PERFORMANCE OF STARTER PIGS FED DIETS BASED ON MALTED AND FERMENTED MAIZE

BY

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DECLARATION

This thesis is a result of my original work and has not been submitted for any other degree at either this or any other university.

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This thesis has been submitted for examination with our approval as University Supervisors.

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Dr. Margaret Nabasirye

DEDICATION

I humbly dedicate this work first; to my father, Eribankya Muhonge Steven Adyeeri; mother, Birungi Josephine Amooti, second; to my fiance Christine A, daughter Beyeza Immaculate; brothers and sisters.

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I am grateful to the almighty God for the gift of life. I know that He has left me to live because he has plans for me. I acknowledge my parents for the love and trust they have in me for they have raised and supported me through good and bad times using the limited resources back at home.

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ABBREVIATIONS

ADFI	–	Average daily feed intake
ADG	–	Average daily gain
Ca	–	Calcium
CM	–	Control-milled whole maize based diet
DIG	–	Apparent digestibility coefficients of nutrients
DM	–	Dry matter
FCR	–	Feed conversion ratio
FTD	–	Fermented maize based diet
M&F	–	Fermented maize after malting
MTD	–	Malted maize based diet
P	–	Phosphorus
TVC	–	Total variable cost
TVP	–	Total value of product

ABSTRACT

Two growth trials involving crossbred (Large white × Landrace) starter pigs were conducted to compare feed intake, growth rate, feed conversion efficiency and cost of feeding malted (MTD), fermented (FTD), fermented maize grain after malting (M&F) and unprocessed (CM) maize grain based diets. In the first trial, sixty four piglets of four-to-six weeks of age initially weighing 6.14±1.3kg were allotted to sixteen groups of four balanced for sex and weight. The groups were assigned to four experimental diets in a completely randomized design (CRD) consisting of four treatments and four replicates. The trial lasted for 56 days. Diets were formulated to contain 17% crude protein and available to pigs *ad libitum*. At the end of the first trial, a digestion experiment using the total collection method was conducted to determine digestibility of DM, CP and energy. In the second trial, a total of sixty piglets weaned at 4, 5, 6 and 8 weeks of age were fed on a diet based on fermented maize grain (which exhibited the best performance and gross margins in trial 1) and their performance followed until piglets attained 8 weeks of age. Processing had no significant effect on the levels of CP, P and Ca ($P > 0.05$). Fermentation and malting increased the ash content to 1.80 and 1.67% respectively from 1.24% in non-processed maize. Processing reduced digestible energy from 4316.3 Kcal/kg in non-processed maize (control) to 4195.3, 4175.1 and 4138.5 Kcal/kg in malted, fermented and maize fermented after malting respectively. Average daily feed intake (ADFI) and gain (ADG) varied in a descending order of 0.726, 0.642, 0.554, 0.527 kg/day and 0.276, 0.244, 0.199, 0.158 kg/day for pigs fed on MTD, FTD, M&F and CM respectively. Feed conversion ratio was similar across all the diets. Apparent digestibility coefficients of DM, energy and CP were similar for all treatments ($P > 0.05$), although malted maize diets had consistently low values. All processing methods increased gross margins with fermented maize based diets resulting into the highest (890shs) gross margins ($P < 0.05$). These data indicate that using fermented maize in diets of starter pigs results in higher performance and reduced feed cost. Malted maize can be used for piglets of low weaning weights because of its ability to stimulate intake although at higher cost. There was a difference in ADFI, ADG and FCR (Feed/Gain) among piglets weaned at different ages when fed fermented maize based diets ($P < 0.05$). The highest ADG of 0.094kg/day ($P < 0.05$) was obtained when piglets were weaned at five weeks of age. Malted and fermented maize based diets are appropriate for weaning piglets as early as five weeks of age instead of the usual eight weeks and improve post-wean performance at low costs.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Overview of pig production

Pig rearing in Uganda is one avenue of supplementing income from the mainly crop farming homesteads (Ouma *et al*., 2014). Compared to ruminants, pigs are prolific, have high feed conversion efficiency, early maturing, require small space and easy to manage hence they are preferred by farmers. Farmers use income from the sale of pigs to cater for some basic family needs including medical bills, school fees and improved welfare among others (Ouma *et al*., 2014). The post-wean period is however characterized by poor performance as exhibited by low feed intake and poor growth (Sørensen *et al*., 2009 and Naranjo, V.D. 2010). Low feed intake results into low weight, poor quality baby piglets that finally fetch less income to the farmer. The burden of low feed intake and stuntedness is also passed on to the farmer buying piglets because they delay to attain market or sexual maturity.

The cause of poor post-wean performance is low feed intake that is inadequate to meet the nutritional requirements of weaned piglets (Pluske *et al.*, 1997; Lalles *et al*., 2007 and Naranjo, V.D. 2010). This is complicated by lack of appropriate piglet weaner diets that permit a smooth transition from suckling to solid feed. In Uganda, pigs are fed on commercial or home mixed concentrates, crop residues, forages, brewers waste and kitchen left overs (Ouma *et al*., 2014). The most appropriate weaner diets are those based on ingredients that are highly digestible and palatable to meet the piglets' digestive capacity. Milk derived products like dried whey, dried whey permeate (Mahan, 1993), milk chocolate product (Naranjo, V.D. 2010) and spray-dried plasma protein (Van Dijk *et al*., 2001) have been used to boost feed intake and growth in weaned piglets. However, these ingredients especially commercial protein supplements are expensive and largely unavailable in Uganda.

In Uganda, piglets are mostly weaned on cereal based diets characterized by low intakes and low digestibility for this stage of pigs. As an alternative, farmers prolong suckling of piglets to two months to avoid feed related problems at weaning. The long lactation increases the farrowing interval and at the same time reduces the number of piglets produced per sow per year as compared to early weaning (Naranjo, V.D. 2010) as sows do not come on heat while suckling or take long to return to heat after weaning due to poor body condition. Post-weaning performance of piglets and sows fed maize and sorghum meal based diets respectively was improved using the restricted suckling and split-wean technique (Kugonza and Mutetikka, 2005).

Piglets like other young mammals are simultaneously faced with multiple stressors like nutritional, immunological and psychological stress at weaning (Lallès *et al.*, 2007; Weary *et al.*, 2008 and Kim *et al*., 2012). Most important is nutritional stress as piglets change from the sows' milk to a solid feed that is usually inadequate in terms of nutrients, less digestible and less palatable. As a result of weaning stress, the post-wean period is characterized by reduced feed intake, increased susceptibility to enteric diseases and reduced growth rate (Naranjo, V.D. 2010). The reduced growth of piglets upon weaning negatively impacts the pig production sector (Pluske *et al.*, 1997; Lallès., 2007) as pigs delay to attain reproductive or slaughter weight.

1.2 Malted and fermented maize as pig feed

Processing cereals in the diets of weaned piglets offers potential to increase nutrient availability to young pigs. Malting and fermentation are effective biological (enzymatic) methods of processing that are efficient in reducing anti-nutritional factors at the same increasing the bio-availability and digestibility of particular nutrients (Mahgoub and Elhag, 1998; Liang *et al*., 2008; Jørgensen *et al*., 2010). Malting maize reduces its phytate content and at the same time increases its hydrochloric acid extractable minerals (Sokrab *et al*., 2012). In rice, fermentation effectively reduces phytate compared to soaking (Liang *et al*., 2008).

Cereal grains are enriched with starch and protein deposits naturally meant for the grain to fulfill its biological functions. The mobilization of storage compounds to support seedling growth during germination is one biological function that has over the time been utilized by humans (Shewry and Mattew, 2001). Pre-germination of grains increases the activity of hydrolytic enzymes that break down grain storage compounds into more simple and digestible fractions. The process also initiates chelating of minerals with protein molecules thereby increasing their bioavailability in addition to reducing anti nutritional compounds like phytates and protease inhibitors. The end result of germination is enhanced digestibility and nutrient value of sprouted grains above that of un-germinated grains (Peer and Leeson 1985; Chavan and Kadam 1989; Chung *et al*, 1989 and Sokrab, A.M. *et al.*, 2012).

During fermentation, lactic acid bacteria, yeast and some fungi change sugars in grains into organic acids but most important is lactic acid which is responsible for the change in taste, flavor, texture and the acidity that reduces harmful or diarrhea causing oraganisms (Mugula *et* *al*., 2003; Canibe and Jensen 2003; Nout, 2009). The process of fermentation improves the digestibility of organic matter, crude protein, and calcium (Canibe and Jensen, 2012). Scholten *et al*., (1999) demonstrated that fermented diets have the potential to improve growth performance of pigs compared to non-fermented diets. Feeding fermented liquid diets to weanling piglets has also been shown to prevent detrimental changes in mucosal architecture after weaning (Scholten *et al.*, 2002).

Though research on the use of fermented diets in feeding pigs has been done, most workers have concentrated on fermented liquid feed (Canibe and Jensen, (2007); Plumed-Ferrer and Von Wright, (2009); Jørgensen *et al*., (2010) and Canibe and Jensen, (2012). Information regarding the performance of piglets weaned on dry fermented maize based diets is lacking.

1.3 Problem statement

Weaning is a complex process that includes separating piglets from the sow, exposure to environmental, social and psychological stress, diseases, and most important, switching from the sow's milk to a dry feed (Pluske *et al.,* 1997). The failure to adopt to feeding on weaner diets and stress especially for the early weaned piglets may be manifested through belly nosing associated with high levels of water intake that reduce feed intake (Widowski *et al*., 2008). In general, growth rate and feed intake at weaning are low and highly variable (Sørensen *et al*., 2009).

The digestive system of a newly weaned pig is inadequately developed (Tokach *et al*., 1989; Mahan *et al*., 2004) and this explains the poor digestion of nutrients in weaner diets (Leibbrandt *et al*., 1975). At weaning, both digestion and absorption of nutrients is hindered by the physical and biological changes occurring in the small intestine of the piglet (Pluske *et al*., 1997). A highly palatable and digestible post-weaning diet is critical in the piglet's transition from the highly digestible sow's milk. Though highly digestible, weaner diets containing milk derived products such as dried whey, dried whey permeate and milk chocolate products (Mahan, 1993; Naranjo, 2010) reduce the post-wean growth lag, they are expensive and not readily available in Uganda. The available diets fed to piglets are either less palatable or digestible and as a result feed intake, digestibility, feed efficiency and growth rate are reduced.

The capacity of digestive enzymes to break down sugars, starch and proteins is variable and takes long before attaining full potential. As a result, the early weaned piglets' digestive system is unable to adequately digest and absorb nutrients in diets based on cereal grains (Greg, 2002). Formulating weaner diets based on more palatable ingredients provides the means of improving palatability and feed intake at weaning (Solà-Oriol *et al*., 2009b).

Dietary manipulations aimed at reducing feed related weaning stress have not given promising results. Supplementing weaner diets with colostrum has no beneficial effects on gut structure and microbial modification (Huguet *et al.,* 2006). A milk based starter diet improved feed intake but did not affect body weight gain, feed conversion efficiency (Boudry *et al.*, 2002) and post-weaning performance (Armstrong and Clawson, 1980). Weaner diets supplemented with multi-enzymes have no effect on voluntary feed intake and average daily gain (Officer, 1995).

The drop in energy intake and nutrient digestibility observed in piglets at weaning appear unavoidable hence the need for approaches that stimulate fast recovery and performance upon weaning. Processing of cereal grains improves the sensory, nutrient levels and availability of bioactive compounds (Katina *et al*., 2007). Use of malted or fermented cereals especially maize in weaner diets are available alternatives towards improved post-wean feed intake, digestion and growth rate. Germination increases amylase activity, increases the amount protein, soluble sugars and minerals available (Traor'e *et al*., 2004). The increase in soluble sugars imparts the sweet taste characteristic of germinated cereals which is probably responsible for the increased palatability. Fermentation improves the taste, flavor and texture of cereals resulting into improved palatability, feed intake and nutrient digestibility of fermentation products (Prescott *et al*., 1996; Canibe *et al*., 2007).

This study aimed at evaluating the effect of including malted and fermented maize in weaner diets on nutrient availability, feed intake, digestibility, growth rate, and its feed cost implications to finally come up with weaner diets based on malted and fermented maize grain for weaned piglets.

1.4 Research objectives

1.4.1 General objective

The overall objective is to develop appropriate cereal based diets that permit early weaning for increased productivity and profitability of pig production in Uganda.

1.4.2 Specific objectives

i. To determine the effect of malting and fermentation of maize on nutrient availability.
ii. To determine the effect of malting and fermentation of maize on feed intake, growth rate, feed conversion efficiency of pigs and cost implications.
iii. To evaluate the effect of maize processing on weaning age

1.5 Study hypothesis

i. Malting and fermentation increases nutrient availability of maize.

ii. Malting and fermentation of maize increases feed intake, growth rate , feed conversion efficiency & reduces cost of feed
iii. Malting and fermentation of maize reduces weaning age

1.6 Justification of the study

Feed intake in post weaned piglets is low and variable which negatively impacts on performance during the wean-to-finish period (Darryl and Arturo, 2007). When piglets are separated from the sow and offered dry feed and plain water, they find difficulty in initiating feed consumption (Lalles *et al*., 2007). Since piglets do not eat enough feed to allow maximum protein deposition, highly palatable and digestible diets should be provided to cater for their inefficiency to digest and absorb nutrients (Gaines *et al*., 2003). Post-weaning digestive complications like villous atrophy can be reduced and growth improved by increasing feed intake (Dong and Pluske, 2007). In Uganda, piglet weaner diets based on highly palatable and digestible ingredients especially milk derived products are not applicable. The current milk supply is low, does not meet the market demand and processing by-products are scarce as most of the milk is consumed in its fresh form. There is need to find alternative feedstuffs of high nutrient availability and one possibility is the use of cereals. Malting and fermentation of maize are biological alternatives towards improved feed intake and growth rate.

CHAPTER TWO

LITERATURE REVIEW

2.1 The impact of weaning

The days following weaning in pigs are characterized by low feed intake, negligible weight gain and sometimes are associated with diarrhea (Armstrong and Clawson, 1980). The physical and chemical changes in small intestines upon weaning contribute to the post-wean growth check that negatively impacts on commercial pig production (Pluske *et al*., 1997). The changes in the small intestine influence digestion, absorption of nutrients, mucosal physiology and immunity (Lallès., 2008). Weaned piglets are susceptible to pathogenic enteric diseases due to the immature immune system. The immature immune system at weaning is linked to a non-functional intestinal barrier arising from damaged mucosa and altered tight junction functionality (Kim *et al*., 2012).

Reduced growth, diarrhea and sometimes death are common in newly weaned piglets. High incidences of diarrhoea result into reduced weight gain, that is, a reverse relationship exists between the prevalence of diarrhoea and weight gain (Madec *et al*., 1998). At weaning, piglets secrete inadequate amounts of digestive enzymes to fully breakdown the ingested nutrients. At the same time, the piglet maternal immunity is also declining. Hence nutritional and therapeutical approaches are needed to reduce cases of post-wean digestive disorders that account for more than half of the mortality cases that occur upon weaning. Reducing the protein content in weaner diets is one nutritional strategy aimed at protecting weaned piglets from digestive disorders (Heo *et al*., 2010).

When formulating diets of weaned pigs, the economics of the present pig industry requires us to consider a number of factors. First is to adjust pigs to simple and relatively low cost diets as soon as possible after weaning. Secondly, to maximize feed intake of newly weaned pigs as they go through the energy dependant growth stage and finally to consider the digestive physiology of the weaned pig to formulate diets with highly digestible ingredients that complement the pattern of digestive enzymes secreted at weaning (Nelssen, 1990).

2.2 Nutrient requirements of weaner piglets

At weaning, piglets weighing between 5-10kg are expected to consume 460g (90 percent dry matter basis) of feed daily and attain a growth rate of 250g/day. To achieve this performance (250g/day), piglets require digestible energy of 1,560kcal/day in addition to protein, calcium and total phosphorus at 92, 3.7 and 3g/day respectively. Though little or no feed is consumed on the first day of weaning, feed intake increases linearly during the entire post-wean period (NRC, 1998).

Major dietary components can be altered from the standard levels to suit the stage of development of the pigs' digestive system. Kim *et al*., (2012) recommended reducing dietary protein, non-starch polysaccharides (NSP) and iron in the first days upon weaning for high post-wean performance. Altering protein quantity and quality in piglet diets is one way of manipulating the gastrointestinal structure and function (Lange *et al*., 2010). Yue and Qiao, (2008) maintained villous height and adequate disaccharidase activities at relatively low protein levels of 18 percent. However, reducing protein levels to 17 percent retards growth, feed efficiency, villous height and disaccharidase activities (Yue and Qiao, 2008). The reduction in performance due to low dietary protein in weaner diets can be overcome by supplementing with amino acids (Le Bellego *et al*., 2002).

2.3 Intestinal bio-physical changes associated with weaning

The reduced growth experienced upon weaning results from reduced digestion and absorption of nutrients brought about by both physical and biological changes that occur especially in the small intestine. The changes in villous height and crypt depth in the small intestine are influenced by changes in nutrition (elimination of sow's milk, change in nature and composition of diet), presence of enteropathogenic bacteria and their interaction with diet or intestinal mucosa, failure to adapt to stress and utilization of cytokines as regulators of intestinal immunity. At weaning, the baby pig is deprived of colostrum, milk-borne growth factors and hormones yet these are important in the differentiation and development of the small intestine. Use of exogenous growth factors and dietary supplementation with non-essential amino acids are two ways of manipulating the functioning of the digestive tract (Pluske *et al.*, 1997).

Starter diets supplemented with colostrum significantly lower pH, increase villous height though the crypt depth and the ratio of villous height to crypt depth do not differ significantly in the first two weeks (Huguet *et al.*, 2006). At weaning, milk and cereal based starter diets show no significant change in jejunum macrostructure in the first four days implying that the villus and crypt structural changes that occur at weaning are due to other factors like reduced feed intake, stress, and inflammation but not the change in diet (Boudry *et al*., 2002). Inclusion of Antibiotic growth promoters-AGP in weaner diets containing excess crude protein reduces diarrhea and digestive disorders, improves growth rate and feed efficiency of weanling pigs (Cromwell, 2001;

Kil and Stein, 2010). However, use of AGP results into antibiotic resistant bacterial strains and long term residual effects when such pork is consumed (Gallois *et al.*, 2009). Withdraw of AGP reduces weight gain, feed consumption and increases the chances of mortality (Stein, 2002). Use of a low-protein weaner diet (18%CP) and fermented liquid feed with intake limited to 75% of *ad libitum* intake immediately after weaning are some of the management strategies that enable elimination of AGP. The result is reduced growth rate though compensatory growth occurs with access to diets of higher crude protein (Kil and Stein, 2010).

Starter pig performance is improved by dietary lactose, which plays an important role in maintaining a good intestinal environment. However, the dietary levels of lactose required to attain maximum growth rates decline as the pig becomes older and their digestive enzymes attain the potential to hydrolyze the complex components in cereal grain (Mahan *et al*., 2004).

Increased secretion and modification of pancreatic juices is delayed by low levels of feed intake upon weaning. The inadequate secretion of digestive juices results into reduced digestibility of nutrients, a phenomenon well-known in periods when piglets are experiencing post-wean anorexia (Isabelle, 2005). Hedemann *et al*., (2003) reported that weaning results into shortening of the villi and change in enzyme activity. Kelly *et al.,* (1991) described the fall in enzyme activity as an age dependent phenomenon. The reduction in the specific activity of lactase and sucrase after weaning is associated with the reduction in villous height and an increase in crypt depth in the small intestine up to the fifth day post-weaning (Pluske *et al.*, 1996). However, villi height and enzyme activity are gradually recovered in the subsequent days following weaning.

At weaning, piglets are able to digest nutrients in the form they are secreted in sows' milk. This implies that ingredients used in weaner diet formulation should be based on nutrient digestibility, amino acid density and stimulatory effects on feed intake (Nelssen, 1990). Diets containing highly palatable and digestible ingredients should be fed at weaning to stimulate feed intake and afterwards turn to feeding simple diets containing less palatable and digestible ingredients that are less expensive (Dritz *et al.,* 1996). The aim of feeding weaned piglets is to meet their nutritional requirements for maintenance, growth, and reproduction at a reasonable cost (Greg, 2002 and Adesehinwa, 2008). Weaner diets should also be palatable to minimize the initial anorexia at weaning (Sola-Oriol *et al,*. 2007).

2.4 Feeding complex versus simple diets

Himmelberg *et al*., (1985) described simple diets as maize-soybean meal-based diets with minimal inclusion of milk, processed cereals, and animal protein-based ingredients as opposed to complex diets. At weaning, piglets consume small quantities of feed by virtue of their small stomachs. Feeding small quantities of complex diets helps to overcome the risk insufficient intake of nutrients especially when the feeds provided are of low nutrient density. Complex diets cost more than simple diets but contain more palatable and digestible ingredients to take care of the inadequate enzymes in the digestive systems of weaned piglets (Gaines *et al*., 2003). Feeding complex diets increases feed intake and feed efficiency thereby reducing days to market weight (Himmelberg *et al*., 1985; Gaines *et al*., 2003 and Mahan *et al*., 2004).

Weaning age and diet complexity influence average daily gain for a few days post weaning. Delaying weaning to more than three weeks of age results into fast growth compared to pigs weaned earlier (Dritz *et al.*, 1996). This implies that early weaned piglets are more prone to post weaning histological and biochemical changes in the gastrointestinal tract than late weaned pigs (Pluskel *et al*., 1997). Higher feed intake and faster gains can be achieved by delayed weaning (Armstrong and Clawson, 1980).

Piglets feeding on complex diets grow faster and have a more favourable gain:feed ratio compared to piglets fed on simple diets but have similar feed intake (Wolter *et al*., 2003). Feeding complex starter diets to heavy piglets weaned at three weeks of age led to more feed consumption, improved feed conversion and improved weight gain than light pigs fed a simple diet. This is because heavier pigs have the ability to consume more feed (Dritz *et al*., 1996). Weaning heavy piglets and at the same time increasing starter diet allowance increases pig weight and growth rate. However, light and heavy pigs at weaning were found to have the same feed efficiency throughout their growth period (Magowan *et al*., 2011).

Increasing diet complexity improves average daily gain only in the early period after weaning but had no effect on average daily gain for pigs weighing 7 to 18.7kg (Dritz *et al*., 1996 and Wolter *et al*., 2003). Gaines *et al*., (2003) concluded that piglet performance is affected when they are turned to simple diets from a complex diet fed in the initial first days and that complex or simple weaner diets have no influence on the immune response of piglets to *Escherichia coli*. High protein or energy levels do not improve post-wean performance and instead, high energy levels depress average daily gain and feed efficiency. Adding cow's milk or fat in weaner diet proved not beneficial. However, adding non fat dried milk to weaner diets resulted in improved performance (Armstrong and Clawson, 1980).

Weaning light piglets negatively affects their post weaning performance even when starter diets rich in the required nutrients are used. Lighter pigs at weaning gain less, are less efficient in feed utilization and don't exhibit compensatory growth from weaning to market weight compared to heavier pigs (Mahan *et al*., 1998). Though all piglets are faced with weaning stress, light and early weaned piglets are more susceptible to stress.

2.5 Management and nutritional approaches of improving post-wean performance

Post weaning performance can be enhanced by manipulating the diet (Sørensen *et al*., 2009) and by improving hygiene and management (Madec *et al*., 1998). Improved post-weaning performance can be achieved by subjecting piglets to one week of intermittent suckling (restricting suckling to 14 out of 24hours per day) before weaning at 26days. However, better performance can be realized when the one week of intermittent suckling is followed by an extra week of lactation before finally weaning at 33days of age (Berkeveld *et al*., 2009). It is important to ensure high feed intake prior to weaning such that piglets can effectively adapt to solid feed as a strategy to reduce weaning stress. Reducing the piglets' suckling frequency eases the changeover to solid diets thereby improving post-wean weight gain as piglets start consuming adequate amount of solid feed before weaning (Weary *et al.*, 2008).

Earlier research by Kugoza and Mutetikka (2005) indicated that restricting piglet suckling resulted in higher creep feed intake as a measure to cater for shortage of nutrients brought about by reduced milk intake. Increased consumption of high quality pre-weaning diets during suckling allows higher live body weight at weaning and stimulates early post-weaning feed intake necessary for improved post weaning performance (growth) and health (Bruininx *et al*.,2002).

Reduction in the frequency of suckling during the lactation period, better performance (feed gain and weight gain) and reduced aggressiveness among piglets at weaning can be achieved by allowing litters of uniform age to mingle freely in the early days of lactation (Weary *et al.*, 1999).

Use of specific supplements in diets of sows in the late stages of gestation improves the performance of weaned piglets due to the positive influence the sow diet supplements have on piglets' gut structure and health (Leonard *et al*., 2010). Providing a high allowance of starter diets to piglets in groups of uniform weight also improves feed efficiency and growth (Magowan *et al*., 2011).

2.6 Use of cereals as animal feeds

Cereal grains and their by-products are important sources of energy used in pig feeding (Mwesigwa, 2011). They make up more than 50% of the basal proportion of concentrates fed to livestock. Although they are used principally as energy sources, cereal grains also supply significant amounts of proteins, vitamins and minerals (Maner, 2000).

Maize is a major staple crop to a large proportion of the population and feed for livestock in East Africa. In Uganda, the annual production of maize stands at 2,551,000 tonnes compared to sorghum (437,000tonnes), millet (292,000tonnes) and rice (233,000tonnes) (UBOS 2012). Nout, (2009) reported nutrient levels of 9.4% crude protein, 4.2% fat and 73.6% carbohydrates of which fiber makes up to 2.6% of the carbohydrates. Myer *et al*., (2009) reported values of 8.5% crude protein, 0.24% lysine, 0.02% Calcium, 0.25% phosphorus and 3300Kcal per kg.

According to NRC, (1998), maize contains 8.5, 3.6, 0.03, 0.28 percent for crude protein, fat, calcium and phosphorus respectively including 3530kcal/kg of digestible energy.

In Uganda, wheat bran, maize bran, maize grain, wheat pollard and sorghum are important sources of energy (Kugonza and Mutetikka, 2005; Mwesigwa, 2011). Maize is the most common grain used for feeding pigs due to its low fibre and high energy content (Medel *et al.*, 2004). The energy value of maize is used as a reference value on which other energy sources are compared. Although maize is rich in highly digestible starch, the physical barrier of fat and protein formed around the starch granules reduce its digestibility (Svihus *et al*., 2005). Mwesigwa, (2011) indicated that feeding wheat bran to pigs improved growth, feed efficiency and carcass attributes compared to maize bran or maize grain.

Another problem associated with maize is inadequate minerals, which is worsened by the presence of phytic acid that reduces mineral bioavailability (Nout, 2009). Though total phosphorus in most cereals is adequate to meet the nutritional requirements of animals, the phosphorus is in the non-available form of phytate yet maize grain lacks phytase enzyme required to degrade phytate phosphorus (Eeckhout and Daepe, 1994; Carlson and Poulsen, 2003).

While maize is a major ingredient and energy source in most animal feeds, its protein is of low quality due to an imbalance of amino acids coupled with low levels of lysine and tryptophan. Since protein composition is an important aspect when formulating animal feeds, use of maize as animal feed requires supplementation with protein sources of better amino acid balance (Shewry, 2007). Grain sorghum is another alternative to maize. The price of grain sorghum is usually 80-85% that of maize. If fed to pigs, good quality grain sorghum has 95% of the feeding value of maize, compared to wheat which has a feeding value of between 98-100% (Myer *et al*., 2009).

Though available in inadequate levels in maize, lysine is one of the essential dietary amino acids required for better performance. Lysine being the first limiting dietary amino acid, a diet formulated to supply the correct amount of lysine, is more likely to contain adequate levels of other essential amino acids (Myer *et al*., 2009).

The nutritive value of sorghum is diminished because of low digestibility of protein and starch (Wong *et al*., 2009). The cause of poor digestibility of sorghum protein is due to both endogenous (disulphide and non-disulphide cross linking, kafirin hydrophobicity and changes in protein secondary structure) and exogenous factors (grain organizational structure, polyphenols, phytic acid, starch and non-starch polysaccharides). During milling or cooking, proteins may interact with both protein and non-protein components. The interaction results into the formation of indigestible products and formation of physical barriers that prevent access of enzymes to the protein (Duodu *et al*., 2003).

Wong *et al*., (2009) analyzed the properties of two sorghum lines with a common pedigree but differed in protein and starch digestibility. The difference in digestibility between the two lines was a result of varying quantities of disulfide-bonded proteins, the differing nature of the protein matrix and its interaction with starch, presence or absence of non-waxy starch and granule-bound starch synthase.

Currently, a number of processing technologies have been used in improving cereal grain digestibility. These include; cooking (Scholten *et al.,* 1999; Medel *et al.,* 2004; Hong and Linderg., 2007), extrusion (Amornthewaphat and Attamangkune., 2008), malting (Chavan and Kadam., 1989; El maki et al., 1999; Traore' *et al*., 2004; Abbas and Musharaf., 2008; Elemo *et al*., 2011), fermentation (Nabila et al., 2000; Canibe *et al.,* 2007; Van Winsen *et al.,* 2002), and grain refinement (Duodu *et al*., 2002).

2.7 Effect of cooking on the nutritional value of cereals

Cooking has no positive effect on the nutritional attributes of most cereals. Irrespective of the genotype, cooking reduces the in-vitro protein digestibility of cereals. Fageer and Tinay, (2004) reported a reduction in protein digestibility and albumin+globulin fraction after cooking maize. The reduction in albumin+globulin fraction and protein digestibility is due to the folding of protein molecules resulting from the formation of disulphide bonds upon cooking. The formation of disulphide bonds upon cooking reduces the susceptibility of storage protein to digestive enzymes (Yousif, 2000). The extent of reduction in protein digestibility is greater for sorghum compared to maize due to the formation of disulphide-bonded oligomeric proteins that occur to a greater extent in sorghum than in maize (Duodu *et al*., 2002). Fageer and Tinay, (2004) observed that cooking cereals reduces protein availability through a reduction in G3-glutelin fraction while increasing insoluble protein.

Cooking sorghum in the presence of a reducing agent, 2-mercaptoethanol increases protein digestibility to a level comparable with other cereals. When sorghum is cooked in presence of a reducing agent, protein digestibility is increased by 25% compared to 5% for maize. The addition of reducing agents appears to prevent the formation of protein polymers linked by disulfide bonds (Hamaker *et al*., 1987).

The protein bodies of sorghum and maize are located between the starch granules embedded in a protein matrix. The protein matrix is made up of primarily glutelin proteins that exist in form of polymers bound by intermolecular disulfide linkages. Reducing agents are commonly used to open up the protein matrix through cleavage of disulfide bonds hence allowing digestive enzymes more access to protein bodies (Wall, 1971). Duodu *et al*., (2003) suggested that gelatinized starch affects protein digestibility since cooked sorghum samples treated with alpha-amylase had higher protein digestibility.

Though Medel *et al*., (2004) reported improvement in digestibility and growth in the first ten days of weaning, cooking cereal based pig feed prior to feeding results into no measurable effects (Hong and Lindberg, 2007). Apart from increasing the cost of feed (The`venot *et al*., 1992) and reducing profits (Hong and Lindberg, 2007), cooking reduces protein digestibility and extractability (Isabel *et al*., 2010).

2.8 Effect of malting on the nutritional value of cereals

Malting is the germination of cereal grains under controlled conditions with the primary objective of activating hydrolytic enzymes absent in non-germinated cereals (Dewar *et al*., 1997). It is a combination of three basic operations including steeping, germination and drying.

Maturation after germinating and de-germing after drying are modifications included in the malting process in some countries (Traore' *et al*., 2004).

Malting has different effects on different cereals which can be positive or negative. Malting is important in converting nutritionally poor quality plant protein to higher quality for feeding human and monogastric animals. Germinating maize increases soluble sugars (Traore' *et al*., 2004), the concentration of lysine and tryptophan but decreases zein, which is a major protein component (Tsai *et al.*, 1975). Traore' *et al*., (2004) reported a slight increase in the protein content of maize compared to red sorghum.

Germinating low tannin sorghum for three days reduced crude protein and metabolisable energy by 1.1% and 3.8% respectively but increased tannin content by 42%. Feeding broiler chicks on low tannin sorghum germinated for more than three days resulted into reduced body weight gain (Abbas and Musharaf, 2008). Elemo *et al*., (2010) reported no significant increase in crude protein content of germinated sorghum. According to Tizazu, (2009), the change in the nutrient composition is influenced by germination period and variety of sorghum.

Maize grain protein is made up of zein, albumin, globulin and glutelin. Zein is a major protein component ranging from 31 to 50% of the maize protein. Zein is made up of glutamine, leucine, proline in adequate amounts, lysine and tryptophan in very small amounts. Increasing the time of malting decreases the proportion of zein while increasing the proportion of albumin and globulin (Fageer and Tinay, 2004).

When a cereal is malted, much of the nitrogen in the kernel is transferred to the roots and shoots and prolamin is the major source of nitrogen transferred. Prolamins are degraded to small peptides and amino acids. The breakdown of storage protein in the kernel and its translocation into the roots and shoots increases protein nitrogen in the later. This is followed by an increase in all the nine essential amino acids but most important is asparagine and glutamine in sorghum malt that also appears in germinated wheat and maize (Taylor *et al*., 1985).

Germinating brown rice for 24hours increases their content of protein, crude fibre and minerals like Fe, Ca, Zn, Cu and Mn but reduces total carbohydrate content in the final malt (Hossam *et al*., 2010). Germinating high or low phytate maize decreases the major and trace minerals but instead increases their hydrochrolic acid extractable portions in the initial four days of germination (Sokrab *et al*., 2012).

Germination of maize involves the synthesis of simple sugars from the breakdown of carbohydrates. The sucrose content of germinating cereals decreases during the initial steeping period but increases by three fold in maize and more than three fold in red sorghum and millet during the entire germination period (Bond and Glass., 1963). Glucose and fructose content of cereals increases steadily during germination beyond the levels of sucrose (Traore' *et al*., 2004) because amylase catalyzes synthesizes of more simple sugars exceeding what is required by the metabolically active growing embryo (Helland *et al*., 2002).

During sprouting, some energy is lost by the grain in form of increased temperature, carbon dioxide and moisture. However, the magnitude of the nutritional improvement is influenced by the type of cereal, seed quality and sprouting conditions (Chavan and Kadam, 1989).

Malting is one of the natural processing methods which can be applied to improve protein digestibility. Malting improves the vitamin and amino acid content of maize and sorghum unlike fermentation. However, both methods have no detrimental effect on the overall protein quality (Matilda *et al.,* 1993). Germinating low tannin sorghum resulted in 31% and100% increase in crude protein and tannin respectively but decreased metabolizable energy by 6%. The degradation of starch to soluble sugars to meet seedling requirements explains the decline in metabolisable energy of germinated sorghum (Abbas and Musharaf, 2008).

Phytic acid is the principle storage form of phosphate but chelates with proteins and vitamins limiting their bioavailability (Fageer and Tinay, 2004). The positively charged ions like calcium bind to the negatively charged phosphate in phytic acid to become insoluble and unavailable. Over 80% of the total phosphorus in seed is stored in the form of phytic acid mainly in the embryo. It is the level of phytic acid in maize grain that influences the amount of extractable calcium and phosphorus (Sokrab *et al*., 2012). During germination, phosphorus and calcium content of low and high phytate genotypes of maize respectively increases (Bohn *et al*., 2008; Sokrab *et al*., 2012).

Though the increase in protein digestibility depends on the variety of sorghum (Makokha, 2002 and Tizazu, 2009), diets based on germinated sorghum have improved nutritional values compared to the un-germinated sorghum (Elemo *et al*., 2010).

2.8.1 Enzymes associated with germination of cereals

Malting is a valuable traditional source of enzymes specifically amylase needed to increase soluble sugar from the mobilization of starch (Traore' *et al*., 2004). Cereals contain amylolytic enzymes with beta-amylase found in a majority of cereals except maize where alpha-amylase dominates (Dziedzoave *et al.*, 2010). Raw cereal seeds exhibit negligible amylase and germination increases their alpha-amylase activity (Helland *et al*., 2002; Adewale *et al.,* 2006).

The activity of alpha-amylase increases with increased germination time for rice and maize, while that of sorghum and millet starts declining after nine days (Dziedzoave *et al.*, 2010). Optimum amylase activity of most sorghum cultivars can be obtained after steeping for 20hours followed by germination for 96hours (Ratnavathi and Bala, 1991). Red sorghum and millet attain higher amylase activity than maize after three days of germination, upon sun drying, the amylase activity reduces. Unlike sorghum and millet, the amylase activity of maize instead increased on sun drying though not beyond that of sun dried sorghum and millet (Traore' *et al*., 2004). Apart from having low alpha-amylase activity compared to sorghum and millet, alpha-amylase produced from maize has a low affinity for soluble starch and easily denatured beyond 30^{o}C (Adewale *et al.,* 2006). Yellow maize exhibits a higher enzyme activity compared to white maize (Eneje *et al*., 2004).

The initial step of steeping shows no significant effect on the levels of phytate. Sun drying germinated cereals shows a significant reduction in phytate content, which is more pronounced in millet, red sorghum and the least reduction occurs in maize. Soaking and germinating cereals increases their total cyanide content. However, sun drying the germinated maize seeds reduced the cyanide levels to approximately the original values in raw maize though in red sorghum, sun drying instead further increased the cyanide content (Traore' *et al*., 2004). Germinating sorghum reduces the level of phytate, phytate:iron and phytate:zinc ratio (Tizazu, 2009).

Supplementing weaner diets with enzymes also improves nutrient digestibility. Addition of xylanase or phospholipase to wheat-soybean based piglet weaner diets increases nutrient digestibility especially for the case of protein and crude fibre though the effect is more pronounced when the two enzymes are added in combination (Diebold *et al.*, 2004).

2.8. 2 Losses incurred during malting

Germinating maize reduces dry matter content upon drying depending on the period of germination (Helland *et al*., 2002). Eneje *et al*., (2004) reported that malting losses as a result of root and shoot growth within the first 3 days of malting where similar for both white and yellow maize irrespective of the time of steeping but increasing the germination period beyond 3 days resulted in malting losses being higher in white maize than yellow maize. Bond and Glass (1963) reported a 4.7% loss in dry weight of maize germinated for 14days while Traore' *et al*., (2004) reported a 14% decrease in dry matter of grain upon germination which was probably due to the use of sucrose as a respiratory substrate.

2.9 Effect of fermentation on the nutritional value of cereals

Fermentation is a cereal processing technique practiced widely in Africa and Asia to modifying the nutritional and sensory values of porridges, cooked gels and non-alcoholic beverages (Nout, 2009). Prescott *et al*., (1996) described fermentation as a dynamic process where starch and sugar are transformed by microbes into fermentation products that include; lactic acid, organic acids and alcohol. Cereals including maize, sorghum, rice and millet are fermented using lactic acid bacteria, yeast and fungi to produce a desirable taste, flavor, acidity, texture and above all, improve nutrient digestibility. The nutritional value and density of fermented cereal products can further be improved by mineral fortification, co-fermentation especially with legumes like cowpea and dephytinization (Nout, 2009).

In the early days, spontaneous fermentation utilized the naturally occurring microbes in milled grain (Poutanen *et al*., 2009). In feeds, the fermentation process is started by endogenous micro-organisms and the process is split into two phases. In the initial phase, low numbers of lactic acid bacteria, low concentration of organic acids but high levels of yeast and pH are observed. The second phase is characterized by high numbers of lactic acid bacteria and concentration of organic acids but reduced pH and enterobacteriaceae (Canibe and Jensen 2003).

Currently, the fermentation process is enhanced by use of starter microbial cultures and it's a controlled process. Lactic acid bacteria have beneficial effects in terms of improved feed quality and animal health (Plumed-Ferrer and Von Wright, 2009). Fermented diets are characterized by pH between 3.5 and 4.5, high levels of lactic acid, but less acetic acid and alcohol. Elyas *et al* (2002) reported pH values of 3.9 after 24hours of fermentation.

2.9.1 Effect of fermentation on gut health and ecology

Feeding fermented liquid feed to pigs improves their gastrointestinal health through reducing gastric pH and increasing gastric lactic acid (Mikkelsen and Jensen, 2000). Fermented feed compared to the normal dry feed reduces the number of enterobacteriaceae in the piglet gut (Van Winsen *et al*., 2002). Fermented cereal based diets in liquid form have the potential to replace antibiotics as growth promoters (Plumed-Ferrer and Von wight, 2009).

Fermented feed improves total tract digestibility of crude protein, increases total organic acids, which consequently influences gut bacterial ecology (Hong and Lindberg., 2007). The bacterial ecology of the gastro intestinal tract is influenced by high concentrations of lactic acid, volatile fatty acid in combination with large numbers of lactobacilli and low pH (Canibe *et al.*, 2007). Fermented feeds influence bacterial ecology through reducing the levels of *Enterobacteriaceae* especially *Salmonella spp* and elevating the undissociated form of lactate in the stomach contents (Van Winsen *et al*., 2002). The undissociated lactate and volatile fatty acids are the likely causes of reduced pathogenic bacteria due to their bactericidal effect (Rusell and Diez-Gonzales, 1998). However, the role of undissociated volatile fatty acids in reducing pathogenic bacteria is down played by Van Winsen *et al*., (2002) who reported high pH values in feces of pigs fed fermented feed. Morishita and Ogata, (1970) and Fransen *et al*., (1995) attributed the reduction in enteric pathogens to reduced substrates available for their growth due to increased nutrient digestibility of fermented feeds in the small intestines.

Temperature plays a significant role in reducing *the Enterobacteriaceae* population. Salmonella can still be detected after 72hours when feed is fermented at low temperature. Increasing the temperature to 30^{o}C reduces Salmonella to non-detectable levels within 48hours (Beal *et al*., 2002).

Spontaneously fermented feed is risky to the pigs and consumers as *Enterobacteriaceae* and yeasts have on many cases been detected in the fermentation product (Plumed-Ferrer and von Wright, 2009; Scholten *et al*., 2002). Use of standard starter cultures like lactic acid bacteria inoculated cultures is one way of improving the fermentation process and health of the pigs fed fermented feed (Plumed-Ferrer and von Wright, 2009).

2.9.2 Effect of fermentation on performance of pigs

Fermented diets have the potential to improve growth of pigs by lowering gastric pH, bacteria population and reducing the physical activity of pigs (Scholten *et al*., 1999). Fermenting cereal grains before addition of other ingredients improves growth, palatability, induces increased growth of yeast and eliminates microbial decarboxylation of free amino acids (Kil and Stein, 2010). Fermenting already mixed feeds reduces average daily gain and feed intakes (Canibe *et al*., 2007). The reduction in growth of piglets feeding on fermented mixed liquid feeds is due to microbial amino acid degradation (Pedersen, 2001).

2.9.3 Effect of fermentation on protein digestibility

Weanling piglets produce relatively small amounts of hydrochloric acid to adequately attain the required pH for the functioning of pepsin in the stomach (Bolduan *et al*., 1988). In spontaneously fermented feed, lactic acid bacteria convert sugars into lactic acid and acetic acid consequently lowering the pH of the stomach when ingested. This provides the favourable pH for the functioning of pepsin thus improving protein digestion (Plumed-Ferrer and von Wright, 2009).

The lowering of the pH during fermentation selectively enhances specific enzymes like amylases, proteases, hemicellulases and phytases. Fermented diets also stimulate pancreatic secretion, nutrient absorption in addition to modifying villi architecture as the feed moves from the stomach to small intestines (Scholten *et al*., 1999). The nutritional profile of fermented cereals is therefore brought about by enzyme induced changes and microbial metabolic products (Poutanen *et al*., 2009). The protein in normal dry feeds is inefficiently utilized by weanling pigs. This is because the major sources of protein used in weaner diets increase and maintain a high pH in the piglet stomach due to their high buffering capacity (Bolduan *et al*., 1988). Nabila *et al.*, (2000) reported an increase in protein digestibility during natural fermentation of maize probably due to decreased pH and increased protein content specifically zein, the major protein fraction.

Natural fermentation of some cultivars of pearl millet increases in-vitro protein digestibility and protein content to the maximum value in the initial 24 hours after which it remains relatively constant with increased fermentation time (Elyas *et al*., 2002). In a 24 hour inoculated fermentation, protein, ash and lipid content of pearl millet were not significantly changed, however, glycine, lysine and arginine levels decreased. Fermentation of pearl millet on the other hand increased soluble sugars at the expense of carbohydrates (Osman., 2011). The improved nutritional value however depends on the fermentation conditions and the ingredients used (Canibe and Jensen. 2012).

Germinating or fermenting germinated maize increases its ascorbic, riboflavin and niacin content beyond that of non-germinated maize (Lay and Fields, 1981). Fermenting maize after germination increases its percentage relative nutritive value beyond that of germinated or non-germinated maize (Lay and Fields, 1981).

Phytic acid is known to interfere with the utilization of nutrients especially proteins and minerals. Seeds of raw cereals contain high levels of phosphorus in the bound form of phytate.

Phytase enzyme is commonly used to increase availability and digestibility of phosphorus in maize based diets (Columbus *et al*., 2009). Fermentation has the potential to lower anti-nutritional factors in cereals. Fermenting cereals with low moisture content reduces phytate and increases phosphorus digestibility compared to dry grains (Piepera *et al*., 2010).

Fermenting pearl millet using a starter culture lowers phytic acid content in addition to reducing activities of trypsin and amylase inhibitors (Osman., 2011). Natural fermentation is equally effective in reducing antinutritional factors. Natural fermentation reduces total polyphenols to the least value within 24hours of fermentation, while phytic acid continues to reduce with increasing days of fermentation (Elyas *et al*., 2002). Though germination also reduces phytic acid, it's notable for increasing polyphenol in the sprouting cereal grain (Sokrab *et al*., 2012).

Enzymatic methods of processing (malting and fermentation) are more efficient in phytic acid reduction than the physical methods which include milling, soaking, and heating (Mahgoub and Elhag., 1998, Liang *et al*., 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The experiments were conducted at Makerere University Research Institute Kabanyolo (MUARIK) which is located at an altitude of 1200m above sea level. The area experiences a bimodal rainfall pattern with April to May and October to December as the first and second rainy seasons respectively. January and July are the driest months in a year. The average annual rainfall is 1500mm. The mean daily maximum and minimum temperatures of the area are about 27^0C and 17^0C respectively.

3.2. Processing of maize

3.2.1 Malting

Maize grain was sorted to remove foreign materials. The grains were layered uniformly on thick moist jute sacks laid on a concrete floor and sprinkled with water. The wet grains were covered with another layer of sacks and left to germinate for 3days (72 hours). The malt was sprinkled with water and turned twice a day to ensure uniform germination and adequate aeration. After the third day, the malt (with radicals still attached) was sun dried to a moisture content of 15%. It was then milled using a 2.5mm sieve before mixing it with other ingredients to make a balanced ration (Table 1).

3.2.2 Fermentation

Clean maize grain was milled and mixed with water to form dough in the ratio of 1:1 (w/v). The dough was left to ferment in a gunny bag for 1day (24hours) at room temperature. The fermented dough was sun dried to 15% moisture content.

3.2.3 Fermented malted maize

Part of the malted grain was milled and mixed with water (1:1w/v) to form a dough. The dough was fermented for 24hours (1day) and sun dried to 15% moisture content.

3.3 Experimental diets

Four diets were used in the experiment. The chemical composition of the diets used is shown in Table 1. Diet 1 was based on whole maize-CM (control). Diets 2, 3 and 4 contained malted maize-MTD, fermented maize-FTD, and maize subjected to fermentation after malting- M&F. All diets were formulated to contain a minimum of 17% crude protein (CP).

Table 1: The composition of experimental diets on dry matter basis

Ingredients	MTD	FTD	M& F	CM
Malted maize(kg)	61	-	-	-
Fermented Maize(kg)	-	61	-	-
Fermented Malted maize(kg)	-	-	61	-
Whole Maize/Control(kg)	-	-	-	61
Fish Meal (kg)	24	24	24	24
Cotton Seed Cake (kg)	12	12	12	12
Dicalcium Phosphate(kg)	2	2	2	2
Vitamin Mineral Premix(kg)	0.5	0.5	0.5	0.5
Salt(kg)	0.5	0.5	0.5	0.5
Total(kg)	100	100	100	100
Chemical Analysis				
DM (%)	90.6	90.6	91.9	90.4
Digestible Energy(Kcal/kg)	2321.6	2710.9	2461.3	2558.9
Protein-CP(N×6.25)%	17.1	17.4	17.4	17.1
Phosphorus (%)	1.26	1.04	1.097	1.24
Calcium (%)	0.036	0.033	0.038	0.030

3.4 Experiment 1: Effect of processing on feed intake, average daily gain and feed conversion efficiency

3.4.1 Experimental animals

A total of sixty four weaned Large White×Landrace piglets (thirty two males and thirty two females) of four-to-eight weeks of age weighing 6.14±1.3kg were used. Piglets were ear tagged, weighed, de-wormed and treated against mange using Ivermectin.

3.4.2 Experimental design

Piglets were divided into sixteen groups balanced for sex and weight. The diets were randomly allocated to the piglets in the groups in a completely randomized design (CRD) consisting of four treatments and four replicates.

3.4.3 Economic benefit of feeding malted and fermented maize based weaner diets

Gross margin values resulting from the use of each diet were calculated as the difference between total value of product (TVP) and total variable cost (TVC).

Total value of product (TVP) is the value of output in terms of daily weight (ADG) gain resulting from feeding a particular experimental diet. TVP was calculated as shown below.

$TVP = P_y \times TPP$

Where:

P_y is the market price of pork per kilogram in Uganda shillings at the time of the experiment.

TPP (Total Physical Product) is the average daily weight gain due to a particular experimental diet.

Total variable cost (TVC) is the input in terms of cost of experimental diets. The total cost of each diet included the cost of processed maize and other ingredients used to make a complete diet. The cost of processed maize (malted, fermented and fermented malted maize) was based on the cost of materials which included sisal bags used as malting surfaces, gunny bags for fermenting, labour and milling expenses.

TVC was calculated as shown below.

$TVC = P_X \bullet X$

Where:

X is the quantity of the variable inputs.

P_X is the cost of variable inputs.

Total fixed costs (TFC) are the costs that applied to all and did not vary across the treatments. These included cost of feeding, cleaning and de-worming costs. These were not included in calculating gross margins. The manure produced by pigs was neither valued nor included in the calculation of gross margins.

3.5 Experiment 2: Evaluation of performance of piglets weaned at different ages

3.5.1 Experimental animals

Based on results of performance and gross margins in experiment 1, fermented maize (FTD) was selected and it's potential to permit early weaning evaluated in experiment 2. Piglets from sows in MUARIK piggery unit were used. Upon attaining the target age, piglets were separated from the sow and moved to clean pens. In the pens, piglets were ear tagged and weighed before starting on the FTD. Three piglets (picked at random) from each litter (sow) were weaned at four (Treatment1), five (Treatment 2), and six (Treatment 3) weeks of age in a split-wean technique.

Piglets had ad-libitum access to feed and water. Performance (ADFI, ADG and FCR) of piglets weaned at different weeks was followed up to eight weeks of age and was compared to the performance of those weaned at eight weeks, the control (Treatment 4) treatment.

3.5.2 Experimental design

Upon weaning, piglets were fed on FTD in a completely randomised design comprising of four treatments and 5 replicates. Three piglets per pen per treatment formed an experimental unit. A total of 60 piglets were used.

3.6 Data collection and analysis (Experiment 1 & Experiment 2)

Piglets were weighed and the initial weights recorded. The daily rations of each diet were split into two portions. One portion was offered in the morning and the second in the evening. The residues from the previous day's feed were weighed before introducing the days' feed to obtain the previous day's feed intake. Weekly weights of piglets were measured during the feeding trial. Weekly weight gains were calculated as final live weight minus initial live weight. Feed conversion ratios (FCR) were calculated as a ratio of feed intake to weight gain.

Data collected were subjected to ANOVA using the general linear model procedure of SAS (2003). Treatment means were separated using the LSD. The model for the feeding trial was

$$Y_{ij} = \mu + T_i + e_{ij}$$

where ; Y_{ij} = *R*esponse variable *e.g. ADG, ADFI, FCR*

μ = General mean

T_{ij} = Effect of diet (expt 1) or Effect of weaning age (Study 2)

e_{ij}= Random error

3.7 Effect of processing on nutrient digestibility

3.7.1 Animals and housing

Four intact male pigs were selected at the end of the first experiment and used in the digestibility trial. The pigs used weighed 26.6±2.63kg. They were housed individually in locally designed wooden cages with a 60cm clearance from the ground and allowing quantitative total collection of faeces. The floor of each cage was lined with metallic wire net to facilitate collection of feces.

3.7.2 Experimental Design

The experiment was carried out as a 4×4 Latin square, with a change-over arrangement of treatments with 4pigs and 4 periods. The 10day periods consisted of 5 days of adaptation and 5days of data collection. The linear model below was used:

$$y_{ijk} = \mu + T_i + \rho_j + \Upsilon_k + e_{ijk}$$

Where;

y_{ijk} = dependent variable of diet i in period j and given to animal k,

μ = overall mean,

T_i = effect of diet i,

ρ_j = effect of period j,

Υ_k = effect of animal(pig) k and

e_{ijk} = residual effect.

3.8.3 Data collection

The experimental period was ten (10) days. Pigs were allowed five days to get accustomed to the metabolism crates. Data on feed intake, refusal, and total fecal collection was taken for a period of five days. Pigs were subjected to 12 hours of starvation before the experimental diets to get rid of gastro intestinal contents due to preliminary feeding.

Apparent digestibility coefficients of nutrients (DIG) were calculated on dry matter basis as the proportion of nutrients consumed, which did not appear in feces as described by Agudelo *et al*. (2010).

$$\text{DIG} = \frac{(\text{Nutrient consumed} - \text{Nutrient in feces})}{\text{Nutrient consumed}} \times 100\%$$

3.8 Chemical analysis

Samples of feed and feces were analyzed for moisture, crude protein, ether extract, Ca, P and ash according to procedures of AOAC (1990). Ether extract was determined after acid hydrolysis. Digestible energy (GE) of feeds was calculated from the proximate components using the equation described by Noblet and Perez (1993) i.e.,

DE = 4151–12.2%Ash + 2.3%CP+3.8 %EE – 6.4%CF

Where: Ash = Crude ash,

CF = Crude fiber,

CP = Crude protein (N x 6.25),

DE = Digestible energy (kcal/ g) and

EE = Ether extract.

CHAPTER FOUR

RESULTS

4.1 Effect of malting and fermentation on the chemical composition of maize

The chemical composition of processed and non-processed maize is summarized in Table 2. The crude protein levels of 9.1, 8.8, 8.3% in malted, fermented, and maize fermented after malting respectively did not significantly differ ($P > 0.05$) from 10.5% in the control. High levels of total phosphorus were present in malted (0.67%), fermented (0.58%) and maize fermented after malting (0.55%) but did not significantly differ ($P > 0.05$) from 0.45% in the non-processed maize. There was no significant effect of malting and fermentation on calcium levels though subjecting maize to malting before fermentation slightly but not significantly reduced calcium levels ($P > 0.05$). Fermentation and malting increased the ash content to 1.80 and 1.67% respectively compared to 1.24% in non-processed maize. Fermenting malted maize reduced the ash content to 1.29%.

Non processed maize (control) had significantly higher ($P < 0.05$) digestible energy of 4316.3 Kcal/kg compared to 4195.3, 4175.1 and 4138.5 Kcal/kg in malted, fermented, and maize fermented after malting respectively. Malting and fermentation significantly increased the dry matter of maize ($P < 0.05$). Subjecting maize to malting before fermentation significantly reduced its dry matter content ($P < 0.05$).

Table 2: The chemical composition of processed maize (as is basis)

	Malted maize	Fermented maize	Fermented malted maize	Control/Whole maize	SEM	P-value
Crude Protein (%)	9.1	8.8	8.3	10.5	0.67	0.27
Total Phosphorus (%)	0.67	0.58	0.55	0.45	0.18	0.56
Calcium (%)	0.034	0.038	0.022	0.035	0.01	0.61
Digestible Energy(Kcal/kg)	4195.3^{b}	4175.1^{c}	4138.5^{d}	4316.3^{a}	0.6455	0.0001
Ash (%)	1.67^{b}	1.80^{a}	1.29^{c}	1.24^{d}	0.006	0.0001
DM%	89.6^{b}	90.1^{a}	88.1^{d}	88.7^{c}	0.05	0.0001

Means in the same row with the same superscripts are not significantly different

4.2 Effect of malting and fermentation on feed intake, average daily gain and feed conversion efficiency

The effects of malting and fermentation on feed intake, average daily gain and feed conversion efficiency are summarized in Table 3. There was a significant difference in the final live weights of pigs fed on the four treatment diets ($P < 0.05$). Piglets fed on malted maize based weaner diet (MTD) attained the highest live weight (23.63kg) at 8weeks while piglets that were fed the control (CM) diet attained the lowest live weight (15.75kg). There was no difference in the final live weight of pigs fed on fermented and malted prior to fermentation based weaner diets ($P > 0.05$).

Processed maize based diets improved performance of weaned piglets compared to unprocessed maize based diets (control). Feeding MTD resulted in increased feed intake (0.726kg/day) compared to FTD (0.642kg/day), M&F (0.554kg/day) and CM (0.527kg/day). Piglets fed on MTD had higher ADG (0.276kg/day) than CM (0.158 kg/day). There was no difference ($P > 0.05$) in ADG for piglets fed FTD (0.244kg/day) and M&F (0.199kg/day). There was no difference ($P > 0.05$) in the FCR among treatments.

Table 3: Effect of processed maize based weaner diets on piglet performance

	MTD	FTD	F&M	CM	SEM	*P*-value
Mean Initial live weight(kg)	6.25	6.5	6.25	5.81	0.498	0.86
Mean Final live weight(kg)	23.63[a]	21.25[ab]	18.81[ab]	15.75[b]	2.153	0.20
ADFI(kg/day)	0.726[a]	0.642[b]	0.554[c]	0.527[c]	0.023	0.0001
ADG(kg/day)	0.276[a]	0.244[ab]	0.199[ab]	0.158[c]	0.030	0.165
FCR(Feed/Gain)	4.06	4.03	4.72	4.29	0.645	0.9043

Means in the same row with the same superscripts are not significantly different

4.3 Effect of processing maize on the cost-benefit ratio of weaner diets

The effect of processing maize on the cost of piglet weaner diets is summarized in Table 4. Processing maize increased the unit cost of weaner diets compared to the control, which had the lowest unit cost. Malting, fermentation and fermentation of malted maize increased the unit cost of weaner diets by 25%, 9% and 34% respectively. Malting, fermentation and fermentation of malted maize increased the daily cost (TVC) of feeding pigs by 73%, 33% and 41% respectively.

Though malting resulted into the highest daily cost of feeding a piglet (sh. 1,062/=), it led to the highest average daily gain (0.276kg). The control diet had the lowest daily cost of feeding a piglet (sh. 616/=) and so was the average daily gain (0.158kg).

The total value of daily gain (TVP) differed across the different processing methods ($P < 0.05$). MTD resulted into the highest total value of daily gain (sh. 1,932/=) compared to FTD (sh. 1,708/=), M&F (sh. 1,393/=) and CM (sh. 1,106/=). All the four experimental diets resulted into positive gross margins. There was a difference in the gross margins across all the processing methods ($P < 0.05$). FTD resulted in the highest gross margin (sh. 890/=) followed by MTD (sh. 869/=) and M&F (sh. 526/=). The control had the lowest gross margin (sh. 489/=).

Table 4: Gross margin as affected by malted and fermented maize based weaner diets

	MTD	**FTD**	**F&M**	**CM**	**SEM**
Average Daily Feed Intake (kg)- X	0.726	0.642	0.554	0.527	0.023
Cost of feed/kg(shs)-P_x	1,464	1,274	1,564	1,169	-
Total value of input-TVC(shs) = $P_X \bullet X$	1063	818	867	616	-
Average Daily Gain-TPP (kg)	0.276^{a}	0.244^{ab}	0.199^{ab}	0.158^{c}	0.030
Total Value of daily gain-TVP = $P_y \times TPP$	1,932^{a}	1,708^{ab}	1,393^{ab}	1,106^{c}	212.25
Gross margin (shs) = TVP –TVC	**869^{b}**	**890^{a}**	**527^{c}**	**490^{d}**	**-**

Means in the same row with the same superscripts are not significantly different

P_y = 7,000 U.shs per kg (2500U.shs =1$).

4.4 Performance of piglets weaned at different ages when fed fermented maize

Performance of piglets weaned at different ages and fed on fermented maize (FTD) is summarized in Table 5. There was a significant difference in ADFI, ADG and FCR among piglets weaned at different ages. Weaning piglets at four weeks resulted into the highest ADFI ($P < 0.05$). The lowest ADFI was recorded for piglets weaned at six weeks. The highest ADG ($P < 0.05$) was obtained when piglets were weaned off at week five. There was no significant difference in ADG of piglets weaned at four weeks and those weaned at five or six weeks. There was a significant difference ($P < 0.05$) in FCR among treatments. Weaning at week six produced the lowest FCR while weaning at week four produced the highest FCR.

Table 5: Performance of piglets weaned at different ages when fed fermented maize

	Week 4	Week 5	Week 6	Week 8	P-value
ADFI(kg/day)	0.263^{a}	0.189^{ab}	0.097^{c}	0.099^{c}	0.0001
ADG(kg/day)	0.087^{ab}	0.094^{a}	0.071^{b}	0.094^{a}	0.060
FCR(Feed/Gain)	3.106^{a}	2.095^{b}	1.550^{c}	1.650^{c}	0.0001

Means in the same row with the same superscripts are not significantly different

4.5 The effect of malting and fermentation on nutrient digestibility

The apparent digestibility coefficients of three major dietary components by pigs fed MTD, FTD, M&F and CM are summarized in Table 6. The apparent digestibility of dry matter (DM) was highest in fermented based diets and lowest in whole maize based diets but did not differ among all the diets ($P > 0.05$). The apparent digestibility of CP was highest in fermented based diets and lowest in malted maize based diets but did not differ among the four diets ($P > 0.05$). The apparent digestibility of gross energy did not differ among the treatment diets ($P > 0.05$).

Table 6: Apparent digestibility coefficients of dietary components by pigs fed MTD, FTD, M&F and CM

	Processed maize based weaner diets					
Nutrient	MTD	FTD	M&F	CM	SEM	P-value
DM (%)	69.9	73.2	72.3	68.5	3.02080	0.7176
Energy	72.0	78.2	75.4	79.3	2.91612	0.3562
CP (%)	69.2	72.3	71.9	70.7	1.06992	0.1921

Means in the same row with the same superscripts are not significantly different

CHAPTER FIVE

DISCUSSION

5.1 Effect of malting and fermentation on the chemical composition of maize

The dry matter of maize was significantly increased by sun drying fermented (90.1%) and malted maize (89.6%) compared to the control-whole maize (88.7%). Helland *et al*. (2002) reported a maximum of 93% dry matter in germinated maize after drying. Traor'e *et al*, (2004) observed a slight decline in percentage dry matter of sun dried malted maize. This was attributed to the hydration of substrates in the endosperm which initiates a chain of metabolic reactions that finally lower the dry matter content of the grain. When the germinated maize is sundried, the resultant dry matter is comparable with that of raw maize (Traor'e *et al*., 2004). In rice, all wet processing methods that include soaking, fermentation and malting reduce dry matter by 16% with soaking causing more loss in dry matter (Liang *et al*., 2008). Traore' *et al*., 2004 reported a 14% decrease in dry matter of cereal seed during germination which is probably due to the use of sucrose as a respiratory substrate. In fermented liquid feed, the DM and energy at the end of fermentation is reduced. This is due to the breakdown of sugars into carbon dioxide, lactic acid, and ammonia (Canibe and Jensen., 2012). The increase in concentration of Klason lignin at the expense of carbohydrates confirms the loss of dry matter during fermentation (Jørgensen et al., 2010).

The protein content of 10.5% in non-processed maize is close to 9.4%, 10.8% and 11.3% reported by Nout, (2009), Eneje *et al*. (2004) and Fageer and Tinay (2004) respectively. Malted and fermented maize have 9.1 and 8.8% crude protein respectively, which are levels below 10.5% of unprocessed maize and the minimum level of 11.3% reported by Fageer and Tinay

(2004). Traore' *et al.* (2004) reported an increase in the protein content of maize upon malting and addition of malted maize to maize flour increases the levels of albumin and globulin that improve protein quality (Fageer and Tinay, 2004). Microbial protein synthesis during fermentation also increases protein content (Elyas *et al.,* 2002).

Malting and fermentation increase the mineral-ash content of maize. The increase in the ash content of maize reported by Traore' *et al.* (2004) is evidence that the levels of major minerals; that is calcium and phosphorus rise upon malting. Bohn *et al*., (2008) and Sokrab *et al*., (2012) reported an increase in phosphorus and calcium content of low and high phytate genotypes of maize respectively upon germination.

The two processes of malting and fermentation result in non-significant levels of calcium. Sokrab *et al* (2012) reported an increase in hydrochrolic acid extractable calcium at the expense of total calcium in the initial four days of germination. In the initial four days of germination total calcium decreases from 75 to 70mg/100g while extractable calcium increases from 69.8% to 78%.

In this study, the energy content of maize was reduced upon fermentation. This is in accordance with the reduction in total sugars and non starch polysaccharides and the associated reduction in dry matter of cereals reported by Jørgensen *et al* (2010).

Malting maize grain reduces the energy content. The rise in temperature and carbondioxide given off during germination explain the decline in the energy levels of malted maize (Chavan and

Kadam, 1989) The reduction in energy could also be explained by the loss of energy rich lipids during germination (Traore' *et al.*, 2004). The conversion of sugars to lactic acid, carbon dioxide and ammonia during fermentation also explains the reduction in the energy value of fermented maize based diets (Canibe and Jensen., 2012).

In general, the changes in the chemical composition of maize upon germination are influenced by the metabolic activities within the seed during germination. The increase in alpha-amylase activity of maize at the time of germination is responsible for the increased metabolic breakdown of complex sugars to simple sugars (Helland *et al*., 2002 and *Eneje et al*., 2004). Canibe and Jensen (2012) also concluded that both dry matter and energy are reduced by the process of fermentation. This was attributed to nutritional changes associated with fermentation especially with sugars being broken down into carbon dioxide, lactic acid and ammonia. During the germination of maize, amylase breaks down starch and other complex sugars to glucose and maltose. The levels of glucose increase during germination (Traore' *et al*., 2004). The nutrient composition of germinated sorghum and maize follow a similar trend. This implies that crude protein, total phosphorus and calcium increase during germinating (Tizazu, 2009).

5.2 Effect of malting and fermentation on feed intake, average daily gain and feed conversion efficiency

The higher feed intake associated with malted maize can be attributed to the sweet taste of simple sugars that accumulate during the germination/malting process. Malting increases the soluble sugars in maize which then impart the sweet taste responsible for higher feed intake of malt based weaner diets (Traore' *et al*., 2004). Traore' *et al*., (2004), recorded an increase in primary (glucose and fructose) and secondary (sucrose) sugars during malting. Fermented maize based weaner diet improved feed intake, gain and gain-feed ratio as compared to the control diet. A study by Canibe and Jensen (2003) showed that feeding fermented feed resulted in reduced average daily gain and feed intake as opposed to non-fermented dry feed. However, it improved feed efficiency and reduced enterobacteria along the pig's gastro intestinal tract. The cause of these conflicting results is probably attributed to use of fermented liquid feed and fermentation of the compound feed as opposed to fermented dry feed of which only maize grain was fermented. Also, the differences seen with fermentation may be due to use of spontaneous fermentation in the study as opposed to fermentation using starter microbial cultures used in other studies.

Canibe *et al*. (2007) reported that fermenting cereal grain alone as opposed to fermenting the compound feed resulted in higher average daily gains. This is due to elimination of microbial degradation of free amino acids that occurs in fermenting compound feeds. In the study, fermenting the ground cereal before addition of other ingredients increased dietary lysine, yeast, ethanol and pH above the values indicated for fermented compound feed. In addition low counts of enterobacteriaceae and less fermentation metabolites were observed in cereal grains fermented alone. Addition of a fermented cereal like wheat to liquid pig feed causes favorable mucosal architectural changes upon weaning (Scholten *et al*., 2002). The positive influence of fermentation on the absorptive mechanism of the piglet induces higher feed intakes and growth (Scholten *et al*., 1999). The improved performance of piglets fed on fermented cereal based diets is explained by an increase in the surface area of the absorptive mechanism in the small intestine due to elongation of the villi and associated high villu:crypt ratio (Scholten *et al*., 2002).

The improvement in average daily gain can be due to the negative effect of fermented feed on enterobacteriaceae and the associated reduction in incidences of diarrhea. Fermenting feeds increases the undissociated form of lactic and acetic acid and decreases the enterobacteriaceae population in the gastro-intestinal tract of pigs compared to unfermented feeds (Mugula *et al*., 2003). The cause of the reduction in the enterobacteriaceae population in the gastro-intestinal tract of pigs fed on fermented feed is not well understood. This is because the pH of feces voided by pigs fed on fermented feed was higher than when fed normal feed in spite of the increase in volatile fatty acids (Van Winsen *et al*., 2002). The degradation of starch during fermentation gives rise to readily digestible substrates and consequently better feed efficiency. A study by Mugula *et al*., (2003) showed that spontaneous fermentation of maize for 12 hours increases glucose and maltose while reducing fructose.

5.3 Gross margin as affected by feeding malted and fermented maize based weaner diets

The low gross margin associated with M&F is due to the high cost (P_X) related to its production. The high cost of M&F is due to the combined procedures of malting and fermentation that increase labor costs. The cost of processing maize was the major differentiating factor in the calculation of feed cost. This is because the quantities of ingredients used in all the experimental diets were similar. The lowest average daily inputs (total variable cost-TVC) recorded in fermented maize weaner diets was due to the low cost of feed- P_X. The low cost of fermented maize based diets is explained by the few procedures of fermenting, which cost less compared to other processing methods.

Feeding MTD yielded the highest total value product. This indicates the potential of the diet for efficient utilization of readily available nutrients upon malting. All diets yielded positive gross margins although it is more cost-effective to feed fermented based diets to wean piglets. In case of low weight piglets at weaning, malted maize based diets becomes cost-effective. This is because malt based weaner diets effectively stimulate feed intake compared to fermented based diets.

5.4 Performance of piglets weaned at different ages when fed fermented maize

Performance in terms of daily feed intake and growth of piglets at different ages of weaning was much lower than that stated by NRC, (1998). The low performance in the current study is probably due to the low initial weight, feed intake and protein content of diets. Piglets weaned at 4weeks of age exhibited high feed intake but low feed efficiency. Mahan, (1993) also noted that early weaned light piglets are associated with low weight gain and feed efficiency as compared to heavy piglets. According to (NRC, 1998), feed intake increases linearly during the post-wean period.

Weaning at week 5 resulted in improved performance in terms of daily gain and better feed efficiency as compared to weaning at 4 weeks of age. Increasing weaning age increases post-weaning weight gain in addition to reduced chances of mortality (Main *et al*., 2004).

Weaning at week 6 resulted in the lowest feed to gain ratio. However, it yielded low body gain because of low feed intake. This is because of the piglets’ reluctance to feed but have a developed digestive system to digest the feed.

5.5 Apparent digestibility coefficients of three major dietary components by pigs fed malted, fermented, and malted and fermented maize based diets

The apparent digestibility coefficients of DM, energy and CP did not significantly differ among the four diets. Fermented maize based diet increased digestibility of dry matter by 4.7 percentage units compared to the control. Jørgensen *et al*. (2010) found increases of 3 and 1 percentage units in dry matter digestibility for barley and wheat based diets respectively.

The digestibility of energy in fermented maize based diet was reduced by 1.1 percentage units compared to the control. Jørgensen *et al*. (2010) reported an increase in digestibility of energy in barley and wheat by 3 and 1 percentage units respectively. Jørgensen *et al*. (2010) attributed the increase to the partial degradation of substrates present in the milled grain upon fermentation making them more available to digestion in the gastrointestinal tract of the pig.

Processing maize has no significant effect on protein digestibility. Hong and Lindberg, (2007) also did not find any improvement in the digestibility of protein and organic matter upon fermentation. However, Elyas *et al*. (2002) reported an increase in protein digestibility upon fermentation to a maximum value within 24 hours of fermentation. Lyberg *et al*., (2006) and Hong and Lindberg (2007) also reported an improvement in the ileal and total tract digestibility of protein, neutral detergent fibre, organic matter, phosphorus and calcium when fermented feeds are fed to pigs. The improvement in protein digestibility reported by Lyberg *et al*., (2006) and Hong and Lindberg (2007) is due to the low pH that enhances the activity of pepsin in the stomach (Plumed-Ferrer and von Wright, 2009). In addition, fermented diets stimulate pancreatic secretion, nutrient absorption and also modify villi architecture as the digesta moves from the stomach for better utilization (Scholten *et al*., 1999).

Fermented feeds also negatively impact on the levels of enterobacteriaceae in the piglet gut, improves gastrointestinal health and digestibility of nutrients (Mikkelsen and Jensen, 2000; Van Winsen *et al*., 2002; Jørgensen *et al*., 2010). The variations in protein digestibility are due to the difference in the inoculum used, feeding fermented liquid feed as opposed to fermented dry feed and the differences in fermentation temperature.

The improvement in protein digestibility, though not significant, appears to be a function of phytic acid levels in the cereal grain. Increasing germination time reduces phytate content and increases the rate of protein digestibility. Phytate in maize flour can be reduced by 45 to 71% when malted maize is added. Protein digestibility also increases with increasing amount of malt added to maize flour (Fageer *et al*., 2004).

Abd Elmoneim *et al*., (2010) reported an increase in protease and amylase activity with germination time. Protease and amylase breakdown proteins and carbohydrates in grains into their respective simple forms. This improves digestibility and absorption of proteins and carbohydrates. In sorghum, malting improved protein digestibility of low and high tannin varieties (Makokha *et al*., 2002).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Malting, fermentation and fermenting malted maize reduce the digestible energy content of maize. Feed intake is highly increased by malting and fermentation in that order. Fermenting malted maize has no beneficial effect on feed intake.

Malted and fermented maize based diets improve performance of weaned piglets. Fermenting malted maize reduces the performance of weaned piglets below that of malted or fermented maize based diets.

All the three processing methods of malting, fermentation and fermenting malted maize improve average daily gain. The feed conversion ratio is not affected by any of the three processing methods.

All the three processing methods in the study yielded positive gross margins. This implies that it is profitable to wean off piglets especially with fermented or malted maize based weaner diets. Feeding fermented maize based weaner diets resulted in the highest gross margins followed by malted maize based weaner diets. Fermentation procedures on the other side are simple, effective and suitable to the local household conditions. Feeding piglets on fermented maize based diets at five weeks of age improves post-weaning live weight gain and feed conversion efficiency.

6.2 Recommendations

Weaning piglets can be done at five weeks of age instead of the usual eight weeks using fermented maize based weaner diets to improve piglet performance and sow productivity.

Although weaner diets based on malted maize cost more than those based on fermented maize, they are cost-effective when weaning light piglets as they are more effective in stimulating feed intake and weight gain.

6.3 Further research:

Investigate the effect of malted and fermented maize diets on the performance of other categories of pigs. Use of starter cultures and controlled conditions of fermentation should be explored to guarantee feed safety and quality instead of spontaneous fermentation as in the current study.

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