percent, backfat thickness and loin eye area in finisher pigs slaughtered at 180 days

Index	R^2	Diet				p-value
		Basal	CPCM	RPL	RBN	
KO%	50.20	66.89^b	68.20^{ab}	75.01^a	67.06^b	0.01
BFT mm	35.20	9.48^a	15.77^b	13.68^{ab}	15.05^{ab}	0.03
LEA cm^2	59.01	20.46^c	24.11^{bc}	26.46^{ab}	29.21^a	0.01

Means on the same row with different superscripts are significantly different.

CPCM=cold pressed canola meal, RPL=rice polishing, RBN=rice bran, KO=killing out, BFT=back fat thickness, LEA=loin eye area.

7.3.6 Villous height and crypt depth

Computation of least square means for villous height showed that the model was significant; F = 13.23, p = 0.01 (Table 24). The mean ileal villous height of pigs offered RBN diet (307.71 $\pm$ 9.03µm) was significantly higher ($p \leq 0.05$) than the mean value for pigs offered the basal diet (283.58 $\pm$ 8.61 µm). Pigs offered RPL diet had a significantly lower ($p \leq 0.05$) mean villous height (237.72 $\pm$ 7.63 µm) compared to the mean value for pigs offered the basal diet.

Table 24: Effects of experimental diets on ileal villous height and crypt depth on finisher pigs slaughtered at 180 days

Morphological feature	N	Diet			
		Basal	CPCM	RPL	RBN
Villous height in µm	96	283.58^a	268.43^a	237.72^b	309.71^c
		(8.61)	(7.14)	(7.63)	(9.03)
Crypt depth in µm	96	158.23^a	192.58^b	159.39^a	175.4^{ab}
		(6.66)	(6.66)	(5.68)	(7.69)

Means on the same row with different superscripts are significantly different.

µm=micrometers, CPCM=cold pressed canola meal, RPL=rice polishing, RBN=rice bran, numbers in parenthesis indicate standard errors.

Computed least square means for crypt depth showed that the model was significant; F = 6.19, p = 0.00. The mean ileal crypt depth of pigs offered the CPCM diet (192.58 $\pm$ 6.66 µm) was significantly larger ($p \leq 0.05$) than the mean value for pigs offered the basal diet (158.23 $\pm$ 6.66 µm). The mean ileal crypt depth of pigs offered the RPL (159.39 $\pm$ 5.68 µm) and RBN

(175.4 ± 7.69 μm) diets were not significantly different from the mean ileal crypt depth of pigs offered the basal diet.

7.4 Discussion

i. Pig growth between 99 - 180 days of age

Results from the study showed that though the basal diet was high in protein (195g/kg), pigs offered a low protein (≥ 160g/kg) and high ether extract diet (≥45g/kg) had higher ($p \leq 0.05$) weight gain. Pigs offered a rice bran diet which was high in NDF and low in protein (≤ 150g/kg) had higher ($p \leq 0.05$) average daily gain compared to pigs fed on the basal diet. These findings pointed to a lower requirement for protein in finisher pig diet between 99 - 180 days of age. This finding corroborated the finding of Gallo *et al*. (2015) who associated higher daily gain in low protein and high fibre diets with a decreased incidence of scours associated with high levels of dietary protein. The faster growth in high NDF diets could also have been attributed to pig's ability to utilise dietary fibre more efficiently for energy production as they grow. This paradigm has been associated with an increase in the fibrolytic microbial population in the ileum, caecum and the large intestines (Bach-Knudsen *et al*., 1991; Kil *et al*., 2010). Among the main products of lower gut fermentation in pigs are gases (such as hydrogen, carbon dioxide and hydrogen), lactic acid and short chain fatty acids (SCFA) such as butyric acid. SCFA are rapidly absorbed into the blood stream and contribute up to 30% of energy requirements of growing pigs (Varel, 1987; Mosenthin, 1998; Shi and Noblet, 1994).

Though evaluation of palatability of the diets was not within the scope of this study, it also appeared that rice polishing diet was more palatable than other diets. This period was characterised by a linear growth pattern for all 4 diets which implied that tissue accretion was also linear in this phase of growth. Similar results were described by Bikker *et al*. (1995) and Quiniou *et al*. (1996) showed that protein deposition increased linearly with increased energy intake until maximum protein deposition is reached, after which no further protein deposition occurs.

ii. Killing out percentage

This study showed that pigs with the highest live weight at slaughter and average daily gain also had the highest ($p \leq 0.05$) killing-out percent. Among the factors that affect killing out percentage are breed, sex, diet, and environmental factors that affect growth such as type of housing, stocking density, ambient temperature and humidity. In the study however, these variables with the exception of diet were held constant. Results of a study done on lambs by Wood *et al.* (1983) showed that the contribution of non-carcass components such as offals, omental fat and diaphragm to live weight of an animal decreased with an increase in live weight, therefore explaining the increase in killing out percentage with increased live weight. Various studies (Kass *et al*., 1980; Jin *et al*., 1994) have shown that an increase in dietary fibre results in an increase in gut length and weight which would reduce the killing out percentage. However, this study did not establish a relationship between high fibre diet and a decrease in killing-out percentage but rather with higher live weight.

iii. Back fat thickness

Results of this study showed that subcutaneous fat accretion was significantly higher ($p \leq 0.05$) in pigs offered CPCM diet which was high in lipid compared to pigs offered the basal diet which was lower in lipids but equivalent in protein content. There was however no difference in fat accretion between pigs offered RPL diet which was high in lipid and low in protein, pigs offered RBN diet which was low in lipid and rich in dietary fibre and pigs offered the basal diet. This implies that in low protein diets (140 -150g/kg), increasing the concentration of ether extract to approximately 45g/kg could be useful in energy compensation without compromising back fat deposition compared to the basal diet. In the current study, preliminary findings showed that canola meal used in pig diet had an ether extract concentration of 80.1 + 3.9 g/kg owing to its rich content of mono and polyunsaturated fatty acids primarily 62% oleic acid, 22% linoleic acid and 10% linolenic acid (Xie and Dunford, 2017) common in cold pressed vegetable oil seed meals. Therefore, cold pressed canola meal when incorporated in CPCM diet probably resulted in a higher amount of unsaturated fatty acids in the diet. Results of a study by Chilliard (1993) also reported that diets high in unsaturated fatty acid resulted in more lipogenic activity in rats and pigs. Kloareg *et al*. (2007) reported that fat deposition on the carcass is a reflection of dietary fat present in feeds, such that inclusion of unsaturated fats in diets resulted in subcutaneous fat deposition while saturated fats such as tallow in pig diets resulted in increased intramuscular fat deposition. Inclusion of fats rich in unsaturated fatty acids in protein rich diets could therefore result in an undesirable effect of increased subcutaneous fat deposition.

iv. Loin eye area

Results of this study showed that pigs offered the RBN diet which was low in protein and ether extract and rich in dietary fibre had a larger loin eye compared to the basal diet; $p \leq 0.05$. This implied that low protein, high fibre diet would be beneficial in increasing lean growth in pigs at 99 - 180 days. Pigs offered the RPL diet which was low in protein and high in lipids also had a larger loin eye size than pigs offered the basal diet; $p \leq 0.05$.

Lowering dietary protein in finisher pig diets did not have any negative effect on carcass yield (Gallo *et al*., 2015). A study by Sung-Wook *et al*. (2015) however showed that the protein value of rice bran protein was much higher than that of vegetable proteins and was comparable to that of casein; therefore, could be used as a substitute to animal protein. This could also have contributed to a larger loin eye size since amino acid balance of a diet is an important determinant of muscling in pigs (Sundrum *et al*. 2011) However, there is need to carry out further investigation on the role of rice bran protein vis-a-vis the contribution of dietary fibre in rice bran on pig growth.

v. Intestinal morphology

Results of this study showed that pigs offered high fibre RBN diet had significantly longer ($p \leq 0.05$) ileal villi compared to pigs offered the basal diet. Pigs offered high lipid low fibre RPL diet had shorter ($p \leq 0.05$) villi compared compared to pigs fed on the basal diet. Crypt depth in pigs offered CPCM and RBN diets were significantly larger ($p \leq 0.05$) than in pigs offered the basal diet. Studies in pig nutrition have indicated the significant role played by diets in changing the histological appearance of the gut (Agyekum and Nyachoti, 2017). Studies by Jin *et al*. (1994), Brunsgaard (1998) and Serena *et al*. (2008) showed that diets rich in fibre were associated with an increase in proliferation of mucosal cells with resultant increase in mucin production, increased villous height and crypt depth. Insoluble fibres have however been reported to have an abrasive effect on the intestinal mucosa. The ability of dietary fibre to alter intestinal epithelial morphology depends on the digesta viscosity which is influenced by solubility of dietary non-starch polysaccharides (Montagne *et al*., 2004).

Ileal crypt depth in pigs offered the RPL diet were significantly smaller ($p \leq 0.05$) than in pigs offered the basal diet, suggesting that protein concentration in the diet could probably have a role in variation in intestinal mucosal morphology.

7.5 Conclusion and recommendations

7.5.1 Conclusion

i. Rice polishing in finisher pig diets resulted in improved average daily gain, killing-out percent, loin eye area and a decrease in villous height.

ii. Rice bran in finisher pig diets resulted in improved average daily gain, loin eye area and ileal villus height.
iii. Cold pressed canola meal in finisher diets did not change growth rate, increased back fat thickness and ileal crypt depth.

The performance of finisher pigs improved with lower protein, higher fibre isocaloric diet with higher lean tissue deposition and increased ileal mucosal surface area. Higher dietary protein was associated with decreased villous height. Higher dietary fat was associated with increased BFT which was undesirable.

7.5.2 Recommendations

This study recommended the following:

i. Studies into the the role of dietary fat on ileal mucosal morphology which was inconclusive in this study.
ii. The possible role of glycosinolates and other anti-nutritional factors present in canola meal in altering gut morphology.

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CHAPTER EIGHT

INFLUENCE OF VALUE CHAIN GOVERNANCE ON SMALLHOLDER PIG ENTERPRISE COMPETITIVENESS

Abstract

Pig production in Kenya has the potential to generate employment opportunities as a result of the increasing trends in pork demand coupled with high turn-over rate of pig production enterprise compared to other domestic livestock enterprises. However, as a result of globalisation, there is currently a consumer driven increase in quality assurance and safety requirements for food commodities including meat. These standards as well as the need for producers to remain profitable define features of value chain governance that influence enterprise competitiveness that include technology adoption, market access, product quality and work quality. Twenty seven variables from a survey of 144 pig enterprises in 3 geographically and demographically distinct Counties in Kenya were used to develop 5 indices using Porter's diamond methodology. The 5 indices were subjected to Principal Component Analysis using SPSS statistical software to extract 2 components which were latent variables for enterprise competitiveness. The 2 components were then subjected to gaussian generalised linear model and analysis of variance to estimate the value chain governance features as determinants of smallholder pig enterprise competitiveness. Results showed that Value chain governance features that influenced pig enterprise competitiveness positively were ease of market access, product quality, technology adoption with coefficients of 0.13, 0.6 and 4.09, $p \leq 0.05$. The study concluded that work quality in pig enterprises negatively influenced competitiveness with a coefficient of -0.35, $p \leq 0.05$. This study recommended capacity building in the use of technology, improvement of infrastructure to ensure good quality pork and access to markets. The study also recommended mainstreaming of decent work concepts in policy making so as to contribute to improved working conditions.

Key words: Competitiveness, Decent work, Factor analysis, Porter's diamond, Value chain governance

8.1 Introduction

Despite the increasing local demand for pork and pork products, smallholder pig production in Kenya is faced with constraints relating to the socio-economic and institutional environment that govern production. These constraints have contributed to low productivity and low competitiveness putting to doubt the sustainability of these enterprises. Low productivity is associated with the low scale of production, limited access to inputs, and high transaction costs and thin markets with many sellers, poor prices, few buyers and limited access to information. To overcome most of these challenges, the value chain approach has been employed in pro-poor development initiatives with the aim of improving the competitiveness of smallholder producers by upgrading along the value chain. An important outcome of upgrading is that the actors benefit from improved earnings and the working lives of employees improves, thereby creating decent work opportunities.

The United Nation's 2030 global agenda in Sustainable Development Goal number 8 (SDG 8) aims at promoting inclusive and sustainable economic growth, full and productive employment and decent work for all by 2030. The agricultural sector remains a major contributor to economic growth and employment in developing and least developed countries. In Kenya for example, the sector employs about 70 - 75% of the country's labour force along all value chains (GOK, 2010; The World Bank, 2012). Low productivity in smallholder agricultural production however poses a challenge to achieving SDG 8. The current trends of increased population growth, urbanisation and globalisation have resulted in increased demand for high caloric diets, increased consumer awareness and demand for food safety and quality standards. These have resulted in a shift from traditional production systems to more organised agri-food value chains with well coordinated governance systems.

Value chain governance characterises the linkages between actors in the chain and how these linkages affect the flow of a product from one node of the value chain to the next. Value chain governance literature therefore focuses on the product (quality), the process (technology), production environment (labour and environmental standards) and market logistics (quantity produced, price, nature of markets) (Dolan and Humphrey, 2000; Geraffi *et al*., 2005; Ouma *et al*., 2017). Analysis of value chain governance is therefore important in identifying leverage points in improving competitiveness (Gereffi *et al*., 2005). Powerful actors in the value chain influence producers' capacity, market access and distribution of gains along the chain (Gereffi and Frederick, 2009).

The International Labor Organization (ILO) proposed the concept of decent work to counter the damages caused by the neo-liberalism. Decent work was defined as “productive work realized in freedom condition, equity, security and human dignity” (ILO, 2012). The 4 pillars of decent work include employment creation, guaranteeing rights at work, social protection and social dialogue (ILO, 2015). The ILO developed a set of variables that have been used in the formal sector for measurement of decent work deficits as described in ILO (2012). Different conceptualizations of decent work exist in the global policy arena resulting from the different institutional perspectives (Ruggiero *et al*., 2015). Likewise, in the informal sector, there are challenges in measurement of decent work using the ILO indicators due to sector uniqueness and differences in socio- cultural attributes of labour in the developing countries (Gongora, 2016).

Pig value chain governance in Kenya lacks coordination and linkages between actors in the value chain. This has resulted in a lack of coordination of production and marketing activities with poor information flow. As a result, smallholder farmers have not benefited from expanding market opportunities due to production and market inefficiencies.

This study generated latent variables from enterprise data that was used as the dependent variable in a general linear model to evaluate the influence of value chain governance features on the competitiveness of smallholder pig enterprises and implications on decent work conditions of producers.

8.2 Materials and methods

8.2.1 Study area, sampling procedures and data collection

The study area, sampling techniques and data collection were as described in section 4.2 in Chapter Four.

8.2.2 Conceptual model and variables

The assumption of this study was that there is a correlation between competitiveness and economic success though there may be no causal relationship (Schutzhoffer, 2014). Twenty seven variables (Table 25) that impact on any of the 4 primary activities of the value chain, that is, inbound logistics, production operations, outbound logistics and marketing and support services (Figure 8) were selected from the enterprise. All the variables were re-coded such that their scale was one directional with a negative to positive effect scale. The 27 variables were used to compute 5 indices which were determinants of competitive advantage as described in the Porter's diamond approach. They were weighted on the same scale such that they all had equal contribution to the latent variable to be computed using PCA.

Bakan and Dogan (2012) provides a theoretical framework for evaluation of competitiveness of institutions or nations using the Porter's diamond approach. This model consists of four determinants of competitive advantage that include; factor conditions, demand conditions, related and supporting institutions, and firm's strategy.

Table 25: Comparison of weighted mean scores of variables used to compute 5 indices for Principal Component Analysis between research sites

Variable	County			p-value
	Busia N=52	Nakuru N=30	Kiambu N=62	
Technology adoption				
Improved breeds for upgrading?	0.06^{a}	0.33^{b}	0.58^{c}	0.01
Use of concentrate feeds?	0.08^{a}	0.53^{b}	0.45^{bc}	0.01
Access to training from media?	0.56^{a}	0.97^{b}	0.95^{b}	0.02
Dewormed pigs in last 6 months?	1.81^{a}	1.8^{3a}	1.90^{a}	0.65
Sprayed pigs in last 3 months?	1.31^{a}	1.13^{a}	1.31^{a}	0.65
Quality control				
Pig housing?	0.9^{a}	1.97^{b}	1.4^{b}	0.01
Pig vaccination campaign?	0.37^{a}	0.23^{a}	0.19^{a}	0.11
Do you slaughter pigs at home?	1.27^{a}	0.8^{b}	0.9^{b}	0.03
Is the pork at home inspected?	0.46^{a}	1.2^{b}	1.1^{b}	0.02
Pigs slaughtered in slabs only?	0.87^{a}	0.8^{a}	0.9^{a}	0.78
Slab workers have health certificates?	0.75^{a}	0.6^{ab}	0.24^{b}	0.04
Production efficiency				
Sow furrowing interval	5.01^{a}	5.18^{a}	5.75^{b}	0.04
Sow weaning rate	4.55^{a}	4.12^{ab}	4.01^{b}	0.05
Income per unit/day	0.24^{a}	0.93^{b}	1.61^{c}	0.01
Market access				
Distance to the market	2.1_{a}	2.63^{b}	2.81^{b}	0.01
Price offered at the market	1.08^{a}	1.43^{ab}	1.69^{b}	0.02
Availability of buyers	1.81^{a}	2.5^{b}	2.66^{b}	0.02
Constrained by infrastructure?	1.5^{a}	2.77^{b}	2.6^{b}	0.01
Constrained by amenities e.g. water?	0.55^{a}	0.07^{b}	0.05^{b}	0.01
Constrained by consumer perception?	1.23^{a}	1.03^{ab}	1.03^{b}	0.04
Do you weigh pigs during sale?	0.08^{a}	0.43^{b}	0.32^{b}	0.03
Do you keep enterprise records?	0.35^{a}	0.57^{a}	0.37a	0.18
Are you a member of any FBO	0.1^{a}	0.13^{a}	0.16^{a}	0.52
Factor conditions (labour/ work				
Participation ratio by gender	0.1^{a}	0.2^{a}	0.24^{a}	0.19
Wage equality by gender	0.98^{a}	0.47^{b}	0.73^{c}	0.01
Contribution to social security scheme	0.04^{a}	0.03^{a}	0.00^{a}	0.37
Contribution to health insurance	0.04^{a}	0.07^{a}	0.02^{a}	0.78

Means on the same row with different superscripts are significantly different.
FBO=Farmer based organisation.

Porter's theory postulates that these factors interact with each other to form conditions where innovation and competitiveness occur. These determinants correspond to the value chain governance features discussed earlier and therefore the model is useful in identifying variables that influence competitiveness of enterprises.

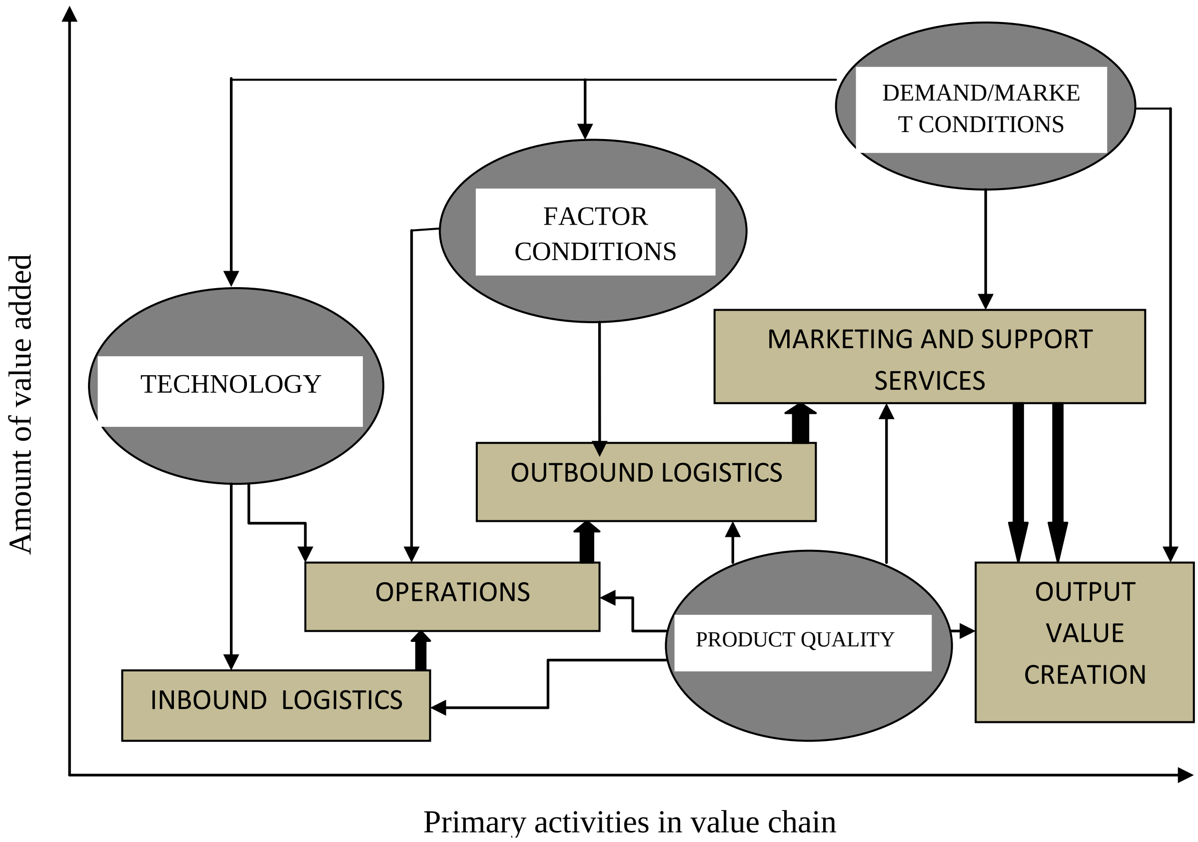

Figure 8: Determinants of competitiveness using value chain concept

8.2.3 Data analysis

To evaluate competitiveness of enterprises, the 5 indices were subjected to PCA using SPSS statistical software. Principal Component Analysis (PCA) is a tool that is used to restructure data so as to reduce the number of variables in a process known as data reduction or dimension reduction (Pallant, 2007). PCA generates components which act as latent variables which can then be given a name and used for evaluation of a concept of interest which in this case was competitiveness.

Prior to performing PCA, the suitability of data for factor analysis was assessed using the Kaiser-Meyer-Oklin and The Bartlett's Test of Sphericity. A gaussian general linear model was computed with the components as the dependent variables to identify value chain governance features that were determinants of enterprise competitiveness. A comparison of enterprise competitiveness using derived components was done between study areas, feeding decisions, gender and education levels of participants using ANOVA.

8.3 Results

8.3.1 Governance in the pig value chain at the production node

Differences in the actors in the production node were identified by observation as described in Figure 9. There were no large scale pig farmers in Busia County, however, smallholders in Nakuru and Kiambu Counties reported that they obtained breeding stock from large scale farmers locally. Smallholders in Busia County reported that feed suppliers were few making it difficult to access high quality feeds. It was also difficult to access veterinary services in Busia County and therefore, the cost of such services were high when available. Extension services from government officers were easily available in all study areas. Breeding services were mainly provided by local boars where a monetary fee was charged in Nakuru and Kiambu Counties but payment was mainly non-monetary in Busia County where parties agreed that the owner of the boar would choose a piglet of his choice upon farrowing.

Pig production activities had different target markets. The main objective of smallholders in Busia County was to sell piglets soon after weaning which was a quick source of income for these farmers. Mature pigs were often sold before the second farrowing. Smallholders in Nakuru and Kiambu Counties mainly sold breeding pigs as in-pig sows and also finished pigs for slaughter.

Pig trade in Busia County was controlled by brokers who bought pigs directly from farmers and transported them on motor bikes. Smallholders reported that it was these brokers who determined the price of pigs. In Nakuru and Kiambu Counties, owners of slaughter slabs and pork outlets such as pork eateries were the main buyers. Sale of pigs was organised and structured because the price was dependent on the weight of pigs.

Pig value chain governance structure in Busia County was therefore spot market governance with many sellers and buyers, significant flexibility in market entry and exit and insecure transactions. Though there was no full integration the level of vertical integration (transport and slaughter) was more in Nakuru and Kiambu County where some pig farmers owned pork outlets, and therefore, the governance system was partially heirarchical.

8.3.2 Estimating the influence of value chain governance features on competitiveness using PCA

Inspection of the correlation matrix revealed the presence of some coefficients of 0.3 and above (Table 26). The Kaiser-Meyer-Oklin value was 0.61 indicating sufficient sampling adequacy. The Bartlett's test of sphericity reached statistical significance; $\chi^2 = 84.45$, $p \leq 0.01$, supporting the factorability of the correlation matrix (Pallant, 2007).

Table 26: Correlation matrix of PCA indices showing coefficients above 0.3.

	Index				
	Technology	Quality Control	Market access	Factor conditions	Production management
Technology	1.0	0.33*	0.38*	-0.04	0.48*
Quality control	0.33*	1.0	0.32*	0.06	0.11
Market access	0.38*	0.32*	1.0	-0.07	0.18
Factor conditions	-0.4	0.06	-0.07	1.0	0.01
Efficiency	0.48	0.11	0.18	0.01	1.0

* = coefficients greater than 0.3

PCA revealed the presence of 2 components with Eigen values exceeding 1, explaining 25% and 23% of the variance respectively (Appendix XVI). An inspection of the screeplot revealed a break after the second component and therefore, the first 2 components were retained.

Table 27: Pattern and Structure Matrix with Oblimin Rotation of 2 factor solution of indices of competitiveness

Index	Pattern coefficients		Structure coefficients		Communalities
	C1	C2	C1	C2	
Quality Control	0.91*	0.38*	0.92*	0.41*	0.99
Factor conditions	0.09	-0.04	0.08	-0.04	0.01
Technology	-0.07	0.97*	-0.05	0.97*	0.95
Production management	-0.1	0.49*	-0.08	0.49*	0.25
Market access	0.17	0.4*	0.18	0.4*	0.19

C1=component 1, C2=component 2, major loadings for each index with (*)

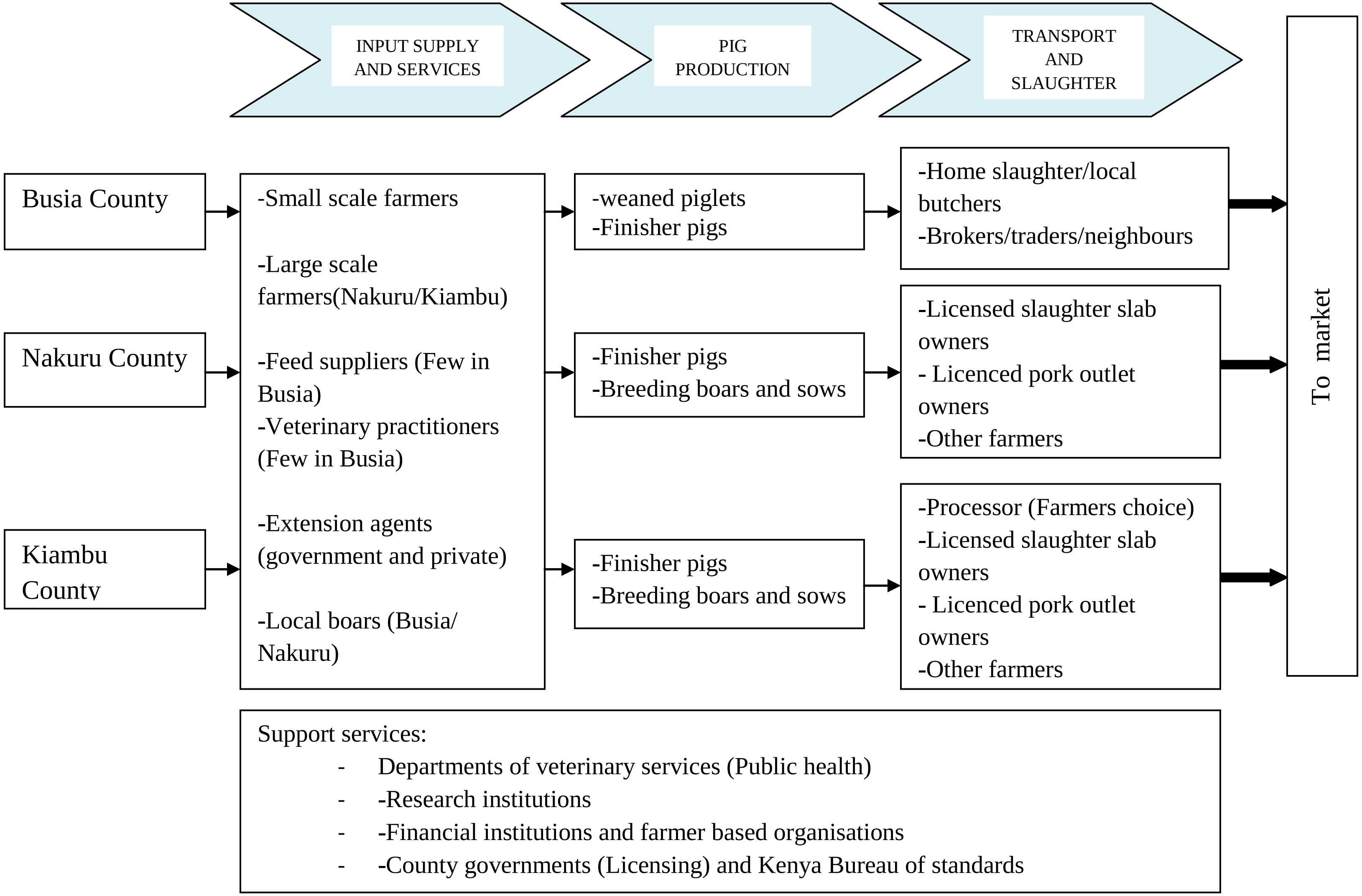

Figure 9: Comparison of pre-market pig value chain actors and functions between study areas

The oblimin rotation was performed and the 2 component showed a strong loading for all variables with 4 out of 5 variables loading more on component 2 (C2) as shown on Table 27 and one variable (quality control) for component 1 (C1).

Regression factor scores for each component were treated as new cases for the new variables represented by C1 and C2 (Pallant, 2007). Since the 2 components were latent variable for enterprise competitiveness, a significantly higher mean meant that the rating for competitiveness by the test was higher. The model for C1 was insignificant while results for C2 showed that the variances of the means were significantly different and the model was also significant where the mean value for enterprises in Busia County was the lowest ($p \leq 0.05$). The mean values for Kiambu and Nakuru Counties were comparable (Table 28).

Table 28: Comparison of competitiveness of smallholder pig enterprises using latent variables generated from Principal Component Analysis

Latent variables for competitiveness	County			p-value
	Busia (N=52)	Kiambu (N=62)	Nakuru (N=30)	
Component 1	-0.14[a]	-0.01[a]	0.27[a]	0.18
Component 2	-0.53[a]	0.37[b]	0.14[b]	0.01

Means on the same row with different superscripts are significantly different.

Results of a gaussian generalised linear model with C1 and C2 as the dependent variable showed that the coefficients for technology adoption (4.09), product quality (0.6), market access (0.13) and quality of work (-0.35) were all significant; $p \leq 0.05$ (Table 29).

Results of T-test on C2 between feeding decisions showed that smallholder enterprises that fed pigs on AFR were less competitive than enterprises that used commercially compounded feeds $t(144) = -7.53$, $p \leq 0.05$. A comparison of means of the 2 components between genders of household head showed that the means for C1 were insignificantly different. The means for male and female household heads for C2 were significantly different at 0.1 and -0.39 respectively; $t = 2.57$, $p \leq 0.01$. Results of comparison of the mean values of C1 and C2 between levels of education (pre-secondary school, secondary school and post-secondary school levels) showed that there was a consistent and significant increase in the mean value of C2 with an increase in education level; $F = 16.37$, $p \leq 0.05$. Results of a comparison of the mean values for C2 between age (≤ 35, 36 - 50 and ≥ 50 years) showed that the group of ≤ 35 years had a lower mean value than ≥ 50 years, $F = 4.81$, $p \leq 0.05$.

Table 29: Determinants of pig enterprise competitiveness using Component 2

	N = 143, AIC = -67.04, log likelihood = 4793.16			
Variable	Coefficient	Standard error	z-value	p-value
Technology adoption	4.09	1.3	1.3e+16	0.01
Market access	0.13	3	3.0e+14	0.01
Quality control	0.6	1.5	1.5e+15	0.01
Work quality	-0.35	-6.2	-6.2e+16	0.01
Constant	-3.19	-8.3	-8.3e+15	0.01

C2 = component 2 representing enterprise competitiveness, AIC = Akaike information criterion

8.4 Discussion

This study evaluated the influence of features of value chain governance on enterprise competitiveness and the reality of working lives of smallholder pig producers. These features are attributes that are derived from linkages with other value chain actor through vertical or horizontal integration as buyers, sellers, service providers or regulatory institutions (Ouma *et al*., 2017).

Results of this study showed that pig value chain governance features had significant influence on the competitiveness of smallholder enterprises as well as the working life reality of pig producers in Kenya. Quality control, a fuction of the Veterinay and Public Health departments, was found to be a significant feature of value chain governance that positively influenced enterprise competitiveness. Parameters used in conceptualisation of quality were pig housing and meat hygiene which are both policy issues in disease control and quality assurance. Lack of proper housing and free-range systems of pig production are often associated with increased incidence of diseases such as African Swine Fever and Foot and Mouth diseases which are highly fatal in pigs. These production systems are also of public health concern as a result of increased prevalence of worm infestation leading to diseases like hydatidosis. In Busia County, home-slaughter of pigs was a common practice and it is likely that most of the pork was consumed uninspected. Such practices circumvent the the quality assurance process vested in mandatory meat inspection and could erode consumer confidence in the product offered to the market.

Technology adoption was the most significant feature of value chain governance in determining enterprise competitiveness. This outcome can be attributed to access to information/ knowledge about relevant technologies and availability of technologies. Use of improved breeds and high quality feeds were the relevant technologies in this study. Smallholders' linkages with animal feed suppliers as well as with other pig breeding farms contribute positively to access to these technologies. Poor infrastructure and weaker access to information could have led to low demand and therefore lower adoption of these technologies like in Busia County which reflected negatively on enterprise competitiveness.

Market access is an important feature of value chain governance because it dictates how gains are distributed along the value chain (Gereffi and Frederick, 2009). Poor roads were a challenge to delivery of pigs to the market in Busia County. As a result, smallholders transported pigs while fastened on motorbikes, a method that was limiting in terms of the size of pig that could be transported. Due to this challenge, smallholders also preferred to stock smaller breeds of pigs particularly the indigenous breed, and also sell breeding sows after their first farrowing. Access to water was a challenge in peri-urban production systems with possible negative effects on hygiene and pig performance. Lack of storage facilities such as refrigerators resulted in pork spoilage. Smallholders interviewed in Busia County reported that pig buyer preferred smaller pigs which they could slaughter and sell before there were signs of spoilage.

The market structure for mature pigs and weaned piglets in Busia County was primarily spot market governance with many buyers and sellers with limited information sharing between participants and marked independence of choice as described by Webber and Labaste (2010). The market price of pigs was determined by pig buyers most of whom were intermediaries who also acted as transporters. In Kiambu and Nakuru Counties, the market structure was more vertically integrated since pig buyers were owners of slaughterhouses and pork joints which sold value added (roasted or cooked) pork. This market structure provides actors with the benefit of reduced *ex ante* and *ex post* transaction costs that relate to information search, loss in transit and completion of contractual obligations and in this way contributes to improves farm-gate prices and enterprise competitiveness.

Besides the product, process and markets, this study explored the working life reality and decent work status of pig farmers as a feature of value chain governance and drew relationships to enterprise competitiveness. Results in this study showed that working conditions in their current state had a negative contribution to enterprise competitiveness. The assumption of existence of such a relationship was attributed to such studies as Fields (2003), Ahmed (2003) and Guimaraes (2013) who demonstrated that economic development and human development contribute positively to decent work. Guimaraes (2013) concluded that work for human security is closely related to economic security. Larion (2013) emphasised the need to include the decent work agenda in pro-poor work policies in this statement;

> *"For workers who face extreme poverty, decent work is the shift from subsistence to existence and it is the main means to get out of poverty (Andrei Popescu, 2008)".*

The concept of quality in agri-food chains is demand driven owing to increased consumer awareness of food safety and quality standards. Quality standards however extend beyond the finished product to the process of production, including work standards. The quality of work is an essential policy issue and therefore becomes an important feature of value chain governance and can be looked at from the perspective of the 4 pillars of decent work.

i) Creation of employment opportunities

As earlier reported, among the attributes of value chain governance that were found to positively influence enterprise competitiveness and are key in creation of employment were infrastructure (roads and water), quality assurance and food safety policies, access to information and inputs. Indicators of employment rate used in this study were wage rate and number of hours worked per day. Results of this study showed that the mean number of hours worked per day for both household and hired labour was less than 1.5 hours. Wage workers were found in only 18.75% of enterprises in all study areas and were mainly employed on task-based assignments which were dependent on the population of pigs at a particular time. It was observed that pig population in enterprises was highly variable owing to factors such as disease outbreaks and market dynamics. This implied that these workers were underemployed probably because smallholder pig enterprises were not large enough to provide full employment. However, some respondents reported that pig keeping was not labour intensive and as a result, labour was only hired for short assignments like cleaning.

Access to employment opportunities to both men and women was examined using wage ratio. The mean ratio of female : male average daily wage was higher in Busia County (0.98) and lower in Kiambu and Nakuru Counties (0.77 and 0.47 respectively), $F = 5.26$, $p \leq 0.05$). This was an indicator of participation in pig keeping activity by gender in the study locations. In Busia County, pig keeping was seen as part of womens' household activities was less commercialised. As pig keeping enterprises became more commercially competitive, the wage ratio became less favourable for women indicating more dominance of the enterprises by men. ILO (2012) and Guimaraes (2013) reported similar results that women work and earn less than men because of "*the precarious nature of their work as well as cultural expectations that they take care of children and the elderly family member*".

ii) Rights at work

This aspect of work addresses itself to freedoms that are granted to workers by national labour laws in regards to gender equality, elimination of child labour and formalisation of work. Majority of workers in the sub-sector were own-account workers and those hired on short assignments. Formalisation of work under these work arrangements was often not practical, constituting one of the major challenges in organising workers in informal agriculture, similar to the findings of Lopez *et al*. (2016). Child labour was recorded in less than 1% of the pig enterprises where most respondents considered it risky to involve children in pigs rearing activities.

iii) Social protection

The indicators of social protection used in this study included contribution to national health insurance and social security schemes as well as other obligations of employers. Majority of own account workers did no contribute to either the National Hospital Insurance Fund (NHIF) or the National Social Security Fund (NSSF) (53.5 and 68.1% respectively). Less than 5% of wage workers contributed to these schemes. Only 2.8% of wage workers had their hospital bills paid by their employers where injuries were sustained at work. Results showed that own-account and wage workers in more competitive smallholder enterprises were more likely to contribute to these schemes probably associated with higher disposable incomes. Low incomes often exclude workers in the informal sector from contributory social security and health schemes thereby keeping them in a cycle of poverty. Larion (2013) argued that social security is a powerful tool in the fight against poverty and insecurity.

iv) Social dialogue

The most common form of tripartism in smallholder agriculture is participation in farmer based organisations such as marketing cooperative societies. In large scale production such as in horticulture farms in Kenya, workers are organised in representative organisations which are useful in engaging employers and government. Results of this study showed that only

13.2% of smallholder pig farmers were members of a cooperative society. Results also showed that cooperative membership was associted with increased enterprise competitiveness; $t = 2.74$, $p \leq 0.05$. Among the benefits of membership to farmer based organisations such as marketing cooperatives is access to information through extension services, access to credit and stable farmgate prices as a result of organised marketing. In effect, these institutions reduce transaction costs along the value chain thereby improving incomes of producers.

The results of this study showed that pig value chain governance has significant effects on enterprise competitiveness and decent work status of producers.

8.5 Implications for policy

As a result of globalisation and increasing awareness of consumer rights, agricultural production trends today are moving towards introduction of strict standards in production. Markets of agricultural produce on the other hand are demanding a traceable footprint of the commodity right from the producer. To increase production and expand markets for such produce, it is inevitable that the production environment must be safe for workers and safe to deliver a wholesome product to the market while ensuring sustainable use of resources.

The findings of this study bring to light the need for policy focus on value chain governance issues such as; (i) enhancing commercialisation of the pig subsector especially in western Kenya through creation of market linkages, value addition, improving infrastructure such as roads, slaughterhouses and provision of clean water and empowering farmers through marketing organisations, (ii) building farmers capacity through training, (iii) focus on farmers' social protection by encouraging them to social security and health schemes, (iv) gender mainstreaming in pig value chain and (v) treating decent work agenda as a cross-cutting issue.

Development of value chains in agriculture promotes institutionalism which has both supply side and demand side implications for the decent work agenda (Schutzhoffer, 2014). On the demand side, higher wages stimulate formation of human capital through enabling workers to enhance their knowledge thereby enhancing their competitiveness. From the new institutional theory, it can be argued that an improvement in human capital may have a multiplier effect on enterprise income associated with reduced transaction costs associated with lack of technical knowhow. The increasing population with 35% of Kenyans being between 15 - 35 years (UNDP, 2013) youth unemployment at 67% (Kaane, 2014) should be a concern for policy makers with the view of attracting them into agriculture. This can only be practical if work opportunities are decent. Social protection should encourage workers to work in the informal economy.

8.5 Conclusion and recommendations

8.5.1 Conclusion

This study concluded that value chain governance had significant influence on pig enterprise competitiveness. Among the features of value chain governance, technology adoption had the strongest influence on enterprise competitiveness followed by product quality and market access. The quality of work in pig enterprises negatively influenced competitiveness of pig enterprises.

8.5.2 Recommendations

To improve smallholder participation in the pig value chain, this study recommended capacity building in the use of technology such as in pig breeding, disease control and pig feeding; improvement of infrastructure to ensure good quality pork and access to markets. The study also recommended mainstreaming of decent work concepts in policy making as a cross-cutting issue so as to contribute to improved working conditions.

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CHAPTER NINE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 Rationale of the study

The underlying rationale of this study is the loss of income opportunities associated with feeding decisions and weak competitiveness potentially resulting in poor enterprise performance in smallholder pig production systems. The motive of the study was to estimate the nutritional value of alternative feeds in use and to experimentally use the selected alternative feed resources to evaluate their effects on carcass characteristics and gut morphology. The study also evaluated the role of biotechological intervention using commercial exogenous enzymes on improving performance of pigs fed diet rich in dietary fibre. Finally the study explored the influence of value chain governance on competitiveness of smallholder pig enterprises. The study tested the hypotheses that:

i. The daily nutrient allowance for dry matter (DM), crude protein (CP) and metabolisable energy (ME) in alternative feed resources (AFR) are not significantly different from the recommended daily allowance (RDA) for DM, CP and ME and have no significant association with reproductive performance.
ii. Inclusion of selected AFR in isocaloric weaned piglet diets has no significant influence on average daily feed intake (ADFI), average daily weight gain (ADG), metabolisable energy: ADG (ME: ADG) ratio and feed cost: ADG (FC: ADG) ratio.
iii. Inclusion of exogenous multi-enzyme complex in selected AFR diet of weaned piglets had no significant influence on feed digestibility, ADFI, ADG, ME: ADG ratio and FC: ADG) ratio.
iv. Inclusion of selected AFR in diets of finisher pigs has no significant association with variations in carcass characteristics and gut morphology.
v. There is no significant relationship between value chain governance features (technology use, quality control, market access and labour conditions, production efficiency) at the production node and competitiveness of smallholder pig enterprises in Kenya.

The study selected representative smallholder pig enterprises in Busia, Nakuru and Kiambu Counties which represented the major smallholder pig production regions in Kenya. They also reflected the different production systems largely influenced by varying intensities of urbanisation. Selection of Sub-counties within a County was done on *a priori* basis. Identification of smallholder pig producing households was done using a snowball technique. An effort was made to obtain maximum variation in feed resource use by ensuring that sampling was done over a wide area within a sub-county thereby avoiding potental bias that would result from common access to a particular feed resource. A cross-sectional survey was conducted at household level and captured demographic and enterprise data at herd and sow levels. Pretested structured questionnaires were in personal interviews. Experimental research design was used to evaluate use of AFR in pig diets in a controlled environment at Egerton University Tatton Agricultural Park. This allowed for consistent and accurate measurements as well as disease control and management since the farm is a quarantine zone. Feed, feacal and urine analysis were subjected to laboratoy analysis for proximate and detergent fibre fractions and gross energy determination at the Egerton University, Department of Animal Science Nutrition Laboratory.

Mixed analytical methods were applied for this study using SPSS, STATA and SAS® statistical software. Descriptive statistics (frequencies, means, standard deviation and percentages) were used to describe smallholders' demographic characteristics and enterprise management practices. Inferential statistics with chi-square test were employed to establish differences in frequencies of the data. Heckman 2 step selection model was used to estimate determinants of choice to use commercially compounded pig feeds. Quantitative data analysis was used on all experimental data where analysis of variance was computed using ANOVA and GLM procedures. Principal component analysis was used to evaluate decent work deficits.

9.2 Implications of the findings

9.2.1 Feeding decisions and nutrient allowance associated with alternative feed resources and implications on sow performance

Preference for commercially compounded feeds among smallholder farmers in peri-urban enterprises in Kiambu and Nakuru Counties was approximately 50%. In rural enterprises in Busia County, the preference for commercially compounded feeds was very low at less than 10%. The location of the enterprise relative to a major urban area appeared to influence the level of enterprise commercialisation as well as access to inputs including feeds. Incomes in enterprises in rural areas were generally low and therefore, smallholders likely fed their pigs on any feedstuff that was available on the farm or within the locality that was of little or no monetary value. Access to government extension services influenced decisions to use commercially compounded feeds positively. Enterprises where the household head was female were more likely to use commercially componded feeds. This could have been explained by the fact that search for and ferrying AFR was labour intensive since most AFR were bulky. On the other hand, tending pigs was probably seen more as a gendered female domestic chore while selling of pigs was seen as a male task.

The finding that access to AFR influenced decisions to use commercially componded feeds negatively is suggestive of smallholders' experiences on pig and enterprise performance when both classes of feeds are used. The smallholders enterprises were either unable to break-even due to the high cost of feeds or did not acheive their performance targets due to commercial feed quality and the likelihood of underfeeding.

Home-made feed formulations were popular in peri-urban enterprises and were found to supply sufficient quantities of crude protein, however, it was observed that farmers may fail to observe benefits from their use since the diets were lacking in essential nutrients. It was observed that no mineral and vitamin premixes were included in the diets. Home-made feed formulations and agro-industrial by products were found to provide higher daily allowances for crude protein and energy, however, to compensate for the low energy in these diets, farmers used bigger rations to feed pigs motivated by the lower cost of these feeds. It would thus be important to evaluate farmers' margins so as to conclude on their overall performance. It was evident in this study that institutional swill, market and farm waste did not offer significant value in terms of daily nutrient allowance. Sows fed on commercially compounded feeds had higher fertility (27.9%) than sows that were not fed on these feeds at all; $t = 4.49$, $p \leq 0.05$. Sows fed on farm residue had an extended maturity age by 6% compared to sows that were not fed on farm residue.

Some AFR could be useful for feeding pigs when used in proportions that provide sufficient daily nutrient allowance since some are rich in some dietary components. The use of AFR such as institutional swill, farm and market residue should be discouraged through farmer training. Pig diets have implications on successful fetal implantation, survival and development. Low average daily gain is often associated with malnourishment besides other factors related to genetics. Therefore informed use of locally available feed resources could improve growth rates, fertility of sows and overall productivity of smallholder pig enterprises.

9.2.2 Bio-economic values associated with inclusion of selected alternative feed resources in diets of weaned pigs.

The results of this study demonstrated that some AFR can be used to improve growth of pigs as well as reduce the cost energy and monetary cost of feeding pigs. In this study, cold pressed canola meal, rice polishing and rice bran were used in the test diets. Substituting soybean meal with cold pressed canola meal as a protein source did not affect the apparent digestibility of the diet as well as the apparent digestibility of nitrogen. *Brassica napus* seeds from which canola meal is made are known to contain which have astringent properties. Since pig tongues are heavily endowed with taste buds, the astringent properties of glycosinolates could have affected feed palatability and feed intake. However, inclusion of canola meal in weaned piglet diet at the rate of 15% in place of soybean meal did not affect feed intake. Cold pressed canola meal diet reduced the cost of feeding in Kenya Shillings for every 1 kg increase in body weight by 24.44% attributed to the lower cost canola meal compares to soybean meal.

Substituting maize with rice polishing or rice bran at 15% in diets of weaned piglets did not affect the apparent digestibility of the diets. The apparent digestibility of nitrogen was also not affected. Therefore, inclusion of rice polishing and rice bran in weaned piglet diets at the rate of 15% did not increase the dietary fibre to a level that affected feed digestibility and nitrogen digestibility, however, piglets offered RBN diet had a higher feed intake per kg body weight as compared to the piglets fed on the basal diet. This could have been associated with a decrease in nutrient density associated with a higher amount of dietary fibre and also with a higher rate of passage through the gastro-intestinal tract.

Diet with rice polishing performed better by 9.4% than the basal diet in terms of metabolic energy requirement per kilogram weight gained. Rice polishing diet had a higher ether extract value compared to the basal diet, though the 2 diets were isocaloric. Use of rice polishing resulted in a 22.7% reduction in the cost of feeding for every 1 kg increase in body weight. Though rice bran was relatively cheap, it did not reduce the cost of feeding owing to higher feed intake and the cost of increasing dietary ME of RBN diet using vegetable oil to make it isocaloric with the basal diet.

9.2.3 Benefits of dietary exogenous enzymes in weaned piglets fed rice bran diet

Owing to the high cost of animal feeds, there is increasing interest in improving feed efficiency. Technological innovations that have been studied include use of dietary exogenous enzymes, probiotics, prebiotics and organic acids. Studies on the use of dietary exogenous enzymes in swine nutrition have reported mixed results. This situation could be explained by differences in the composition of non starch polysaccharides (NSP) between feedstuffs as well as variation within feedstuffs as a result of climatic and edaphic differences. Microbial sources of carbohydrases have also been reported to have varying efficacies. The mode of action of exogenous enzymes is unclear but is hypothesised to improve digestibility of energy, protein and fats by reducing viscosity of digesta by acting on NSP. Exogenous enzymes have been reported to allow greater energy release, decrease digesta viscosity in the gastrointestinal tract and reduce feeding cost (Cowieson, 2010; Stefanello *et al.*, 2016).

Natuzyme® a commercially available multi-enzyme complex was added into a pig diet that was rich in dietary fibre. To evaluate benefits, weaned piglet performance was compared with that of piglets fed a basal diet and a fibre rich diet without dietary exogenous enzymes. Natuzyme® multi-enzyme complex had no effect on dry matter digestibility of the diet, however, there was an increase in dietary digestible energy by 8.7% and a 12.5% increase in apparent digestibility of nitrogen. This was most likely associated with xylanase and protease in the multi-enzyme complex since rice bran has a high level of xylose. The result is also indicative of the presence of bound proteins which are probably liberated by the action of carbohydrases. Result indicated that there was a 13.4% reduction in feed intake but there was no change in average daily gain. There was a 12.77% improvement in metabolisable energy: average daily gain ratio and a reduction in the feed cost: average daily gain ratio by 12.25%.

The benefits observed may not be obvious in smallholder enterprises since there was no improvement in weight gain and only a few farmers kept records. It would however be useful to showcase such benefits through farmer education using extension agents. Otherwise, most smallholders may view commercial multi-enzyme complexes as an extra cost on the enterprise.

9.2.4 Effects of selected alternative feed resources on carcass characteristics and ileal mucosal morphology

Among commonly used measurements of carcass yield are carcass weight relative to pig live weight (killing-out percent), loin eye area as an indicator of muscling and back fat thickness. Proliferation of intestinal mucosal cells and an increase of intestinal villous height result in an increase in digestive and absorptive surface area. This study evaluated the effects of dietary fibre and lipids on carcass characteristics and structure of the ileal mucosa in growing - finishing pigs. Pigs fed on a low protein low fibre diet had the highest final weight before slaughter and killing-out percent (KO%). This implied that though this diet was the richest in dietary fiber, the role of fibre on increasing gut weight was not as significant as the overall weight of pigs in determining KO%. Use of a diet that was low in protein (159g/kg) and high in lipids (45g/kg) resulted in a higher average daily gain compared to pigs on the basal diet. This performance implies the lower requirement of dietary protein in finishing pigs. Pigs fed on a high protein high lipid diet had the highest size of back fat. Canola meal present in this diet was rich in unsaturated fatty acids which promote the undesirable effect of deposition of subcutaneous fat. This brings to light the limitations of using polyunsaturated fatty acids in animal feed. A further disadvantage associated with such oils is oxidative rancidity, thereby reducing palatability.

Pigs offered low protein low lipid diets had the largest loin eye size which implied that this diet supported lean growth. This finding implies that use of some alternative feed resources that have lower protein values compared to conventional protein sources like soybean meal could be attempted. Diets that are higher in NSP could also be used in finishing pigs since results showed increased gut surface area probably contributing to improved performance. These findings corroborated Wate *et al*. (2014) who concluded that a wide range of fibrous feeds may be appropriate for use in diets of late finishing pigs without detrimental effects on performance.

9.2.5 Influence of value chain governance on competitiveness of smallholder pig enterprises

Value chain governance characterises the linkages between actors in the chain and how these linkages affect the flow of a product from one node of the value chain to the next. Analysis of value chain governance is therefore important in identifying leverage points in improving competitiveness. Pig value chain governance in Kenya lacks coordination and linkages between actors in the value chain. This has resulted in a lack of coordination of production and marketing activities with poor information flow. As a result, smallholder farmers have not benefited from expanding market opportunities due to production and market inefficiencies. This study used principal components to evaluate the influence of value chain governance features on the competitiveness of smallholder pig enterprises and implications on decent work conditions of producers.

9.3 Conclusions

This study concluded that:

i. The mean daily nutrient allowances for dry matter, crude protein and metabolisable energy associated with alternative feed resources (AFR) were significantly lower than the recommended daily allowance and was associated with delayed maturity, reduced litter sizes and longer farrowing intervals in sows.

ii. Inclusion of cold pressed canola meal and rice polishing in isocaloric diets of weaned piglets between 56 - 99 days had no effect on average daily feed intake (ADFI) and average daily weight gain (ADG) but significantly improved the metabolisable energy: average daily gain (ME: ADG) and feed cost: average daily gain (FC:ADG) ratios. Inclusion of rice bran in piglet diets did not offer any bio-economic benefits.

iii. Inclusion of Natuzyme® multi-enzyme complex in rice bran diet of weaned piglets significantly increased the apparent digestibility of nitrogen and reduced ME: ADG and FC: ADG ratios but had no effect on ADFI and ADG.

iv. Inclusion of AFR in finisher pig diets was associated significant changes in carcass characteristics and gut morphology such that; low protein high fibre diet resulted in higher lean tissue deposition and increased ileal mucosal surface area while the diet higher in lipids was associated with increased BFT.

v. Value chain governance features (Technology, quality control, market access and factor conditions) were associated with significantly increased competitiveness in pig enterprises while labour conditions resulted in a negative relationship.

9.4 Recommendations

9.4.1 Recommendations for policy making

i. Capacity building for farmers and extension agents on feed testing and formulation to demonstrate improved reproductive performance of sows through proper feeding.

ii. Promoting the use of beneficial alternative feed resources such as cold pressed canola meal and rice polishings while providing training on the negative effects of fibrous feedstuffs like rice bran on piglet performance.

iii. Technology transfer in the use of bio-technology such as exogenous dietary enzymes to improve digestibility of fibrous feedstuff such as rice bran.

iv. Promoting use of AFR that are higher in fermentable dietary fibre in balanced finisher pig diets to improve lean carcass deposition through increased digestive and absorptive capability.

v. Capacity building in the use of technologies such as in pig breeding and disease control; improvement of infrastructure to ensure good quality pork and ease of access to markets. Mainstreaming of decent work concepts in policy making as a cross-cutting issue is critical in contributing towards improving enterprise competitiveness.

9.4.2 Recommenditions for further research

The study recommended further research in the following areas:

i. Use of technologies such as ensiling, dehydrating and compacting to improve safety and viability of use of alternative feed resources.

ii. The role of individual exogenous enzymes to help understand their mode of action in increasing apparent digestibility of nitrogen.

iii. Comparative efficacies of commercially available exogenous enzymes in pig diets.

iv. The role of dietary fat in AFR on ileal mucosal morphology and carcass fat quality.

v. The role of glycosinolates and other anti-nutritional factors present in canola meal in altering gut morphology.

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APPENDICES

Appendix I: Research clearance permit from the National Commission for Science Technology and Innovation

CONDITIONS

1. The License is valid for the proposed research, research site specified period.
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REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEARCH CLEARANCE PERMIT

Serial No.A 15393

CONDITIONS: see back page

THIS IS TO CERTIFY THAT:
DR. JONAH NDIRITU MUTHUI
of EGERTON UNIVERSITY, 0-20100
NAKURU, has been permitted to conduct research in *Busia* , *Kiambu* , *Nakuru* *Counties*

on the topic: *NUTRITIVE VALUE, BIO-ECONOMICS OF ALTERNATIVE PIG FEED USE AND PRODUCERS DECENT WORK DEFICITS AMONG SMALLHOLDERS IN KENYA*

for the period ending:
17th August,2018

Permit No : NACOSTI/P/17/47318/18281
Date Of Issue : 18th August,2017
Fee Recieved :Ksh 2000

Applicant's Signature

Director General
National Commission for Science, Technology & Innovation

Appendix II: Authority to use farm animals

JONAH N. MUTHUI
KD11/13603/14
DEPARTMENT OF ANIMAL SCIENCE,
EGERTON UNIVERSITY,
16TH JUNE 2016

THE DEAN
FACULTY OF AGRICULTURE,
EGERTON UNIVERSITY.

Through
THE FARM MANAGER,
TATTON AGRICULTURAL PARK,
EGERTON UNIVERSITY.

Through
THE CHAIRMAN,
DEPARTMENT OF ANIMAL SCIENCE
EGERTON UNIVERSITY

Dear sir,

R.E. AUTHORISATION TO USE FARM ANIMALS FOR RESEARCH

I am a PhD student in the Department of Animal Science (Animal Nutrition), Egerton University. I have submitted my research proposal to the graduate school and currently organizing for data collection. Part of my study will involve pig feeding experiments using 48 post-weaning piglets. These experiments will be conducted between September and December 2016. To facilitate accuracy and consistency of data and ease of supervision, I am kindly requesting for permission to use piglets from Tatton Agricultural Park Pig Unit as well as a section of the pig unit for my research experiments.

Further to my request, I wish to assure you that I will work closely with the staff to maintain the prescribed hygiene standards, take care of the health of piglets assigned to me and handle the piglets according to stipulated procedures.

Thank you,

Yours faithfully,

Jonah N. Muthui (KD11/13603/14)

Approved. 24/6/2016

Forwarded & recommended subject to availability of the piglets at that time. 22/6/16

Forwarded and recommended 21/6/2016

EGERTON UNIVERSITY
RECEIVED
23 JUN 2016
FACULTY OF AGRICULTURE

Appendix III: Institute of Primate Research Approval

INSTITUTE OF PRIMATE RESEARCH

P.O. Box 24481 - 00502 Karen, Nairobi. Tel: (+254-20) 2606235 Fax: (+254-20) 2606231
URL: www.primateresearch.org | Email: directoripr@primateresearch.org

NATIONAL MUSEUMS OF KENYA

aaalac

INSTITUTIONAL REVIEW COMMITTEE (IRC)

FINAL PROPOSAL APPROVAL FORM

Our ref: **ISERC/11/2017**

Dear **Jonah Ndiritu Muthui,**

It is my pleasure to inform you that your proposal entitled "Nutritive Value, Bio-Economics and Biotechnological Intervention in Alternative Pig Feed Use and Producers' Decent Work Deficits in Kenya." has been reviewed by the Institutional Review Committee (IRC) at a meeting of 20th February 2018.

The proposal was reviewed on the scientific merit and ethical considerations on the use of animals for research purposes.

The committee is guided by the Institutional guidelines as well as International regulations, including those of WHO, NIH, PVEN and Helsinki Convention on the humane treatment of animals for scientific purposes and GLP.

This proposal has been approved and you are bound by the IPR Intellectual Property Policy.

Signed .... Chairman IRC: Dr. NGALLA JILLANI

Signed .... Secretary IRC: DR. FAITH ONDIEKI

Date:

INSTITUTE OF PRIMATE RESEARCH
INSTITUTIONAL REVIEW COMMITTEE
P. O. Box 24481-00502 KAREN
NAIROBI - KENYA
APPROVED 12/06/2018

Appendix IV: Pig population in Nakuru County in 2014

Sub County	Estimated pig population
Naivasha	11,493
Gilgil	2155
Bahati	1912
Nakuru West	1134
Njoro	726
Molo	586
Rongai	424
Nakuru East	200
Subukia	133
Kuresoi	102
Total	**18,866**

(*Source: Data provided by the County Director of Livestock Production-Nakuru County)*

Appendix V: Questionnaire for household interviews

QUESTIONNAIRE TO EVALAUTE SMALLHOLDER PIG FARMERS' FEEDING STRATEGIES AND DECENT WORK DEFICITS

Introduction

I am a researcher from Egerton University conducting a survey of smallholder pig farmers' feeding strategies and market features

- I am collecting information on feeding strategies and their implications on performance
- The results will be used to address poor performance by providing necessary information to extension service providers and other stakeholders in the pig industry. All information will be treated confidential
- I am kindly asking for your consent to be part of the study
- **Household consent obtained [Yes____] [No_____] Thank you.**

General Information :

Name of household head			
Name of main respondent	**Location of Farm**	**Telephone contact**	
3. Relationship of respondent to household head? *00=Head of hhd; 01=Spouse;; 02=Child ; 03=Farm labourer ; 04=Others (specify)*			[__ __]
4. Gender of the head of the household *01=Male, 02=Female*			[__ __]
5. Age of head of the household in years			[__ __]
6. Highest level of education of household head *00= no formal education; 01= Primary; 02 = Secondary; 03=Certificate level training; 04=Diploma level training; 05=Graduate level training*			[__ __]
7. Primary occupation or source of livelihood *01=Pig farming; 02=Cash and food crops; 03=Salaried employment; 04=Business ; 05=Remittances; 06=others (specify)*			[__ __]
8. Other livestock enterprises *(indicate number)*	*Cows* [__ __] Sheep & goats [__ __] Chicken [__ __] Others [__ __]		
9. Pig farming experience	*Years in pig farming*		[__ __]
10. Land allocation	Livestock [__ __] Hectares	Crops [__ __] Hectares	

Section A: Routine Management

A/1: Pig Unit Inventory

	Indeginous breeds	Improved Crosses	Other breeds	Total	Market value for each
Breeding Boars	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]
Breeding Sows	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]
Barrows and Gilts	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]
Post- Weaning piglets	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]
Pre-weaning piglets	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]
Total	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___ ___]

A/2: Individual heart girth measurement (Measure of length in centimetres)

	No 1	No 2	No 3	No 4	No 8
Breeding Boars	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Breeding Sows	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Barrows and Gilts	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Post- Weaning piglets	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Total	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]

A/3: In the table below, indicate the management practices carried out and when it was done

Management practice	√ OR X (Tick appropriately)	Frequency	
Iron Injection (Day 1 - 3)	[___ ___]	[___ ___]	
Castration of males	[___ ___]	[___ ___]	***Codes***
Tooth Clipping	[___ ___]	[___ ___]	*00= Done frequently*
Spraying with acaricide	[___ ___]	[___ ___]	*01= Rarely done*
Vaccination eg Foot and Mouth	[___ ___]	[___ ___]	*02=Never done*
Record Keeping	[___ ___]	[___ ___]	
Routine weighing	[___ ___]	[___ ___]	
Deworming	[___ ___]	[___ ___]	

A/4: In the table below, indicate the features of the pig housing system

Structures	√ OR X (Tick appropriately)	
Pig stay/ shelter	01 = temporary [___ ___]	02=Permanent [___ ___]
Floor	01=Concrete [___ ___]	02= Others [___ ___]
Husbandry system	01=Intensive [___ ___]	02= Others [___ ___]
Farrowing pens provided	01 =Yes [___ ___]	02 = No [___ ___]
Maternity area provided	01 = Yes [___ ___]	02 = No [___ ___]

Section B: Feed resources

B/1: In the table below indicate the extent to which these barriers pose a challenge to feeding pigs.

Barrier/ challenge		***Codes***
High cost of feeds	[__ __]	*01=not serious problem*
Lack of stockists / dealers of pig feed	[__ __]	*02=a problem sometimes*
Lack of information on where to get the feeds	[__ __]	
High cost of transport	[__ __]	*03=a common problem*
Poor quality of feeds	[__ __]	
No money to buy feeds	[__ __]	*04= most common problem*
Knowledge on which feed to use	[__ __]	

B/2: In the table below, indicate the type of feed currently in use to feed pigs

	Type of feed resource	**Frequency of use**	**Specify type of feed eg. sweetpotato vines, whey etc**
1	Commercially blended feeds	[__ __]	
2	Alternative feed resources		
	Home- made formulation	[__ __]	
	Agro-industrial by-products (whey, brewers grain)	[__ __]	
	Swill from institutions	[__ __]	
	Slaughterhouse waste (blood and offal content)	[__ __]	
	Market waste	[__ __]	
	Farm residues and unmarketable produce	[__ __]	

B/3: In the table below, indicate the total cost incurred in acquiring the feed resource used. ***Specify the unit of purchase in Kg.***

Feed resource	**Purchase price**	**Transport**	**Telephone cost**	**Other costs**
Commercially compounded feeds	[__ __]	[__ __]	[__ __]	[__ __
Alternative feed resources				
Home- made formulation	[__ __]	[__ __]	[__ __]	[__ __
Agro-industrial by-products(whey,brewers grain)	[__ __]	[__ __]	[__ __]	[__ __
Swill from institutions	[__ __]	[__ __]	[__ __]	[__ __
Slaughterhouse waste (blood and offal content)	[__ __]	[__ __]	[__ __]	[__ __
Market waste	[__ __]	[__ __]	[__ __]	[__ __
Farm residues and unmarketable produce	[__ __]	[__ __]	[__ __]	[__ __]

B/4: In the table below, indicate the amount and amount of feed currently in use **(In Kg/ pig/day)**

Feed resource	**Boars**	**Sows**	**Growers**	**Post weaning piglets**
Commercially compounded feeds	[__ __]	[__ __]	[__ __]	[__ __]
Alternative feed resources				
Home- made formulation	[__ __]	[__ __]	[__ __]	[__ __]
Agro-industrial by-products (whey, brewers grain)	[__ __]	[__ __]	[__ __]	[__ __]
Swill from institutions	[__ __]	[__ __]	[__ __]	[__ __]
Slaughterhouse waste (blood and offal content)	[__ __]	[__ __]	[__ __]	[__ __]
Market waste	[__ __]	[__ __]	[__ __]	[__ __]
Farm residues and unmarketable produce	[__ __]	[__ __]	[__ __]	[__ __]
Others (Specify)	[__ __]	[__ __]	[__ __]	[__ __]

Section C: Production and Reproductive Performance

C/1: Provide details of each sow in the herd

										Farrowing dates (dd/mm/yy)	
NO.	Breed (A)	Source of the sow (B)	Sire of the sow (C)	Parity now	Age now (Months)	Number of farrows on the farm	Price when bought (ksh)	Value now if were sold (Ksh)	Age first farrowed (months)	Current farrowing	Previous farrowing
1.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
2.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
3.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
4.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
5.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
6.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
7.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
8.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
9.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]
10.	________	[___]	[___]	[___]	[___]	[_ _]	[___]	[___]	[___]	[___]	[___]

Codes for Table C/1

Breed
01 = Indigenous
0 =Improved cross
03 = Others (Specify)

Source of the sow
01 =Born on the farm
02= Bought from other farms
03= Bought from commercial large scale dairy farm

Sired through
01= Own boar
02= Other farmers' boar
03= Private AI

Section D: Barriers in Obtaining a market for pig

D/1: In the table below, rank in order of magnitude the barriers you have experienced when in need of pig markets

Barriers to obtaining market	Nature of problem
Bad consumer perception	[__ __]
Distance to buyer	[__ __]
Few buyers	[__ __]
Poor pricing	[__ __]
Poor infrastructure	[__ __]
Lack of slaughter facilities	[__ __]
	[__ __]
	[__ __]

Codes
01=not serious problem
02=a problem sometimes
03= very common problem

D/2: In the table below indicate the estimate age, weight and price of sold pigs in the last 12 months

Group	Age	Weight	price	Buyer
Sows	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
Boars	[__ __]	[__ __]	[__ __]	
	[__ ___]	[__ __]	[__ __]	
Growers (Barrows, gilts, entire males)	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
Post weaning piglets	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	
	[__ __]	[__ __]	[__ __]	

Codes for Table C/2

Buyer
01 = Trader
02 = Butcher
03 = Other farmer for breeding

D/3: In the table below, indicate the age approximate value and cause of death for pigs lost in the last 12 months

Group	Age (Mths)	Value (Ksh)	Cause of death
Sows	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
Boars	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
Growers (Barrows, gilts, entire males)	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
Post weaning piglets	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
	[__ __]	[__ __]	[__ __]
Pre - weaning piglets			

Codes for Table D/3

Cause of death

01 = Died due to disease
02 = Died due to injury
03 = Poisoning
04 = Stolen
05 = Killed due to disease/ deformity
06 = Others (Specify)

Section E: Nature of work

E/1: Indicate the source amount and cost of labour involved in pig production on a daily basis

	Ease of access	Number of workers	Hours per day	Wage (Ksh/day)
Family labour				
-Male adult	[__ __]	[__ __]	[__ __]	[__ __]
-Female adult	[__ __]	[__ __]	[__ __]	[__ __]
-Children ≥ 13 years	[__ __]	[__ __]	[__ __]	[__ __]
Hired labour				
-Male adult	[__ __]	[__ __]	[__ __]	[__ __]
-Female adult	[__ __]	[__ __]	[__ __]	[__ __]
-Children ≥ 13 years	[__ __]	[__ __]	[__ __]	[__ __]

Codes for Table E/1

Ease of access

01 = Easily available
02 = Seasonally available eg. during school holidays
03 = Hardly available

E/2. In the table below, indicate the relevant information concerning your enterprise.

	(*Tick appropriately*)
Do you use of ICT to get information? e.g. phone, internet	1= Yes[__], 0=No[__]
Do you do selection of breeder pigs?	1= Yes[__], 0=No[__]
Do you report disease outbreak to veterinary officer?	1= Yes[__], 0=No[__]
Do you seek movement permits when moving pigs?	1= Yes[__], 0=No[__]
Do you do any form value addition? e.g. cuts, roasting	1= Yes[__], 0=No[__]
What is the frequency of injury during work?	1=low [__], 2=High [__]

Appendix VI: Heckman 2-step regression results estimating decision to use commercially compounded feed

```
Probit regression                                 Number of obs   =        143
                                                  Wald chi2(7)    =      47.54
Log likelihood =  -53.02828                       Prob > chi2     =     0.0000

------------------------------------------------------------------------------
      FTCOMM |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     EDUCSUM |    .478773   .1533324     3.12   0.002      .178247    .7792991
       WEANT |   .1131807   .0351668     3.22   0.001      .044255    .1821065
     FTHMADE |  -2.380499   .5718971    -4.16   0.000    -3.501397   -1.259602
    FTAIBYPR |   -1.38892   .2646537    -5.25   0.000    -1.907632    -.870208
     FTSWILL |  -.8068918   .3157785    -2.56   0.011    -1.425806   -.1879773
   LANDLIVST |  -.0768044    .490003    -0.16   0.875    -1.037193    .8835837
    LANDCROP |   .0771087   .1376283     0.56   0.575    -.1926378    .3468552
------------------------------------------------------------------------------.

Heckman selection model -- two-step estimates   Number of obs      =       143
(regression model with sample selection)        Censored obs       =        96
                                                Uncensored obs     =        47

                                                Wald chi2(8)       =   3241.61
                                                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
FTCOMM       |
      COUNTY |   .1004092   .0194861     5.15   0.000     .0622172    .1386013
    HHGENDER |   .1881633   .0333184     5.65   0.000     .1228605     .253466
     EDUCSUM |  -.0127393   .0180067    -0.71   0.479    -.0480318    .0225532
   STSHELTER |   .2719949   .0278354     9.77   0.000     .2174385    .3265512
    TRNPSECT |   .0149357   .0081237     1.84   0.066    -.0009864    .0308578
    TRNGOVEX |   .1016252   .0505208     2.01   0.044     .0026063    .2006442
    SLTSSLAB |   .0146858    .029759     0.49   0.622    -.0436408    .0730123
     TDFVALU |  -2.12e-06   2.16e-06    -0.98   0.327    -6.35e-06    2.12e-06
     EDUCSUM |    .478773   .1533324     3.12   0.002      .178247    .7792991
       WEANT |   .1131807   .0351668     3.22   0.001      .044255    .1821065
     FTHMADE |  -2.380499   .5718971    -4.16   0.000    -3.501397   -1.259602
    FTAIBYPR |   -1.38892   .2646537    -5.25   0.000    -1.907632    -.870208
     FTSWILL |  -.8068918   .3157785    -2.56   0.011    -1.425806   -.1879773
   LANDLIVST |  -.0768044    .490003    -0.16   0.875    -1.037193    .8835837
    LANDCROP |   .0771087   .1376283     0.56   0.575    -.1926378    .3468552
-------------+----------------------------------------------------------------
mills        |
      lambda |   .0244475    .028364     0.86   0.389    -.0311449    .0800398
-------------+----------------------------------------------------------------
         rho |    0.30181
       sigma |  .08100356
------------------------------------------------------------------------------

.
```

Appendix VII: Proximate and detergent fibre composition of sampled commercially compounded feeds in grams per kilogram (g/kg DM basis)

Sample number	Dry matter	Ash	Crude protein	Ether extract	Hemicellulose	Cellulose	Lignin
Busia County							
BS5	81.6 (0.2)	148.5 (0.5)	109.3 (4.6)	6 (0.7)	219.1 (8.5)	89.7 (4)	43.2 (1.8)
BS9	80.8 (0.3	147 (0.4)	107 (2.5)	6 (0.2)	196 (8.8)	98 (8.3)	45.7 (2.3)
BS17	81.2 (0.4)	147 (6.1)	129.8 (1.2)	8.5 (0.3)	207.3 (11.7)	77.9 (3.4)	40.7 (1.5)
Nakuru County							
NS119	83 (1.2)	118.8 (1.3)	130.3 (2.9)	15.3 (0.4)	281.8 (6.7)	104 (4.1)	29 (0.6)
NS128	83.2 (1.1)	127.2 (1.8)	133.7 (0.7)	16 (0.3)	272 (5.8)	89.9 (3)	27.8 (0.8)
NS133	89.4 (0.4)	123.3 (3)	130.8 (4)	15.5 (0.2)	256.6 (16.9)	105.3 (4.5)	32 (0.5)
NF123	73.6 (1)	139.7 (2.1)	120.3 (2.7)	13.8 (0.4)	268.2 (4.6)	119.3 (3.4)	32.6 (1.5)
NF128	76.6 (1)	139.3 (1)	115.5 (1.6)	12.8 (0.6)	269.4 (5.9)	120.6 (2.4)	40.2 (1.4)
NF143	80.9 (1)	141.8 (1.8)	119 (0.6)	13.8 (0.3)	259.7 (5.9)	110.5 (4.7)	44.1 (1.7)
Kiambu County							
KS70	93.4 (0.1)	124.9 (0.7)	173 (1.7)	35 (2.1)	175.6 (7.5)	59 (2.7)	18.5 (1.8)
KS88	86.3 (2.8)	121.3 (1)	162.5 (1.2)	32.8 (1.2)	206.9 (9.3)	73.5 (5)	21.4 (1.6)
KS112	87.6 (0.6)	129.5 (0.8)	175.4 (3.3)	38.4 (1.1)	229.2 (7.4)	70.9 (1.5)	19.6 (1)
KS114	80.6 (0.7)	128.1 (0.3)	173.4 (1.8)	38.3 (0.3)	220.2 (6.3)	106.6 (4.3)	23.8 (1.2)
KF74	78.1 (0.1)	115.1 (0.3)	176.1 (3.1)	41.1 (0.9)	190.5 (9.1)	108.3 (0.3)	23.7 (2.2)
K102	79.5 (0.7)	119.4 (0.5)	179 (3.9)	40.7 (0.5)	207.2 (3.4)	115.1 (5.4)	22.4 (1.6)
KF105	78.6 (0.5)	114.4 (0.6)	174.4 (2.6)	37 (0.3)	212.4 (0.7)	110.2 (3.2)	23.9 (2)

Appendix VIII: Nutrient values of home-made feeds simulated in Evapig®

Feed ID	CP%	EE%	NDF%	ADF%	Lignin%	ME	Lysine%	Met%	Ca%	P%
B006	19.7	14.66	19.77	9.28	3.27	12.52	0.82	0.35	0.54	1.69
B035	15.66	16.12	19.75	8.58	3.12	12.55	0.6	0.27	0.29	1.7
B039	11.98	4.28	50.28	14.19	2.22	8.81	0.39	0.17	0.47	0.31
K055	19.65	3.21	21.19	6.66	1.68	12.55	0.8	0.03	0.15	0.7
K085	20.35	3.03	30.04	8.45	1.71	12.1	0.45	0.27	0.08	0.67
K086	25	3.18	24.87	9.38	2.33	12.16	0.98	0.39	0.43	0.83
K109	20.6	3.5	29.08	9.65	2.64	10.79	0.73	0.33	1.85	0.93
N142	20.67	3.65	36.56	12.03	3.35	9.92	0.71	0.32	0.53	1.09
N135	17.44	3.59	30.85	9	2.47	11	0.56	0.24	0.29	0.9
N136	5.39	2.53	63.03	26.03	9.95	5.57	0.17	0.07	0.12	0.21

Key: CP=crude protein, EE=ether extract, NDF=neutral detergent fibre, ADF=acid detergent fibre, Met=digestible methionine in kilojoules per kg, Ca=calcium, P=phosphorous

Appendix IX: Nutritional value of grain by-products commonly used in smallholder pig enterprises

By-product	DM%	CP%	EE%	NDF%	ADF%	CF%	ME (Kcal/kg)	Reference
Wheat pollard	87.9	19	5.3	30	10	8	2871	NRC, (2012)
	87.9	14.92	3.52	22.94	6.5	4.9	2937	Noblet *et al*. (1993)
	90	16.3	4.9	-	-	8.8	-	Aanyu & Ondhoro (2016)
Wheat bran	87.38	15.08	4.72	40.6	14	11	1833	NRC, 2012
	87.1	14.77	3.48	39.63	11.85	9.17	2199	Noblet *et al*. (1993)
	88.64	15.83	-	47.13	14.67	-	2547	Fekede *et al*. (2015)
	89.1	13.8	3.27	41.1	14.7	4.55	-	Gonzaleza *et al*. (2015)
Maize bran	88.50	11	6.3	51	17	10	2584	NRC,2012
	87.8	10.84	3.6	52.24	14.57	12.81	2018	Noblet *et al*. (1993)
	89.94	9.85	3.1	61	16.7	-	-	Liu *et al*. (2014)
	89	10.1	2.7	-	-	10.6	-	Aanyu & Ondhoro (2016)
Rice bran	91.06	14	16	24	18	13	2997	NRC,2012
	90.11	13.79	16.4	20.54	8.92	7.76	2970	Noblet *et a*l. (1993)

Appendix X: Nutritional value of food processing waste commonly used in smallholder pig enterprises

By-product	DM%	CP%	EE%	NDF %	ADF %	CF%	ME Kcal	Reference
Bakery by-product	90.8	12.3	5.39	2	5.5	-	3856	NRC, 2012
Blood meal	93.23	88.65	4.72	-	0	-	3773	NRC, 2012
Fish meal		63.28	5.97	-	0	0.24		NRC,2012
Brewers grain	92	26.5	4.72	48.7	20.14	-	1920	NRC,2012
Tomato pomace	-	20.91	14.14	-	-	50.6	-	Silva *et al*., 2016
	92.07	18.15	6.6	-	-	42	-	Rezaeipour *et al.* 2012
	94.6	20.93	10.22	55	42	22.7 37.4	-	Khadr and Abdel-Fattah (2008)

CP=crude protein, EE=ether extract, NDF=neutral detergent fibre, ADF=acid detergent fibre

Appendix XI: Nutritional value of farm residue and vegetable waste commonly used in smallholder pig enterprises

	Moisture %	DM%	ASH%	CP %	EE%	NDF%	ADF%	ME Kj/kg	REF
SPV	76.54	22.03		11.59		36.58	32.8		A
		29.4	7.5	12		46.6	34.7		B
	72.38	20.7	11.7	11.5		35.4	35.4		C
	71.05	19.7	11.7	11.2	2.2	40.9	30.3	9.2	D
			13.1	15.9	3.6	43.5			E
Amaranth	69.6		4.04	15.86	6.77				F
Cabbage	93.02	6.94	0.67	1.8	6.42				G

A= Figueiredo *et al*. (2012), B=Pedrosa *et al*. (2015), C=Ly *et al*. (2010), D=Katongole *et al.* (2008), E=Ngoc *et al*. (2012), F= Akin-Idowu *et al.* (2017), G=Tayyeb *et al*. (2017)

DM=dry matter, CP=crude protein, EE=ether extract, NDF=neutral detergent fibre, ADF=acid detergent fibre, ME=metabolisable energy, SPV=sweet-potato vines

Appendix XII: Piglet data on feed intake and feacal output between day 9 - 35 of the feeding experiment

DIET	Pig ID	Mean Feed Intake (g/day)	Mean Feacal output (g/day)	Dietary Protein (%)	Faecal protein (%)
Basal	7	1223.01	400.86	19.47	14.08
Basal	3	1235.65	381.19	19.47	14.08
Basal	11	1310.64	341.84	19.47	14.08
CPCM	12	1347.01	434.6	19.38	12.11
CPCM	23	766.7	194.58	19.38	12.11
CPCM	28	927.3	188.84	19.38	12.11
RPL	21	632.65	121.64	15.81	14.64
RPL	24	875.14	238.02	15.81	14.64
RPL	20	1098.67	259.15	15.81	14.64
RBN	32	1073.31	250.27	14.93	9.78
RBN	19	671.74	212.98	14.93	9.78
RBN	29	1346.18	506.71	14.93	9.78

Key: CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet

Dietary and feacal protein were computed as the Nitrogen titre X 6.25.

Appendix XIII: Comparison of urine protein output between experimental diets for piglets between day 75 and 96 of age

	Diet				p-value
	Basal	CPCM	RPL	RBN	
Mean body weight (kg)	17.79	17.75	21.74	19.12	0.65
Urinary protein (g/litre)	3.5 (0.7)	2.2 (0.7)	5.1 (1.1)	1.9 (0.8)	0.13
Urine output (ml/kgbwt/day)	55.78	59.48	45.86	65.67	

Key: CPCM=cold pressed canola meal diet, RPL=rice polishing diet, RBN=rice bran diet

Urinary protein was computed as the Nitrogen titre X 6.25.

Normal urinary protein for swine is 3.5 - 6g/dl (Blood and Radostits, 1989)

Appendix XIV: Steps in preparation of histological slides

1. Tissue fixation: Should be done as soon as possible after tissue collection. Immerse tissue sections (about $2cm^3$) in 10% buffered formalin for 24 hours. Volume of fixative should be 10 times that of the tissue.

2. Tissue dehydration: Use graded ethanol series from water through 70% - 90% - 95% - 100% Ethanol. This minimises tissue shrinkage.

3. Clearing: This replaces the dehydrating fluid with a fluid that is miscible with ethanol and the embedding medium such as zylene.

4. Infiltration and embedding is done using paraffin wax to provide external support to tissues during sectioning. Impregnation of tissue with wax is done at the melting point of wax (54 - 60^oC)

5. Sectioning using a microtome. Tissues are sectioned at thickness varying from 2 - 25 µm.

6. Sectioned tissues are mounted on glass slide.

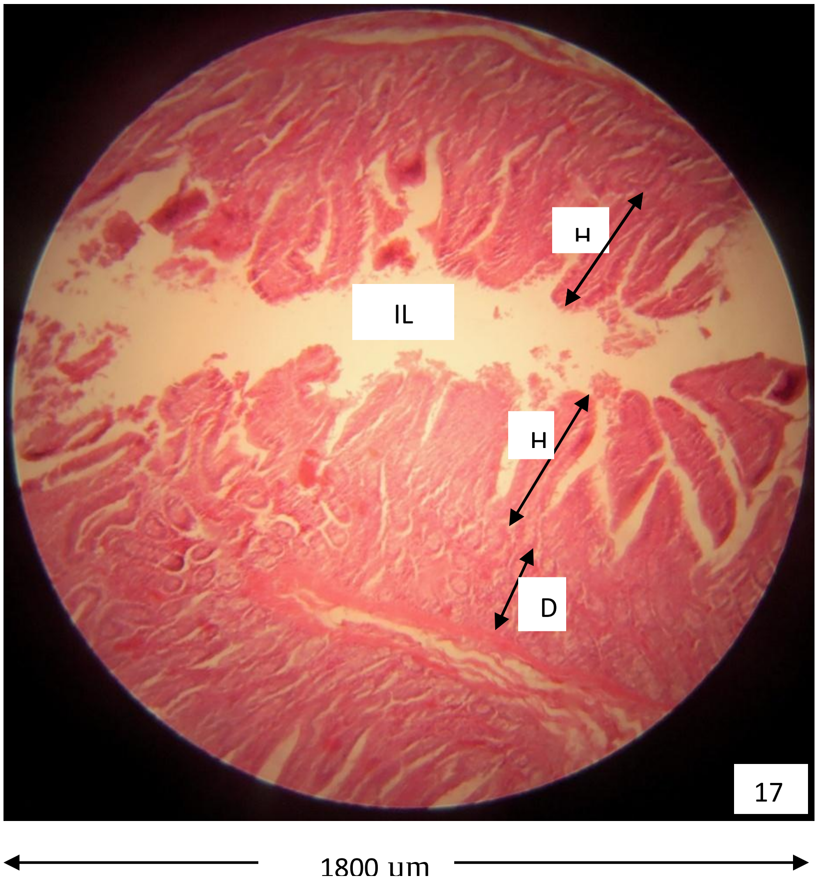
7. Removal of paraffin wax

8. Rehydration

9. Staining with hematoxylin for 15 minutes, wash in tap water for 20 minutes then stain with eosin for 2 minutes.

10. Examine under a microscope: Nuclei appear blue while cytoplasm appears pink.

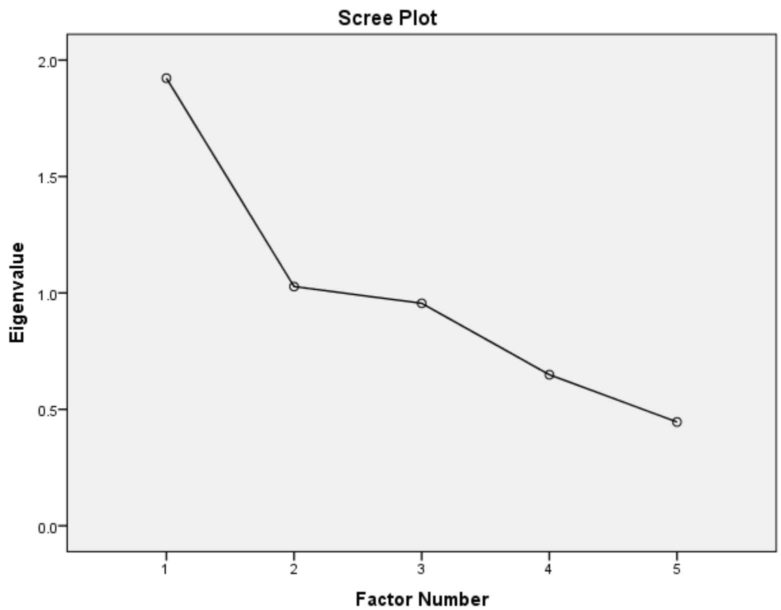
Appendix XV: A 10 X 10 magnification of an ileal section illustrating measurement of ileal villous height and crypt depth



Key: H=villous height, D=crypt depth, IL=intestinal lumen

Diameter of field =1800 μm.

Appendix XVI: Scree plot showing 2 components with Eigen values greater than 1



Appendix XVII: List of publications and conference presentations

1. Estimation of daily nutrient allowances for pigs fed with alternative feed resources in smallholder enterprises in Kenya. *Tropical Animal health and Production*. https://doi.org/10.1007/s11250-018-1757-6.

2. Beneficial effects of non-conventional feedstuffs on carcass characteristics and ileal mucosal morphology of finisher pigs. *Egyptian Journal of Veterinary Sciences.* https://ejvs.journals.ekb.eg/article_21255.html. DOI:10.21608/ejvs.2018.5040.1047.

3. Decent Work deficits in Agriculture: Concepts, Measures and Solutions. A summer school report held at Universidad Autónoma de Yucatán (UADY) Merida, Yucatan, Kassel University Press. https://www.unikassel.de/einrichtungen/fileadmin/datas/einrichtungen/icdd/ICDD_Summer_school_2016__Observations_and_Reflections_on_Decent_Work_Deficits_in_Agriculture.pdf

4. Pig nutrition; feeding practices in smallholder enterprises in Kenya and outcomes on performance. Paper presented at the KVA workshop at Aberdare Resort Hotel on 29th Nov 2018

5. Smallholder pig production practices and enterprise bio-indicators along the rural-urban continuum in Kenya. Paper presented at the International PhD workshop on: "Constructing research frameworks on the sustainable development goals in Africa's policy environment" at the University of Cape Coast, Ghana on 10th April 2018..

6. Alternative feed resources; A bio-economic evaluation of Brassica Napus seed meal in improving incomes of pig producers. Paper presented at the International Centre for Development and Decent Work held at Egerton University, Njoro, Kenya on 3rd to 12th March 2017

7. Social Dialogue to enhance collective bargaining in smallholder agriculture in Sub-saharan Africa. Paper presented at the Global Labour University Conference at Wits University, Johannesburg, South Africa on 30th September 2016.