EFFECTS OF ENSILED SWEET POTATOES (*IPOMEA BATATAS*) ON BLOOD GLUCOSE, NUTRIENT DIGESTIBILITY AND GROWTH PERFORMANCE OF LARGE WHITE x LANDRACE CROSSBRED MALE PIGS

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DECLARATION OF ORIGINALITY

I **(Joseph Muthivhi)** hereby declare that this dissertation is entirely my original work with the exception of such references and quotations that have been attributed to their authors or sources. This dissertation has never been submitted for any degree or examination in any other university.

Candidate's signature:

Date: 27 February 2019

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ADG	Average daily gain
ADL	Acid detergent lignin
ANOVA	Analysis of variance
ARC	Agricultural Research Council
AUC	Area under curve
BW	Birth weight
Ca	Calcium
CF	Crude fibre
CP	Crude protein
CRD	Completely randomised design
DE	Digestible energy
DF	Dietary fibre
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
EE	Ether extract
ENSP	Ensiled sweet potato
FAO	Food and Agriculture Organisation
FCR	Feed conversion ratio
Fe	Iron
GE	Gross energy
GI	Glycemic index

GLU	Glucose
IAUC	Incremental area under curve
ISF	Insoluble fibre
K	Potassium
MAGE	Maximum amplitude of glycemic Excursion
Mg	Magnesium
Mn	Manganese
NDF	Neutral detergent fibre
NRC	National Research Council
NSP	Non-starch polysaccharide
OGTT	Oral glucose tolerance test
OMD	Organic matter digestibility
SAS	Statistical Analysis System
SF	Soluble fibre
SPV	Sweet potato vine
TIA	Trypsin inhibitor activity

ABSTRACT

The study comprised two experiments. The aim of the first experiment was to compare postprandial blood glucose changes and the glycemic index responses of growing pigs fed either control (CON), glucose (GLU) or ensiled orange-fleshed sweet potatoes (EOFSP). Nine Large White x Landrace crossbred male pigs weighing 32 ± 2.5 kg BW of same age were housed in pairs and moved into metabolism crates individually for sampling in a temperature-controlled room (ranging from 23.8 ºC to 26.8 ºC). The three pairs were each fed one of control (CON), glucose (GLU) or ensiled orange-fleshed sweet potatoes (EOFSP) alternately after fasting for 12 hours in a crossover design. Glucose concentrations were then measured after meals every 15 minutes for 3 hours. There were no differences in minimum glucose concentration, glycaemic index, fasting glucose and incremental area under curve ($P > 0.05$) between pigs fed CON and GLU meals. Pigs on EOFSP however had 10.7 % higher GI than those on CON. Pigs on GLU had greater total area under curve and maximum glucose excursion ($P < 0.05$) than those on CON and EOFSP. The biphasic glucose curve pattern was higher in all treatments ($P < 0.05$) than the monophasic and triphasic patterns and the pigs on EOFSP diets had a greater proportion of triphasic patterns. The second experiment evaluated the effects of feeding total mixed rations containing EOFSP silage at 5 inclusion levels (0, 8, 16, 24 and 32 %) on nutrient digestibility and growth performance of growing pigs. Thirty Large White x Landrace grower male pigs, weighing between 28.6 ± 5.35 kg BW were blocked by weight and allocated to five experimental diets containing 0, 8, 16, 24 and 32 % EOFSP. A digestibility trial using the total collection method and a growth performance study were undertaken. Pigs that were fed the 32 % EOFSP diet had higher ($P<0.05$) dry matter digestibility (DMD) than those fed the 16 % diet, while those on 0 %, 8 %, 16 % and 24 % diets had similar DMD ($P>0.05$). Pigs on the 32 % diet had higher ($P<0.05$) organic matter digestibility (OMD) and crude protein digestibility (CPD) than those fed 16 and 24 % EOFSP diets. Pigs fed on the 24 and 32 % EOFSP diets had higher neutral detergent fibre digestibility (NDFD) ($P<0.05$) than those on the 16 % diet. Pigs fed on the control diet had lower acid detergent fibre digestibility (ADFD) ($P<0.05$) than those fed on 8 %, 24 % and 32 % EOFSP diets. Pigs that were fed 24 and 32 % EOFSP diets had higher ($P<0.05$) average daily gain (ADG) than those fed CON and

8 % EOFSP diets. Pigs that were fed the 32 % diet had higher ($P<0.05$) average daily feed intake (ADFI as is) than those fed the CON, 8 % and 16 % EOFSP diets. Pigs fed the 8 % and the 32 % diets consumed more ADFI (DM) than those on the CON diet. Pigs that were fed the CON diet had lower ($P<0.05$) feed conversion ratio (FCR as is) than those fed the 8 % diet. There was no difference ($P>0.05$) in FCR (as is) in pigs fed the CON, 16 %, 24 % and 32 % EOFSP diets. Pigs fed the 8 % diet had higher FCR (DM) ($P<0.05$) than those fed the 16 %, 24 % and 32 % diets. Given that it has been demonstrated that a high GI prompts an increase of insulin over time which enhances feed intake it can be concluded that the 10.7 % higher GI in pigs fed EOFSP than the CON fed pigs could translate to higher feed intake and better growth performance of pigs. It was also concluded that ensiled orange-fleshed sweet potatoes can be incorporated in growing pig diets up to 32 % with no negative impact on digestibility of nutrients and growth performance.

Keywords: silage, glycemic index, feed intake, orange-fleshed sweet potatoes

CHAPTER 1 : INTRODUCTION

1.1: Background

Pig farmers have a restricted range of ingredients to formulate pig diets (Kanengoni *et al*., 2015). This affects productivity of small-scale pig farmers who are forced to use swill and other inappropriate feed ingredients due to increased food competition with man. This has prompted research into finding alternative feed ingredients to include in pig diets. Sweet potatoes (*Ipomoea batatas* (L.) Lam.), although mainly cultivated to feed humans, is sometimes fed to animals because of seasonal surpluses (Oke and Workneh, 2013). Furthermore, the difficulty of storing a high-quality product after harvesting, inappropriate handling plus storing techniques result in substantial postharvest losses (Sugri *et al*., 2017). Sweet potatoes can replace maize as an energy source. According to Woolfe, (1992) sweet potato roots' metabolizable energy (14.8 MJ/kgDM) compares favourably to that of maize (14.5 MJ/kg DM).

Sweet potatoes are one of the essential cultivated crops in the developing countries (FAO, 2013). They are produced in over 100 countries and ranked fifth according to global tuber and root crop production (FAOstat 2012). South Africa produced between 50 000 and 60 000 tons of sweet potatoes during a period between 2008 and 2012 (NDA, 2008; DAFF, 2012). However, this excluded production by the informal sector. The sweet potato roots differ in shape, flesh and skin colour and include white, orange, yellow and purple flesh. Yellow and orange-fleshed sweet potatoes are rich in organic provitamin A (β-carotene) (van Jaarsveld *et al.,* 2005). According to Low *et al.* (2007), intake of orange-fleshed sweet potatoes (OFSP) significantly increased vitamin A in human beings. Sweet potatoes also contain substantial quantities of vitamin C, and have a high content of protein, starch, and other nutrients (Bovell-Benjamin, 2007; Laurie *et al*., 2012).

Sweet potatoes, however, contain raffinose, a non-starch polysaccharide (NSP) and trypsin inhibitors (TI), which decrease palatability and digestibility of feed (Bradbury *et al*., 1985; Dominguez, 1992). The TI content varies between sweet potato cultivars ranging from 2.6 up to 32.0 TUI/g (Ravindran, 1995). According to Li *et al*. (1991), the low levels of protein content and the TI activity impact negatively on pig metabolic processes resulting in low growth performance. The presence of TI in sweet potatoes contributes to dietary proteins unavailability to animals (Zhanga *et al*., 2001).

One of the ways to reduce anti-nutritional factors of sweet potatoes is by heating to 80 °C (Dominguez, 1992). This is likely to also increase the availability of simple sugars by disrupting the hydrogen bonds between starch granules thereby initiating hydrolysis which in turn positively affects the glycaemic index (GI) of the diet. The GI of foods reflects the rate of starch digestion of food (Jenkins *et al*., 1981; Giubert *et al*., 2011). A high GI of the diet results in elevated postprandial blood glucose and insulin concentrations (Bell and Sears, 2003). The role of insulin in porcine nutrient metabolism is well documented (Cote *et al*.,1982; Bellinger *et al*., 2006). Insulin promotes fat accretion and increases amino acid transport in cells. Pigs fed a high-GI starch source had higher growth rate and improved energy retention compared to those fed a low-GI starch which enhanced growth (Bolhuis *et al*., 2008).

Cooking sweet potatoes, however, is time consuming and needs energy sources such as coal, gas, wood and electricity which is an additional cost to the farmer. This is a constraint to the smallholder farmers whose time is taken by other farming activities. Ensiling sweet potatoes is less labour intensive and ensiling has been reported to reduce the non-starch polysaccharides (NSP) content of high fibre ingredients (Khan *et al*., 2006; Rezaei *et al*., 2009). In addition, ensiling may provide farmers with the possibilities to add value to the sweet potatoes silage by mixing them with cheap feed resources such as whey, brewer’s grain or fruit pulp. It was reported that ensiling sweet potato vines would reduce a number of anti-nutritional components in the forage including linamarin (Cardoso *et al*., 2005). However, information on the feeding of ensiled OFSP roots-based diets to pigs is limited. Thus, this study investigated the impacts of ensiled OFSP on blood glucose, nutrient digestibility, and growth performance of pigs.

1.2: Objectives

The main objective was to evaluate the nutritional value of ensiled orange fleshed sweet potatoes to growing pigs. The specific objectives were**:**

(i) To compare blood glucose and the glycemic index responses of growing pigs fed either control (CON), glucose (GLU) or ensiled OFSP diets, and

(ii) To evaluate the effects of dietary inclusion of OFSP silage at 5 inclusion levels (0, 8, 16, 24 and 32 %) on growth performance and nutrient digestibility of Large White x Landrace male pigs

1.3: Purpose of study

The purpose was to ascertain the potential and optimum use of ensiled OFSP on pig performance

1.4: Hypotheses

(i) Ensiling OFSP will not affect glucose metabolism in growing pigs

(ii) Inclusion of ensiled OFSP in growing pigs' diets has no effects on growth performance and digestibility of nutrients

CHAPTER 2 : LITERATURE REVIEW

2.1: Introduction

Pigs require a well-balanced diet for optimal growth and production. Conventional feed ingredients used in commercial pig feed formulations meet nutritional requirements; however, they are relatively expensive. Smallholder farmers cannot afford these feeds and they instead use alternative, unconventional feedstuffs. Literature on alternative unconventional feed ingredients is limited. However, alternative feedstuffs such as sweet potatoes, brewer's grains, dried distillers' grains with soluble and cassava leaves are potential replacements for higher priced commodities traditionally used in pigs' diets (Lackey, 2010). There is need to evaluate their nutritive value before making recommendations on inclusion levels in pig diets without compromising pig production.

2.2: Use of alternative feedstuffs in pig nutrition

2.2.1: Available types of alternative feedstuffs

Smallholder pig farmers contribute about 30% to the national pig population (FAO, 2012). They are usually the worst affected by high feed costs. Agricultural by-products are potential alternatives that can be used to address the problem of high feed costs as they are cheaper and readily available in the different communities. These by-products are usually region specific, depending on the agricultural activities practiced in the different geographical areas. Examples of such agricultural by-products with potential as pig feed include; potato peelings, whey, sweet potato roots, fruit pulp, brewer's dried grain and maize cobs (Tobias, *et al*., 2014).

2.2.2: Value of alternative feedstuffs

The attraction for alternative feedstuffs is growing because most of them are often thrown away due to under usage. Thus, they are often available and cheap. If possible, ways are found to improve their nutritive value, then it could help to improve local economies by integrating local crop and livestock farming activities. Sweet potato roots and other crops have been utilized as alternative high-energy feed in large-scale livestock production systems as a source of protein (Giang *et al*., 2004). They can be used fresh or processed (Murugan *et al*., 2012). Sweet potatoes are important in developing countries because they adjust easily to new conditions and produce huge quantities of food per unit area in dry conditions, giving them an edge over main staple crops (DAFF*,* 2011). In addition, sweet potatoes are easy to propagate, and are adaptable to a range of climate and edaphic conditions. Sweet potato roots are readily available in some communities. They are mainly consumed fresh and are a seasonal crop that have seasonal gluts resulting in some being thrown away (DAFF, 2011).

2.2.3: Disadvantages associated with the use of alternative feedstuffs

Major disadvantages in the utilization of some forages as energy and protein sources in pig diets are their unpalatability and indigestibility, which may reduce intake of feed leading to unavailability of nutrients (Rosales, *et al*., 1993; Bui, 2000). The effects of non-starch polysaccharides, and anti-nutrients in most vegetable feedstuffs used in pig diets are established (de Lange *et al.*, 2000). Furthermore, their high moisture content makes it unsuitable to mix with other ingredients (FAO, 1987). Odenigbo *et al*. (2012) reported that low dry matter content in feedstuffs necessitated an increased uptake to meet energy requirements of animals. Disadvantages of feeding alternative feedstuffs to livestock in fresh form are costs, storage and transportation (Terril *et al*., 2007).

2.3: Use of sweet potatoes in pig nutrition

An (2004) described sweet potatoes, as dicotyledonous plants belonging to the *Convolvulaceae family*. It can grow with or without fertilizers and can survive in different soil types, but its yields depend on climate and soil conditions (An, 2004). According to Bovell-Benjamin (2007) and Islam (2006) sweet potatoes are a multipurpose crop utilized as food for humans, forage and as unprocessed industrial material. Sweet potato roots are an important feed for livestock production in many

Asian countries, China and Uganda (Scott, 1991). The roots are utilized as fresh or silage or sun-dried to feed farm animals (Yeh and Bouwkamp, 1985).

Developments of strains such as OFSP that can provide natural bio-accessible beta-carotene (van Jaarsveld *et al*., 2005) have improved the nutritive value of sweet potatoes. The energy content of sweet potato roots is better than that of other root crops such as cassava and potato. Carbohydrates of tubers range between 25 - 30 % and water makes up 58 - 72 % (Janssens, 2001). Leaves have about 3 % protein, almost double the quantity of other tubers (Woolfe, 1992).

Uncooked sweet potato roots have trypsin inhibitors (TI) (Bradbury *et al*., 1992), which adversely impact protein metabolism (Peters *et al.*, 2001; Hou and Lin, 2002). This inhibitor activity can reduce digestive processes of pigs resulting in low performance of growing and finishing pigs (Li *et al*., 1991). According to Parul (2014), anti-nutritional factors can be harmful or cause discomfort to humans, growth performance of animals by limiting voluntary intake, metabolism and assimilation of other feed components. Cooking can, however, remove trypsin inhibitors (Alonoso, *et al*., 2000).

2.4: Anti-nutritional factors in sweet potatoes

2.4.1: Phytic acid

Phytic acid (dihydrogen phosphate) is present in sweet potatoes but in low concentrations. Phytic acid is the principal storage composite of plant phosphorus (P). The phytic acid binds to metallic cations to form phytates which are consequently insoluble complexes, thereby slowing their absorption by monogastrics (Baidoo *et al*., 2003; NAS, 2005; Vashishth *et al*., 2017). This makes phytic acid the main storage compound of organic phosphorus in plants (Raboy 2001; Steiner *et al.,* 2007). Lack of phosphorus and other essential minerals in monogastrics can be caused by the cations binding to the phytic acid (Gibson *et al*., 2006).

2.4.2: Trypsin inhibitors

Sweet potatoes are the first non-leguminous plants reported to have trypsin inhibitors (Sohonie and Bhandarkar, 1954). According to Bolhuis (2003) trypsin inhibitors in animal diets form permanent enzyme-trypsin inhibitor complexes. Consequently, this results in reduced intestinal trypsin concentrations and impaired protein digestibility, leading to retarded animal growth. *In vitro* studies have indicated a strong inhibition of trypsin which could imply a significant impairment of protein digestion and dietary nitrogen metabolism *in vivo* (Woolfe, 1992). A significant variation in trypsin inhibitor activity between sweet potato varieties has been noted (Zhang and Corke, 2001; Toyama *et al.*, 2006). Therefore, for improved utilization of this feedstuff, there is need for development of cultivars with high protein content and low trypsin inhibitor activity, as well as the use of microwaves to significantly reduce trypsin inhibitor activity in sweet potato roots (Ravindran *et al.,* 1995; Kiran and Padmaja, 2003).

2.4.3: Oxalates

The sweet potato leaves that are uncooked contain between 73 and 89 mg/100 g of oxalates (Ravindran *et al.,* 1995). A high concentration (about 308 mg/ 100 g) has been reported in dry sweet potato samples (Lebot 2009; Antia *et al*., 2006). Sweet potato roots also contain oxalates, both in a free or a calcium salt form and at levels comparable to other root crops (Lebot 2009). High levels of oxalate intake are associated with an impaired bioavailability of calcium as described by the intermediate calcium absorption index (Weaver *et al.*, 1997). Like the deactivation of trypsin inhibitors, appropriate thermal treatment of sweet potato leaves such as boiling in water significantly lowers the total oxalate content (Antia *et al*. 2006).

2.4.4: Tannins

Tannins are complex phenolic polymers classified as either hydrolysable or condensed tannins (Rao and Desothale 1998). They have an inhibitory effect on enzymes (trypsin, amylases, chymotrypsin and lipases). Furthermore, tannins also inhibit optimal absorption of dietary iron, compromise protein digestion and to a lesser degree available carbohydrates and fat (Griffiths 2000). Kunyanga *et al.*

(2011) reported that sweet potatoes exhibited higher tannin levels than pumpkin, butternut and amaranth leaves which is in contrast to the results of Olayiwola *et al.* (2009).

2.5: Enhancing the quality of sweet potatoes

2.5.1: Cooking

Most of the freshly produced sweet potatoes are prepared by boiling, frying and baking and served in various dishes (Laurie 2004), while insignificant quantities are processed and exported (DAFF, 2011). Carotenoid content was reduced between 5-14 % of the fresh sample by cooking or boiling sweet potatoes for 30 minutes (Hagenimana *et al*., 1999a). After boiling for 30 minutes, Van Jaarsveld *et al.* (2006) reported beta-carotene losses of up to 12 and 24 % in open and closed pots respectively. Cooking sweet potatoes does not only improve starch and other nutrient digestibility but also significantly reduces the effect of anti-nutrients such as trypsin inhibitors (Dominguez 1990). Although cooking sweet potatoes is time consuming and needs a lot of energy, it is necessary, to improve feeding value (Peters *et al.*, 2001).

2.5.2: Drying

Sun-drying sweet potato roots is a common practice in Africa (Silayo *et al*., 2003). The drying process includes crushing or slicing into chips followed by spreading the material on stones or dried cow dung (Bechoff *et al.,* 2008). This process takes several days to achieve suitable dryness. The dried material can be stored for a long period or it can be milled into flour (Nogueira *et al*., 2018). Sweet potato flour is used to partially substitute wheat flour in the bakery industry (FAO 2004; da Silva *et al*., 2017).

Information on the effect of drying methods on sweet potato carotenoid retention is limited (Hagenimana *et al*. 1999b). However, the influence of drying methods on sweet potato improved retention of carotenoid (Hagenimana *et al*., 1999a;

Bengtsson *et al.*, 2008). Up to 73 and 91 % total carotenoid content can be retained with sun- and oven-drying respectively (Vimala *et al*., 2011).

2.5.3: Ensiling

According to Dom and Ayalew (2010), the most commonly used method to increase feed palatability is by processing it through ensiling. Ensiling is the most suitable conservation method for high-moisture crops with long term storage prospects. The method has been widely used to preserve forage nutrients through anaerobic fermentation of sugars lactic acid and other organic acids (Weinberg *et al.,* 2003; Moran 2005). Proper ensiling techniques are, however, paramount for maintaining high nutritional quality of silage material during the storage period (Muck 1988). Lactic acid bacterial inoculants can be used to enhance fermentation and good silage quality (Seale 1986). The improved sweet potato silage quality increases organic matter and dry matter intake and digestibility leading to enhanced animal performance (Chamberlain 1982; Bolsen *et al*., 1996; Khalid *et al*., 2013). Ensiling sweet potatoes inactivates both trypsin and chymotrypsin inhibitors, thereby, eliminating the need for any thermal treatment (Peters *et al*. 2001).

2.6: Challenges of ensiling sweet potatoes

Technological developments in harvesting, drying, chopping crops to small pieces have come about in order to reduce some important challenges on silage quality (Huhtannen *et al.,* 2013). Improving the technique of chopping sweet potatoes using manual machine helps to solve some challenges associated with ensiling sweet potatoes. Chopping plant material to short lengths facilitates enhanced compaction and anaerobic conditions. The ideal chop length should be 1-3 cm (Tan *et al.,* 2017). To facilitate easy compaction, plant moisture content must be at least 50%. Water content of more than 75 % results in sour silage with high nutrient leakage and unpalatability (Moran, 2005).

2.7: Responses of pigs fed sweet potatoes

2.7.1: Metabolic responses

Studies on physiological responses of pigs fed sweet potatoes are scarce. However, because starch forms a large proportion of tubers, it would be expected that the most impact would be on glucose metabolism. The extent of starch digestion has effects on postprandial glucose levels (Parada and Aguilera, 2011). Consequently, this will influence insulin levels which stimulate lipogenesis, diminish lipolysis and increases amino acid transport in cells (Bell and Sears, 2003). In studies of postprandial responses, lower plasma glucose and insulin concentrations were observed on pigs that were fed a fibrous diet (Ramonet *et al.,* 2000; Farmer *et al*., 2002).

2.7.2: Digestibility of nutrients

Diets with high levels of sweet potato inclusion reduced nutrient digestibility because of increased dietary fibre content (Close 1993). The total digestibility of dry matter and crude fibre decreased with increasing sweet potato leaf and shoots in the diets of pigs (Dominguez and Ly 1997). However, Dominguez (1992) reported a high digestibility of energy and fibre in sweet potato diets fed to pigs. In contrast, a partial replacement of maize by sweet potato meal resulted in non-significant differences in dry matter and gross energy (GE) digestibility, but a significant decrease of crude protein (CP) digestibility (Tor-Abbidye *et al.* 1990).

2.7.3: Growth performance

The bulkiness of pig diets influences their voluntary feed intake due to gut fill as bulky feeds tend to induce feelings of satiety (Kyriazakis and Emmans 1995). Substitution of 40 % maize meal by sweet potato root chips, resulted in reduced average feed efficiency and daily weight gain (Manfredini *et al.,* 1993). This was due to the trypsin inhibitors, anti-nutritional factors in sweet potato roots which compromise protein digestion. Sweet potato leaves in pig diets are also associated with a reduced voluntary dry matter intake (Gonzalez *et al.,* 2003). The negative impact of trypsin inhibitors is more pronounced when unprocessed sweet potato substitutes cereals in pigs' diets (Dominguez 1992). Sweet potato and soyabean meal retarded growth of pigs compared to corn and soyabean meal (Naskar *et al*., 2008)

2.8: Effects of type of fibre

2.8.1: Soluble fibre

Dietary fibre (DF) can be categorized into either soluble or insoluble depending on its solubility in solvents such as water or weak alkali. In general, insoluble dietary fibre increases digesta rate of passage and faecal bulk whereas soluble dietary fibre increases the viscosity and hydration properties (Bach Knudsen, 2001). While hydration of digesta increases the rate of microbial fermentation, viscosity tends to inhibit enzymic digestion. Soluble fibre delays gastric emptying and decreases absorption of macronutrients, resulting in lower postprandial glucose and insulin levels (Latimer and Haub, 2010). Pectins and hemicelluloses form the soluble dietary fibre (Dhingra *et al*., 2012). The proportion of these fibre components determines the susceptibility of the forage material to microbial fermentation in the large intestines of monogastrics.

Bacteria in the colon of pigs ferment soluble fibre rapidly (Noblet and Le Goff 2001). Increased bacterial population in the colon is a sign of elevated excretion of faecal bacteria (Chen *et al*., 1998). Dietary fibre is the primary energy source for microbial fermentation (Williams *et al*. 2001). The dietary fibre influences the composition and quantity of the intestinal microbe population and their fermentation end products (Pieper *et al*., 2008). The effect of fibre content on the prevention of certain metabolic diseases has been reported (Thomsen *et al*., 2007; Wellock *et al*., 2007). High intake of soluble fibre is associated with a slow passage of digesta due to its viscosity (Anderson 1985; Schneeman 1998).

2.8.2: Insoluble fibre

Insoluble dietary fibre increases the outflow rate of digesta and increases passage rate (Rainbird and Low 1986, 1999). The insoluble fibre is primarily composed of cellulose and lignin. These components are less utilised and fermented by gastrointestinal bacteria (Graham and Aman, 1991). In addition, insoluble dietary fibre promotes volatile fatty acids production (Tagang *et al*., 2010; Reilly *et al*., 2010). Furthermore, insoluble fibre prevented post weaning colibacillosis in piglets (Mateos *et al*., 2006; Kim *et al*., 2008). Insoluble fibre reduced the digestible energy of diets (Graham and Aman, 1991). The resistant of insoluble dietary fibre to fermentation is caused by the presence of lignin (Bach Knudsen, 1997). According to Varel and Pond (1985) higher intake of insoluble fibre reduced microbial utilization of fibre and increased faecal matter (Davidson and McDonald, 1998; Bach Knudsen, 2001). Freire *et al*. (2000) found that insoluble fibre accelerated intestinal passage rate when different fibre sources including beet pulp, wheat bran, soybean hulls and *Medicago sativa* were part of the diet of piglets after weaning. Furthermore, it was observed that *Medicago sativa* high fibre content reduced the transit time.

2.9: Conclusion

Sweet potatoes (*Ipomoea batatas* (L.) Lam.), although mainly produced to feed people can be forage for animals because of seasonal gluts. Yellow orange-fleshed sweet potatoes are rich in bio-available carotenes. The sweet potato roots can be utilized in their fresh or processed form, to feed livestock in resource-limited farming systems and usually as a supplement to other conventional feedstuffs. Sweet potatoes, however, contain anti-nutritional factors which decrease palatability and digestibility of feed. Ensiling, cooking and drying sweet potato vines reduce anti-nutritional factors but the most cost effective is ensiling.

CHAPTER 3 : EVALUATING THE EFFECTS OF ENSILED ORANGE FLESHED SWEET POTATOES (*IPOMEA BATATAS*) ON BLOOD GLUCOSE IN GROWING LARGE WHITE X LANDRACE PIGS

Abstract

The aim of the first experiment was to compare blood glucose and the glycemic index responses of growing pigs fed either a normal commercial diet used as a control (CON), glucose (GLU) or ensiled orange fleshed sweet potatoes (EOFSP) in a randomized cross-over experimental design. Nine Large White x Landrace crossbred male pigs weighing 32 ± 2.5 kg BW of same age were housed in pairs and moved into individual metabolism crates for repeated sampling in a temperature-controlled room (ranging from 23.8 ºC to 26.8 ºC). Each day before sampling, feed was removed from the feed troughs from 17:00 hours and pigs were fasted overnight. The following day, from 07:00, pigs were fed the experimental meals. Drops of blood samples were collected by pricking an ear vein from each pig at 0, 15, 30, 45, 60, 90, 120, 150, and 180 min after the meal to measure repeated glucose concentrations using hand held devices. Glucose concentrations were plotted over time and measurements taken included the maximum and minimum concentrations, the number of peaks and troughs, the glycemic index (GI) and area under the curve. There were no differences in minimum glucose concentration, GI, fasting glucose and incremental area under curve ($P > 0.05$) between pigs fed CON and GLU meals. Pigs on EOFSP however had a tendency to a 10.7 % increase in GI than those on CON implying that more energy in the form of glucose was available from the EOFSP diet than the CON diet. Pigs on GLU had greater total area under curve and maximum glucose excursion ($P < 0.05$) than those on CON and EOFSP owing mainly to the fact that glucose from the GLU diet was more readily available compared to the CON and EOFSP diets. The proportion of pigs displaying the biphasic glucose curve pattern was higher in all treatments than the proportion of those displaying the monophasic and triphasic patterns. The biphasic pattern of the

glucose curve has been hypothesized to represent a more efficient disposal of the glucose concentrations to baseline. There was a high proportion of pigs fed the EOFSP diet that displayed the triphasic pattern compared to pigs fed CON and GLU meals. This may imply a more sustained availability of energy from the EOFSP diet compared to the CON and GLU diets. Given that it has been demonstrated that a high GI prompts an increase of insulin over time which enhances feed intake it can be concluded that a tendency of 10.7 % increase in GI in pigs fed EOFSP relative to CON fed pigs could translate to higher feed intake and better growth performance of pigs.

Keywords: glucose curve, glycemic index, area under curve, orange-fleshed sweet potatoes

3.1 Introduction

Blood glucose concentration, glycaemia, is a critical indicator of postprandial carbohydrate metabolism. Blood glucose levels increase soon after feeding, the extent of which depends on the source of carbohydrate, and return to the normal range 2-3 hours post feeding (Frøslie *et al*., 2013). Oral glucose tolerance tests (OGTT) are routinely used to measure how well the body’s cells can absorb glucose, after ingestion of a given amount of sugar. The blood glucose concentrations are normally plotted over time because whole glucose excursions give more information on tolerance compared to discrete blood glucose values (Sakaguchi *et al*., 2015). Coupled to this, the glucose area under the curve (AUC), which is an index of whole glucose excursion after glucose loading, and the glycemic index (GI) have been developed to further understand and compare postprandial glycaemia (Frøslie *et al*., 2013; Sakaguchi *et al*., 2015).

The GI concept classified human starchy foods depending on the increase of post feeding plasma glucose response after meals of equal carbohydrate (Parada and Aguilera 2011; Drew *et al*., 2012). Wolever *et al*. (2003) had reported that the blood glucose response increased linearly as carbohydrate ingestion increased from 0 to 50 g, and tended to level off when carbohydrate ingestion increased from 50 up to 100 g. The GI is calculated as area under the glucose response curve for a selected meal within an individual expressed as a percentage of the area under a glucose response curve of a control meal. The GI actually reflects the extent of starch digestion (Hermansen *et al.* 2006; Parada and Aguilera, 2011). The concept of GI in pig nutrition was modified by Menoyo *et al*. (2011) by arranging a cereal scale from low to high GI. Cereals with high GI prompted an increase of insulin over time resulting in enhanced feed intake of up to 13.6% (Giuberti *et al*. 2011).

Glycemic index is affected by the type and quantity of carbohydrates in feed (Willett *et al.,* 2002). However, lipids and proteins also influence the glycemic response (Foster-Powell *et al.* 2002; Hermansen *et al*, 2006). The impact of new feeds or processing of unconventional feeds on blood glucose in pigs has not been investigated extensively. It would be important to know to what extent ensiled OFSP affects blood glucose because this would be a direct reflection on the extent of starch digestibility. The aim of the study was to determine blood glucose concentrations and their patterns over time plus the glycemic index responses of growing pigs fed either the commercial diet (CON), glucose (GLU) or ensiled OFSP.

3.2: Materials and methods

3.2.1: Animals and housing

Nine Large White x Landrace crossbred male pigs weighing 32 ± 2.5 kg body weight of the same age were housed in pairs. Animals were kept individually in metabolism crates for sampling in a temperature-regulated room (with temperatures ranging from 23.8 ºC to 26.8 ºC). The commercial diet containing digestible energy and protein content of 14 MJ/kg and16% respectively and balanced for lysine to meet and exceed the nutrient recommendation for growing pigs was fed (NRC, 1998).

3.2.2: Diets and experimental design

Fresh samples of a sweet potato (*Ipomoea batatas*) variety, Bophelo, were obtained from Agricultural Research Council- Vegetable and Ornamental Plant Institute (ARC-VOPI; GPS coordinates - 25.6014° S, 28.3603° E) in Pretoria. Bophelo was bred at

ARC-VOPI for flavour, texture, drought tolerance and to have a high vitamin content (Laurie *et al*., 2015). It produces nice uniform tubers, and has an above average harvest and stores well. The roots were washed with tap water and sliced into small (2-3 cm) pieces using a manual sweet potato shredder. The sweet potato pieces were then spread out on the floor overnight for wilting to reduce the moisture content. The silage was kept in sealed airtight 210 l drums and stored for at least 90 days prior to feeding. On opening samples was taken for determination of pH, water soluble carbohydrates, volatile fatty acids, lactic acid and proximate analyses measurements. The experiment was arranged in a randomized cross-over design. Pigs were randomly allocated (in triplicate) to one of three diets namely glucose (GLU), ensiled orange-fleshed sweet potatoes (EOFSP) and control (CON) in the first week and to a different diet in the second week and to the third diet in the third week in a three-way cross-over design. The blood sampling was done 3 days per week on alternate days over three weeks resulting in 27 measurements per treatment. The three diets used in the study were; ensiled orange-fleshed sweet potatoes (EOFSP), a diet of pure glucose (GLU) and a normal commercial diet for growing pigs which acted as a control (CON). Each of experimental diets had 50 g of glycemic carbohydrates per kilogram of the diet.

3.2.3: Measurements

Feed was removed daily from the feed troughs at 17:00 and the pigs fasted overnight. In the morning at 07:00, the pigs were fed the experimental diets. Few drops of blood were collected by pricking an ear vein at 0, 15, 30, 45, 60, 90, 120, 150 and 180 min following a meal using a technique prescribed by Drew *et al*. (2012) and for immediate glucose readings and recording a hand-held device was used (Accutrend® Plus, glucoplus). This was done by a qualified, registered veterinarian. The sampling was repeated on day 3 and 5. After each blood sampling, pigs were housed in groups according to the experimental meal and given unrestricted access to commercial feed. The feed was withdrawn the previous day at 17:00 when the pigs fasted for testing the following day.

The glucose concentration was plotted against time to obtain glucose curves. These were then used to obtain the total response to glucose intake expressed as the area under curve (AUCs) which were estimated using the trapezoidal integration rule in Stata (2017) and with glucose and time expressed as mmol/l, and minutes respectively. The total area under curve (TAUC, mmol h/l) was calculated as the whole area under the curve. To correct for the variations in fasting plasma glucose between individuals the incremental area under the curve (IAUC) was calculated by subtracting the baseline value of fasting plasma glucose. The degree of glucose fluctuation measured as the maximum amplitude of glycemic excursion (MAGE), was determined as the difference between the highest and lowest glucose concentration over 180 min. Glucose response curve shapes were classified into monophasic, biphasic and triphasic curves by Tschritter *et al*. (2003) depending on the number of peaks the graphs displayed. The monophasic curve is when plasma glucose is improved to maximum after 30 - 90 minutes of a load of an oral glucose but start decreasing until 180 minutes with a final descending move to 0.25 mmol/l between 90 and 120 minutes. The glucose curve that reached a lowest point after first increase and increased again to 0.25 mmol/l until 180 min is called biphasic. The triphasic curve depends on the number of increases and decreases. The threshold of 0.25 mmol/l blood glucose change was chosen to limit false classification due to imprecision of instruments. The glycemic index for each meal was determined by using averaged results as according to Wolever *et al*. (1991):

$$GI_{ijk} = A_{ijk}/A_{ijglucose\ diet}$$

Where GI_{ijk} is the glycemic index for the i^{th} pig in the j^{th} period for the k^{th} ingredient, A_{ijk} is the area under the glucose response curve for the i^{th} pig in the j^{th} period for the k^{th} ingredient, and $A_{ijglucose\ diet}$ is the area under the plasma glucose response curve for the i^{th} pig in the j^{th} period for the glucose diet.

3.2.4: Statistical analysis

Fasting plasma glucose, maximum and minimum glucose concentrations, total AUC, incremental AUC, glycaemic index, MAGE were analyzed using analysis of variance model in the statistical program, Stata (2017). The model used was:

$$Y_{ij}=u_i+ \alpha_j+e_{ij}$$

Where Y_{ij} is the overall fasting plasma glucose, maximum and minimum glucose concentrations, total AUC, incremental AUC, glycaemic index, MAGE;

μi is the overall mean common to all observations;

α_j is the effect of diet (CON, GLU, EOFSP)

ε_{ijk} is the random error.

Treatment means were separated using Fishers protected least significant difference at 5% level of significance.

3.3: Results

Plasma glucose responses in Large White x Landrace growing pigs fed glucose (GLU), ensiled orange-fleshed sweet potatoes (EOFSP) and a control diet (CON) are presented in Table 3.1. There were no differences (P > 0.05) in glycaemic index (GI), fasting plasma glucose, incremental area under curve (IAUC) among the three diets. The tendency (P = 0.06) of IAUC in pigs fed GLU being higher than those on CON and EOFSP meals was observed. The total area under the curve (TAUC) and maximum amplitude of glucose excursion (MAGE) were higher (P<0.05) for of pigs fed GLU than for pigs that were fed CON and EOFSP.

Table 3.1 Plasma glucose responses (mean ± SEM) in Large White x Landrace growing pigs fed glucose (GLU), ensiled orange-fleshed sweet potatoes (EOFSP) and control (CON) meals

Meal	Meal weight (g)	Fasting plasma glucose (mmol/l)	Total AUC	Incremental AUC	Glycaemic index	MAGE (mmol/l)
CON	**50**	3.5±0.86	668^a±14.4	111±19.1	0.75±0.124	1.4^a±0.30
GLU	**50**	3.5±0.72	723^b±16.5	174±21.8	1.05±0.124	3.1^b±1.21
EOFSP	**50**	3.4±0.64	654^a±14.4	118±21.9	0.84±0.145	1.8^a±1.20
P-value		0.947	0.0014	0.062	0.2233	0.0001

AUC – Area under curve; MAGE – Maximum amplitude of glucose excursion

The shape characteristics of plasma glucose curves in Large White x Landrace growing pigs fed glucose (GLU), ensiled sweet potatoes (EOFSP) and a control diet (CON) meals are shown in Table 3.2 and Figures 3.1 and 3.2. There was similarity ($P > 0.05$) of minimum plasma glucose among pigs fed GLU, CON and EOFSP. Pigs on GLU showed higher ($P < 0.05$) maximum plasma glucose than those fed CON and EOFSP. There were generally more individual pigs exhibiting the biphasic curve pattern than the monophasic and triphasic patterns of pigs that consumed CON and GLU diets. The pigs that were fed EOFSP diet had similar proportions exhibiting biphasic and triphasic patterns being higher than the monophasic pattern (Figures 3.1 and 3.2).

Table 3.2 Shape characteristics of plasma glucose curves in Large White x Landrace growing pigs fed glucose (GLU), ensiled orange-fleshed sweet potatoes (EOFSP) and control diet (CON) meals

Meal	Fasting Glucose	Max Glucose	Min glucose	Proportion of pigs showing glucose curve pattern		
	mmol/l	mmol/l	mmol/l	Monophasic (%)	Biphasic (%)	Triphasic (%)
CON	3.5±0.86	4.6^{a}±1.00	2.9±0.45	22.2	57.8	20
GLU	3.5±0.72	5.9^{b}±1.10	2.8±0.54	17.0	63.8	19.1
EOFSP	3.4±0.64	4.6^{a}±1.22	2.9±0.46	17.6	39.2	43.1
P-value	0.947	0.0001	0.877			

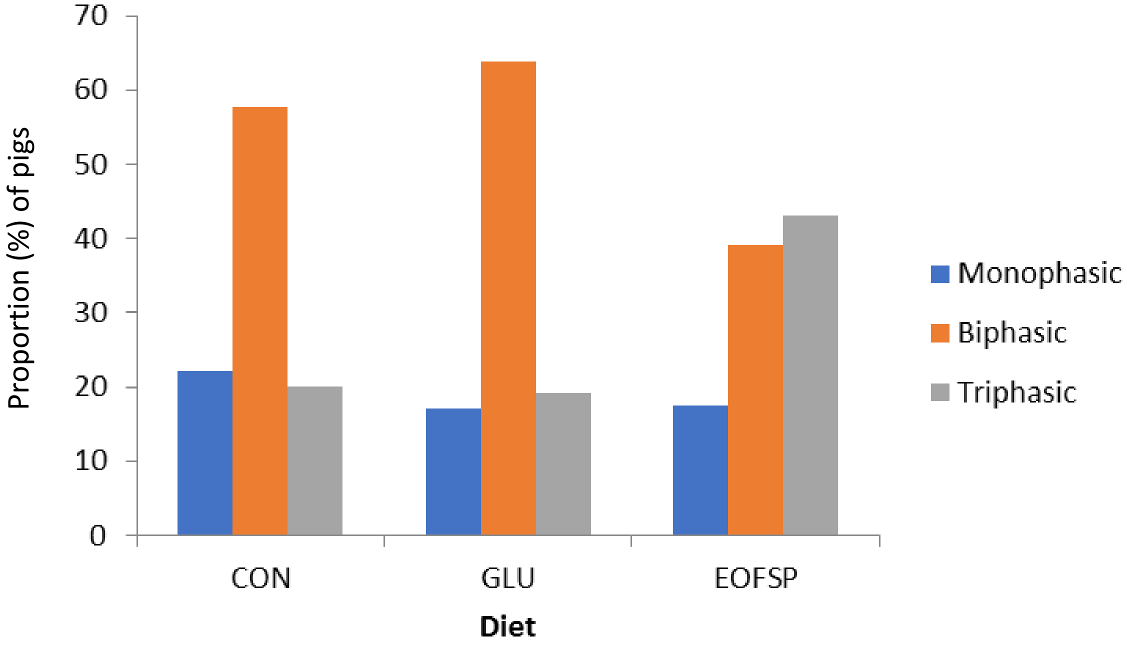
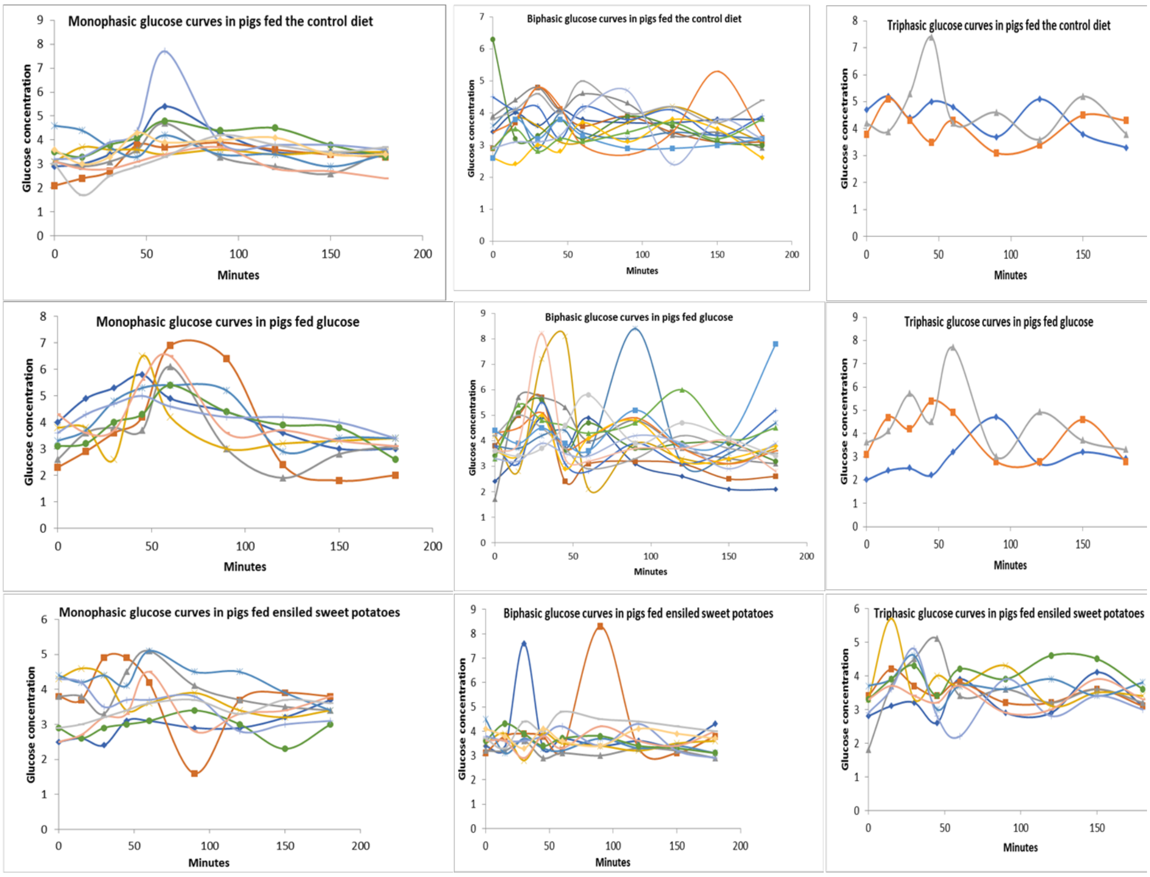


Figure 3.1 Proportion (%) of pigs exhibiting mono-, di- and triphases on plasma glucose curve when fed one of control (CON), glucose (GLU) or ensiled orange-fleshed sweet potato (EOFSP) meals

The monophasic, biphasic and triphasic glucose curves are in Figure 3.2. The increase of glucose concentrations were steeper in pigs fed glucose than in pigs fed ensiled orange-fleshed sweet potatoes. Glucose curves in pigs fed glucose and CON also appeared more uniform and consistent than those of pigs fed ensiled orange-fleshed sweet potatoes



The number of curves in each figure correspond to the number of pigs

Figure 3.2 Individual glucose curves showing monophasic, biphasic and triphasic patterns in pigs fed the control diet, glucose and ensiled orange-fleshed sweet potatoes

3.4: Discussion

The study evaluated the impact of ensiling on nutritive value of EOFSP by comparing blood glucose concentrations and patterns over time and the GI responses of growing pigs fed CON, GLU or EOFSP meals. Blood glucose concentrations measured postprandial are discrete, ordered measurements from an underlying, continuous process (Frøslie *et al*., 2013) and do not provide complete information on glucose metabolism postprandial (Sakaguchi *et al*., 2015). This has necessitated the use of indices such as the area under curve (AUC), which integrates the entire blood glucose response over time, and glycemic index (GI) to allow meaningful comparisons among individuals and feeds. The AUC is a measure of the individual's ability to metabolise glucose after a meal to the normal range within a given time. To correct for the variations in fasting plasma glucose between individuals the incremental area under the curve (IAUC) is calculated by subtracting the baseline value of fasting plasma glucose. Jenkins *et al*. (1981) defined the GI as the total area under the curve (TAUC) for the plasma glucose response after ingestion of feed relative to that produced through a reference food with a comparable amount of carbohydrate. There were no differences in AUC, IAUC and GI between CON and EOFSP meals suggesting that ensiling was effective in processing starch in OFSP, making it possible for pigs to digest and utilize the carbohydrates. The boiling method has been reported to produce lower GI levels compared to baking, frying and roasting (Bahado-Singh *et al.,* 2011). Although not statistically different pigs fed on EOFSP had a 10.7 % higher GI than those fed the CON (0.84 vs 0.75) implying that more energy in the form of glucose was available from the EOFSP diet than the CON diet. The exact implications of this are, however, not clear.

The MAGE (degree of fluctuation), was the greatest in the GLU fed pigs; but no difference between pigs fed CON and EOFSP diets was observed. The glycemic variability represented by MAGE is of important clinical concern because of its negative impacts on insulin regulatory mechanisms, oxidative stress and food intake (Kaur *et al*., 2015). Pigs with a higher GI and MAGE are likely to consume more feed. This was observed by Giuberti *et al*. (2011) when cereals with high GI resulted in increased insulin response, which in turn caused an increase in feed intake by up to 13.6%.

Some concerns have been raised that the use of the AUC, which integrates the entire blood glucose response over time, may not be appropriate because it fails to take into account the shape of the curve (Franz, 2003). Theoretically, it is possible that the carbohydrates in some foods elicit a sharp glucose ‘‘spike’’ that disappears quickly and undershoots the baseline value and yet have the same AUC as the carbohydrates that provoke a more gradual rise and fall in blood glucose (Brand-Miller *et al*., 2009). The proportion of pigs that had the biphasic curve was higher in all treatments than those having the monophasic and triphasic curves. However, the pigs fed EOFSP meal had a higher proportion of triphasic curves than pigs fed the CON and GLU meals. The differences in morphologies of glucose curves following the OGTT were attributed to glucose tolerance, insulin sensitivity, insulin secretion, gender and rate of gastric emptying (Tschritter *et al*. 2003; Nolfe, *et al*. 2012). Considering that these results are from human studies some of these may be extrapolated to pigs as well because both are omnivores. Findings in the current study suggest that the type of meal may also influence the morphology of the glucose curve possibly through influencing the rate of gastric emptying.

3.5: Conclusion

It can be concluded that feeding EOFSP diet had a glycaemic index (10.7 %) higher than the commercial diet and can translate to pigs fed EOFSP having a higher feed intake than pigs that were offered the commercial diets. Pigs given EOFSP meal had higher proportions of triphasic patterns than those fed the CON and GLU meals suggesting that EOFSP influenced the morphology of the glucose curve differently to the GLU and CON. Further studies on optimum inclusion levels of ensiled OFSP and their effects on performance of growing pigs need to be undertaken before recommendations can be made.

CHAPTER 4 : DETERMINATION OF THE EFFECTS OF LEVEL OF ENSILED ORANGE-FLESHED SWEET POTATOES (*IPOMEA BATATAS*) ON NUTRIENT DIGESTIBILITY AND GROWTH PERFORMANCE OF PIGS

Abstract

The study evaluated the effects of feeding diets containing incremental concentrations of ensiled orange-fleshed sweet potato (EOFSP) on digestibility of nutrients and growth of pigs. Thirty Large White x Landrace grower male pigs, weighing 28.6 ± 5.35 kg BW were blocked by weight and allocated to five experimental diets containing 0, 8, 16, 24 and 32 % ensiled orange-fleshed sweet potatoes. A digestibility trial using the total collection method and a growth study were undertaken. Pigs that were given the 32 % diet had higher (P<0.05) dry matter digestibility (DMD) than those fed the 16 % diet, while those on the 0 %, 8 %, 16 % and 24 % diets had similar (P>0.05) DMD. Pigs that were fed the 32 % diet showed higher (P<0.05) organic matter digestibility (OMD) and crude protein digestibility (CPD) than those fed the 16 and 24 % diets. Pigs fed on the 24 and 32 % diets had higher neutral detergent fibre digestibility (NDFD) (P<0.05) than those on the 16 % diet. Pigs fed 0 % diet showed lower acid detergent fibre digestibility (ADFD) (P<0.05) than those on the 8 %, 24 % or 32 % diets. Pigs fed the 24 and 32 % diets showed higher (P<0.05) average daily gain (ADG) than pigs fed 0 % and 8 % diets. Pigs that were fed the 32 % diet had higher (P<0.05) average daily feed intake (ADFI) than those fed the 0 %, 8 % and 16 % diets. Pigs fed the 8 % and the 32 % diets consumed more ADFI (DM) than those on the 0 % diet. Pigs fed the 0 % diet had lower (P<0.05) feed conversion ratio (FCR as is) than those fed the 8% diet. Similar (P>0.05) FCR in pigs fed the 0 %, 16 %, 24 % and 32 % diets were observed. Pigs that were fed the 8 % diet had higher FCR (P<0.05) than those offered the 16 %, 24 % and 32 % diets. It can be concluded that ensiled OFSP can be included in feed up to 32 % for growing pigs without affecting the digestibility of nutrients and growth performance.

Keywords: feed intake, daily gain, feed conversion ratio

4.1: Introduction

High pig feed costs are challenging the livelihoods of smallholder farmers, which has led to research to find alternative, cheaper feedstuffs such as sweet potatoes. Sweet potatoes has a high content of digestible energy but is low in crude protein levels (Domínguez 1992). Feeding raw sweet potatoes can, however, cause reduction in nutrient utilization and result in poor performance of pigs (Anonymous 2005). According to Woolfe (1992) sweet potatoes and their by-products can be fed to all livestock after processing. Complete substitution of corn with cooked sweet potatoes in pig fattening has been reported (FAO, 2012). Cooking sweet potatoes is however, labour and energy intensive especially for the smallholder farmers and is not a viable option. A more sustainable way of utilizing sweet potatoes can involve ensiling. Ensiling of sweet potatoes can help in improving the digestibility of all nutrients (Domínguez, 1992). Ensiled sweet potatoes can effectively substitute 50 % of a standard commercial ration (Dom and Anyalew, 2010).

Sweet potato is an ideal feedstuff for livestock, with roots and vines providing energy and protein respectively and can be fed in its fresh or processed form (Woolfe, 1992) The use of sweet potato for pig production is common in many countries including Vietnam (Bottema, 1992). In China, the world's largest sweet potato producer, most of the crop is processed for animal production and industrial products (Akoetey *et al*., 2017). There are a number of important benefits associated with the sweet potato-pig systems for resource-poor farmers. These include income generation, provision of manure and value-addition of unsuitable roots by converting into animal products (Peters, 1998). Sweet potatoes can grow in difficult cultivated land conditions; requiring little labour and chemical fertilizers (Karyeija *et al*, 1998). They are a cheaper, nutritious food option for developing countries (Mbithe *et al.*, 2016).

Improved sweet potato strains with better nutritive value such as orange-fleshed sweet potatoes (OFSP), that can provide naturally bio-available β-carotene, have been added to the market (van Jaarsveld *et al*., 2005). There is limited research on the nutritional value of sweet potatoes as animal feed. The aim of the study was therefore to evaluate the effects of feeding graded concentrations of OFSP silage in total mixed rations on digestibility of nutrients and performance of growing pigs. It was hypothesized that ensiled OFSP can be used to feed growing pigs without negative effects on nutrient digestibility and performance of growing pigs.

4.2: Materials and methods

4.2.1: Animal and housing

Thirty Large White x Landrace grower male pigs, weighing between 28.6 ± 5.35 kg BW were selected from the ARC-Animal Production Institute, Irene pig herd. The animals were individually housed in commercial grower houses under an intensive production system and supplied with a space allowance of 0.5 m^2. The pigs were provided with 12-hour lighting in the form of natural light during the day.

4.2.2: Diets and experimental design

A total mixed ration was formulated to meet or exceed the nutritional requirements of growing Large White x Landrace grower male pigs (NRC, 1998) which was used as a basal diet. A bulk diet containing 320 g/kg ensiled sweet potatoes was also formulated and used as diluent diet as shown in Table 4.1. Ensiled orange-fleshed sweet potato diets conforming to 80, 160, 240 and 320 g/kg of the dilution diet (320 g/kg) at different proportions (Gous and Morris 1985), were formulated, which translated to 0% (CON), 8%, 16%, 24% and 32% EOFSP.

The feed was fed *ad libitum* and pigs had free access to water through drinking nipples. Pigs were adapted to the diets and acclimatized to the environment for one week and were then fed until the first batch reached 60 kg BW. The experimental design was a completely randomised block, with weight as a blocking factor. The pigs were allocated to the five experimental diets of six pigs (replicates) per diet.

Table 4.1 Ingredient composition (g/kg) of the basal and dilution diets concentrations

Ingredients (g/kg)	Experimental Diets	
	Basal diet	Dilution diet
Ensiled sweet potatoes	0	320
Maize	292	124
Soyabean oilcake	184	231
Wheat bran	100	0
Hominy chop	400	300
Feed lime	13	8
Monocalcium phosphate	8	15
[1]Vit-Mineral premix	2	2
Calculated composition of diets		
Nutrient (%)		
Dry matter	88.3	69.7
Crude protein	16.5	16.5
Neutral detergent fibre	22.9	17.5
Acid detergent fibre	7.2	6.6
Ether extract	4.4	3.0
Digestible energy (MJ/kg DM)	13.3	13.7
Lysine	0.82	0.82
Calcium	0.8	0.8
Phosphorus	0.6	0.6

[1]The Vit-Mineral premix contained the following; selenium 0.3 mg and zinc 100 mg, 4.5 mg vitamin B2, 0.03 mg vitamin B12, 2.5 mg vitamin B6, 25 mg niacin, 12 mg calcium pantothenate, 190.5 mg choline, 0.6 mg folic acid, 0.05 mg biotin, 40 mg manganese, 100 mg zinc, 125 mg copper, 1 mg iodine, 100 mg ferrous.

4.2.3: Determination of digestibility

After one month of feeding, faeces and experimental diets were collected for four days to ascertain the digestibility coefficient of dry matter (DM), crude protein (CP), gross energy (GED), ether extract (EE), organic matter (OM), neutral detergent fibre (NDF) and acid detergent fibre (ADF). A modified total collection method was used. The faeces used for laboratory analyses were collected by the grab sampling method 24 hourly from each pig to prevent contamination with urine and feed and stored at -20 °C pending analyses. All the other faeces excreted from each pig for the week were collected and weighed to determine total faecal output. After the four-day collection period, faeces were thawed overnight and dried at 60 °C for 48 hours. The faeces were stored per pig and mixed thoroughly for chemical analysis. The following formula was used to calculate digestibility of nutrients.

$$\text{Nutrient digestibility (\%)} = \frac{\text{Nutrients consumed (g)} - \text{Nutrients in faeces (g)}}{\text{Nutrients consumed (g)}} \times 100$$

4.2.4: Data collection for growth performance study

Individual weight of animals was obtained at the start of the experiment and weekly until 20% of the pigs attained the target weight of 60 kg after which the pigs were slaughtered. The pigs were slaughtered the same day over a period of 2 hours. The weight difference between feed offered and the orts was used to measure daily feed intake. These measurements were used to determine the average daily gain (ADG), dry matter intake (DMI) and to calculate the feed conversion ratio (FCR).

4.2.5: Chemical analyses

Only dried samples were used for chemical analyses. Dry matter, OM and CP were were analysed following the procedures from the Association of Official Analytical Chemists (AOAC 1990). Neutral detergent fibre and acid detergent fibre (ADF) were determined according to method of Van Soest *et al*. (1991).

4.2.6: Statistical analyses

Data were analyzed using SAS (2012). Analysis of variance was used to test for differences in digestibility coefficients of DM, OM, NDF, CP and ADF. ANOVA was also used to analyse for treatment effects on animal performance parameters (ADFI, ADG, and FCR). The model used was:

$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$;

where:

Yijk is the performance parameter (ADFI, ADG and FCR) and digestibility coefficients of DM, OM, NDF, CP and ADF;

μ is the overall mean response common to all observations;

αi is the j^{th} inclusion level (0, 80, 160, 180, 240, 320 g/kg)

and εijk is the residual error.

The Fisher's protected least significant difference (LSD) method was used to separate treatment means at 5% level of significance. The relationship between inclusion level of ensiled orange-fleshed sweet potatoes and average daily gain and feed intake was evaluated using linear regression analysis.

4.3: RESULTS

Digestibility coefficients of growing pigs fed diets containing different inclusion levels (0 – 32 %) of ensiled orange-fleshed sweet potatoes are shown in Table 4.2. Pigs that were fed the 32 % diet had significantly higher ($P<0.05$) dry matter digestibility (DMD) than those given the 16 % diet, while those on 0 %, 8 %, 16 % and 24 % diets had similar DMD ($P>0.05$). Pigs on the 32 % diet had higher ($P<0.05$) organic matter digestibility (OMD) and crude protein digestibility (CPD) than those fed the 16 and 24 % diets. There was similarity ($P>0.05$) in OMD and CPD of pigs fed the 0 %, 8 %, 16 % and 24 % diets. Pigs fed on the 24 and 32 % diets showed higher neutral detergent fibre digestibility (NDFD) ($P<0.05$) than those fed 16 % diet. Similarity was revealed ($P>0.05$) in NDFD in pigs fed the 0 %, 8 %, and 16 % diets. Pigs fed the 0 % diet had lower acid detergent fibre digestibility (ADFD) ($P<0.05$) than those fed on 8 %, 24 % and 32 % diets.

Table 4.2 Digestibility coefficients (mean ± SEM) of growing pigs fed diets containing different inclusion levels (0 – 32%) of ensiled orange-fleshed sweet potatoes

Parameters	Treatment					
	0%	8%	16%	24%	32%	P-value
DMD	0.76^{ab} ±0.02	0.74^{ab}±0.02	0.71^{a} ±0.03	0.77^{ab} ±0.02	0.81^{b} ±0.02	0.03
OMD	0.77^{ab} ±0.02	0.76^{ab}±0.02	0.73^{a} ±0.03	0.73^{a} ±0.02	0.82^{b} ±0.02	0.02
CPD	0.75^{ab} ±0.02	0.73^{ab}±0.02	0.69^{a} ±0.03	0.71^{a} ±0.02	0.81^{b} ±0.03	0.01
NDFD	0.69^{abc}±0.03	0.65^{ab}±0.03	0.64^{a} ±0.03	0.75^{bc} ±0.03	077^{c} ±0.03	0.01
ADFD	0.30^{a} ±0.04	0.48^{b} ±0.04	0.45^{ab}±0.06	0.56^{b} ±0.05	0.54^{b} ±0.06	0.004

DMD – dry matter digestibility; OMD – organic matter digestibility; CPD – crude protein digestibility; NDFD – neutral detergent fibre digestibility; ADFD – acid detergent fibre digestibility

The growth performance parameters of pigs are in Table 4.3. Pigs that were fed the 24 and 32 % diets had higher (P<0.05) average daily gain (ADG) than those fed 0 % and 8 % diets. There were no differences in ADG (P>0.05) in pigs fed 0 %, 8 % and 16 % diets. Similarly, there were no differences (P>0.05) in ADG in pigs fed the 16 %, 24 % and 32 % diets. Pigs fed the 32 % diet had a significantly higher (P<0.05) average daily feed intake (ADFI as is) than those fed the 0 %, 8 % and 16 % diets. There were similarities (P>0.05) of ADFI in pigs fed the 0 %, 8 %, 16 % and 24 % diets. Pigs fed the 8 % and the 32 % diets consumed more ADFI than those on the 0 % diet. There was no variation (P>0.05) of ADFI in pigs fed the 0 %, 16 % and 24 % diets. Pigs that were fed the 0 % diet had lower (P<0.05) feed conversion ratio (FCR) than those fed the 8% diet. There was similarity (P>0.05) of FCR in pigs that consumed the 0 %, 16 %, 24 % and 32 %. Similarly, there were no differences (P>0.05) in FCR in pigs fed the 8 %, 16 %, 24% and 32 % diets. Pigs fed the 8 % diet had higher FCR (P<0.05) than those fed the 16 %, 24 % and 32 % diets. There was no difference in FCR (DM) (P>0.05) in pigs fed the 0 %, 16 %, 24 % and 32 % diets and between the 0 % and the 8 % diets.

Table 4.3 Growth performance parameters (mean ± SEM) of growing pigs fed diets containing different inclusion levels (0 – 32%) of ensiled orange-fleshed sweet potatoes

Parameters	Treatment					
	0 %	8%	16%	24%	32%	P-value
ADG (kg)	0.48^{a} ±0.04	0.47^{a} ±0.04	0.57^{ab}±0.04	0.64^{b} ±0.05	0.61^{b} ±0.03	0.03
ADFI (kg as is)	1.36^{a} ±0.09	1.85^{a} ±0.07	1.81^{a} ±0.07	1.98^{ab}±0.11	2.09^{b} ±0.07	0.004
ADFI (kg)	1.24^{a} ±0.07	1.55^{b}±0.06	1.38^{ab}±0.06	1.47^{ab}±0.09	1.46^{b} ±0.06	0.007
FCR (as is)	2.9^{a}±0.29	4.0^{b}±0.25	3.2^{ab}±0.25	3.1^{ab} ±0.36	3.4^{ab} ±0.23	0.01
FCR	2.7^{ab}±0.25	3.3^{b} ±0.21	2.5^{a} ±0.21	2.3^{a} ±0.30	2.4^{a} ±0.19	0.006

ADG – average daily gain, ADFI – average daily feed intake, FCR – feed conversion ratio

The linear regression of ADG and ADFI with increase in inclusion level of ensiled orange-fleshed sweet potatoes were plotted and displayed in Table 4.4 and in Figure 4.1. The linear increase in $ADFI_{as\ fed}$ and ADG as the inclusion level of ensiled orange-fleshed sweet potatoes were increased ($P<0.05$) was observed. There was no linear relationship between $ADFI_{DM}$ and inclusion level of ensiled sweet potatoes ($P>0.05$).

Table 4.4 Linear regression of average daily gain (ADG) and average daily feed intake (ADFI) (DM) with increase in inclusion level of ensiled sweet potatoes

Parameter	Coefficient	Std error	P-value	95% Conf. Interval	Adj-R^2
ADG					
Level	0.004	0.0017	0.028	0.00046-0.00757	0.13
Constant	0.441	0.034	0.000	0.37122-0.5105	
$ADFI_{as\ fed}$					
Level	0.0151	0.0042	0.001	0.0066-0.0237	0.29
Constant	1.504	0.0821	0.000	1.336-1.6725	
$ADFI_{DM}$					
Level	0.0009	0.0033	0.786	-0.00586-0.00767	-0.033
Constant	1.351	0.064767	0.000	1.218-1.484	

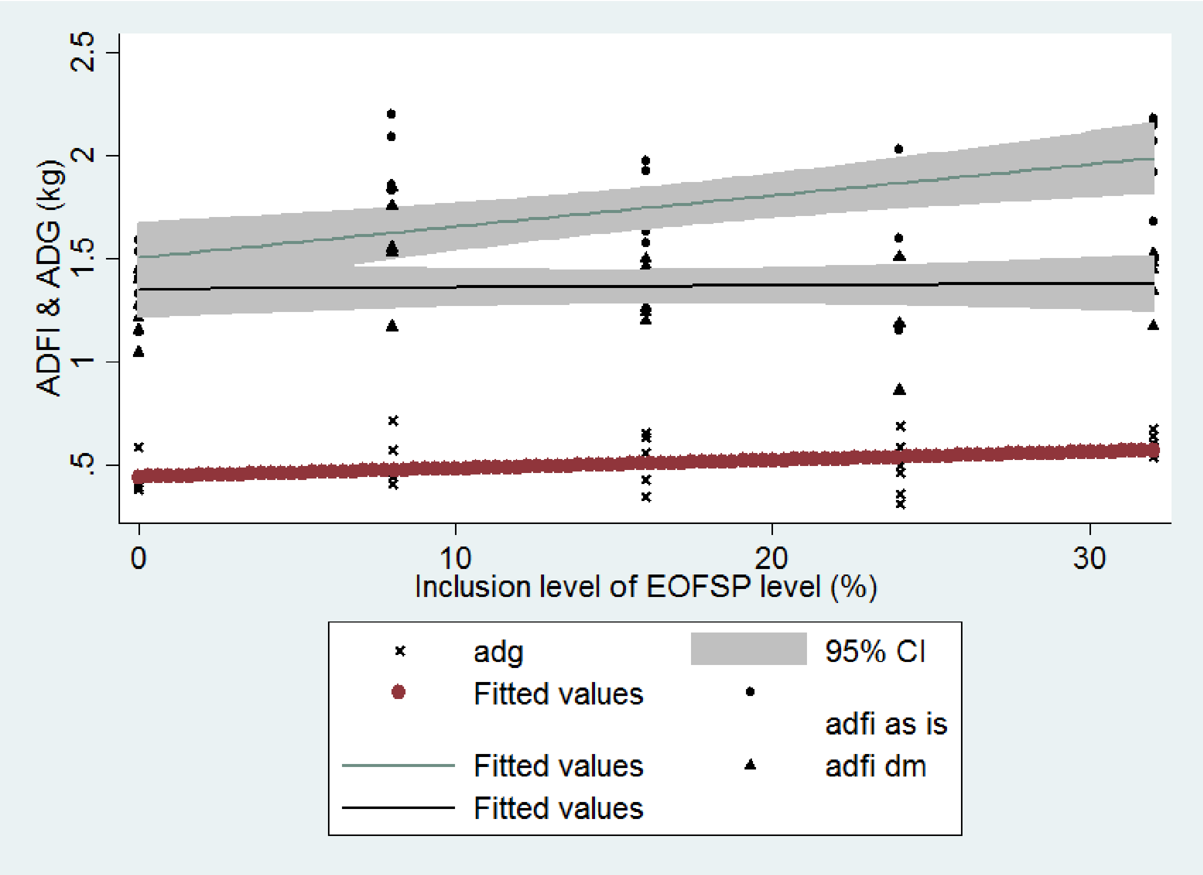


Figure 4.1 Responses of average daily gain (ADG) and average daily feed intake ($ADFI_{DM}$) with increasing inclusion level of ensiled orange-fleshed sweet potatoes

4.4: Discussion

Pigs that were fed the 32 % diet had higher DMD, OMD and CPD than those fed the 16 % diet. Contrastingly, Naskar *et al.* (2008) reported that DM and CP digestibility were inversely proportional to the levels of fresh sweet potato tuber supplementation in both 10 kg and 15 kg body weights of pigs. The differences in digestibility trends between that study and this one could be due to differences in weights of pigs, because heavier pigs tend to have a higher capacity to digest feeds. Alternatively it could be that ensiling in this study enhanced the digestibility of the different nutrients. There was an improvement in digestibility of nutrients in this study unlike the findings by Tor-Abbidye *et al.* (1990) where there was no similarity in DM digestibility when maize was substituted by sweet potato by-product meal. This study justified the use of ensiled orange-fleshed sweet potatoes as suitable alternative compared to maize in the diets of pigs. This study further strengthens the rationale of ensiling sweet potatoes. Furthermore, in a related study, Bui (2000) observed that ensiled cassava leaf was digested better than sun-dried when fed to growing pigs.

Noblet and Perez (1993) reported that increased fibre content in the diet reduced the apparent faecal digestibility of nutrients and organic matter but in this study pigs fed on the 24 and 32 % diets had higher NDFD than those fed the 16 % diet. Pigs fed the CON diet showed lower ADFD than those fed on 8 %, 24 % and 32 % diets. The most likely explanation for the disparity is that the sweet potatoes in this study were ensiled. Dom *et al.* (2016) also observed that apparent total tract digestibility of OM and DM in high fibre diets containing cassava roots which were either ensiled or boiled and milled were higher than in diets fed a standard commercial feed.

Pigs that were fed the 24 and 32 % diets had higher ADG than those fed CON and 8 % diets. Similarities in the dry matter intake and ADG when pigs were fed different sweet potato diets was observed. Pigs fed the 32 % diet had higher ADFI than pigs fed the CON, 8 % and 16 % diets. Giang *et al.* (2004) raised grower pigs on either of two diets, (sweet potato meal or sweet potato silage) and observed that pigs on the highest inclusion (60%) of sweet potato meal had the highest ADG and FCR. Dom and Ayalew (2009) observed that feeding growing pigs sweet potato silage at 50% of a standard diet (14% CP) resulted in lower dry matter intake, and no effect on ADG which is similar to the results of the current study as there was similarity in ADG of crossbred (Large White x Landrace) growing pigs fed ensiled sweet potatoes. Giang *et al.* (2004) proposed that reduction in DM intake of sweet potato silage diets could be due to the bulkiness and feed with high fibre content. Increasing level of sweet potato root meal in grower pigs' diets decreased its voluntary feed intake (Gonzalez, *et al.,* 2002*),* which is different from the present study. Pigs fed the 8 % and 32 % diets had higher ADFI (DM) than those on the CON diet. However, pigs that were fed the CON diet had lower feed conversion ratio (FCR as is) than those fed 8% diet. The FCR (DM) was higher for pigs fed the 8 % diet than those fed 16 %, 24 % and 32 % diets. The FCR of the pigs was the highest on dry sweet potato vines and lower on pigs that are fed ensiled sweet potato vines.

4.5: Conclusion

The ensiled OFSP can comprise up to 32 % of the growing pig diet without adverse impact on growth performance and nutrient digestibility.

CHAPTER 5 : GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1: General conclusions

The main objective of the study was to evaluate ensiled OFSP on pig production. The first specific objective was to compare blood glucose and the glycemic index responses of growing pigs fed either control (CON), glucose (GLU) or ensiled OFSP. There were no differences in AUC, IAUC and GI between CON and EOFSP meals suggesting that the pigs were able to use and digest well the carbohydrates in sweet potatoes to the same extent as in the CON. Pigs on EOFSP diet tended to have 10.7 % higher GI compared to those fed CON. The MAGE was the same between the pigs fed CON and EOFSP diets. Pigs with a higher GI and MAGE are likely to consume more feed. In this study the proportion of pigs having the biphasic pattern was higher in all treatments than those having the monophasic and triphasic patterns. However, pigs fed EOFSP meal showed a higher proportion of triphasic patterns than those fed the CON and GLU meals. These findings suggest that type of meal may influence the morphology of the glucose curve possibly through rate of gastric emptying.

The second objective was to ascertain the effects of feeding total mixed rations containing OFSP silage at 5 inclusion levels (0, 8, 16, 24 and 32 %) on growth performance and nutrient digestibility of Large White x Landrace male pigs. The pigs that were fed the 32 % diet had higher CPD, DMD and OMD compared to those fed the 16 % diet. This may probably be because ensiling improved the digestibility of the different nutrients. Pigs that were fed the 24 and 32 % diets had higher ADG than those fed 0 % and 8 % diets. Pigs that consumed the 32 % diet showed higher $ADFI_{as\ fed}$ than those fed the 0 %, 8 % and 16 % diets.

The results of this study indicate that ensiled OFSP can be used at inclusion levels of 32 % without negative effects on glycaemic index, fasting glucose, incremental area under curve and minimum glucose, digestibility of nutrients and growth performance. Sweet potatoes are readily available as animal feed for grower pigs.

5.2: Recommendations

Findings of this study recommend that:

i. On-farm studies be performed using the experimental diet containing EOFSP at 32 % inclusion level and a cost-benefit analysis be done before making recommendations to the farmers
ii. Programmes should be developed to encourage smallholder farmers keeping pigs to grow orange fleshed sweet potatoes as a potential animal feed resource
iii. Steps should be taken to quantify sweet potatoes being thrown away by farmers growing sweet potatoes, fresh produce markets and retailers and developing mechanisms to supply these to smallholder farmers keeping pigs
iv. Training material on cost effective ways of ensiling should be prepared for extension officials and farmers

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