Response in growth performance, blood metabolites, nutrient digestibility, digesta characteristics and carcass characteristics of Windsnyer pigs fed increasing levels of potato hash silage

By

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DECLARATION

I, **Cyprial Ndumiso Ncobela,** declare that;

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ABSTRACT

To conserve Windsnyer pigs, it is inevitable to characterise their ability to utilise locally available feed resources such as ensiled potato hash. The broad objective of the study was to determine the response of Windsnyer pigs to potato hash silage inclusion. In experiment 1, the specific objective was to determine voluntary feed intake and growth performance of Windsnyer pigs fed on increasing levels of potato hash silage. Thirty-six growing Windsnyer pigs (19 kg ± 5.59) (mean ± standard deviation (SD)) were individually and randomly assigned to six experimental diets containing 0, 80, 160, 240, 320 and 400 g/kg DM of potato hash silage. Six pigs were fed on each diet *ad libitum* for six weeks. Increasing levels of potato hash silage caused a decrease (P <0.05) in average daily gain (ADG), gain to feed (G/F) ratio and scaled average daily gain (SADG). The average daily feed intake (ADFI) interacted significantly (P <0.05) with the inclusion level of potato hash silage and week of feeding. There was a quadratic increase (P <0.05) in ADFI. Using piecewise regression, potato hash silage can be included up to 240 g/kg DM in Windsnyer pigs without undermining growth performance.

In experiment 2, the objective of the study was to determine the relationship between nutrition-related blood biochemistry of Windsnyer pigs and potato hash silage in growing Windsnyer pigs. In a completely randomized design, 36 clinically healthy male growing Windsnyer pigs were randomly allotted to individual pens. The diet contained six increasing levels (0, 80, 160, 240, 320 and 400 g/kg) of potato hash silage fed into pigs for five weeks. These pigs were allowed *ad libitum* access to the diets and water. There was a positive linear relationship (P <0.05) between ensiled potato hash and albumin concentration. Globulin concentration increased quadratically (P >0.05) as inclusion levels of potato hash increased. The activity of alkaline phosphatase was related to inclusion levels of potato hash silage. There was quadratic increase (P <0.001) in alkaline phosphatase as the inclusion levels of potato hash increased. The equation was: alkaline phosphatase = $4.488X^2 + 20.124X + 29.18$.

In experiment 3, the objective of the study was to determine the relationship between nutrient utilisation and rate of digesta passage against different levels of potato hash silage in growing Windsnyer pigs. Six pigs that were randomly assigned to six diets containing 0, 80, 160, 240, 320 and 400 g/kg of potato hash silage, were also used in the current experiment. They had an initial body weight of 34 ± 4.78 kg (mean ± SD) and were fed diet comprising different levels of potato hash silage for seven days. All diets were blended with chromium oxide (Cr_2O_3) before data collection. The water and feed were offered *ad libitum*. There was a positive correlation (P <0.05) between transit time (TT) and dry matter digestibility (DMD), organic matter digestibility (OMD), crude protein digestibility (CPD) and neutral detergent fibre digestibility (NDFD). The mean retention time (MRT) was positively correlated (P <0.05) to DMD, OMD and CPD. Increasing inclusion of potato hash silage resulted in a linear decrease (P <0.05) in digesta transit time (TT). The mean retention time (MRT) decreased quadratically (P <0.05) as inclusion levels of potato hash silage increased. There was a linear decrease (P <0.05) in organic matter digestibility (OMD), crude protein digestibility (CPD), and neutral detergent fibre digestibility (NDFD) as inclusion levels of potato hash silage increased.

The objective of Experiment 4 was to determine changes in physicochemical properties of the digesta in different compartment of the gastrointestinal tract (GIT) of growing Windsnyer pigs when fed different levels of potato hash silage. The study commenced when the pigs were 37 ± 4.89 kg (mean ± SD). The feed and water were offered *ad libitum*. Inclusion levels of potato hash silage related to (P <0.05) scaled stomach, colon and caecum weights. Only scaled digesta weights from colon was related (P <0.05) to inclusion levels of potato hash silage. The inclusion levels of potato hash silage was related (P <0.05) to digesta pH from ileum and distal colon. The swelling capacity of digesta from the ileum decreased linearly (P <0.01) with inclusion levels of potato hash silage. There was a positive linear relationship (P <0.05) between swelling capacity of the digesta from caecum and inclusion levels of potato hash silage. The water holding capacity of digesta from the ileum decreased linearly (P <0.01) with inclusion levels of potato hash silage. The water holding capacity of digesta from the caecum decreased quadratically (P <0.01) with increasing levels of potato hash silage. Digesta from proximal colon also showed a linear decline (P <0.01) with inclusion levels of potato hash silage. Digesta from distal colon increased linearly (P <0.01) with increasing levels of potato hash silage.

In the experiment 5, the objective of the study was to determine response in carcass traits and primal pork cuts of growing Windsnyer pigs fed on different levels of potato hash silage. Thirty-six growing Windsnyer pigs with slaughter weight of 36 kg ± 4.89 (mean ± SD) that were previously assigned to six experimental diets containing 0, 80, 160, 240, 320 and 400 potato hash silage g/kg DM were used. There was a quadratic increase in warm carcass weight (P <0.001) and cold carcass weight (P <0.001) as inclusion levels of potato hash silage increased. A linear (P >0.05) increase in dressing percentage was observed. The cooler shrink decreased quadratically (P <0.05) as inclusion levels of potato hash silage increased. Increasing levels of potato hash silage resulted in a linear decrease in carcass length (P >0.05). There was a negative linear (P <0.01) relationship between eye muscle area and inclusion of ensiled potato hash increased. There was a positive quadratic relationship (P <0.05) between hindquarter length (HQL) and inclusion levels of potato hash silage. The hindquarter circumference (HQC) decreased linearly (P >0.05) as the inclusion levels of potato hash silage increased. There was a linear decrease (P <0.01) in backfat thickness as inclusion levels of potato hash increased. There was a linear increase in dressing percentage and linear decrease in backfat thickness as inclusion levels of potato hash silage increased.

Keys words: Blood metabolites; Carcass; Digesta passage; Feed intake; Gastrointestinal tract; Inclusion level; Mean retention time; Nutrient digestibility; pork ; Swelling capacity; Water holding capacity;

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DEDICATIONS

….To almighty God….

…..To life because is too short…..

…To young, upcoming generation that believe in education ….

……To my precious and loving Mother, Fusi Elizabeth Ncobela…..Rest in peace. I will always love and respect you.

My favourite quote

…… "The two most important days in your life are the day you are born and the day you find out why." ***Mark Twain****……*

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LIST OF ABBREVIATIONS

Abbreviation	Description	Units
ADF	Acid detergent fibre	g/kg DM
ADFD	Acid detergent fibre digestibility	None
ADFI	Average daily feed intake	kg
ADG	Average daily gain	kg
AOAC	Association of Official Analytical Chemists	None
ARC	Agricultural Research council	None
CP	Crude protein	g/kg DM
CPD	Crude protein digestibility	None
Cr_2O_3	Chromium oxide	g
DAFF	Department of Agriculture Forest and Fisheries	None
DE	Digestible energy	MJ/kg DM
DFT1	Dorsal fat thickness at first rib	mm
DFT2	Dorsal fat thickness at last rib;	nn
DFT3	Dorsal fat thickness at last lumbar vertebra;	nn
DM	Dry matter	g/kg
DMD	Dry matter digestibility	None
EE	Ether extract	g/kg DM
G:F	Gain to feed ratio	None
GE	Gross energy	MJ/kg DM
GIT	Gastro intestinal tract	None
HQC	Hindquarter circumference	cm

HQL	Hindquarter length	cm
HQWP	Hindquarter weight proportion;	%
LW×LR	Large White × Landrace	None
MRT	Mean retention time	Hours
NDF	Neutral detergent fibre	g/kg DM
NDFD	Neutral detergent fibre	None
NLIN	Non linear	None
OM	Organic matter	g/kg DM
OMD	Organic matter digestibility	None
PBP	Potato by-product	None
PHM	Potato hash meal	None
RSREG	Response surface	None
RWP	Rib weight proportion	%
SADG	Scaled average daily gain	g/kg BW per day
SD	Standard deviation	None
SFI	Scaled feed intake	g/kg BW per day
SWC	Swelling capacity	(ml/g)
SWP	Shoulder weight proportion	%
TT	Transit time	Hours
WHC	Water holding capacity	(g_{water}/g_{feed} DM)

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

The global pork production and consumption is expected to increase by 75 % in 2020 in response to the increasing world human population, which is likely to double in 2050 (FAOSTAT, 2012). The increase in pork production is, however, driven by fast-growing pigs produced for commercial production, ignoring the contribution of slowing-growing pigs. For example, the South African Pork Producers' Organisation is chiefly representing the commercial pork producers of South Africa, excluding the slow-growing pigs which are kept mostly by resource-limited farmers. In Southern Africa, a significant population of slow-growing pigs is found in Mozambique, South Africa, Malawi, Namibia, Botswana, Zambia and Zimbabwe (Chimonyo *et al*., 2006). In South Africa, in particular, Kolbroek and Windsnyer pigs are common indigenous breeds kept by resource-limited households (Ramsey *et al*., 2000). Windsnyer pigs are amongst indigenous pigs that are in a threshold of extinction. This is due to indiscriminate breeding which leads to genetic erosion, negligence, negative perception about their production system, poor marketing channels and bias in historical carcass grading scheme (Halimani et al., 2012). Windsnyer pigs are also sidelined because of their small frame size, slow growth rate, stocky body, high fat deposition and hard black fur during dehairing of the carcass and relatively little research that aims to improve Windsnyer pig production (Halimani *et al*., 2012).

The genetic uniqueness of Windsnyer pigs is also pressed by high human population, evolution of production systems and unpredictable effect of change in climate (Halimani et al., 2010). There are also no policies that favour the conservation of Windsnyer pigs (Chimonyo and Dzama, 2007). Nonetheless, Windsnyer pigs play a central role to the livelihood of the rural households as they are used as a source food, income and security (Halimani et al., 2012). Windsnyer pigs are narrow bodied with either short or long nose. The commercial value of Windsnyer pigs lie on their fertility and nutritious and tastier pork. They are hardy and they have the ability to convert food with a low quality food very efficiently. Imported pig breeds are battling to thrive, reproduce and produce to their potential under conditions found in smallholder production systems. The merit of Windsnyer pigs, which are being underestimated, is that they thrive under harsh conditions such as rampant spread of disease, high parasite burden, high temperatures, poor plane of nutrition and poor hygiene that prevails in small production system (Chimonyo *et al*., 2006). There is, therefore, need to conserve this breed and use these traits to the advantage of Windsnyer pig farmers to overcome chances of imported pig breeds to replace Windsnyer pigs. This helps in achieving the goal of increasing their contribution to the welfare and livelihoods of the resource-poor.

Windsnyer pig production has a capacity to improve food and nutrition security of less well-off households, if challenges such as feed shortages and feeding strategies that markedly affect pig production are given full attention. Windsnyer pigs do not have reliable feed resources. They scavenge for all sorts of chewable and ingestible feed materials and most of them are fibrous (Madzimure, 2011). Kanengoni *et al*. (2015) characterised Windsnyer pigs as better utilisers of high fibrous and low quality feeds, such as ensiled maize cobs because of their specialised microorganism found in the hindgut. To consolidate these findings, there is need to identify other locally available, fibrous feeds such as potato hash that can used as feed for Windsnyer pigs.

Potato hash is a potato by-product derived from production of chips and snacks (Nkosi *et al*., 2010). It contains starch (700 g/kg DM), metabolisable energy (ME) of 11.2 MJ ME/ kg DM, crude protein (CP) of 105 g/kg DM, and a crude fibre (CF) of 58.5 g/kg DM (Thomas *et al*., 2010). It is available in large quantities and it can be used as a reliable feed resource for pigs. Drawback of utilising potato hash is that it is bulky with high levels of moisture that make it prone to putrefaction if unused in within a week. It is, therefore, worthwhile to process potato hash as a strategy to prolong their shelf life, to fill the gaps of feed shortages throughout the year. This promotes their usage as source of dietary energy and fibre for pigs and will, in turn, solve disposal challenges facing the food processing industry. The methods used to process and preserve potato hash should be appropriate for farmers to maintain a low cost of production whilst ensuring both environmental and financial sustainability. Processing and preservative methods such as boiling, liquid fermenting, sun drying and ensiling are compatible methods for pig farmers.

Liquid fermentation has been explored as a preservative technique to store high moisture by-product such as potato hash (Canibe and Jensen, 2003; Thomas, 2016). The challenge of using liquid fermentation to preserve feeds is that the preservation period is short. In addition, aerobic stability is unknown. Another major challenge of using liquid fermented feed is that it is difficult to predict actual feed intake when feed is mixed with water during feeding. Ensiling is, therefore, considered suitable method to preserve high moisture feedstuff such as potato hash (Nkosi *et al*., 2010). Ensiling is a long-term preservation method that is inexpensive, easy to conduct and is appropriate for farmers who are in a low financial standing. Therefore, there is need to explore the influence of ensiling potato hash on pig performance. To comprehend the impact of potato hash silage in Windsnyer pig production, it is crucial to determine its effect on feed intake, growth performance, blood metabolites, rate of passage and carcass characteristics.

1.2 Justification

In Sub-Saharan Africa, very low proportions of cereal grains find use as animal feeding (Smale *et al*., 2013). This is due to their prohibitive prices (Kanengoni *et al*., 2015). High costs of cereal grains are also not sustainable for slow-growing pig genotypes that are commonly kept by smallholder farmers. Competition by humans, animals and the biofuel industry for feed resources fuel the high costs and shortages of cereal grains (Wadhwa *et al*., 2013). Shortages of feed resources are further aggravated by environmental disasters such as droughts, floods and frosts. The existing competition is compromising sustainability of pig production, which has a narrow range of conventional feed ingredients available. The high expenditures and minimal use of cereal grains have reached a point where it is inevitable to quest for alternative feed ingredients such as potato hash previously deemed to be of no nutritive value for monogastric animals.

Over the world, there has been a notable decline in consumption of fresh potatoes that is offset by a steady growth in consumption of processed products (DAFF, 2013; FOASTAT, 2015) such as canned food, snacks, chips, starch products and potato frozen products. Since large quantities of potatoes are channeled to processing, high amounts of potato hash that is generated and industries are facing a challenge of environmentally friendly disposal because of high cost implications. For example, Nkosi *et al*. (2010) reported that about 50 tonnes of potato hash is generated per day in one of the potato chips producing company in South Africa. Moreover, potato hash putrefies rapidly if unused immediately due to the considerably high levels of moisture. There is, therefore a need for sustainable and preservative methods to exploit it as feed ingredients.

Recently, there has been an increased consciousness of the need for practices that contribute towards environmental protection. This has led to an interest in synergizing waste management and sustainable animal feed production as complementary methods for recycling (Angulo *et al*., 2012). The exploitation of potato hash as an ingredient in pig feeds, thus, reduces a large and increasing amount of potato waste generated every year in potato producing countries. Dumping or burning potato hash present potential air and water pollution challenges. Moreso, high-moisture by-products are also difficult to burn. It is crucial to assess the potential of potato hash as pig feedstuffs to ensure stable supply of feeds for pigs. Potato hash is available in large quantities, which can provide an alternative sustainable feeding system for pigs.

Determining the relationship between inclusion levels of potato hash silage and feed intake is useful to accurately quantify the amount of potato hash silage to be incorporated in the diet without hindering growth performance. Determining any possible changes in nutritionally-related blood metabolites of pigs fed inclusion levels of ensiled potato hash is crucial to assess the level of toxicity and its impact to the wellness of pigs. Generally, reports on flow of the digesta of ensiled high moisture by-products fed to pigs are rare. To render clear picture on how slow growing pigs efficiently utilise low quality feedstuff, there it is essential to determine the response in rate of passage and nutrient digestibility of Windsnyer pigs fed ensiled potato hash silage. To understand the relevance and contribution of potato hash silage to the Windsnyer pig, there is need to relate inclusion levels of potato hash silage to physicochemical properties of digesta. This assists pig farmers to understand the value of potato hash silage to the pig. Physicochemical properties of the digesta determine the functional, physical, nutritional and physiological effects of potato hash silage. Response in carcass characteristics of Windsnyer pigs fed graded levels of potato hash silage helps pig farmers to make decision to choose primal pork cuts to be used for either selling or consumption. When evaluating the suitability of a non-conventional feedstuffs for pig feeding, it is fundamental to understand its effects on the final product such as carcass characteristics and primal pork cuts.

1.3 Objectives

The broad objective of the study was to valorise ensiled potato hash as a feed resource for slow-growing Windsnyer pigs. The specific objectives were to:

1. Determine voluntary feed intake and growth performance of slow-growing Windsnyer pigs fed increasing levels of potato hash silage;
2. Assess changes in nutritionally-related blood biochemistry of slow growing Windsnyer pigs fed on different levels of potato hash silage;
3. Determine relationship between incremental levels of potato hash silage against rate of digesta passage and nutrient utilisation in slow growing Windsnyer pigs;
4. Relate varying levels of potato hash silage to physicochemical properties of the digesta in slow growing Windsnyer pigs; and
5. Determine the response in carcass traits and primal cuts of pork from slow growing Windsnyer pigs fed on graded levels of potato hash silage.

1.4 Hypotheses

Hypotheses tested were that:

1. Incorporation of ensiled potato hash in Windsnyer pig diets improves voluntary feed intake up to an optimum inclusion level beyond which higher levels negatively affect average daily gain and gain: feed (G\F) ratio;

2. There is positive linear relationship between nutritionally-related blood biochemistry of Windsnyer pigs and inclusion levels of potato hash silage;
3. As the inclusion level of potato hash silage increase, the mean retention time and nutrient digestibility is reduced quadratically;
4. There are positive changes in physicochemical properties of the digesta of Windsnyer pigs when fed on increasing levels of potato hash silage influences; and
5. Response in carcass traits and primal cuts of pork from slow-growing Windsnyer pigs is related in a positive linear fashion to the inclusion levels of potato hash silage.

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CHAPTER TWO: LITERATURE REVIEW

Published in Animal Feed Science and Technology (Appendix 3)

2.1 Introduction

The use of potato by-products (PBP) as alternative feed for pig farmers requires exploration. Potato by-products are abundantly available and considered as debris and yet they have potential to be valuable feed ingredients. Chemical and bulk properties of PBPs vary largely with processing and type of PBP generated. Ordinarily, they are good sources of energy, starch, partly fibre and have low levels of protein. They contain dry matter (DM) ranging from 100 to 300 g/kg, while starch levels lie between 30 and 560 g/kg DM. Neutral detergent fibre (NDF) vary greatly (ranging from 40 to 410 g/kg DM) (Nelson, 2010). The objective of the review is to explore the potential of PBPs as an energy source for pigs. The review discusses the production, physico-chemical and chemical composition of PBPs. It also reviews aspects such as processing and preservative techniques used by pig farmers.

2.2 Smallholder pig production in Southern Africa

About 25 % of pigs kept in Southern Africa are raised under smallholder production system (Krecek *et al*., 2004). The common breeds kept include Kolbroek, Windsnyer, non-descript breeds and Large White × Landrace crosses mainly for selling, consumption and as investments (Madzimure *et al*., 2012; Munzhelele *et al*., 2016). Most farmers keep a maximum of 10 sows in the herd (Munzhelele *et al*., 2016). The proportion of the different indigenous breeds in the herds are unknown. These pigs are usually raised under the extensive system and, to a lesser extent, backyard with little input for housing, feeding and health care (Madzimure *et al*., 2012). The growth performance of Large White × Landrace crosses and other imported, fast growing breeds is compromised under such harsh conditions. These fast-growing genotypes cannot withstand the high ambient temperatures, low plane of nutrition and general poor management measures under smallholder production system (Chimonyo *et al*., 2001). Indigenous genotypes are often overlooked due to their undesired physical attributes such as slow growth rate, compact body conformation and their predominantly black pigmentation. Indigenous pigs are well adapted to the backyard and scavenging production systems (Chimonyo and Dzama, 2007). The small frame size of indigenous pigs is also beneficial to smallholder farmers who normally experience pig feed shortages. Indigenous pigs also deposit subcutaneous fat (Holness, 1991) and can easily be trimmed off and used as lard for cooking purposes (Chimonyo and Dzama, 2007).

Despite huge potential of smallholder pig production to improve food and nutrition security of undernourished rural households, several challenges limit their productivity (Madzimure *et al*., 2012). One of the major challenges to pig productivity is the inconsistent availability and quality of feed resources (Chiduwa *et al*., 2008). Instead of expensive conventional feed resources, smallholder pig farmers feed rotten maize, hominy chops, coarse maize meal, maize husks, green maize, kitchen waste, vegetables, pumpkins, watermelons, groundnut shells, fruits, grasses and brewers waste to pigs (Madzimure, 2011). These feedstuffs are highly fibrous but are efficiently utilised by the slow-growing pig genotypes (Kanengoni *et al*., 2015). The diet for pigs is, however, not nutritionally balanced and sustainable to improve smallholder pig production. Feed shortages and poor feed quality, therefore, play an important role to low productivity of pigs in smallholder production system. Feed shortages are mostly experienced during the dry seasons such that pigs are obliged to scavenge in the bushes, garbage areas, fields and roads (Chikwanha *et al*., 2007). Consequently, smallholder pig farmers slaughter their pigs or sell to reduce the number of pigs per household (Chiduwa *et al*., 2008). There is, therefore, the need to identify feed resources such as PBPs that have a potential to be sustainable for the betterment of smallholder pig production.

2.3 Availability and production of potatoes

In 2013, about 376 453×10^3 tonnes of potatoes were produced worldwide (FAOSTAT, 2015). Potatoes that were directed to processing increased from 116 400×10^2 tonnes in 2008 to 130 478×10^2 tonnes in 2011 (FOASTAT, 2015). In Africa, where smallholder pig production is commonly practised, South Africa is the fourth top producer of potatoes with an estimate of 2 252×10^3 tonnes of potatoes following Algeria (4 928 028), Egypt (4.8 × 10^6) and Malawi (4 35 955) in that order (FOASAT, 2015). According to Potatoes South Africa (2014), at least 20 % of South Africa's total table potatoes production are processed every year. The quantity of potatoes taken to processing is increasing yearly due to the expansion in the fast-food industry, the higher average income of the population, rapid rate of urbanization and the influx of international processing companies. About 635 potato South African farmers are active and their potato production is worth about 116 988 995 USD a year (DAFF, 2013). In addition, more than 1000 small-scale farmers are farming potatoes. In South Africa, potatoes production is not seasonal. Different provinces plant and market potatoes in different seasons ensuring a continuous supply of fresh potatoes throughout the year (Potato South Africa, 2014).

2.4 Nutritional composition and bulk characteristics of potato by-products

To enlarge the period of availability of PBPs with the aim to minimise feed shortages in the pig-feeding scheme, there is a need to determine their nutritional and physical composition. This helps in determining appropriate feeding strategies for smallholder pig farmers. Understanding the effect of PBPs on performance of pigs is also contingent upon understanding the chemical and physicochemical composition.

Quality of PBPs vary with the area of potato production and the method of extracting the starch. Because of these variations, it was deemed necessary to assess PBPs separately. Common PBPs are potato peels, potato pulp, and potato hash.

2.4.1 Potato peels

Kaparaju and Rintala (2005) defined potato peels as the outer epidermal layer of potatoes that is removed during processing. Waste generated by peeling process contributes considerably to the total waste produced during potato processing. The nutritional and physical properties of potato peels are quite variable depending on the environmental conditions, cultivar, growth and storage, and according to processing treatment and procedures (Whittemore, 1977).

Processing procedures such as lye, steam and abrasion peeling highly influence PBP nutrient composition particularly the starch of potato peels. Lye processing involves the use of sodium hydroxide (lye) followed by mechanical peeling. Hinman and Sauter (1978) reported that potato peeling using the lye processing procedure produced about 14 % of solids. The lye procedure also yielded between 500 and 560 g/kg DM starch, 56 g/kg DM of crude protein, 76 g/kg DM of crude fibre, 69 g/kg DM ash and 1 g/kg DM of fats. Peels produced through lye processing are highly alkaline (pH 12 to 14) and should be neutralised before being considered as feed to animals. Lye peels are stable microbiologically and feeding value does not get lost when stored provided the pH remains high.

Lunen *et al*. (1989), on the other hand, described steam peeling as when potatoes are subjected to steam pressure at a temperature of about 200^{o}C for few seconds. Notably, sodium hydroxide is not used in the process. The peel is removed by a scrubber and leaves the processing line as gelatinous slurry containing about 15 g/kg DM. Potato peels have a variable DM content ranging from 120 to 276 g/kg DM, and 123 to 170 DM g/kg of crude protein (Table 2.1). Steaming effectively deactivates proteolytic enzyme inhibitors and partially denatures the starch (Lunen *et al*., 1989). The potato starch has about 20 % amylose (Noda *et al*., 2008) that is not generally accessible by digestive enzymes. The abrasion peeling method gives more starch, less dietary fibre and lignin than the steam peeling procedure (Camire *et al*., 1997). It is, therefore, pertinent to have background information about processing procedure used to generate potato peels when estimating their nutritive value. The high ash content of potato peels shows that there is some contamination from soil adhering to the potato skins (Nicholson *et al*., 1988).

As depicted in Table 2.1, potato peels are a good source of energy with 10.9 MJ/kg DM of metabolisable energy and dietary fibre while low in protein and calcium. The high dietary fibre of about 410 g/kg NDF in potato peels can promote pig welfare, enhancing gut health and microbial population and growth in the hindgut. Dhingra *et al*. (2012) reported that bulk and true density of extracted potato peel fibre was observed to be 246.3 and 1855 $kg.m^{-3}$, respectively. Water-holding capacity of potato peel fibre ranges from 5.05 to 5.60 g of water g^{-1} dry sample.

2.4.2 Potato pulp

Potato pulp is generated from the production of starch from raw potatoes and used as feed for livestock (Okeno *et al*., 2005). Potato pulp is made up of cell walls of potato tuber including the skin, and residual intact cells containing starch that are mixed with potato liquid (Mayer and Hillebrandt, 1997). It is rich in starch, cellulose, hemicelluloses, pectin and salts (Mayer and Hillebrandt, 1997). Nutritional composition and physical properties of potato pulp largely depend upon botanical origin and the type of processing used (Serena and Bach Knudsen, 2007).

Table 2. 1: Chemical composition of potato by-products

Components	Potato peels	Potato pulp	Potato hash
Dry matter (g/kg)	120 – 276	142 -170	150 -155
Metabolisable energy for pigs (MJ/kg DM)	10.9	-	11.2 -11.4
Ether extract (g/kg DM)	5.0 - 21.1	6 - 6.2	100 -110
Water soluble carbohydrates (g/kg DM)	10.0	-	22
Starch (g/kg DM)	323 – 521	177 - 249	700 -704
Crude protein (g/kg DM)	123 – 170	49 - 61	105 -110
Calcium (g/kg DM)	0.07 - 2.40	-	-
Phosphorous (g/ kg DM)	0.23 - 2.50	-	-
Ash (g/kg DM)	62.2 -111	36	39 - 43.1
Crude fibre (g/kg DM)	61.0-125	205	57.5 - 58.8
Neutral detergent fibre (g/kg DM)	410	353 - 462	360- 370
Acid detergent fibre (g/kg DM)	63.0	262 -342	153 -163
Acid detergent lignin (g/kg DM)	38.0	35	50.0 - 53.2
Hemicellulose (g/kg DM)	347	227	207
Cellulose (g/kg DM)	25.0	202	110
Sources	Edwards *et al*., 1986; Nicholson *et al*., 1988; Lunen *et al*.,1989; Scholten *et al*. 2001b; Hossain *et al*., 2015	Serena and Bach Knudsen, 2007; Pastuszewska *et al*.., 2009;Omer *et al*., 2011; Dhingra *et al*., 2012;	Nkosi, 2009; Thomas *et al*., 2010.

As shown in Table 2.1, potato pulp has high moisture content and low levels of crude protein. Kita (2002) compared potato pulp and raw potato, the starch content was relatively low in potato pulp, which is counteracted by an increase in the concentration of residues in dietary fibre with cellulose and total dietary fibre being around 10 times higher in potato pulp than in raw potato. Potato pulp consists of about 55 % of non-starch insoluble carbohydrates (mainly cellulose), 45 % of soluble fraction (mainly pectins) and has low viscosity and high water-holding capacity. Serena and Bach Knudsen (2007) reported that potato pulp had a high content of soluble fibres, which resulted in high water holding capacity and swelling capacity (16.2 ml/g). Similarly, Pastuszewska *et al*. (2009) indicated low viscosity (0.89 millipascal-second), high swelling, and water binding capacity. The swelling capacity of starch is directly associated with the amylopectin content because the amylose acts as a diluent and inhibitor of swelling (Singh *et al*., 2003).

Serena and Bach-Knudsen (2007) analyzed the constitutive sugars of the different fibre fractions of potato pulp. Potato pulp had high levels of dietary fibre (612 g/kg DM), uronic acids (156 g/kg DM) and galactose (133g/kg DM). This clearly indicates that potato pulp is rich in pectic substances (Pastuszewska *et al*., 2009). Swelling of fibre-rich feedstuffs such as potato peels within the aqueous medium of the gut affects digesta water uptake and mineral absorption, and determines diffusion rate and the response of intestinal smooth muscles to bulky diets (Elhardallou and Walker, 1993). Potato starch swells reversibly due to the imbibition of more than 50 % water by weight (Nelson, 2010). High swelling capacity (8.3 ml/g) of potato pulp, therefore, tend to occupy more space in the gut, thereby limiting feed intake (Ndou *et al*., 2013). Physicochemical properties of potato pulp limit its utilisation for growing pigs, while in sows and finishing pigs, the potential is higher primarily due to their enhanced ability to utilise fibrous feeds (Bindelle *et al*., 2008).

2.4.3 Potato hash

Potato hash, a by-product derived from the production of snacks and chips, is available mostly in South Africa as an animal feed (Nkosi *et al*., 2010). Potato hash is made of potato peels (which contribute the largest portion), starch, rejected raw potatoes and small quantities of yellow maize. Potato hash is available in large quantities that can provide an alternative sustainable feeding system for smallholder farmers. Whittemore (1976) reported that harvesting season and cultivar also influence nutritional profile of potatoes and their by-products.

As shown in Table 2.1, potato hash has high moisture content. The high levels of moisture has a considerable effect upon nutrient concentration and could have a filling effect in the gut. Such information could be of paramount importance when predicting voluntary feed intake of pigs. The water contents vary with processing and water usage during processing. High starch content from potato hash might be attributed to the processing method used and may play a major role for the wellness of pigs. Potato starch has resistant granules (resistant starch) that are resistant to breakdown by endogenous enzymes. The resistant starch is not absorbed in the small intestine, passes to the large bowel, and beneficially modifies gut microbial populations (Englyst *et al*., 1992). High mega joules of metabolisable energy found in potato hash suggest that it can successfully substitute cereal grains. Nkosi (2009) reported that potato hash contains low levels of water-soluble carbohydrates. Potato contains low levels of the major minerals, except potassium (27.9 g/kg DM), which is in great excess (Whittemore, 1977; Van Lunen *et al*., 1989). High NDF content of potato hash indicates a reduction in nutrient density and bulkiness. Information on swelling capacity, water holding capacity and viscosity of potato hash is not available in the literature.

2.5 Nutrient digestibility of potato by-products

The digestibility of DM and energy is consistently high for a whole range of potato products (Table 2.2) but the digestibility of crude protein is low. Similarly, in a digestibility study with pigs, Whittemore *et al*. (1973) reported that the apparent digestibility coefficients of energy for cooked potato flour, dried potato dice and raw mash were 0.96, 0.95, and 0.92, respectively. The high energy and DM digestibility indicates that pigs digest processed PBPs easily. Small proportion of DM that escapes the foregut may also have different bulk equivalents thereby influencing digesta transit and gut emptying in growing pigs (Kyriazakis and Emmans, 1995). Friend *et al*. (1963) reported that potato pulp has a crude protein content of about 70 g/kg DM and only 25 % digestible (Table 2.2). These findings emphasize the need for deactivate protease inhibition and protein supplementation of pig rations containing potato pulp. The high digestibility of crude protein in steam potato peel indicates that heating sufficiently deactivates the proteolytic enzyme inhibition.

Standardized ilieal digestibility (SID) of crude protein and amino acids, which accounts for endogenous losses, is also required. In piglets, Urbaityte *et al.* (2009) reported that SID of indispensable amino acids in potato protein range from 75 to 92 %. The SID of amino acids and crude protein for different PBPs and effects of glycoalkaloids (GAs) on SID of crude protein and amino acids in pigs needs investigation. Ensiling improves the digestibility of NDF and acid detergent fibre (ADF) by microorganisms that break down fibre fraction. Ensiling can modify the structure of the fibrous components in the feedstuff such as potato hash during fermentation and improve their utilization (Kanengoni *et al*., 2015).

2.6 Response in performance of pigs fed on potato by-products

Lunen *et al*. (1989) used the dose-response approach to assess performance of pigs fed on graded levels of steamed potato peels.

Table 2. 2: Apparent total tract digestibility coefficients of nutrients in pig diets containing potato by-products

Nutrient	Steam peel	Dried potato pulp	Fermented potato pulp	Potato hash silage
DM	0.882	0.807	0.815	0.964
OM	-	-	-	93.29
GE	0.86	0.785	0.806	-
CP	0.782	0.255	0.762	0.965
EE	-	-	-	0.986
NDF	-	-	-	0.684
ADF	-	-	-	0.655
Sources	Lunen *et al*., 1989	Friend *et al*., 1963	Li *et al*., 2011	Thomas *et al*., 2012

DM, dry matter; OM, organic matter; GE, gross energy; CP, crude protein; EE, ether extract; NDF, Neutral detergent fibre; ADF, acid detergent fibre.

No differences were found among treatments on feed intake and growth performance (Table 2.3). This suggests that steaming process destroyed possible detrimental components in the potato peel diets that may have compromised feed intake and growth performance. Differences in steaming temperature and duration, variety of potatoes, processing managements and proportion of starch components may, however, influence appropriate inclusion levels of steamed potato peel. Edward *et al*. (1986) and Nicholson *et al*. (1988) recommended an inclusion level of 250 g/kg of steamed potato peel in finishing pigs, whereas Lunen *et al*. (1989) suggested that steamed potato peels could be incorporated into the diet up to 300 g/kg. Edward *et al*. (1986) reported a reduction in body weight gain and dressing percentage of pigs when fed on steamed liquid potato peels could be explained by high crude fibre (60.1 g/kg DM) and low digestibility of dietary energy. There is no contemporary data on the effect of dried potato pulp on the performance of pigs. As shown in Table 2.3, feeding fermented potato pulp had a positive effect on the performance of lactating sows.

Fermentation by microbes modifies the fibre fraction in potato pulp. During fermentation, microorganisms convert starch and sugars into lactic acids, volatile fatty acids and alcohol (Scholten *et al*., 1999). Sows make use of these products efficiently (Xue *et al*., 2011). Sows have well established microorganisms in the hindgut that ferments fibrous feedstuffs. Therefore, fermenting potato pulp prior to feeding facilitate fermentability and absorption. Feeding fermented potato pulp also increased milk production, although the reason is not clear. Feeding 50 g/kg fermented potato pulp improved body weight gain and feed conversion efficiency without any detrimental effects on carcass traits of growing-finishing pigs. Feeding fermented potato pulp has wellness benefits in pigs. Scholten *et al*. (1999) reported that fermented diets reduce the gastric pH and the number of coliform bacteria in the gut and may positively affect pancreatic secretion, and villus architecture compared with non-fermented diets.

Table 2. 3: **Effect of potato by-product on the performance of pigs**

Potato by-product	Breed	Inclusion level (%)	Processing	Response	Reference
Potato peelings	Yorkshire	0, 10, 15, 20, 25 and 30	Steaming	• No difference on feed intake and growth performance among treatments.	Lunen *et al*. (1989)
	LR x Yorkshire	0, 15, 20 and 25	Steaming	• Faster weight gain and favourable feed conversion for the control diet	Nicholson *et al*. (1988)
	-	0 and 25	Steaming	• Replacement of 50 or 35 % of the meal with liquid potato feed reduced feed intake and live weight gain in finishing pigs.	Edward *et al*. (1986)
Potato pulp	Yorkshire	0, 15, 30 and 45	Dried	• Maximum of 15 % potato pulp allowed satisfactory live weight gain and feed efficiency in growing pigs. • 45 % potato pulp reduced depth of shoulder and loin fat	Friend *et al*. (1963)
	LW X LR	0 and 5	fermented	• Weight loss of lactating sow had a tendency to decrease • Shorter weaning to estrus interval and litter birth weight was high • Higher plasma urea nitrogen and luteinizing hormone.	Xue *et al*. (2011)
	Duroc×LR×LW	0 and 5	fermented	• Increased weight gain and feed intake in growing to finishing pigs • Improved feed conversion • Decreased plasma urea nitrogen and alanine aminotransferase	Li *et al*. (2011)
Potato hash	LW X LR	0 and 40	Ensiled	• Lower final body weight, average daily gain and slow feed conversion ratio in growing pigs as compared to control	Thomas *et al*. (2010)
	LW X LR	0 and 40	Ensiled	• Pigs on the control diet had heavier slaughter weight than those that fed on diets that contained potato hash	Thomas *et al*. (2013)

LR X LW: Large White and Landrace crossbred.

Growth performance of pigs fed on ensiled potato hash diet was reduced (Table 2.3). Inclusion of 400 g/kg potato hash compromises growth performance since the feed is bulky and reduces the nutrient density of the feed (Kyriazakis and Emmans, 1995; Ndou *et al*., 2013). Information on the effect of PBPs on digesta rate passage in pigs is scarce. In rats, potato starch has been reported to shorten transit times (Ferguson *et al*., 2000). On the other hand, Le Blay *et al*. (1999) highlighted that transit time did not change by potato starch-based diet in any time period. There was also a high faecal output in rats fed potato starch. Bhandari *et al*. (2009) reported that pigs fed on 140 g/kg resistant potato starch consumed more feed than pigs fed on 70 g/kg. High feed consumption could be explained by that resistant starch has high water holding capacity that measures the ability of the feed to withhold water. Thus, a diet with a high water holding capacity such as potato peels can hold more water and occupies more space in the gut subsequently feed consumption is affected.

2. 7 Processing methods of potato by-products and effects on nutritional composition

Raw potatoes and PBPs are not palatable and it is difficult to get pigs to consume large quantities of them. At a certain stage of growth, pigs cannot make effective use of PBPs unless it is processed sufficiently to denature the starch and inactivate proteolytic enzyme inhibitors. It is, thereby, vital to process potato by-products with an objective to ease their utilisation whilst preserving them for sustainable and future use. Practical processing procedures that are accessible to smallholder farmers include boiling, sun drying, liquid fermenting and ensiling. These inexpensive processing or treatment methods may be applied to potato peels, potato pulp and potato hash.

2.7.1 Boiling

Boiling, also refereed as water cooking, is defined as cooking of foods in boiling liquid in a pot set on a hot burner (Fabbri and Crosby, 2016). Boiling vary with temperature, intensity of heat and period. It is a common and affordable type of processing of PBPs because it requires locally available inputs such as water, pots, matches and wood sticks. Potato by-products may be prepared by boiling them in the barrel using a steam boiler. Stea *et al*. (2007) reported that boiling of peels and unpeeled potatoes resulted to decrease in folate retention to 72 and 59 %, respectively. In contrast, McKillop *et al.* (2002) reported that boiling of whole potatoes (skin and flesh) for 60 minutes did not reduce folate content. Whittemore *et al*. (1973) boiled potatoes for 20 minutes. The major limiting factor about boiling is that common pots in smallholder production systems have a limited volume. Therefore, the feed can only supply limited number of pigs at a particular time. In addition, the preservation measures after boiling are difficult and unaffordable, indicating that PBPs should be fed shortly after boiling. Boiling PBPs for pigs is common for rural Vietnam. Augustin *et al*. (1979) did a comparative analysis of raw and boiled potato peel and flesh. They reported that boiling did not affect nutrient profile of potato peels and flesh. Potato peel contains significantly higher amounts of ash, crude fibre, protein and riboflavin but less thiamine than the corresponding potato flesh. Boiling retains iron, copper, and carbohydrates (Ikanone and Oyekan, 2014). Whittemore *et al*. (1973) indicated that boiling improves digestibility and utilisation and is acceptable by pigs of all stages. The positive effect of boiling on the nutritive value of potatoes is most likely due to an improvement in the efficiency of dietary nitrogen utilization (Whittemore *et al*., 1975). The plausible explanation regarding the positive effect of boiling on nutritive value is that boiling potatoes denatures the starch and inactivates proteolytic enzyme inhibitors. Likewise, Whittemore (1977) reported that boiling changes the structure of the potato starch granules rendering them susceptible to enzyme attack.

2.7.2 Sun drying

Sun drying is the process of dehydrating moisture content through exposing feedstuffs to sunlight. It is more economical than the use of fresh PBPs. As outlined in Table 2.4, dried potato peels contains 17.2 MJ gross energy, 981 g/kg DM and 82.5 g/kg DM crude protein. Whittemore (1977) argued that the major effect of drying on the chemical composition of potato products is in the content of DM, unless the process also causes potato mass fraction. To facilitate storage and transportation, sun drying of potato by-products is advisable. Sun drying and milling potato pulp results in a powder-like material that can be stored in conventional storage, transported and mixed with other feeds (Dinusson *et al*., 2014). Smallholder farmers from Vietnam usually cut potatoes and sweet potatoes into small pieces by hand and dry them in the sun (Giang *et al*., 2004). Bhila *et al*. (2010) reported that sun drying of agro-industrial by-products reduces microbial load and may be an acceptable method for use by small-scale farmers especially for preservation purposes. Sagar and Kumar (2010), on the other hand, reported that preservation of PBPs through sun drying might reduce quality and lead to product contamination by microbes.

2.7.3 Fermented liquid feed

Fermented liquid feed is defined as a mixture of feed and water stored in a tank at a certain temperature and for a certain time, before it is fed to animals (Canibe and Jensen, 2003). This processing procedure can easily be applied under smallholder farming conditions. It is also referred to as soaking. A short-term perseveration technique is used to store liquid by-products (Edwards *et al*., 1986; Scholten *et al*., 2001a). Its benefits are related to feeding and drinking behaviours particularly to weaned pigs (Canibe and Jensen, 2012).

Table 2. 4: Chemical composition of potato by-products (g/kg DM) processed in different ways

Potato by-product	GE (MJ)	DM	CP	EE	CF	Ash	NDF	ADF	Source
Potato peels									
Dried	17.2	981	82.5	-	-	-	-	-	Whittemore (1997)
Fermented	-	129	18.0	1.5		7.4			Scholten *et al*. (2001b)
Potato pulp									
Ensiled	17.7	158	49.0	6.1	-	26	353	337	Okeno *et al*.(2005)
Ensiled		400	118	13			347	215	Pen *et al*.(2005)
Ensiled	-	-	116	-	-	47	210	174	Nelson *et al*. (2000)
Solid fermented	-	648	92.0	19.2	86.0	24.0	-	-	Li *et al*. (2011)
Dried	-	870	165	-	-	42.3	-	-	Nicholson *et al*.(1964)
Dried	-	888	70.4	1.4	77.5	27.0	-	-	Friend *et al*.(1963)
Dried	16.6	870	90	-	26	-			Whittemore (1997)
Potato hash									
Ensiled (700 PH:300 Maize cobs)	-	337	-	12.0	-	31.4	633	335	Ncobela (unpublished data)
Ensiled (800 PH: 200 *Eragrostis curvula* hay)	-	232	72.3	45	334	60.4	-	-	Nkosi (2009)
Ensiled (700 PH : 300 wheat bran)	18.5	457	158	64.5	-	-	285	94.5	Thomas *et al*. (2010)

GE, Gross energy; DM, Dry matter; CP, crude protein; EE, Ether extract; CF, Crude fibre; NDF, Neutral detergent fibre; ADF, Acid detergent fibre

Edwards *et al*. (1986) explained the on-farm storage and handling of liquid potato feed. The liquid potato was delivered by a truck and was stored in a closed tank. A paddle was fitted inside the tank to prevent separation within the liquid potato feed and provide consistent product for feeding. In a laboratory study, the microbiological quality of liquid potato feed stored for seven weeks was good but nutritive value deteriorated as carbohydrate was transformed to organic acids. In South Africa, liquid fermentation of PBPs and other non-conventional feed resources is gaining interest. Thomas (2016) prepared fermented liquid diets by mixing diet with fresh potato hash with water, at a ratio of 1:2 (diet: water). Canibe and Jensen (2003) fermented liquid feed by storing it in a closed tank under agitation at 20°C for 4 days before being offered to pigs. Scholten *et al*. (2001b) determined effects of a 6-day storage period on changes in nutrients of potato steam peel. The loss of DM for potato steam peel was 6.2 %. The starch also decreased to 24 % and the decrease in gross energy was not significant. As shown in Table 2.4, fermented potato pulp has DM content of 648 g/kg, crude protein of 92 g /kg and 86 g /kg of crude fibre. The high DM content could be associated with the use of solid-state fermentation (Li *et al*., 2011). Scholten and co-workers (2001a) stated that fermenting decreased the pH and acid-binding capacity in potato steam peel during storage. Feeding fermented potato pulp to pigs appears to be an effective means of utilizing a previously underutilized resource (Xue *et al*., 2011). It is not clear whether or not fermenting improves fibre utilisation from of PBPs.

2.7.3 Ensiling

Ensiling is a historical and technological method used to preserve a crop or material of high moisture by producing anaerobic conditions under controlled fermentation (McDonald *et al*., 1991; Ashbell *et al*., 2001). Kanengoni *et al*. (2015) argued that even though ensiling is primarily for preservation of forages, it also reduces fibre levels and improves the utilisation of fibrous feeds. As shown in Table 2.4, Okeno *et al*.

(2005) reported that ensiled potato pulp has 17.7 MJ/kg DM, 158 g/kg, 353 g/kg DM and 337 g/kg DM of gross energy, DM, NDF and ADF, respectively. Ashbell *et al.* (2001) and Nkosi (2009) described simple and affordable ensiling procedure for pig farmers. They reported that PBPs are ensiled by compacting in 200-litre drums lined with a polyethylene plastic bag. After compaction, the plastic bags are knotted and tighten using silo bags and bricks to disallow aerobic conditions. The drum is closed with a rubber lid to prevent any damage to the bags by rodents. These drums are stored at a temperatures ranged from 22 to 29 ^{o}C. Plastic bags and drums are relatively inexpensive and few workers are required to make silage. Smallholder pig farmers can also appreciate this method. It is an efficient way of preserving high moisture by-products if all essential principles of ensiling are followed (Cao *et al*., 2009).

For materials to be well ensiled, they should have high concentrations of water-soluble carbohydrates (WSC), low buffering capacity, a DM content of between 250 to 400 g/kg and host an adequate lactic acid bacteria (LAB) population prior to ensiling (Nkosi and Meeske, 2010). Potato by-products contain relatively low concentrations of WSC and LAB (Okine, 2005; Nkosi and Meeske, 2010). Most lactic acid bacteria are destroyed during the food processing of the potato (Moon, 1981). Therefore, PBPs require silage additives and inoculants to improve the fermentation and nutritive value during ensiling. On the other hand, Okeno *et al*. (2005) indicated that PBPs can be ensiled without use of inoculants and additives. This clearly shows that it depends on the PBP produced and factory processing of the potato food product. Potato by-products also have a DM content that is below the recommended level for making good quality silage (Nkosi, 2009). This necessitates the use of locally available feed absorbents such as barley, straw, bran, sugar beet pulp, hay, straws and poultry litter, maize cobs to raise DM levels, improve compaction and ensiling (Nkosi, 2009). Thomas *et al*. (2010) blended potato hash with wheat bran as absorbents and found 258 g/kg DM and 94.5 g/kg DM of NDF and ADF, respectively.

Okeno *et al*. (2005) showed that ensiling potato pulp with *Lactobacillus rhamnosus* and *Rhizopus oryzae* and their combination reduces the pH and improves the fermentation quality of the potato pulp silage. Nkosi *et al*. (2010) inoculated potato hash silage with *bonsilage forte* and *Lalsil Fresh* bacterial inoculants. The pH, water-soluble carbohydrates, butyric acid and ammonia N was reduced while lactic acid increased. *Bonsilage forte* contains strains of *Lactobacillus paracasei*, *Lactobacillus lactis* and *Pediococcus acidilactici*. The *Lalsil Fresh* has a *Lactobacillus buchneri* and is supplied by National Collection of Industrial, Marine and Food Bacteria, France. Sugarcane molasses and fresh cheese whey can be used as silage additives to ensile high moisture PBPs. They contain WSC, soluble and LAB that can benefit the ensiling process by increasing energy, protein and minerals (Nkosi and Meeske, 2010; Repetto *et al*., 2011). Whey is normally thrown away and sugarcane molasses is cheaply available, making them attractive resources for smallholder farmers (Kanengoni *et al*., 2016).

2. 8 Secondary metabolites present in potato by-products and their implications

The natural function of secondary metabolites is to serve as a defensive mechanism against herbivores, pests and pathogens, metal transporting agents, agent of symbiosis and sexual hormones (Demain and Fang, 2000). The use of the PBPs as pig feed ingredients submits these by-products to different processing and preservation methods that can alter the concentration metabolites. In addition, most of these compounds with high bioactivity are located in the potato's skin, and so are eliminated as PBPs (Akyol *et al*., 2016). These compounds have different physiological actions that could affect pig performance. The common metabolites are glycoalkaloids (GAs), calystegine alkaloids, protease inhibitors, lectins, phenolic compounds, and chlorophyll as well as processing-induced browning compounds and acrylamide (Friedman, 2006). Polyphenolic compounds and GAs are the predominant metabolites in potatoes and their by-products.

2.8.1 Effect of ensiling on natural antioxidants in potato by-products

The food-processing industry generates substantial quantities of phenolic-rich by-products that could be valuable natural sources of antioxidants. Potatoes and PBPs contain carotenoids (lutein, zexanthin, and violaxanthin), flavonoids (catechin and epicatechin) and phenolic acids. Brown (2005) highlighted that antioxidant activity is related to total phenolic acids. Potato by-products contain phenolic acids such as chlorogenic acid (which constitutes about 80 % of the total phenolic acids), gallic acid, caffeic acid and protocatechuic acid (Brown, 2005; Samarin *et al*., 2012). Potatoes also contain, on average, 20 mg per 100 g fresh weight of vitamin C, which may account for up to 13 % of the total antioxidant capacity. Data on the effect of ensiling on PBPs on natural antioxidants are limited. The impact of silage on antioxidants in PBPs is expected to be influenced by several factors such as species of microorganisms, pH, protein and peptides and temperature. Ensiling is a fermentation process that has the ability to improve antioxidant activity primarily due to an increase in the amount of phenolic compounds and flavonoids during fermentation, which is the result of a microbial hydrolysis reaction. Ensiling induces the structural breakdown of plant cell walls, leading to the liberation or synthesis of various antioxidant compounds (Hur *et al*., 2014). These antioxidant compounds can act as free radical terminators, metal chelators, singlet oxygen quenchers, or hydrogen donors to radicals. In the present study, the natural antioxidant were not analysed due to limited resources.

2.8.2 Effect of ensiling on glycoalkaloids in potato by-products

Potato GAs are naturally occurring, nitrogen- containing, and plant steroids with a carbohydrate side chain. The two major glycoalkaloids in domestic potatoes are α-chaconine and α-solanine (Friedman, 2006). Glycoalkaloids are dominant in PBPs because their site of synthesis is situated nearby the skin (Cantwell

1996). These plant steroids exert their toxic effects on the nervous system by interfering with the body's ability to regulate acetylcholine, a chemical responsible for conducting nerve impulses (Cantwell, 1996). Symptoms of animals suffering GAs poisoning include trembling, staggering, convulsions, weakness, diarrhoea, and sudden death (Nelson, 2010). Subjecting potatoes and PBPs to silage as preservation technique could minimise the concentration of GAs. Exposure of potatoes and PBPs to light in the field or marketplace lead to increased synthesis of glycoalkaloids (Vimala *et al*., 2011). Silage methods occurs under anaerobic conditions. These conditions are likely to reduce GAs due that silage method is practiced under protected ultra-violate light. Microorganisms, pH and temperature in the silage are also likely to lead to reduction of GAs. These aspects need exploration.

2.9 Summary

Potato by-products have the potential to be the alternative feed resource in pig production. They are a good source of energy and have acceptable levels of bulk properties and cell wall components. The nutrients from PBPs are digestible. Performance of pigs fed on PBPs vary with inclusion levels and method of processing. The utilisation of PBPs can be maximised through processing and preservation methods. Silage seem to be practical and possible preservation technique for pig farmers both in small and large scale. The processing methods that are accessible to farmers positively affects nutrient profile of PBPs. Lack of evidence on effect on ensiling methods on the concentration of phenolic compounds and potato alkaloids in PBPs warrants further investigation. Once such information is found, it will assists pig farmers to incorporate processed PBPs as an antioxidant for pork product and minimise anti-quality factors associated with using PBPs.

2.10 References

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CHAPTER THREE: Voluntary feed intake and growth performance of slow-growing pigs fed increasing levels of ensiled potato hash silage

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ABSTRACT

The objective of the current study was to relate voluntary feed intake and growth performance of Windsnyer pigs to increasing levels of potato hash silage. Thirty-six growing Windsnyer pigs (19 kg ± 5.59) (mean ± SD) were individually and randomly assigned to six experimental diets containing 0, 80, 160, 240, 320 and 400 g potato hash silage/kg DM. The experimental diets were derived from mixing a summit diet containing no potato hash silage and a dilution diet containing 400 g potato hash silage/kg in different proportions. Six pigs were fed on each diet *ad libitum* for five weeks. Average daily feed intake (ADFI), average daily gain (ADG), gain to feed (G/F) ratio, scaled feed intake (SFI), and scaled average daily gain (SADG) were measured weekly. Increasing levels of potato hash silage caused a decrease ($P < 0.05$) in ADG, G/F ratio and SADG. There were interactions of inclusion level of potato hash silage and week of feeding ($P < 0.05$) on ADFI. Pigs fed on a diet containing 240 g of potato hash silage/kg had higher ADFI in the second, third and fourth week of feeding. There was a quadratic relationship ($P < 0.05$) between ADFI and potato hash silage inclusion level. There was a linear decrease ($P < 0.05$) in ADG and G/F ratio and SADG as the levels of potato hash silage increased. Using piecewise regression, potato silage can be included up to 240 g potato hash silage/kg DM in Windsnyer pigs without negatively affecting growth performance.

Keywords: diet dilution, feed intake, pig performance, potato hash silage, Windsnyer pigs,

3.1 Introduction

Windsnyer pigs, which are found in parts of Mozambique, Northern Zimbabwe and eastern parts of South Africa, are among the population of slow-growing pig genotypes that are indigenous to Southern Africa (Holness, 1991; Halimani *et al*., 2010). The other genotypes include Kolbroek (South Africa) and Mukota

(Zimbabwe). Sadly, these breeds are in danger of extinction due to the introduction of fast-growing imported breeds such as Large White and Landrace, unbalanced admixture through uncontrolled crossbreeding and absence of information regarding these breeds (Halimani *et al*., 2010). Strategies to conserve these indigenous pigs are being developed. For example, the Agricultural Research Council (ARC) of South Africa is keeping a satellite population of Windsnyer pigs for conservation and research purposes. Despite the decreasing populations of slow-growing pig genotypes, they still play a pivotal role in the improvement of livelihoods of smallholder farmers. They provide a quality and tasty protein source and are important components of local economies at village level being used for income generation through selling and as investments (Mushandu *et al*., 2005; Madzimure *et al*., 2012). The marketing channels of pork from these pigs are, however, erratic. These pigs are overlooked because of their slow growth rates, small frame sizes, and excessive deposition of subcutaneous fat and stocky bodies (Chimonyo and Dzama, 2007). Some of these characteristics are, however, favourable, particularly for resource-limited smallholder farmers. The high subcutaneous fat deposited by these breeds can easily be trimmed off and used as lard for cooking purposes (Chimonyo and Dzama, 2007). The small frame sizes and slow growth rates are advantageous as they match the limited available feed resources (Chiduwa *et al*., 2008).

Instead of expensive conventional feeds, smallholder pig farmers feed slow-growing pigs with low quality and nutritionally imbalanced feed resources (Madzimure *et al*., 2012). This includes kitchen leftovers, rotten maize, coarse maize meal, maize cobs, maize husks, vegetables, pumpkins, watermelons, groundnut shells, fruits, grasses and brewers' waste. In a comparative study between Windsnyer pigs and Large White x Landrace, Kanengoni *et al*. (2015b) reported that Windsnyer pigs converted highly fibrous feeds, containing ensiled maize cobs, more efficiently than White x Landrace crosses. Nonetheless, the low productivity of Windsnyer pigs can be attributed to consistently low availability and poor quality of feed.

Consequently, pig farmers slaughter their pigs to keep limited numbers that can be supported by limited feed resources (Chiduwa *et al*., 2008; Ndou *et al*., 2013). It is important to identify other feed resources, such as potato hash, that have potential to sustainably improve productivity of slow-growing pigs.

Potato hash is a by-product derived from the production of snacks and chips (Nkosi and Meeske, 2010). It is made of potato peels, which contribute the largest portion. Potato hash also contains rejected raw potatoes and small quantities of yellow maize (Thomas *et al*., 2010). In South Africa, for example, factories that are manufacturing potato chips are located across nine different provinces and some are situated relatively close to rural areas. Smallholder pig farmers can take advantage of this by establishing cooperative initiatives to collect potato hash in large quantities for a nominal price. Potato hash is a good source of energy and starch, but has high fibre and low levels of protein (Nkosi and Meeske, 2010). It contains 150 g dry matter (DM) /kg, 700 g starch /kg, 11.16 MJ/kg metabolisable energy, 105 g CP/kg DM, 369.6 g NDF/kg DM and 162.5 g ADF/kg DM (Nkosi and Meeske, 2010.). The limitation of utilising potato hash is that, it is bulky with high levels of moisture, making it prone to putrefaction if not used within a short period of time. It is therefore worthwhile to investigate the value of prolonging the shelf life of potato hash by ensiling. Ensiling of wet-by-products is a suitable preservation strategy to ensure a stable supply of feedstuff for pigs (Ashbell *et al*., 2001). For potato hash to be well ensiled, it should have a DM content of between 250 to 400 g/kg (Nkosi and Meeske, 2010). This necessitates incorporating locally available dry feed absorbents, such as maize cobs, to raise DM levels and improve compaction during ensiling.

Very few, if any, dose-response trials have, however, been conducted to accurately determine the optimum inclusion level of potato hash silage that do not depress growth performance of slow-growing indigenous pigs such as Windsnyer pigs. The objective of the study was therefore to determine the effect of varying level of potato hash silage on feed intake and growth performance. It was hypothesized that incorporation of potato hash silage in pig diets improves growth performance up to an optimum inclusion level beyond which higher levels negatively affect average daily gain and gain: feed (G\F) ratio.

3.2 Materials and methods

3.2.1 Study site

The study was conducted at the Agricultural Research Council (ARC), Animal Production Institute, Irene, South Africa. The institute lies at about 25°34'0"S and 28°22'0"E and is approximately 1526 m above sea level. The average annual temperature is 18.7 °C.

3.2.2 Pigs, housing and experimental design

Thirty-six clinically healthy male growing Windsnyer pigs with an average initial body weight of 19 kg ± 5.59 (mean ± SD) were selected from the pig indigenous section of the Agricultural Research Council and used in the current study. The selection of pigs was based on body weight and age. The pigs were aged between three and four months and were already exhibiting signs of sexual maturity. The Windsnyer pigs were moved from the indigenous pig section, where they were housed in groups, to a trial facility where they were individually penned in a completely randomised design. The housing facility was cleaned thoroughly and disinfected a week before the trial was undertaken. The area surrounding the experimental house was also cleaned. The temperature and relative humidity in the experimental house were maintained at 24.5 (± 1. 9) °C and 62.7 (± 15.07) %, respectively. Six pigs were randomly assigned to each experimental diet. An environmental, facility and dietary acclimatisation period of seven days was allowed for pigs before data collection commenced. Feeders were manually adjusted in such a way that the feed was freely available every time. Water was available through low pressure nipple drinkers.

3.2.3 Collection and ensiling of potato hash

Fresh potato hash was collected from Simba®, a local food producing company. The potato hash was blended with ground maize cobs to increase the DM content to between 250 and 400 g/kg for good quality silage. The potato hash-maize cob mixture was in the ratio of 7:3. The potato hash mixture was then ensiled by compacting in 210 litre drums lined with polyethylene plastic bags. After compaction, the plastic bags were knotted and tightened to prevent aerobic conditions. Drums were closed with a rubber lid to prevent damage to bags by rodents. These drums were stored at temperatures ranging from 22 to 29 ^{o}C. The silage drums were opened weekly upon mixing of the diets to prevent spoilage.

3.2.4 Diets and feeding management

A total mixed ration without potato hash silage was formulated to meet or exceed the nutritional requirements of growing Windsnyer pigs (Carter *et al*., 2016) and was used as a basal or summit diet (Table 3.1). A bulky diet containing 400 g potato hash silage /kg was also formulated and used as the dilution diet (Table 3.1). Six diets containing 0, 80, 160, 240, 320 and 400 g /kg of potato hash were derived by mixing the summit and dilution diets in different proportions as described by Gous and Morris (1985). The percentage proportions of summit to dilution diets were 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100. The serial diets were not supplemented with stimulators or inhibitors.

Table 3. 1: Ingredient composition (g/kg DM) of the summit and dilution diets

Ingredient	Summit diet	Dilution diet
Ensiled potato hash	-----	400
Hominy chop	582.5	225.3
Soybean meal	160.6	200
Yellow maize	160.0	100
Wheat bran	40.8	13.7
Molasses	20.0	20.0
Feed lime	20.0	15.0
Lysine	4.6	8.0
Salt	4.0	4.0
Vitamin-mineral premix	4.0	4.0
Monocalcium	3.5	9.7

3.2.5 Chemical and physiochemical analyses of the diets and potato hash silage

Samples of all diets and potato hash silage were collected and analysed in triplicates (Table 3.2). Procedures from the Association of Official Analytical Chemists (AOAC, 2005) were used to determine the dry matter (DM, ID (Identity) 2001.12), ash (ID 942.05), crude protein (CP, ID 990.03) and ether extract (EE, ID 963.15). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to ANKOM Technology Method (Van Soest *et al*., 1991). The NDF content was assayed using heat stable α-amylase (Sigma A3306, Sigma Chemical Co., St. Louis, MO, USA). Digestible energy (DE) of potato hash silage and experimental diets were calculated from the equation adapted from McDonald *et al*. (2010). Digestible energy (MJ/kg) = 17.47+ (0.0076 × CP g/kg) + (0.0158 × Acid hydrolysed ether extract g/kg) - (0.0331× Ash g/kg) - (0.0140× NDF g/kg).

The bulk density of the diets and potato hash silage was measured using the water displacement method, as described by Kyriazakis and Emmans (1995). Briefly, 50 g of feed were weighed and placed into a 250 ml volumetric flask containing 100 ml distilled water in a water-bath at 37 ^{o}C. After mixing, an additional 50 ml of water were added and the contents were allowed to equilibrate for 15 min. Additional 50 ml water were then added. After allowing 15 min to equilibrate, the flask was filled by adding water. The total amount of water contained in the flask was subtracted from 250 ml. The water holding capacity (WHC) of diets was measured using the centrifugation method as described by Whittemore *et al*. (2003). Briefly, about 0.5 g of sample were measured into a known weight of a 50 ml plastic centrifuge tube and 25 ml distilled water was added. The tubes were sealed firmly and shaken intermittently for 24 hours. They were then centrifuged at 6000 ×g for 15 min at 20 ^{o}C. The supernatant was discarded and fresh weight of the sample was determined.

Table 3. 2: Chemical and physicochemical properties of potato hash silage and experimental diets

Component (DM)	Potato hash silage	Potato hash silage inclusion levels (g/kg)					
		0	80	160	240	320	400
Dry matter (g/kg)	337	886	845	801	744	730	662
Calculated DE (MJ/kg DM)	8.50	13.5	13.1	12.4	11.9	11.5	11.1
Crude protein (g/kg)	132	162	156	154	151	148	141
Ether extract (g/kg)	12.0	74.2	72.0	64.0	56.0		43.0
Ash (g/kg)	39.4	47.8	55.7	60.3	65.9	70.9	74.2
Physical properties							
Neutral detergent fibre (g/kg)	633	343	344	373	386	396	407
Acid detergent fibre (g/kg)	335	80.5	85.1	94.5	98.9	103	108
Acid detergent lignin (g/kg)	324	37.3	40.8	48.7	56.2	60.3	64.5
Bulk density (g/ml)	1.14	1.50	1.50	1.47	1.35	1.33	1.24
Swelling capacity (ml/g)	4.85	3.13	3.20	3.33	3.55	3.56	3.70
Water holding capacity (g_{water}/g_{feed} DM)	8.8	3.67	3.87	4.76	5.27	5.34	5.45
Calculated composition (g/kg)							
Dry matter	-	892	-	-	-	-	691
Crude protein	-	160	-	-	-	-	150
Crude fibre	-	57.0	-	-	-	-	220
Ash	-	27.0	-	-	-	-	16.3
Calcium	-	9.12	-	-	-	-	9.16
Phosphorous	-	5.46	-	-	-	-	5.43
Digestible energy (MJ/kg)	-	13.5	-	-	-	-	12.4
Lysine	-	11.5	-	-	-	-	13.5
Methionine	-	0.66	-	-	-	-	0.25

Samples were then dried at 103 ^{o}C for 20 hours. The weight of the fluid retained was calculated from the difference between fresh sample and dried sample. The weight of the fluid retained was divided by the weight of the dried sample to determine WHC, which was expressed in g water/g of dry material. Swelling capacity (SC) was measured according to Canibe and Bach Knudsen (2002). Samples of the experimental diets and potato hash silage, weighing 2 g were transferred into 15 ml measuring plastic tubes. A solution of 9 g/l NaCl containing 0.2 g/l NaN3 was added to a final volume of 10 ml where samples were incubated at 39^{o} C in a water shaking bath overnight. After 16 hours, the shaker was stopped and samples were left in the water for 1 hour before being taken out to measure the volume occupied by the experimental diets and potato hash silage.

3.2.6 Measurements

Average daily feed intake (ADFI), average daily gain (ADG) and gains/feed ratio (G: F), scaled feed intake (SFI) and scaled average daily gain (SADG) were measured. The ADFI was calculated as feed offered minus feed left-over and/or spilled from feeder in each week divided by seven. The ADG for each week was calculated as final weight minus the initial weight divided by seven. The G: F ratio was calculated as ADG divided by ADFI. The SFI and SADG were calculated to account for differences in mean pig weight. The SFI and SADG were calculated as g feed per kg body weight per day and g weight gain per kg body weight per day, respectively. The formula for SFI was $\frac{gramsoffeedperperday}{gramsofbodyweightperday}$

3.2.7 Statistical analyses

The effect of potato hash silage inclusion level, week and their interaction on ADFI, ADG, and G/ F ratio, SFI and SADG were determined using the PROC MIXED procedures (SAS, 2008) to account for weekly repeated measures. A polynomial regression (PROC REG) procedure of (SAS, 2008) was used to determine the relationships between ADFI, ADG, G/ F ratio, SFI and SADG against increasing levels of potato hash silage. The model that was used was:

$Y = B_o + B_1A + B_2A^2 + E$, where

Y = is the response variable (ADFI, ADG, G/ F ratio, SFI and SADG)

B_o= is the intercept

B_1A = linear regression component

B_2A^2 = quadratic regression component and

E = is the error.

The piecewise regression (broken-stick) was performed using NLIN procedure (SAS, 2008) to estimate the threshold value at which inclusion levels of potato hash cause ADFI to be constant or decrease as the incremental diet levels increased.

The model used was as follows:

$ADFI_i = \gamma_o + \gamma_1 (x_i) + \gamma_2 (x_i > x_c) (x_i - x_c) + \varepsilon_i$, when $(x_i > x_c) = 1$

Using parameters (γ_o, γ_1, γ_2) and the x_c, the two segmented simple regression functions were;

$ADFI_j = \gamma_o + \gamma_1 (x_i)$, for $x_i \leq x_c$ and

$ADFI_k = ADFI_o + (\gamma_1+\gamma_2) x_i$, for $x_i \geq x_c$

Where; $ADFI_i$ is when daily feed intake at maximum average

$ADFI_j$ is before inclusion levels of potato hash silage constrains ADFI

$ADFI_k$ is ADFI when potato hash silage inclusion level exceeds the optimum inclusion level

$ADFI_o = \gamma_o - \gamma_1 (x_c)$, where xi =0;

γ_o is the intercept or minimum ADFI when $x_c < 0$; γ_1 is the rate of change of ADFI when $x_i < x_c$; γ_2 is the rate of increase in ADFI when $x_i > x_c$; x_i is the value of the inclusion levels of potato hash silage and x_c is the optimum level of inclusion of potato hash silage beyond which further increase of the diet constrains ADFI; Ixc is the dummy variable with the value 0 and when $x_i < x_c$ and 1 when $x_i \geq x_c$. The entire measurements were considered significant at $P \leq 0.05$.

3.2.8 Compliance with ethical standards

The use and care of the experimental pigs were ethically proved (Reference number: APIEC16/015) by the Agricultural Research Council, Animal Production Institute Ethics committee (Appendix 2).

3.3 Results

Significance levels of the effect of potato hash silage, successive week of feeding and their interaction on the feed intake and pig performance are shown in Table 3.3. Incremental levels of potato hash silage was related to (P <0.05) on ADFI, ADG, gain (G) /feed (F) ratio and SADG. Week of feeding was related to (P <0.01) ADFI. Week of feeding resulted to a decrease in ADG, SADG and G/ F ratio. There was a significant interaction (P <0.05) between inclusion levels of potato hash silage and week of feeding on ADFI and final body weight. Figure 3.1 depicts the interaction between potato hash silage against the week of feeding on ADFI. Pigs fed 400 g/kg potato hash silage had a high feed intake in the first week of feeding.

Table 3. 3: Significance levels of performance of Windsnyer pigs fed on varying levels of potato hash silage for five successive weeks

Performance variables	Inclusion level	Week	Inclusion level × Week
Average daily feed intake	*	***	*
Average daily gain	**	***	NS
Gain : feed ratio	**	***	NS
Scaled feed intake	NS	NS	NS
Scaled average daily gain	*	***	NS

****p* <0.001; ***p*<0.01; **p*<0.05; NS not significant.

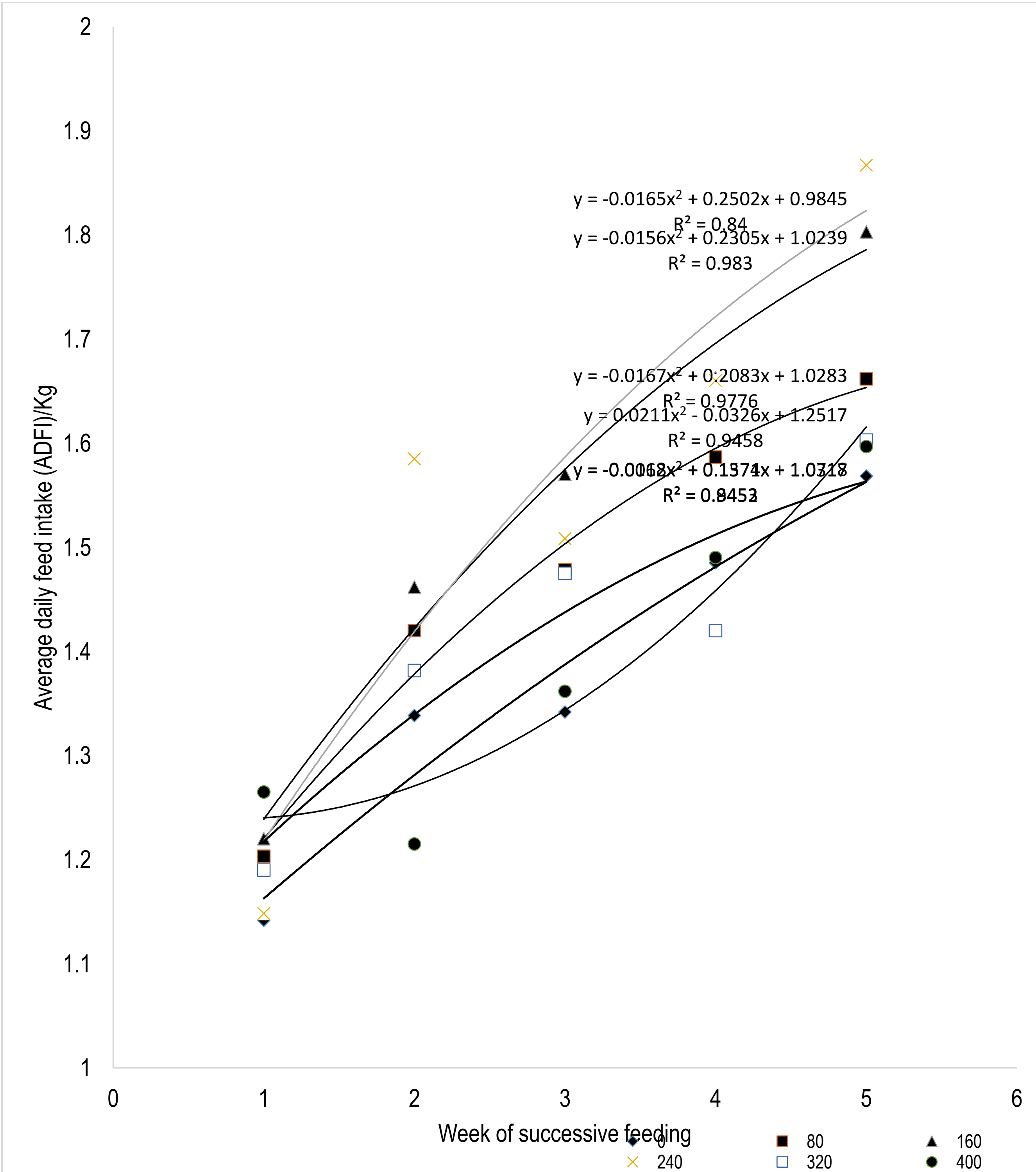

Figure 3. 1: Interaction of week of feeding and varying levels of potato hash silage

In the second week of feeding, pigs fed on 240 g/kg diet of potato hash silage had a high feed intake, whereas in week three, pigs on 160 g/kg diet of potato hash silage consumed more feed. On week four, feed intake for 160 g/kg and 240 g/kg were similar. In the last week of feeding, pigs fed on 240 g/kg had a greater feed intake.

Table 3.4 shows the overall relationship between inclusion levels of potato hash silage with ADFI, ADG, G/F ratio, SFI and SADG in growing pigs. There was a quadratic relationship between potato hash silage inclusion level (P <0.05) with ADFI. As the inclusion levels of potato hash silage increased, the ADFI increased at the increasing rate. Afterward, its rate of increase slowed down until it reached an optimum and then it started decreasing. There was a linear decrease (P <0.05) in ADG and G/F ratio as the potato hash silage level increased. The SADG also decreased linearly (P <0.05) as the potato hash silage level increased. Using piecewise regression, the maximum inclusion of potato hash silage was estimated to be 24 ± 4.72 g/kg and the plateau of ADFI was estimated at 1.55 kg (Figure 3.2). The minimum ADFI was estimated at 1.34 ± 0.081 kg. The rate of change of ADFI was estimated to be 0.02 ± 0.0092 kg. The estimate of rate of increase of ADFI was -0.002 ± 0.0013 kg.

3.4 Discussion

Determining the ability of Windsnyer pigs to utilize the available feed resources is an important initiative to characterize this breed and facilitates identifying ingredients that can be used to feed them in sustainable ways. This helps in efforts to conserve the Windsnyer pigs and other indigenous breeds. The effect of potato hash silage on the feed intake and growth performance of Windsnyer pigs using a dose-response trial is reported for the first time.

Table 3. 4: The relationship between potato hash silage against performance variables of growing pigs

Variable	Potato hash silage inclusion level						SEM	Regression co-efficient		R^2
	0	80	160	240	320	400		Quadratic	Linear	
ADFI (kg)	1.38	1.47	1.54	1.55	1.41	1.39	0.09	107.192748**	-318.375247^{NS}	0.20
ADG (kg)	0.41	0.39	0.33	0.31	0.32	0.24	0.03	379.658111*	-364.018376***	0.44
G:F ratio	0.29	0.27	0.21	0.20	0.22	0.17	0.03	307.128682^{NS}	-278.732047***	0.52
SFI (g/kg BW per day)	44.6	48.9	48.9	57.4	54.6	53.0	6.55	0.004626^{NS}	-0.285812^{NS}	0.10
SADG (g/kg BW per day)	15.9	15.8	14.2	14.2	14.1	11.3	1.25	0.243235^{NS}	-9.015212**	0.24

ADFI-average daily feed intake, ADG-average daily gain, G: F ratio- gain to feed ratio, SFI-scaled feed intake, SADG-scaled average daily feed intake ***p <0.001; **p <0.01; *p <0.05; NS-not significant

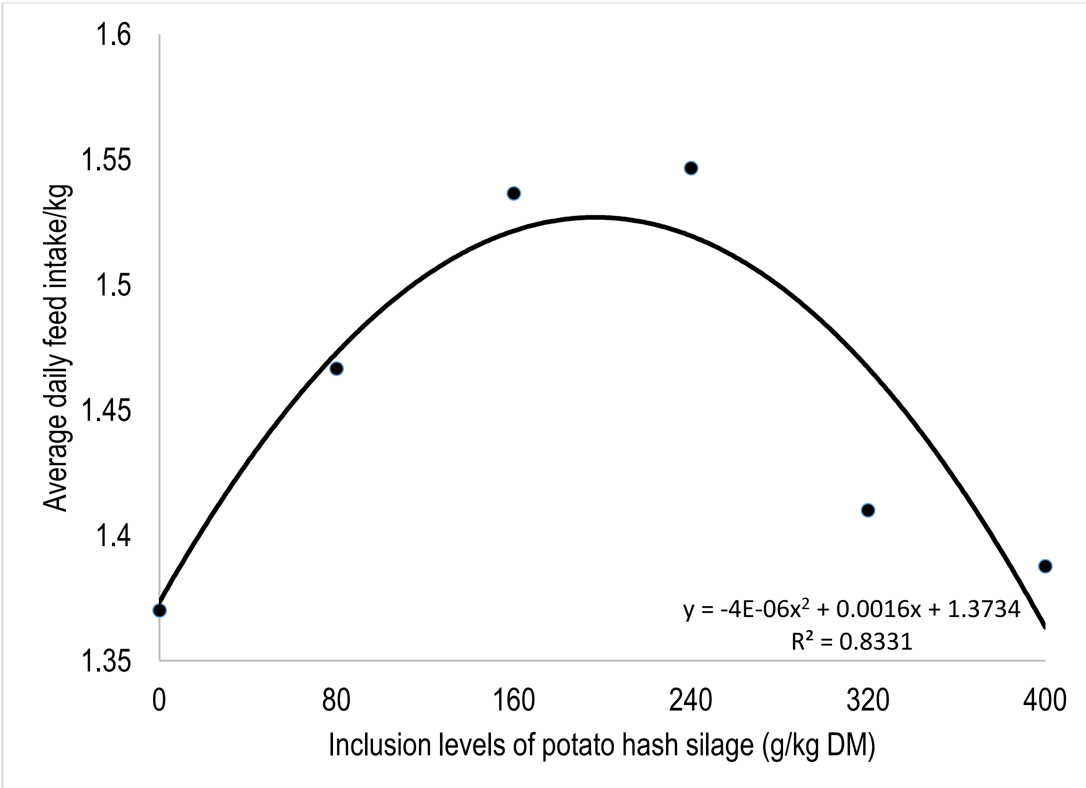

Figure 3. 2: Average daily feed intake of pigs fed on levels of potato hash silage shown with quadratic, plateau functions and estimated values

The method commonly used to measure nutrient requirements of pigs is one in which a basal diet is fed alone with increasing addition of test nutrient in a synthetic form (Gous and Morris, 1985). The drawbacks of this method are that each diet does not have same nutrient balance, which may influence the results. In addition, at high inclusion levels, the nutrient under test may no longer be limiting and pigs might be able to respond further if a new limiting nutrient was added. The diet dilution method is one way to solve these disadvantages. It involves a series of diets prepared by combining different proportions of summit mix (high digestible energy) with relatively low digestible energy. Thomas (2016) conducted a study on feed intake and growth performance of pigs fed liquid fermented potato hash. However, a dose response trial from increasing levels of potato hash silage was not conducted to accurately predict feed intake. It was then necessary to predict feed intake.

To predict pig performance, the starting point is feed intake (Emmans and Kyriazakis, 2001). The utilisation of potato hash can be maximised through processing and preservation methods such as ensiling (Nkosi *et al*., 2010). Potato hash silage can partially substitute energy and fibre-rich feedstuff for pigs such as maize and wheat bran, respectively. Pigs fed 400 g/kg DM of potato hash during the first week consumed more feed than other inclusion levels. An inclusion level of 400 g/kg DM of potato hash is bulkier. Hence, it reduces the density of nutrients. It has been reported that as nutrient density decreases, pigs are prompted to consume more feed to meet their nutrient requirements for potential growth (Kyriazakis and Emmans, 1995). High feed intake of pigs fed the 400 g/kg of potato hash in the first week could mean that these pigs adapted quickly to the diet, leading to improved consumption of the diet to meet their nutrient needs before gut capacity, rate of passage or some other factor constrained intake relative to other inclusion levels in subsequent weeks.

1. The variations in ADFI of pigs fed on different inclusion levels of potato hash silage with time are difficult to explain. They could be linked to variation in body weights (standard deviation of 5.59), which are known to directly influence gut capacity of pigs. It is hypothesized that this, in turn, resulted in the observed variations in feed intake with time. It could also be related to the fact that because feed was offered in large quantities (about 2.5 kg per day) for *ad libitum* feeding, pigs would overeat some diets such that intake was then also influenced by the rate of passage, palatability and not just gut capacity. Another observation from the study was that feeding potato hash silage needs to be gradual and monitored regularly. This is because adding potato hash silage diet to the remaining diet in the feeder could lead to mould development in bottom layers, thereby affecting feed intake. The observation that ADFI of pigs fed on the 240 g/kg DM of potato hash silage increased in week three to five compared to inclusion levels. This could be due to the fact that as the pigs were growing and their nutrient requirements increased, the concomitant increase in gut capacity allowed them to consume more quantities in an effort to meet their nutritional needs. This suggests that 240 g/kg DM inclusion levels of potato hash silage into the diet provides the right balance of all factors affecting feed intake in pigs fed diets containing potato hash silage leading to a gradual increase in take as the pigs grow.

The quadratic relationship of ADFI and potato hash silage level suggests that pigs increased feed consumption to compensate for the increase in indigestible material content so that they could acquire sufficient nutrients to achieve their growth potential (Ndou *et al*., 2013). Changes in ADFI are also linked to bulkiness of the feed, digesta, rate of digesta flow and size of the stomach (Wate *et al*., 2014). Windsnyer pigs are characterised by a small frame size, which may also limit ADFI. The high levels of moisture in potato hash silage diets have a considerable effect upon nutrient concentration and could also have a filling effect in the gut thus affecting ADFI. Potato starch swells reversibly due to the imbibition of more than 50 % water by weight (Nelson, 2010). Potato hash starch has about 45 % of soluble fibre fraction (mainly pectins) which results in high water holding capacity and swelling capacity. The swelling capacity of potato starch is directly associated with the amylopectin content because the amylose acts as a diluent and an inhibitor of swelling (Singh *et al*., 2003). Swollen potato hash silage, therefore, tends to occupy more space in the gut, thereby reducing feed intake (Ndou *et al*., 2013).

A linear decrease in ADG and G/F ratio with increasing levels of potato hash silage was expected. The decrease in ADG of pigs fed graded levels of potato hash silage could be related to unavailability or poor absorption of energy by pigs. Another reasonable explanation could be that during ensiling, micro-organisms did not sufficiently break down fibre from potato hash to facilitate energy absorption and utilisation. It is also possible that the maize cobs that was used as absorbents had a direct influence on utilisation of potato hash by pigs. Despite the fact that Windsnyer pigs have a specialised microbial community that enhances the utilisation of low quality feeds (Kanengoni *et al*., 2015a), they did not efficiently utilise potato hash silage. Potato peels, which contribute the largest portion of potato hash, are the resident sites of metabolites such glycoalkaloids that are poisonous to pigs (Cantwell, 1996). The effect of ensiling potato hash on the potato glycoalkaloids requires further investigation. The linear decrease in SADG with increasing levels of potato hash silage clearly indicated that initial body weight did not affect the daily gain. Using the broken stick model, inclusion of potato hash silage diet beyond 240 g/kg DM constrained ADFI. Unlike Thomas *et al*. (2010) who used 0 and 400 g/kg DM potato hash silage, the dose-response method renders accurate estimation of feed intake. There is a need to predict feed intake using physicochemical properties of potato hash silage so as to accurately determine energy and fibre requirement of pigs.

3.5 Conclusions

The increasing levels of potato hash silage related to ADFI, ADG, G/F ratio and SADG. The inclusion levels of potato hash silage and growth performance of Windsnyer pigs had a negative linear relationship. This suggests the need to inoculants or additives during ensiling to enhance fermentation and henceforth utilisation of potato hash silage by pigs. The ADFI increased with increasing levels of potato hash silage until the threshold was reached, then it started to decrease. Based on the ADFI, it can be concluded that the maximum inclusion level of potato hash silage was 240 g/kg DM. There is a need to determine relationship between inclusion levels of potato hash silage and nutritionally-related blood metabolites of Windsnyer pigs.

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CHAPTER FOUR: Changes in nutritionally-related metabolites of slow growing Windsnyer pigs fed on different levels of potato hash silage

ABSTRACT

The relationship between nutritionally-related blood biochemistry of Windsnyer pigs fed on potato hash silage were estimated. In a completely randomized design, 36 clinically healthy male growing Windsnyer pigs were randomly allotted to individual pens. There were six pigs per diet. The diet contained six increasing levels (0, 80, 160, 240, 320 and 400 g/kg) of potato hash silage fed to pigs for five weeks. Experimental diets were derived from mixing a summit diet containing no potato hash silage and a dilution diet containing 400 g potato hash silage/kg in different proportions.Pigs were allowed *ad libitum* access to diets and water. A polynomial regression was used to analyse the data. There was no relationship between inclusion levels of potato hash silage and albumin: globulin ratio, total protein and uric Acid. There was a positive linear relationship (P <0.05) between ensiled potato hash and albumin concentration. The equation was: Albumin = 7.54X -321.3. Globulin concentration increased quadradically (P >0.05) as inclusion levels of potato hash increased. The equation was: Globulin = 0.0199 X^2- 0.119 X +1.438. The activity of alkaline phosphatase was related to inclusion levels of potato hash silage. There was a quadratic increase (P <0.001) in alkaline phosphatase as the inclusion levels of potato hash increased. The equation was: alkaline phosphatase = 4.488X^2 + 20.124X +29.18. It can be concluded that increasing levels of potato hash silage had a positive linear relationship with nutritionally related blood metabolites.

4.1 Introduction

Windsnyer pigs are of no exception to the common slow-growing genotypes found in rural areas that scavenge and efficiently utilise fibre-rich feed resources and also match financial status of pig farmers (Kanengoni *et al.*, 2015). This breed has a black coat colour, compact body, small body structure and long nose. Windsnyer pigs enjoyed several attributes under extensive production system, which makes them ideal for enhancing food security. These include resistance to endemic diseases, excellent fertility, the ability to survive feed shortages and to use locally available feeds, the ability to withstand temperature extremes and their superior scavenging habits (Chimonyo *et al*., 2001). This necessitates the need of matching Windsnyer pigs with their conducive environment where they can grow and reproduce to their optimum levels.

Unfortunately, the population of Windsnyer pigs is diminishing because of the pig production organisations that are rapidly introducing fast-growing pigs to smallholder production system. The poor feed availability and quality conditions are, nonetheless, not favourable for the optimum production of fast-growing pigs. For example, Thomas *et al*. (2013) reported a reduction in carcass traits of Large White × Landrace when fed potato hash silage. Kanengoni *et al*. (2015) also cited that Windsnyer pigs performed better to ensiled maize cobs than Large White × Landrace pigs. Potato hash is an agro – industrial by-product originating from potato food production industries. It is available in bulk and discarded as waste. It is ordinarily used as silage in combination with absorbents due to its high moisture content (Nkosi and Meeske, 2010). To conserve Windsnyer pigs to avoid promotion of genetic erosion whilst promoting the use of potato hash silage, it is pertinent to firstly determine healthiness and toxicity of potato hash silage to Windsnyer pigs. There is a limited data on the contribution of ensiling as a perseveration method on the toxicity of potato hash silage. The objective of the study was, therefore, to determine changes in nutritionally-related blood biochemistry of slow growing Windsnyer pigs fed on different levels of potato hash silage. It was hypothesised that there is a positive linear relationship between nutritionally-related blood biochemistry of Windsnyer pigs and inclusion levels of potato hash silage.

4.2 Materials and methods

4.2.1 Study site

The study was conducted at Agricultural Research Council (ARC)-Irene, Animal Production Institute, South Africa. The institute lies at 25°34'0"S and 28°22'0"E and is approximately 1526 m above sea level. The average annual temperature is 18.7 °C.

4.2.2 Pigs, housing and experimental design

Pigs, housing and experimental design is as fully described in section 3.2.2.

4.2.3 Collection and ensiling of potato hash

Collection and ensiling of potato hash is described in section 3.2.3.

4.2.4 Preparation of diets

The preparation of diets is described in section 3.2.4.

4.2.5 Chemical and physiochemical analyses of diets and potato hash silage

The chemical and physiochemical analyses of diets and potato hash silage are similar as described in section 3.2.5.

4.2.6 Collection of blood samples and analyses

A 10 ml blood sample from each pig was collected through jugular venipuncture in non-coagulated vacutainer tubes (Becton Dickinson, Franklin, NJ), from each pig. This was done on the last day (day 35) of the trial. Samples were collected between 0700 to 0900h. After collection, blood samples were kept in cooler box with ice. They were then centrifuged (1000 × g 10 min at 25 °C) within two hours of collection, the sera were taken out and stored in polypropylene tubes and kept at - 20 °C, pending analyses. Determination of serum metabolite was done using IDEXX Vettest® Chemistry Analyser (IDEXX Laboratories, Inc., Westbrook, ME. USA). The IDEXX Vettest® Chemistry Analyser employs dry-slide technology that uses a potentiometric end-point. The analyte in the sample catalyzes a reaction sequence to yield products that absorb light at wavelengths in various regions (340-680 nm), diffuses into an underlying layer, and are monitored by reflectance spectrophotometry. The dry slide technology minimizes interferences from lipemic, icteric and hemolysed samples. The General Health Profile evaluated comprised albumin, alkaline phosphatase, total protein, uric acid and globulin (Appendix 1).

4.2.7 Statistical analyses

A PROC GLM (SAS, 2008) procedure was used to determine the effect of potato hash silage inclusion level on nutrition-related blood biochemistry of Windsnyer pigs. A polynomial regression (PROC REG) procedure (SAS, 2008) was used to determine the relationships between inclusion levels of ensiled potato hash and nutritionally related blood chemistry. The model that was used was:

$Y = Bo + B_1A + B_2A^2 + E$, where

Y = is the response variable (nutrition-related blood biochemistry)

Bo= is the intercept

B_1A = is the linear regression component

B_2A^2 = is the quadratic regression component and

E = is the error

4.3 Results

The relationship between inclusion levels of potato hash silage and nutrition-related blood biochemistry of Windsnyer pigs are depicted in Table 4.1. Inclusion levels of potato hash influenced albumin and globulin concentrations. Albumin concentration was generally high than normal range. The globulin concentration was, on the other hand relatively lower that normal range. The total protein concentration was numerically higher than the acceptable range. There was no relationship between inclusion levels of potato hash silage and albumin: globulin ratio, total protein (g/dL) and uric Acid (mg/dL).

As shown in Figure 4.1, there was a positive linear relationship (P <0.05) between ensiled potato hash and albumin concentration. The equation was: Albumin = 7.544X -321.326. The co-efficient of determination was 0.69. A positive quadratic relationship (P <0.05) between ensiled potato hash and globulin concentration was observed. The equation was: Globulin = $0.0199X^2$ - 0.119X +1.438. The co-efficient of determination was 0.84. As inclusion levels of potato hash silage increased, the albumin concentration increased in an increase rate. As inclusion levels of potato hash silage proceeded, albumin concentration increased at the decreasing rate until it reached the maximum, it started to decrease. The activity of alkaline phosphatase was related to inclusion levels of potato hash silage (Figure 4.2). There was a linear increase (P <0.001) in alkaline phosphatase as the inclusion of potato hash increased. The equation was: alkaline phosphatase = 4.488X + 29.18. The co-efficient of determination was 0.94.

Table 4. 1: Relationship between inclusion levels of potato hash silage and nutritionally-related blood metabolites of Windsnyer pigs

Variable	Normal ranges	Potato hash silage inclusion level (g/kg DM)						SEM	Regression co-efficient		Significance levels
		0	80	160	240	320	400		Quadratic	Linear	
Albumin (g/dL)	1.8 -3.3	6.46	6.79	7.42	7.47	6.83	7.19	0.181		7.545	*
Globulin (g/dL)	3.9 - 6.0	2.98	3.35	3.56	3.96	3.14	2.66	0.132	0.0199		*
Albumin: Globulin ratio	N/A	2.2	2.03	2.09	1.89	2.19	2.75	0.126			NS
Total Protein (g/dL)	6.0 - 8.0	9.47	10.1	10.9	11.4	9.97	9.85	0.194			NS
Uric Acid (mg/dL)	N/F	0.39	0.52	0.28	0.48	0.58	0.33	0.101			NS

***p <0.001; **p <0.01; *p <0.05; NS-not significant, N/A-Not applicable; N/F- Not found. Normal ranges were sourced from Kanengoni *et al*. (2017)

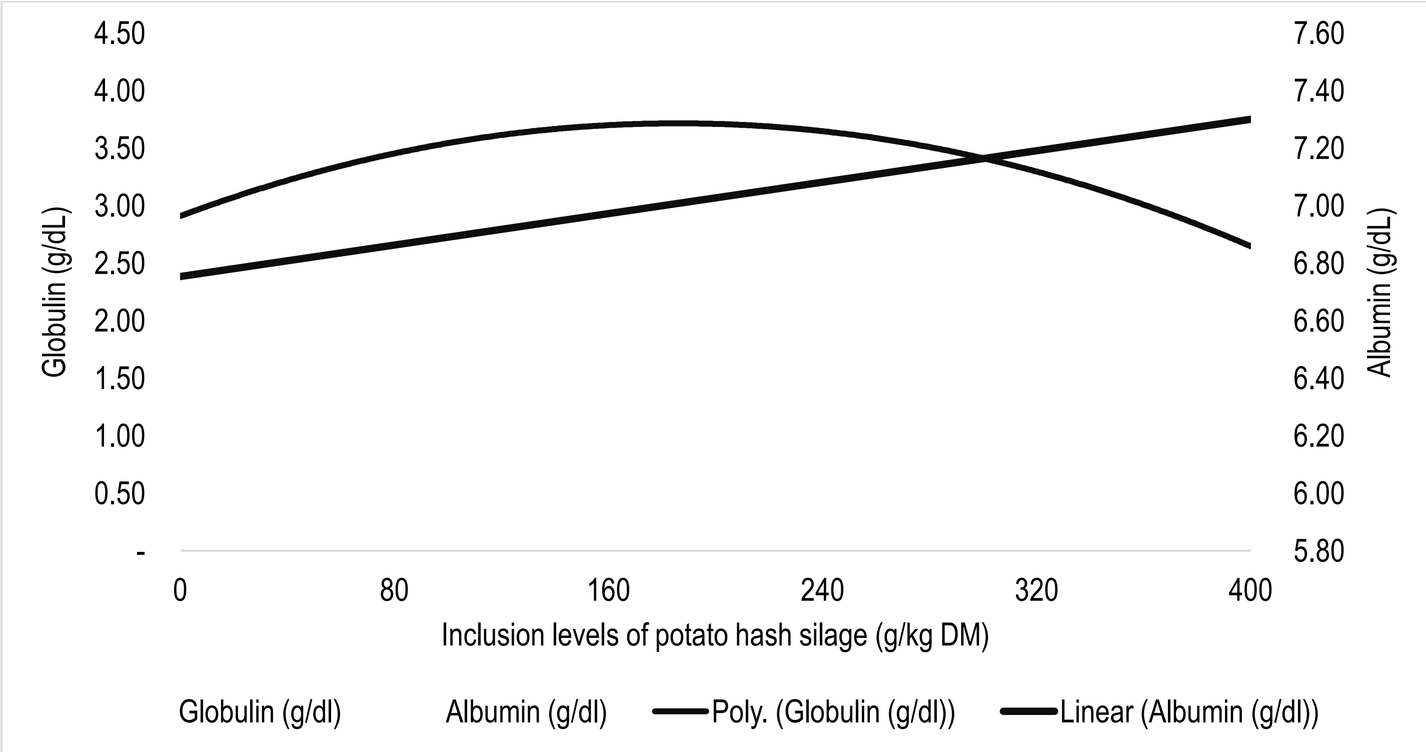

Figure 4. 1: The relationship between inclusion levels of potato hash silage against globulin and Albumin

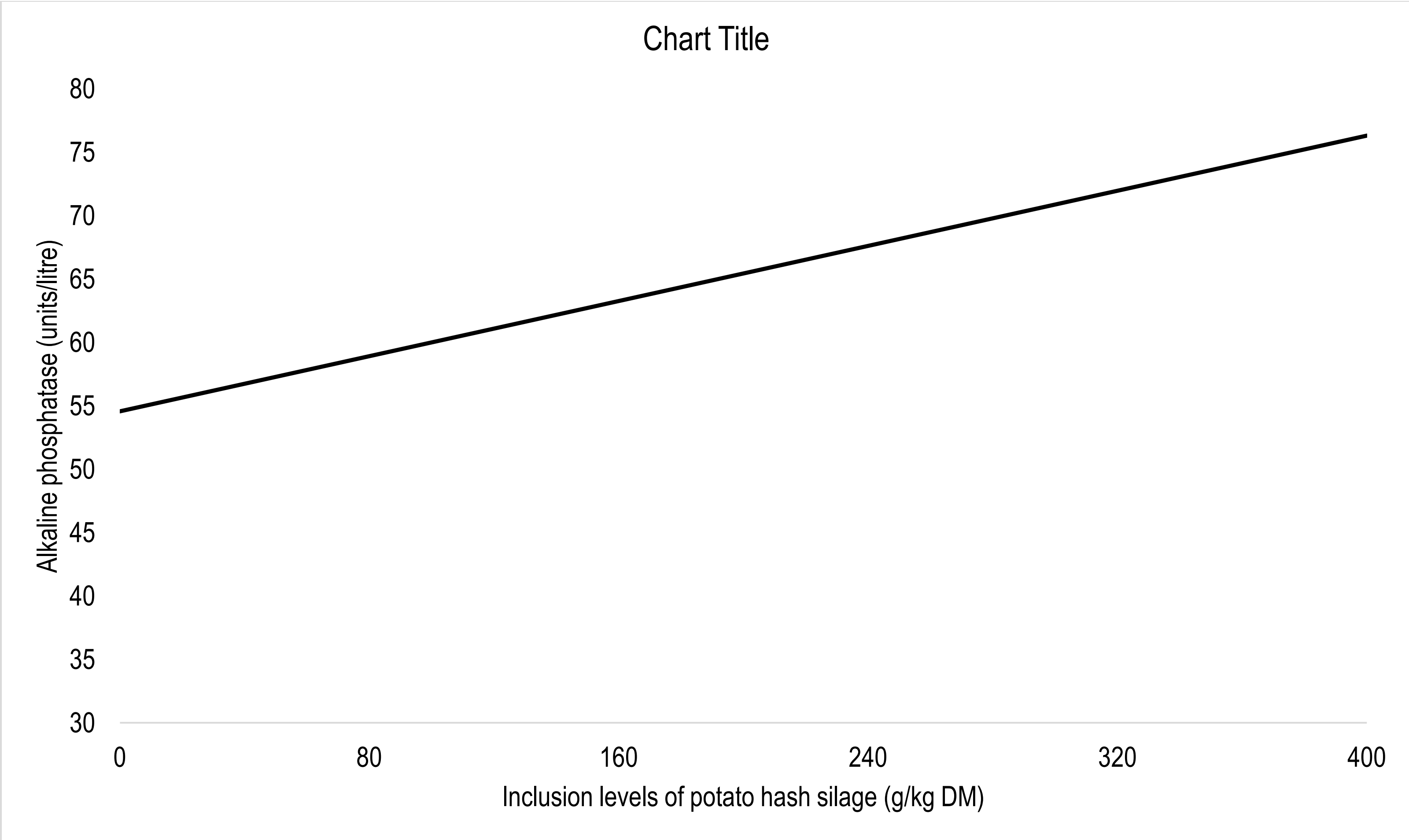

Figure 4. 2: The relationship between inclusion levels of potato hash silage and alkaline phosphatase (normal range, 92 to 294 units/litre)

4.4 Discussion

Characterisation of Windsnyer pig's ability to utilise locally available by-products dependent upon determining their blood metabolites response to these by-products. This is because it is meaningless to utilise abundant and locally available feedstuffs that are toxic and detrimental to pigs. Thus, determining changes in nutritionally-related blood biochemistry is crucial. Serum albumin is a protein produced by the liver that regulate fluid from leaking out of blood vessels, nourishes tissues, and transports hormones, vitamins, drugs, and substances such as calcium throughout the body. The positive relationship between inclusion levels of potato hash silage and albumin was expected. Albumin concentration reflects nutritional status. A linear increase in albumin concentration with increasing levels of potato hash silage contradicts the view that fibrous diets lower protein concentrations (Bakare *et al*., 2016). An increase in albumin concentration could be due to unsatisfied satiety. This is because as inclusion levels of potato hash silage increased, the palatability of the feed was reduced and pigs were refusing to eat when silage diet stayed for overnight. This necessitates the need for gradual feeding of silage diets. Slow-growing pigs such as Windsnyer pigs reach sexual maturity as early as 3 to 4 months (Chimonyo *et al*., 2005). Therefore, the increasing albumin concentration in the present study could be caused by pigs starting to be sexually matured.

The globulins are globular proteins that insoluble in pure water but dissolve in dilute salt solutions. They are excreted from the liver. They help the immune system to fight against infections. A positive quadratic relationship between potato hash silage and globulin is difficult to explain. Slow growing pigs such as Windsnyer pigs are hardy and resistant to diseases and parasites such as *ascaris suum* (Zanga *et al*., 2003; Mohlatlole *et al*., 2013). This could explain high levels of globulin found in Windsnyer pigs. Inclusion of potato hash silage did not influence the serum total protein. Serum total protein is an indirect index that indicates the nutritional protein adequacy (Khanyile *et al*., 2017). Serum protein levels were, however, over the normal range (Radostits *et al*., 2000; Kanengoni *et al*., 2014). This elucidates that the nutrient requirement for Windsnyer pigs are unknown. The uric acid was also not affected by inclusion levels of potato hash silage, but it was low compared to normal range (Radostits *et al*., 2000). Low uric acid concentration, which indicates protein catabolism, suggests sufficient protein consumption (Hlatini and Chimonyo, 2016). The activity of alkaline phosphatase can be used to assess the health of the liver as it originates from osteoblasts and some o f it is excreted in bile (Khanyile *et al*., 2017). A linear increase in activity of alkaline phosphatase as inclusion levels of potato hash silage increased implies that reduction in palatability of silage frustrated pigs. When pigs get frustrated, alkaline phosphatase increased. High levels of testosterone hormone in Windsnyer pigs since they attain puberty early could also be a plausible explanation of increasing alkaline phosphatase. The increased in the activity of alkaline phosphatase was between normal range (Radostits *et al.* 2000; Kanengoni *et al*., 2015). This indicates that increasing levels of ensiled potato hash silage does not have a negative impact on the liver function of pigs.

4.5 Conclusions

Nutritionally-related blood metabolites showed a positive relationship as inclusion levels of potato hash silage increased. The albumin exhibited a positive linear relationship while globulin showed a positive quadratic relationship as inclusion levels of potato hash silage increased. Increasing levels of potato hash silage did not affect total protein and uric acid. The alkaline phosphatase was increased linearly. Nutritionally-related blood metabolites are crucial especially when determining nutrient utilisation and rate of digesta passage of potato hash silage.

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CHAPTER FIVE: Relationship between varying levels of ensiled potato hash silage against the rate of digesta passage and nutrient digestibility in slow-growing Windsnyer pigs

ABSTRACT

To reinforce conservation of endangered Windsnyer pigs, there is a need to characterise their ability to utilise locally available feed resources. The objective of the study was to determine the nutrient utilisation and rate of digesta passage of potato hash silage fed to Windsnyer pigs. Six pigs were randomly assigned to six diets containing 0, 80, 160, 240, 320 and 400 g/kg of potato hash silage. All diets were blended with chromium oxide. After five weeks of feed intake and a growth performance experiment (Chapter 3), pigs with initial body weight of 34 ± 4.59 kg (mean ± standard deviation) were fed diet of potato hash silage for 5 days. The water and feed were offered *ad libitum*. There was a positive correlation (P <0.05) between transit time (TT) and dry matter digestibility (DMD), organic matter digestibility (OMD), crude protein digestibility (CPD) and neutral detergent fibre digestibility (NDFD). The mean retention time (MRT) was positively correlated (P <0.05) to DMD, OMD and CPD. The increasing inclusion of potato hash silage resulted in a linear decrease (P <0.05) in digesta transit time (TT). The mean retention time (MRT) decreased quadratically (P <0.05) as inclusion levels of potato hash silage increased. There was a linear decrease (P <0.05) in organic matter digestibility (OMD), crude protein digestibility (CPD), and neutral detergent fibre digestibility (NDFD) as inclusion levels of potato hash silage increased. There was a negative linear relationship between increasing levels of potato hash silage and digestibility of nutrients. Also, there was a negative quadratic relationship between inclusion levels of ensiled potato hash and MRT. To fully understand the nutritional value of potato hash silage and other agro-industrial by-products, it is important to related nutrient digestibility to rate of passage.

Keywords: nutrient utilization; mean retention time; potato hash silage; passage rate; Windsnyer pigs

5.1 Introduction

To strengthen sustainability of smallholder pig production, the pigs kept by resource-limited farmers should comprise hardy pig genotypes that require less nutrient dense feeds (Mashatise *et al*., 2005). The common slow-growing, indigenous pigs found in Southern Africa are Kolbroek, Mukota and Windsnyer (Halimani *et al*., 2010). Kolbroek pigs are characterised by their spotted colour pattern. They have pricked ears and squashed faces. Similar to Mukota, Windsnyer pigs have dark-coloured skin, are hardy, with stocky compact bodies and long noses. Recently, the population of Windsnyer pigs has dropped significantly and they are on the verge of extinction (Halimani *et al*., 2010). Indiscriminate crossbreeding, political instability and globalisation has exacerbated the situation. In addition, pig production organizations in Southern Africa are in favour of imported breeds and are promoting them to be used in smallholder production systems. This is because they grow fast and have high financial return. The slow-growing pigs are shunned due to their compact body and slow growth rate. Fast-growing imported breeds, however, struggle to survive and reproduce efficiently under marginal planes of nutrition, high prevalence of diseases and harsh environments (Chimonyo *et al*., 2005). As a result, the productivity of imported breeds is lower than that of indigenous pigs given such conditions (Holness, 1991). This brings a strong justification to conserve slow-growing pigs because they have an ability to cope with such factors (Chimonyo *et al*., 2005; Len *et al*., 2009). Conserving slow-growing pig genetic resources and improving their productivity is important to increase return on investment in developing countries (Furukawa *et al*., 2013). Agricultural Research Council of South Africa is conserving purebred Windsnyer pigs for breeding, production and research. There is, therefore, a need to characterize Windsnyer pigs in terms of their ability to utilize locally available and abundant feed resources.

Potato hash is a potato by-product derived from the production of snacks and chips that is deemed a waste product. It is comprised of potato peels, starch, rejected raw potatoes and small proportion of yellow maize. Potato hash is rich in energy, starch, fibre and has low levels of protein. It is available in large quantities, which can provide an alternative and sustainable feeding system for smallholder pig farmers (Nkosi and Meeske, 2010). Potato hash has been overlooked due to its high moisture content that makes it spoil shortly after disposal. The ensiling of potato hash is a cheap and appropriate preservation strategy (Nkosi and Meeske, 2010). During ensiling of potato hash, absorbents are used to raise dry matter content for good quality silage (Thomas *et al*., 2012). Kanengoni *et al*. (2015a) showed that Windsnyer pigs digest nutrients, particularly fibre, better than Large White × Landrace pigs when fed on by-products that are otherwise considered of no nutritional value. Windsnyer pigs therefore, have useful attributes that enables them to utilise feed by-products previously considered of limited nutritional value to pigs. Besides focusing on feed intake, growth performance and nutrient digestion, there is also a need to include rate of passage aspect and relate it with nutrient digestibility. Fibre fermentation in pigs is limited by retention time of the digesta in the gastro intestinal tract (Le Goff *et al*., 2002).

Passage rate and nutrient digestibility provide important information in the assessment of potato hash silage (Kim *et al*., 2007). Rate of digesta passage and nutrient digestibility are affected by chemical and physical properties of the diets, levels of dietary fibre and feeding level (Le Goff *et al*., 2002). Robbins (1993) defined transit time (TT) as the flow of material within or through the entire tract per unit of time. The mean retention time (MRT) is the overall average time between marker ingestion and excretion (Van Weyenberg *et al*., 2006). The objective of the study was, therefore, to assess the relationship between increasing levels of potato hash silage against of digesta passage rate and nutrient digestibility in growing

Windsnyer pigs. The hypothesis of the study was that there is a negative relationship between levels of potato hash silage and MRT and nutrient digestibility.

5.2 Materials and methods

5.2.1 Study site

The study site was described in section 3.2.1.

5.2.2 Pigs, housing and experimental design

A total of 36 clinically healthy male growing Windsnyer pigs with an average initial body weight of 34 ± 4.59 kg (mean ± standard deviation(S.D)), were selected from the Windsnyer pig section of the Agricultural Research Council. The selection of pigs was based on sex, body weight and age. These pigs were aged between five and six months. Windsnyer pigs were moved from the Windsnyer pig section, where they were housed in groups, to a trial facility where they were individually penned in a completely randomised design. The housing facility was cleaned thoroughly and disinfected a week before the trial commenced. The environment that surrounded the experimental house was also cleaned. The temperature and relative humidity in the experimental house was maintained at 24.5 ± 1. 9 °C and 62.7 ± 15.07 (mean ± S.D) %, respectively. Six pigs were randomly allotted to each experimental diet. An environmental, facility and dietary acclimatisation period of seven days was allowed for pigs before data collection commenced. The feed was freely available every time and water was available through low-pressure nipple drinkers.

5.2.3 Collection and ensiling of potato hash

Fresh potato hash was collected from Simba®, a local food producing company. Potato hash was mixed with ground maize cobs to increase the DM content to between 250 and 400 g/kg for good quality silage. The mixing ratio of potato hash and maize cob was 70:30 g/kg. The potato hash-based mixture was then ensiled by compacting in 210 litre drums lined with a polyethylene plastic bag. The drums were closed with a rubber lid to prevent damages to the bags by rodents. Drums were stored at a temperatures ranged from 22 to 29 ^{o}C. The silage drums were opened weekly upon mixing of the diets to prevent spoilage.

5.2.4 Preparation of diets

A total mixed ration was formulated to meet or exceed the nutritional requirements of growing Windsnyer pigs and was used as a basal diet or summit diet. A bulky diet containing 400 g/kg potato hash silage was also formulated to meet nutrient requirement of Windsnyer pigs and was used as dilution diet (Table 3.1). Diets were formulated by diluting a concentrated summit diet with a dilution diet at different proportions (Gous and Morris, 1985). A sequence and series of diets namely 80, 160, 240 and 320 g/kg were formulated from a dilution of summit diet (0 g/kg) with dilution diets (400 g/kg) at different ratios. Six diets including summit and dilution diets were produced. The inclusion ratios of summit and dilution diets are described in section 3.2.4.

5.2.5 Chemical and physiochemical analyses of the diets, potato hash silage and faeces

The chemical and physiochemical analyses of diets, potato hash silage and faeces are similar as described in section 3.2.5 (Table 3.2). In Addition, the concentration of chromium oxide (Cr_2O_3) in the representative diets and faeces was determined using inductively coupled plasma atomic emission spectroscopy.

5.2.6 Measurements

Before offering pigs feed with chromium oxide (Cr_2O_3) inert marker, faecal samples from each pig were collected at 0730 h and were denoted as blank samples. Two grams per kilograms of Cr_2O_3 were thoroughly blended with experimental diets. All diets appeared emerald green. It was ensured that pigs were not hungry before they were offered marked feed. Pigs were offered 1.5 to 2.0 kg at 0800 h. They were, afterwards, supplemented with at most 1 kg at 1700 h depending on the ability to finish feed offered in the morning. The feed was offered to make sure that it was available *ad libitum*. The time when the pig put its head into the feeder was recorded and denoted as initial time of feed consumption. Pigs were visually checked for the first appearance of marker every hour starting from 12 hours of consumption of marked meal. Thereafter, the time at which first appearance of the marked faeces was recorded. Subsequently, the urine-free fresh faecal samples were collected in four-hour interval from pens for 48 hours to determine the concentration of Cr_2O_3. After that, all faeces, in each pen, defecated from 0730h to 1930h were collected once a day for 5 days to cater for the estimation of total faecal weights and nutrient digestibility. These pigs were not stressed. The collected faecal samples were refrigerated at –20 ^{o}C immediately after collection, pending analyses. At the end of the collection period, samples were thawed overnight and dried at 60 ^{o}C for 24 hours before analyses. For the rate of passage experiment, faecal sample for each pig at a given collection time were dried separately and were analysed for Cr_2O_3 concentration. For digestibility experiment, the 5-day faeces for each pig were combined and mixed after the drying period and then a representative sample was analysed. The digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD), neutral detergent fibre (NDFD) and acid detergent fibre digestibility (ADFD) were measured.

5.2.7 Calculation of rate of passage, faecal scoring and digestibility

The TT was measured as the time between consumption of marked meal and first appearance of the marker in the faeces. The mean retention time (MRT) in the entire gastro intestinal tract was calculated by a non-compartmental method. The term non-compartmental was used as no attempt was made to link the MRT to anatomical or physiological compartments (Lalle`s *et al*., 1991). The MRT of the digestive tract was calculated according to equation described by Faichney (1975) for total cumulative feed marker collection:

$$MRT = \sum_{i=1}^{n} m_i \, t_i$$

Where t_i is the time (in hours) between the sampling interval and M_i is the concentration of marker excreted in the faeces.

The faecal scoring in each pig for five days was visually scored as:

1= watery, 2= semi-watery, 3= normal, 4= semi-dry 5= dry.

The digestibility of nutrients was calculated based on Cr_2O_3 concentration. The formula used for the calculation of total tract nutrient digestibility was:

$$ATTD =$$

Where ATTD is the apparent total tract digestibility; Nutrient faeces is the percentage of nutrient in the faeces; Nutrient feed is the percentage of nutrient in the feed; Indicator feed is the percentage of Cr_2O_3 in the feed; Indicator faeces is the percentage of Cr_2O_3 in the faeces.

5.2.8 Statistical analyses

Pearson's correlation coefficients were estimated to determine the relationship between the rate of digesta passage and nutrient digestibility. A PROC GLM (SAS, 2008) procedure was used to determine the effect potato hash silage inclusion level on rate of passage and nutrient digestibility. A polynomial regression (PROC REG) procedure (SAS, 2008) was used to determine the relationship between passage rate and nutrient digestibility with inclusion levels of potato hash silage. The model that was used was:

$Y = Bo + B_1A + B_2A^2 + E$, where

Y = is the response variable (rate of passage and nutrient digestibility)

Bo= is the intercept

B_1A = is the linear regression component

B_2A^2 = is the quadratic regression component and

E = is the error.

5.3 Results

Pigs were healthy and consuming feed with marked meal. The rate of marker recovery ranged from 90 to 95 % in all inclusion levels and was not significant (P >0.05). As inclusion level of potato hash silage increased, the time interval between collection periods was shortened (P <0.05). As shown in Table 5.1, TT positively correlated to dry matter digestibility (DMD) (P <0.01) organic matter digestibility (OMD) (P <0.01), crude protein digestibility (CPD) (P <0.01) and neutral detergent fibre (NDFD) (P <0.01). There was a positive correlation (P <0.05) between MRT against DMD, OMD and CPD.

Table 5. 1: Pearson's correlation coefficients between nutrient digestibility and rate of digesta passage

Component	TT	MRT	DMD	OMD	CPD	ADFD	NDFD
TT		0.03[NS]	0.49**	0.51**	0.56***	0.19[NS]	0.52**
MRT			0.39*	0.35*	0.34*	0.17[NS]	0.31[NS]
DMD				0.53**	0.52**	0.04[NS]	0.35*
OMD					0.79***	0.22[NS]	0.74***
CPD						0.01[NS]	0.73***
ADFD							0.31[NS]
NDFD							

TT, transit time; MRT, mean retention time; DMD, dry matter digestibility; CPD, crude protein digestibility; ADFD, acid detergent fibre digestibility; NDFD, neutral detergent fibre digestibility. ***p<0.001; **p<0.01; *p<0.05; NS not significant.

The relationship between inclusion levels of potato hash silage against feed intake, faecal scoring, rate of passage and faecal output are shown in Table 5.2. The feed intake increased in a quadratic fashion ($P < 0.05$) with inclusion level of potato hash silage. As inclusion levels of potato hash increased, feed intake increased at a decreasing rate. Diet had no effect on faecal scoring ($P > 0.05$). The faeces appeared normal with no apparent signs of diarrhoea or constipation. There was a linear decrease ($P < 0.01$) in TT with increasing inclusion levels of potato hash silage. The coefficient of determination was 0.75. There was a negative quadratic relationship between inclusion levels of potato hash silage and MRT. As inclusion levels of potato hash silage increased, the MRT decreased at a decreasing rate. The coefficient of determination was 0.68.

There was a linear increase ($P < 0.01$) in fresh and dry faecal weight as inclusion levels of potato hash silage increased. The apparent total tract digestibility (ATTD) coefficient of nutrients is shown in Table 5.3. There was a negative linear relationship ($P < 0.01$) between inclusion of potato hash silage and DMD. As the levels of potato hash silage increased, the OMD ($P < 0.001$), CPD ($P < 0.01$), and NDFD ($P < 0.05$) decreased linearly. The coefficient of determination for DMD, OMD, CPD and NDFD was 0.70, 0.72, 0.92 and 0.86, respectively. Incorporating different levels of potato hash silage did not affect ($P > 0.05$) acid detergent fibre digestibility.

5.4 Discussion

Windsnyer pigs, commonly kept under extensive system, do not have reliable feed resources. Farmers feed them cheaper fibrous feed resources because they grow slowly and have low financial returns. It is therefore crucial to source for other potential feed resource such as ensiled potato hash silage that are not utilised by humans as an alternative feedstuff for Windsnyer pigs.

Table 5. 2: Relationship between increasing levels of potato hash silage versus feed intake, faecal scoring and rate of digesta passage by Windsnyer pigs

Variables	Potato hash silage inclusion level (g/kg DM)						SEM	Regression co-efficient		Significance levels
	0	80	160	240	320	400		Quadratic	Linear	
Daily feed intake (kg)	1.52	1.65	1.74	1.92	1.58	1.66	0.07	9.85		*
Transit time (hours)	17.6	19.2	17.8	17.1	15.6	16.5	0.45		-7.14	***
Mean retention time (hours)	23.7	23.8	21.5	20.0	18.3	18.1	2.91	-0.05	1.33	**
Faecal scoring	2.92	2.52	2.87	3.05	4.49	3.08	0.69			NS
Fresh faecal weight (kg)	4.71	5.14	5.67	6.23	7.98	8.55	0.59		0.10	**
Dry faecal weight (kg)	1.35	1.58	1.89	2.23	2.67	3.12	0.37		0.40	**

***p<0.001; **p<0.01; *p<0.05; NS not significant

Table 5. 3: Apparent total tract digestibility (ATTD) coefficient of nutrients in increasing levels of potato hash silage fed to Windsnyer pigs

Variable	Potato hash silage inclusion level (g/kg DM)						SEM	Linear regression coefficient	Significance levels
	0	80	160	240	320	400			
DMD	0.75	0.74	0.73	0.67	0.67	0.64	1.68	-6.12	**
OMD	0.90	0.90	0.90	0.90	0.89	0.89	0.02	-9.99	***
CPD	0.80	0.70	0.64	0.59	0.56	0.49	1.73	-2.12	***
NDFD	0.64	0.65	0.61	0.56	0.48	0.36	2.41	-0.60	*
ADFD	0.45	0.56	0.62	0.64	0.49	0.48	1.63		NS

DMD, dry matter digestibility; CPD, crude protein digestibility; ADFD, acid detergent fibre digestibility; NDFD, neutral detergent fibre digestibility, ADFD, acid detergent fibre digestibility.***$p<0.001$; **$p<0.01$; *$p<0.05$; NS not significant

Utilisation of nutrients by pigs is influenced by two simultaneous and dynamic processes viz. digestion and digesta TT (Wilfart *et al*., 2007). To accurately measure the nutrient utilization by pigs, it is fundamental to relate rate of passage to nutrient digestibility. It is still unclear how slow growing pigs manage to utilize fibrous feeds better than the improved breeds. If the mechanism involves rate of passage then such information may be critical to help in the conservation of these breeds. A positive correlation coefficient between MRT and DMD accorded well with those of Kim *et al*. (2007). When MRT is reduced with increase in inclusion levels of potato hash, the DMD, OMD, CPD and NDFD decreases. A decrease in mean retention, due to high dietary fibre, gives no chance to digestive enzymes to efficiently breakdown feed particles. As a result, microbes in the hindgut are burdened with the duty to ferment high volume of fibrous digesta that will have escaped from the foregut. The digestibility and fermentability is thus compromised. High levels of dietary fibre are associated with faster rate of passage. Kim *et al*. (2007) also suggested that MRT could be used as a potential independent variable in digestibility studies.

The quadratic increase of feed intake suggests that as the feed gets bulkier, pigs are triggered to consume more feed with the aim to meet nutrients requirements (Ndou *et al*., 2013). Linear decrease in transit time suggests that inclusion of potato hash silage reduced the time of digesta flow. Rate of digesta passage is affected by physical and chemical characteristic of the feed, feed processing and feeding level (Le Goff and Noblet, 2001). Potato hash silage has a high water holding capacity. Hydrophilic polysaccharides can absorb water and hold it in the lumen of the gut (Van Weyenberg *et al*., 2006). By so doing, they fasten passage rate of the digesta. Reduction in digesta transit time could be associated with high levels of hemicellulose, a hydrophilic polysaccharide, found in potato hash silage that has a potential to absorb water. The faster rate of passage could be due to high moisture content of potato hash silage. In rats, potato starch has been reported to shorten TT (Ferguson *et al*., 2000).

A quadratic decrease in MRT as inclusion levels of potato hash silage could be due to increasing levels of dietary fibre in these diets. Potato hash silage high levels dietary fibre (mainly NDF and ADF) is attributed to low porosity, low density and may reduce viscosity and MRT (Roehrig, 1988). In addition, non-digestible oligosaccharides and resistant starch (20 % amylose in potato starch) have similar physiological effects in the body such as reduction in MRT as non-soluble polysaccharides and lignin, although not being part of the cell wall structure (Champ *et al*., 2003). Wilfart *et al*. (2007) reported that high fibre content caused a major reduction in MRT in the large intestine.

Potato hash, when blended with maize cobs for silage, is bulky with 337 g/kg DM and 633 g/kg NDF and has low levels of water-soluble carbohydrates (Nkosi and Meeske, 2010). Bulky feeds such as potato hash silage exert a direct physical action in the gastrointestinal tract which increasing peristatic movement (Le Goff *et al*., 2002). When levels of water-soluble carbohydrates are low, feed becomes less viscous and rate of passage is shortened. Dietary fibre induces the laxative nature of the digesta thus, reducing the MRT and consequently compromises microbial activity in the hindgut. The mechanism and impact of water holding capacity and swelling capacity of the feed in the digesta rate of passage is unclear mostly in high moisture by-products with high dietary fibre and indigestible starch and require further investigation. In as much as Windsnyer pigs have enhanced ability to utilise low quality fibrous feeds due to specialised microbial communities (Kanengoni *et al*., 2015b), a decrease in flow rate of the digesta could also be influenced by their small body frame size. Similarly, Le Goff *et al*. (2002) reported that body weight and size of the gastrointestinal tract, particularly the hindgut, affects MRT when pigs fed on fibrous diets. Bulky feed such ensiled potato hash results into bulk faeces. High amount of faeces excreted by pigs when fed high levels of dietary fibre was also observed by Wilfart *et al*. (2007). Le Blay *et al*. (1999) also mentioned high faecal output in rats fed potato starch.

Use of archaic total tract digestibility helps nutritionists to quantify nutrients that are utilised by animal also to determine how much is excreted to the environment. Markers are incorporated into the feed to ensure that the faeces collected are representative of the intake of feed. A linear decrease in digestibility of DM, OM, CP and NDF indicates that as increasing levels of potato hash silage results to high indigestible fibre and reduces the digestibility of nutrients. The results of the present study disagrees with the study Wilfart *et al*. (2007) who reported that the digestibility of dietary fibre is unaffected by dietary fibre level of diets fed to growing pigs. Also dissimilar to the present study, Zhang *et al*. (2013) and Kanengoni *et al*. (2015a) reported an increase in DM, digestibility of insoluble dietary fibre, CP and NDF. Differences in results could be attributed to different designs of experiments, different sources of dietary fibre, breeds, and initial body weight and preservation methods used. Since ensiling arguably reduces fibre fraction and improves the utilisation of fibrous feeds (Kanengoni *et al*., 2015a); it could, therefore, be speculated that the proportion of nutrients digested would have been much less if potato hash was not ensiled. Potato hash has low levels of lactic acid bacteria of which a large proportion is damaged during the potato processing (Nkosi and Meeske, 2010). Therefore, it requires silage additives and inoculants to improve the fermentation and nutritive value during ensiling. In the present study, the reason behind a decrease in nutrient digestibility could be associated to the poor fermentation quality of potato hash silage.

5.5 Conclusions

There is a positive correlation between rate of digesta passage and nutrient digestibility of potato hash silage when fed to Windsnyer pigs. Inclusion levels of potato hash silage caused a quadratic decrease in MRT and also resulted into high faecal output. There was a negative linear relationship between increasing levels of potato hash silage and nutrient digestibility. To further understand utilisation of potato hash by slow growing pigs, there is a need to determine the relationship between inclusion levels of potato hash silage and physicochemical properties of digesta in Windsnyer pigs. To fully understand nutrient utilisation of potato hash silage, it is indispensable to determine changes in physicochemical properties of the digesta throughout the gut compartment.

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CHAPTER SIX: Changes in physicochemical properties of digesta of slow-growing Windsnyer pigs fed on different inclusion levels of potato hash silage

ABSTRACT

The aim of this work was to determine the relationship between inclusion levels of potato hash silage and physicochemical properties of digesta in different compartment of the gastrointestinal tract (GIT) of growing Windsnyer pigs. Six Windsnyer pigs were randomly assigned to one of six diets containing 0, 80,160, 240,320 and 400 g/kg DM of potato hash silage. The slaughter weight of pigs was 36 ± 4.89 kg (mean ± standard deviation). The feed and water were offered *ad libitum*. After 7 days of rate of passage and digestibility experiment (Chapter 5), pigs were humanely slaughtered and eviscerated. Inclusion levels of potato hash silage was related (P <0.05) to scaled stomach, colon and caecum weights. Only scaled digesta weights from colon was related (P <0.05) to inclusion levels of potato hash silage. The inclusion levels of potato hash silage was related (P <0.05) to digesta pH from ileum and distal colon. The swelling capacity of digesta from ileum decreased linearly (P <0.01) with inclusion levels of potato hash silage. There was a positive linear relationship (P <0.05) between swelling capacity of digesta from caecum and inclusion levels of potato hash silage. The water holding capacity of the digesta from ileum decreased linearly (P <0.01) with inclusion levels of potato hash silage. The water holding capacity of digesta from the caecum decreased quadratically (P <0.01) in the digesta. Digesta from proximal colon also showed a linear decline (P <0.01) with inclusion levels of potato hash silage. Digesta from distal colon increased linearly (P <0.01) with increasing levels of potato hash silage. There was a general decline in water holding capacity as digesta flow from the ileum to the distal colon. Physicochemical properties of digesta changes with compartments of the gut in growing Windsnyer pigs.

Keywords: physicochemical properties, digesta, gut compartment, growing pigs

6.1 Introduction

Windsnyer pigs are an indigenous-type breed commonly found in rural areas of Southern Africa where resources are scarce and, if available, poor. Windsnyer pigs have a potential to improve livelihood for resource-limited households. However, information on their production potential and profitability is absent (Halimani *et al*., 2012). The proportion of Windsnyer pigs in the herd is also unknown. Nonetheless, smallholder farmers commonly keep them. Windsnyer pigs are disfavoured due to negative perception about the free-range production system arising from historical bias (Lekule and Kyvsgaard, 2003). Windsnyer pigs are also discriminated because of their slow growth rate, compact body structure and high fat deposition. In addition, policy makers are disapproving their production or encouraging their replacement (Chimonyo and Dzama, 2007). Lack of access markets and viable marketing strategies are among other reasons why Windsnyer pigs are overlooked (Halimani *et al*., 2010).The imported breeds such Large White are, therefore, close to replace Windsnyer pigs.

The importance of Windsnyer pigs lie in the various and desirable attributes such as adaptability to local environment and tolerance or resistant to endemic diseases and parasites (Zanga *et al*., 2003). They have evolved to be better utilizers of fibre-rich agricultural by-products such as maize cobs than imported pigs (Kanengoni *et al*., 2015). These unique traits are revealing an importance of the need to conserve this breed. To have a concrete evidence that Windsnyer pigs efficiently utilise fibre-rich by-products, there is a need to search for more locally available fibrous feedstuffs including potato hash that are abundant and normally neglected or thrown away. The utilisation of agro-industrial by-products as a way to reduce competition for cereal grains has been focus of attention (Wate *et al*., 2014). The use of cereal grains is, moreover, not sustainable for slow-growing pig genotypes such as Windsnyer pigs. Potato hash, a by-product originating from potato processing industry, is highly available for use by both commercial and smallholder pig farmers. It contains low water soluble carbohydrates and high levels of starch (Nkosi, 2009). Potato hash is commonly persevered as a silage (Okine *et al*., 2005; Nkosi *et al*., 2010). High levels of moisture in potato hash has demanded the use of dry absorbents to improve dry matter and compaction during ensiling (Nkosi *et al*., 2010). In addition, Kanengoni *et al*. (2015) argued that ensiling enhances fermentability of fibrous feeds and improves nutrient utilisation by pigs.

Potato hash silage has been reported to influence digesta flow rate and nutrient digestibility (Chapter 4). To have an in-depth understanding on the value of potato hash to Windsnyer, It is necessary to further investigate how potato hash silage relates to physicochemical properties of digesta in different compartments of gastrointestinal tract (GIT). Physicochemical properties such as water holding capacity (WHC), viscosity and swelling capacity (SWC) have a direct effect on digestibility, absorption of nutrients and rate of passage (Stanogiaas and Pearce, 1985; Ngoc *et al*., 2013). Physicochemical properties of potato hash silage are reported for the first time. Water holding capacity and swelling capacity are the physicochemical properties used to measure bulkiness of digesta (Bindelle *et al*., 2008). Weights of GIT compartments are estimated to understand the physiological and anatomical responses of pigs fed on potato hash silage (Wate *et al*., 2014). The objective of the study was to determine changes in bulkiness of digesta and size of GIT compartments of Windsnyer pigs fed increasing levels of potato hash silage. It was hypothesised that there are changes in physicochemical properties of the digesta of Windsnyer pigs when fed on increasing levels of potato hash silage. In addition, the extent to which levels of potato hash silage relates to bulkiness of the digesta may differ with compartments.

6.2 Materials and methods

6.2.1 Study site

The study site was described in section 3.2.1.

6.2.2 Pigs, housing management and experimental design

Thirty-six clinically healthy male growing Windsnyer pigs that were used were used in experiment 1 and 2 were also used in the current study. Pigs had an average initial body weight of 36 kg ± 4.89 (mean ± standard deviation). Pigs were individually penned in a completely randomised design. The temperature and relative humidity in the experimental house was maintained at 24.5 (± 1. 9) °C and 62.7 (± 15.07) %, respectively. Six pigs were randomly selected to each experimental diet. The feed and water was available *ad libitum*.

6.2.3 Collection and ensiling of potato hash

Collection and ensiling method of potato hash is described in section 3.3.2.

6.2.4 Preparation of diets

Diet preparation and feed management are described in section 3.2.4.

6.2.5 Slaughtering of pigs and measurements of digesta pH, digesta compartment and weights

Pigs were transported to the abattoir situated at about 1.5 km from trial facility at 0830 h. Pigs were humanely treated according to the routine abattoir protocols which include ante-mortem inspection. Each pig was stunned using the electrical stunner set 220 Volts and 1.8 Amps with the current flow of 6 seconds. They were subsequently exsanguinated within 10s of stunning for anaesthesia purposes. They were then dipped into heating water at 150^{o} C for 3 minutes. Afterwards, they were de-haired and eviscerated. The GIT (from cardias to rectum) were separated from the carcass. The GIT was ligated at the beginning and end of each gut compartment by double tying and cutting to avoid to the flow of digest from and to other gut compartments. Four gut compartments namely ileum, caecum, proximal and distal colon were used. The ileum was determined as the section, which covers about 100 cm of small intestine before the ileo-caecal ostium (Wate *et al*., 2014). The caecum and colon were considered as part of the gut entering the pelvic cavity and reaching the rectum part of gut that is attached to the anus. The colon compartment was separated into two equal parts viz. proximal and the distal colon. About 20 g of digesta sample was collected from each compartment and put into 50 ml plastic bottles. Immediately thereafter, pH was assessed by inserting Crison 52 02 glass pH electrode. The digesta sample then frozen at -20^{o} C pending analyses of physicochemical properties. The weight of the compartments and digesta was taken using a digital scale. The scaled stomach weight, scaled small intestine weight, scaled caecum weight and scaled colon weight were determined by dividing the weight of the gut compartment by the slaughter body weight. The weights of the gut compartments and digesta were scaled to account for the differences in body weights.

6.2.6 Chemical and physiochemical analyses of diets and digesta

All representative samples of experimental diet and potato hash silage were analysed in triplicates (Table 3.2). The method to analyse the chemical and physicochemical properties is described in 3.2.5. Analyses of digesta WHC was performed on wet materials, while SWC was performed on freeze-dried materials.

6.2.7 Statistical analyses

A PROC GLM (SAS, 2008) procedure was used to determine the effect of potato hash silage inclusion level on physiochemical properties of digesta. A polynomial regression (PROC REG) procedure of

(SAS, 2008) was used to determine the relationships between inclusion levels of ensiled potato hash and physicochemical properties of digesta. The model that was used was:

$Y = Bo + B_1A + B_2A^2 + E$, where

Y = is the response variable (physicochemical properties of the digesta)

Bo= is the intercept

B_1A =is the linear regression component

B_2A^2 = is the quadratic regression component and

E = is the error.

6.3 Results

Results of the relationship between inclusion levels of potato hash silage and scaled digesta and compartments weights are shown in Table 6.1. There was a linear increase (P <0.01) in scaled stomach weight with increasing levels of potato hash silage. There was a negative quadratic relationship (P <0.05) between inclusions of potato hash silage and scaled caecum weight. A linear increase (P <0.05) in scaled colon weight with increasing levels of potato hash silage was observed. The digesta weight increased linearly (P <0.01) with increasing levels of potato hash silage from the colon. The relationship between potato hash silage and digesta pH through the GIT are shown in Table 6.2. The inclusion levels of potato hash silage caused a linear increase (P <0.05) in pH of the ileum digesta. The pH of digesta from the caecum and proximal colon was not related (P >0.05) to levels of potato hash silage. The inclusion levels of potato hash silage linearly (P <0.01) decreased pH of the digesta from the distal colon.

The relationship between inclusion levels of potato hash silage and swelling capacity of digesta is illustrated in Table 6.3. There was a quadratic increase (P <0.05) in swelling capacity of digesta in the stomach. Swelling capacity of digesta from ileum was exhibited a negative linear (P <0.01) relationship when pigs were fed increasing levels of potato hash. There was a positive linear relationship (P <0.05) between swelling capacity of digesta from caecum with inclusion levels of potato hash silage. Inclusion of potato hash silage did not relate (P >0.05) to swelling capacity of the digesta from proximal and distal colon.

Table 6. 1: Relationship between increasing levels of potato hash silage and scaled digesta and compartment weights (g/kg BW per day)

Variable	Potato hash silage inclusion level						SEM	Linear regression co-efficient	Significance levels
	0	80	160	240	320	400			
Compartments weights									
Scaled stomach	9.4	11.6	10.3	11.6	11.6	14.7	0.75	4.210	**
Scaled small intestines	17.0	21.5	20.7	16.8	19.9	22.2	1.85		NS
Scaled caecum	1.6	3.01	1.81	2.9	2.02	3.22	0.47		NS
Scaled colon	11.8	15.3	13.5	17.3	13.1	19.6	1.58	2.974	*
Digesta weights									
Scaled stomach	25.3	17.5	18.5	20.0	32.3	22.1	4.37		NS
Scaled small intestines	8.74	7.18	9.12	8.76	12.2	9.02	1.89		NS
Scaled caecum	14.9	7.59	11.9	10.3	16.9	9.4	2.39		NS
Scaled colon	11.4	13.2	12.9	17.0	16.9	27.6	2.72	0.314	***

***p<0.001; **p<0.01; *p<0.05; ns not significant

Table 6. 2: Relationship between varying levels of potato hash silage and digesta pH in the ileum, caecum, proximal colon and distal colon

Variable	Potato hash silage inclusion level (g/kg DM)						SEM	Linear regression co-efficient	Significance levels
	0	80	160	240	320	400			
Stomach	3.5	3.5	3.4	4.2	3.5	3.4	0.23		NS
ileum	3.8	4.3	5.5	4.5	5.1	5.2	0.18	1.186	***
Caecum	6.1	6.1	6.3	6.4	6.1	6.3	0.11		NS
Proximal colon	6.4	6.5	6.6	6.3	6.2	6.6	0.15		NS
Distal colon	6.8	6.7	6.6	6.4	6.4	6.3	0.11	-8.115	*

***p<0

.001; **p<0.01; *p<0.05; NS not significant

Table 6. 3: Swelling capacity (ml/g DM) of the digesta from gut compartments of Windsnyer pigs fed potato hash silage

Variable	Potato hash silage inclusion level						SEM	Regression co-efficient		Significance levels
	0	80	160	240	320	400		Quadratic	Linear	
Stomach	3.16	3.24	3.45	3.45	3.33	3.59	0.036	0.069		*
Ileum	3.28	2.78	2.68	2.86	2.50	2.75	0.074		-0.042	***
Caecum	2.33	2.52	2.37	2.15	2.28	2.06	0.084		0.0016	*
Proximal colon	3.13	2.85	2.95	2.85	3.12	2.98	0.109			NS
Distal colon	2.45	2.38	2.47	2.45	2.42	2.40	1.605			NS

***p<0.001; **p<0.01; *p<0.05; NS not significant

Results of water holding capacity of the digesta along the GIT of pigs fed potato hash silage is shown in Table 6.4. The water holding capacity of the digesta in the stomach decreased linearly ($P > 0.05$). The water holding capacity of the digesta from ileum decreased ($P < 0.01$) in a quadratic fashion. As potato hash silage increased, the water holding capacity of the digesta decreased at an increasing rate. From the caecum, there was a quadratic decrease ($P < 0.01$) in water holding capacity of the digesta. Digesta from proximal and distal colon respectively decreased and increased linearly ($P < 0.01$) with increasing levels of potato hash silage. There was a general decrease in water holding capacity as digesta flow from ileum to distal colon.

6.2 Discussion

Conservation of Windsnyer pigs is dependent upon, among other factors, their ability to efficiently utilise locally available feed resources. To comprehend how potato hash silage is related to feed intake, rate of passage and nutrient digestibility, it is vital to determine the response in physicochemical properties of the digesta along the GIT. A linear increase in stomach weight with increasing levels of potato hash silage could be increasing levels of dietary fibre in the diet. Ngoc *et al*. (2013) also reported a positive effect of level of dietary fibre on stomach development. The specific properties or structural characteristics of fibre source affect gut development (Len *et al*., 2009). An increase in colon weight suggests that colon is the major site where utilisation of potato hash silage occurs. An increase in weight of the colon observed in pigs fed on fibrous diets is caused by stimulation of epithelium cell proliferation, which are developed by short-chain fatty acids (Iji, 1999; Montage *et al*., 2003). Potato hash has low levels of water-soluble carbohydrates (Nkosi, 2009), which indicates that it has a high dietary fibre fraction. It consists of about 55 % of non-starch insoluble carbohydrates (mainly cellulose) (Serena and Knudsen, 2007). Windsnyer pigs, therefore, utilise potato hash silage by virtue of hindgut fermentation.

Table 6. 4: Water holding capacity (g water/g DM) of the digesta from gut compartments of Windsnyer pigs fed potato hash silage

Variable	Potato hash silage inclusion level						SEM	Regression co-efficient		Significance levels
	0	80	160	240	320	400		Quadratic	Linear	
Stomach	2.68	2.59	3.46	2.14	2.46	2.39	0.361		-0.02629	*
Ileum	4.02	3.77	3.62	3.10	3.33	3.62	0.121	-0.001172		***
Caecum	3.52	3.42	3.33	2.88	3.22	3.55	0.103	-0.001070		**
Proximal colon	2.87	2.78	2.81	2.53	2.42	2.40	0.104		-0.010298	***
Distal colon	2.28	2.63	2.57	2.47	3.03	3.15	0.082		0.004152	***

***p<0.001; **p<0.01; *p<0.05; NS not significant

Freire *et al*. (2000) and Hedemann *et al*. (2006) reported that insoluble non-starch polysaccharides provide substrate that is slowly degradable by microbes in the hind gut, and modulate gut morphology by increasing villus length. A linear increase in digesta weight from the colon verifies that colon is the major niche where potato hash silage is fermented. Results of the present study were in agreement with Wate et al. (2014) who reported a linear increase in colonic intestinal content as maize cob level increased. It is possible that the contribution of resistant starch to the total starch content of potato hash silage had an effluence on the development of colon compartment.

A linear increase in pH in the ileum could be due to pyloric region found in the hind part of the stomach that is responsible for increasing the low pH of digesta before it passes through into the duodenum. Högberg and Lindberg (2006) reported that pigs offered fibre rich diet had higher pH values than pigs offered control diet in the ileum. In the duodenum, there is a secretion of sodium bicarbonate, which produce an alkaline environment that prevent damage of epithelial cell that would be caused by low pH (Banino, 2012). Effect of potato hash silage as a dietary fibre in the pH of ileum digesta could be disturbed by the secretion of digestive enzymes and sodium bicarbonate in the duodenum. Lack of relationship between inclusion levels of potato hash silage and pH in the stomach, caecum, and proximal colon are difficult to justify. A quadratic decrease of pH in the colon could be due to inclusion of maize cobs as an absorbent during ensiling that had an impact on the fermentation of potato hash by pigs. Unlike potato hash, maize cob has high levels of soluble non-starch polysaccharide that is readily available for microbial fermentation (Ndou et al., 2013). Inclusion of soluble non-starch polysaccharides (NSP) in the diet can stimulate the growth of commensal gut microbes, leading to increased production of volatile fatty acid, and a lower pH in the large intestine (Bach Knudsen et al., 1991). Since potato hash is aerobically stable after ensiling under acidic environment (Nkosi and Meeske, 2010), it might have a direct influence on the pH value of the gastrointestinal tract.

Swelling forms the first phase of solubilisation of non-starch polysaccharides (Wate et al., 2014). The incoming water diffuses the macromolecules of fibre matrix components until they are fully extended and disseminated (Canibe and Bach Knudsen, 2002). A quadratic increase of swelling capacity of the digesta in the stomach of pigs when fed potato hash silage could be that potato hash silage has a high swelling capacity (4.85 mg/l) which directly affects swelling of the digesta in the stomach. High fibre content is expected to increase the volume and the extent to which the fibre component expands (Bach Knudsen, 2001). The swelling capacity of ensiled potato hash is also directly associated with proportion of resistant starch. However, in the present study, the resistance starch was not analysed. Potato starch swells reversibly due to the imbibition of more than 50% water by weight (Nelson, 2010). A linear decrease in capacity of swell of ileum digesta could be related to absorption of the liquids substances in the elium. The capacity of the feed particles to swell is, then, reduced. An exposure of the digesta to microbial fermentation in the caecum could be the reason for a linear increase of swelling capacity of the digesta.

A linear decrease in water holding capacity in the stomach and proximal colon and a quadratic decrease in ileum and caecum was not anticipated. It was expected that as potato hash silage increased, the water holding capacity of the digesta will increase along the GIT. This is because water holding capacity is related to the amount, composition and structure features of dietary fibre (Anguita *et al*., 2007). Anguita *et al*. (2007) reported that water holding capacity of the digesta increased from the stomach to ileum and decreased as digesta passed through the hindgut. A general decrease in water holding capacity is in line with the report by Wate et al. (2014) who also performed regression analysis. It is not clear whether or not ensiling and the use of absorbents, viscosity, particle size, digestibility, rate of passage and resistant starch content had direct or indirect influences on the water holding capacity of the digesta. In the distal colon, the increment in water holding capacity as levels of potato hash silage increased was anticipated due to increasing levels of non-starch polysaccharides. Potato hash silage has high content of hydrophilic polysaccharides, such as hemicellulose, which can absorb water and hold it in the lumen of the gut. Likewise, Ndou et al. (2013) reported that insoluble non-starch polysaccharides, such as cellulose and xylans found in potato hash, can hold water as they behave like sponges in the GIT, resulting in considerable bulking properties.

6.3 Conclusions

It can be concluded that inclusion levels of ensiled potato hash is related to compartment weights, pH, swelling capacity and water holding capacity. Inclusion levels of potato hash silage had a linear relationship with scaled stomach and colon weights. Except colon digesta, all digesta weights were not related to inclusion of potato hash silage. Inclusion levels of potato hash silage had a positive linear relationship with pH of ileum and negative linear relationship with distal colon digesta. Swelling capacity and water holding capacity varied with inclusion levels of potato hash and compartment of the GIT. To have an overall view on the effect potato hash silage in growing Windsnyer pigs and pork products, it is pertinent to determine relationship between potato hash silage and carcass characteristics.

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CHAPTER SEVEN: Response in carcass traits and selected primal pork cuts of Windsnyer pigs fed on inclusion levels of potato hash silage

ABSTRACT

The objective of the study was to determine the response in carcass traits and primal pork cuts of Windsnyer pigs fed on diets containing different inclusion levels of potato hash silage. Thirty-six growing Windsnyer pigs with slaughter weight of 36 kg ± 4.89 (mean ± SD) that were previously assigned to six experimental diets containing 0, 80, 160, 240, 320 and 400 potato hash silage g/kg DM were used in the present study. Experimental diets were derived from mixing a summit diet containing no potato hash silage and a dilution diet containing 400 potato hash silage g/kg in different proportions. Six pigs were fed on each diet *ad libitum* for five weeks (Chapter 3) before they were slaughtered. Carcass traits and primal pork cuts were measured. There was a quadratic increase in warm carcass weight (P >0.001) and cold carcass weight (P >0.001) as inclusion levels of potato hash silage increased. A linear (P >0.05) increase in dressing percentage was observed. The cooler shrink decreased quadratically (P >0.05) as inclusion levels of potato hash silage increased. Increasing levels of potato hash silage resulted in a linear decrease in shoulder fat (P <0.05) and carcass length (P >0.05). There was a negative linear (P >0.01) relationship between eye muscle area and inclusion level of ensiled potato hash. There was a positive quadratic relationship (P <0.05) between hindquarter length (HQL) and inclusion levels of potato hash silage. The hindquarter circumference decreased linearly (P >0.05) as the inclusion levels of potato hash silage increased. There were linear increase and decrease in dorsal fat thickness at last rib (DFT2) (P<0.05) and dorsal fat thickness at last lumbar vertebra (DFT3) (P<0.05) as potato hash silage increased, respectively. There was a linear decrease (P <0.01) in backfat thickness as inclusion levels of potato hash increased. Carcass weights, dressing percentage, and backfat thickness were related to inclusion levels of potato

hash silage. Most carcass traits and primal pork cuts are assumed to be related to genetics of the Windsnyer pigs rather than diets.

Keywords: backfat thickness; carcass traits; potato hash silage; primal pork cuts; Windsnyer pigs

7.1 Introduction

Sub-Saharan Africa has widespread populations of slow-growing pigs kept under extensive production system that could benefit from potato by-product diets among which is the South African Windsnyer pig (Kanengoni *et al*., 2014). The possibility of using Windsnyer pigs for fresh and inorganic consumption of pork has, however, not yet been determined. The promotion of organically produced pork from slow-growing pigs on the market might provide options for the health-conscious population (Madzimure *et al*., 2017). Windsnyer pig is being ignored due to number of reasons including that carcasses from it does not make the grade in the biased grading schemes that focus on lean meat production (Halimani *et al.* 2012). Even so, high subcutaneous fat deposition, which is found in the carcass of Windsnyer pigs, is not an under-tapped resource for smallholder pig farmers. Farmers use subcutaneous fat as lard for cooking (Chimonyo *et al*., 2005) and body lotion. Windsnyer pigs are also excluded due to their small frame sizes and compact body structures that are deemed to produce inadequate pork for the increasing human population. However, small frame size is an advantage to smallholder pig farms who frequently experience pig feed shortages. There is, therefore, a need to develop a strategy for smallholder pig farmers to benefit optimally from the production of Windsnyer pigs without boundaries. Utilising slow-growing pigs that are adapted to the local environmental conditions enhances sustainability of smallholder pig production systems (Chimonyo *et al*., 2005).

Slow-growing pigs are likely to be replaced by imported breeds if their meritorious attributes are not exploited. To stress on conservation and intensify production of Windsnyer pigs, it crucial to determine ability of Windsnyer pigs to convert diet containing ensiled potato hash to pork products. Windsnyer pigs utilise locally available, fibrous feedstuffs efficiently and require minimal financial input for production (Chimonyo *et al*., 2005). Potato hash is a potato by-product that is derived from the production of snacks and chips. Potato hash is plenty and has a potential to be used as a cheap alternative feed resources for pigs kept under extensive production system. It is preserved and used in a form of silage due to its high moisture content that shorten its shelf life. Dry absorbents such as maize cobs are used to ensile potato hash because it has a high water content. Ensiling of potato hash is practical and economical feasible for smallholder pig farmers. Fang *et al*. (2014) reported that diets that are high in dietary fibre and have potato resistant starch increase volatile fatty acid concentration in the gut, modulate host gene expression, and eventually influence the adipose metabolism, back fat thickness and pork quality. There is, however, a limited data on dose-response trials that evaluate relationship between ensiled potato hash silage and carcass traits and primal cuts of pork from Windsnyer pigs. The objective of the study was to determine the response in carcass traits and primal pork cuts from slow growing Windsnyer pigs fed on graded levels of potato hash silage. It was hypothesised that response in carcass traits and primal cuts from slow-growing Windsnyer pigs is related in a positive linear fashion to inclusion by inclusion levels of potato hash silage.

7.2 Materials and methods

7.2.1 Study site

The study was conducted at Agricultural Research Council (ARC)-Irene, Animal Production Institute, South Africa as described in section 3.2.1. The use and care of the experimental animals were ethically proved (Appendix 2).

7.2.2 Pigs, housing management and experimental design

A total of 36 clinically healthy male growing Windsnyer pigs that were used were used in experiment 1 were also used in the current study. Pigs had an average slaughter weight of 36 kg ± 4.89 (mean ± standard deviation). Pigs were individually penned in a completely randomised design in the previous experiments. The temperature and relative humidity in the experimental house was maintained at 24.5 (± 1. 9) °C and 62.7 (± 15.07) %, respectively before pigs were taken for slaughter. Six pigs were randomly selected to each experimental diet as described in previous experiment. The feed and water was available *ad libitum*.

7.2.3 Collection and ensiling of potato hash

Collection and ensiling method of potato hash is described in section 3.3.2.

7.2.4 Preparation of diets

Diet preparation and feed management are described in section 3.2.4.

7.2.5 Measurements

Each pig was weighed to determine slaughter weight. The slaughtering of pigs was done as described in 6.2.5. After de-hairing and evisceration, warm carcass weight was measured after dressing using an overhead scale. The dressing percentage was calculated by taking the warm carcass weight as a percentage of slaughter weight. The carcasses were then placed in a cold room and kept at an approximate temperature of 0°C for 24 h, after which cold carcass weights were measured. Cooler shrink, which is the amount of water lost from a carcass in the first 24 to 48 hours after harvest (Schweihofer, 2011), was calculated using the following formula:

(1 – (cold carcass weight / warm carcass weight) x100)

The ultimate pH (pH at 24 h [pH_{24}]) and temperature readings were taken from the longissimus thoracis muscle (eye muscle) with a portable pH meter (EUTECH Instruments, Thermo Fisher Scientific Inc., Singapore) between the third and the fourth rib, 60 mm from the midline. The pH meter had an automatic temperature compensator to adjust the pH for temperature. Before use, the pH meter and electrode were calibrated at pH 4 and pH 7 and was recalibrated in pH buffers after every fourth reading. The head from each carcass was then removed at the at the atlanto-occipital joint, the tail at the junction of the third and fourth sacral vertebrae and the flare fat, kidneys, kidney fat, glands and remaining parts of the diaphragm were also removed. Carcasses were then split into 2 parts along the median plane from the remaining sacral vertebra to the first cervical vertebra with a carcass splitting band saw. Carcass length was measured from the first rib to the pubic bone along the median plane using a measuring tape. Backfat measurements were taken at first rib (dorsal fat thickness at first rib [DFT1]), last rib (dorsal fat thickness at last rib [DFT2]), and last lumbar vertebra (dorsal fat thickness at last lumbar vertebra [DFT3]) off the median plane cut surface. All other carcass measurements were taken from the left side. A cut was made between the 10^{th} and 11^{th} ribs and carried on through the spinal column. The P2 fat measurement was taken on each carcass using vernier calipers over the eye muscle, 60 mm from the carcass midline. Eye muscle length and 3 measurements of the eye muscle width were taken from the cut interface. The eye muscle area (EMA) was estimated using the formula proposed by Zhang et al. (2007) as:

EMA = EML x EMW x 0.7;

where EMW was the average of three width measurements of the eye muscle. EML is the eye muscle length. From the same cut where P2 measurements were taken, a sample joint measuring 2.5 cm thick and 16 cm long measured along the surface of the back of the eye muscle was cut out and weighed. This sample joint was placed in a netlon bag and inserted in a small plastic bag, which was then tied in such a way as to prevent the sample joint from touching the bottom of the plastic bag or air coming into the bag. They were then stored in a refrigerator between 0 and 5°C for 24 h, after which the mass of the water lost was calculated from the weight of the water in the bag and used to calculate drip loss. Thereafter, the primal cuts (shoulder, hindquarter, and rib) from the carcasses were removed on a stationary band saw. The shoulder was removed by cutting between the third and fourth ribs caudally and the junction of the caudal edge of the second rib with the sternum cranially, with the front trotter removed by cutting through the metacarpal region (at the joint of the carpal bones and the radius and ulna) and weighed to get shoulder weight (SW). The rib was cut from between the fourth and twelfth thoracic vertebrae dorsally and along a parallel line 16 cm from the spinal cord midline ventrally. It was weighed to obtain the rib weight (RW). The hind leg was removed between the second and third sacral vertebrae perpendicular to the stretched leg and at the hock joint distally and weighed to get the hindquarter weight (HQW). It was also measured to get the hindquarter length (HQL) from the ischiopubic symphysis to the hock joint and the hindquarter circumference (HQC) in the area of maximum amplitude near the base of the tail. The RW, SW, and HQW were then each presented as a proportion of CCW to give RW proportion (RWP), SW proportion (SWP), and HQW proportion (HQWP), respectively. The selected primal pork cuts are important commercial pork cuts in South Africa.

7.2.6 Chemical and physiochemical analyses of diets and digesta

All representative samples of experimental diet and potato hash silage analysed in triplicates (Table 3.2). The method to analyse the chemical and physicochemical properties is described in section 3.2.5.

7.2.7 Statistical analyses

A PROC GLM (SAS, 2008) procedure was used to determine the effect of potato hash silage inclusion level on carcass traits and primal pork cuts of Windsnyer pigs. A polynomial regression (PROC REG) procedure (SAS, 2008) was used to determine the relationships between inclusion levels of ensiled potato hash and carcass traits and primal pork cuts. The model that was used was:

$Y = Bo + B_1A + B_2A^2 + E$, where

Y = is the response variable (carcass traits and primal pork cuts)

Bo= is the intercept

B_1A =is the linear regression component

B_2A^2 = is the quadratic regression component and

E = is the error.

7.4 Results

There was a positive quadratic relationship between slaughter weight and inclusion levels of potato hash silage. The relationship between inclusion levels of potato hash silage and carcass trains of Windsnyer pigs are shown in Table 7.1. There was a quadratic increase (P >0.001) in warm carcass weight. As inclusion levels of potato hash increased, the warm carcass weight decreased at an increasing rate. Increasing levels of potato hash silage also caused a positive quadratic (P >0.001) response in cold carcass weight. The cold carcass weight also decreased at an increasing rate. A linear (P >0.05) increase in dressing percentage was observed when pigs fed increasing levels of potato hash silage. The cooler shrink decreased quadratically (P >0.05). As inclusion levels of potato hash silage increased, the cooler shrink decreased at an increasing rate. There was a negative linear relationship (P <0.05) between increasing levels of potato hash and carcass length.

Table 7. 1: Relationship between inclusion levels of potato hash silage and carcass traits of slow-growing Windsnyer pigs

Variable	Potato hash silage inclusion level						SEM	Regression co-efficient		Significance
	0	80	160	240	320	400		Quadratic	Linear	
Warm carcass weight (kg)	39.1	33.7	28.7	29.9	30.3	23.7	2.72	0.094	-7.001	***
Cold carcass weight (kg)	37.8	32.9	27.6	28.8	28.7	22.8	2.58	0.092	-6.78	***
Dressing percentage (%)	75.6	73.1	71.1	72.8	69.8	69.1	1.74		3.566	*
Cooler shrink (%)	3.21	4.01	3.75	3.96	5.15	3.48	0.48	-2.797		*
Carcass length (cm)	72.2	69.7	69.2	67.3	68.4	64.0	2.51		-3.969	*
Shoulder fat (mm)	29.5	25.3	28.8	22.5	19.2	19.3	2.08		-0.335	***
Eye muscle area (cm^2)	15.8	14.1	13.4	13.1	10.9	11.3	1.41		-4.189	**
Drip loss (%)	1.21	1.24	2.48	1.19	0.59	1.71	0.47			NS
pH_{24}	5.22	5.20	5.32	5.14	5.26	5.34	0.16			NS

***p<0.001; **p<0.01; *p<0.05; ns not significant

Shoulder fat also decreased linearly (P <0.05) as inclusion levels of potato hash increased. There was a negative linear (P >0.01) response in eye muscle area as ensiled potato hash increased. Drip loss and pH_{24} was not related (P >0.05) to increasing levels of potato hash silage.

Response in primal pork cuts of Windsnyer pigs fed on increasing levels of potato hash are portrayed in Table 7.2. There was a positive quadratic relationship (P <0.05) between HQL and inclusion levels of potato hash silage. As potato hash silage increased, the HQL increased at a decreasing rate. The HQC decreased linearly (P >0.05) as the inclusion levels of potato hash silage increased. There was a negative linear relationship (P < 0.05) between DFT2 and inclusion levels of ensiled potato hash. The DFT3 exhibited a linear decrease (P <0.05) in relation to potato hash silage. Figure 7.1 shows the relationship between inclusion levels of potato hash silage and backfat thickness. There was a linear decrease (P <0.01) in backfat thickness as inclusion levels of potato hash increased.

7.5 Discussion

To conserve and intensify production of Windsnyer pigs, it is crucial to characterise them. The response in carcass characteristics of Windsnyer pigs fed on increasing levels of potato hash silage is reported for the first time. Understanding ability of Windsnyer pigs to convert locally available feed resources into pork products helps to understand the efficiency of these pigs in utilising potato hash silage. A quadratic increase in warm carcass weight could mean that Windsnyer pigs are efficient at utilising diets containing potato hash silage. However, Moset *et al*. (2015) reported a linear decrease in carcass yield of pigs when fed diet containing ensiled citrus pulp.

Table 7. 2: Relationship between inclusion levels of potato hash silage and primal pork cuts measurements of slow growing Windsnyer pigs

Variable	Potato hash silage inclusion level						SEM	Regression co-efficient		Significance
	0	80	160	240	320	400		Quadratic	Linear	
HQL (cm)	34.0	32.0	33.3	31.3	41.4	27.2	2.81	0.089		*
HQC (cm)	45.7	44.2	40.7	42.5	33.6	39.5	2.72		-0.699	*
DFT1 (mm)	16.7	17.2	21.2	18.8	16.2	12.3	2.48			NS
DFT2 (mm)	18.7	18.0	18.3	16.0	16.2	14.0	1.71		-0.269	*
DFT3 (mm)	19.0	20.1	19.3	17.8	14.2	15.3	1.65		-0.876	*
HQWP (%)	18.5	19.5	22.4	21.3	20.8	19.2	1.33			NS
RWP (%)	7.89	7.44	10.2	8.15	7.84	7.62	0.81			NS
SWP (%)	11.7	11.7	14.2	11.9	12.3	12.3	0.86			NS

***p<0.001; **p<0.01; *p<0.05; ns not significant. HQL = hindquarter length; HQC = hindquarter circumference; DFT1 = dorsal fat thickness at first rib; DFT2 = dorsal fat thickness at last rib; DFT3 = dorsal fat thickness at last lumbar vertebra; HQWP = hindquarter weight proportion; RWP = rib weight proportion; SWP = shoulder weight proportion

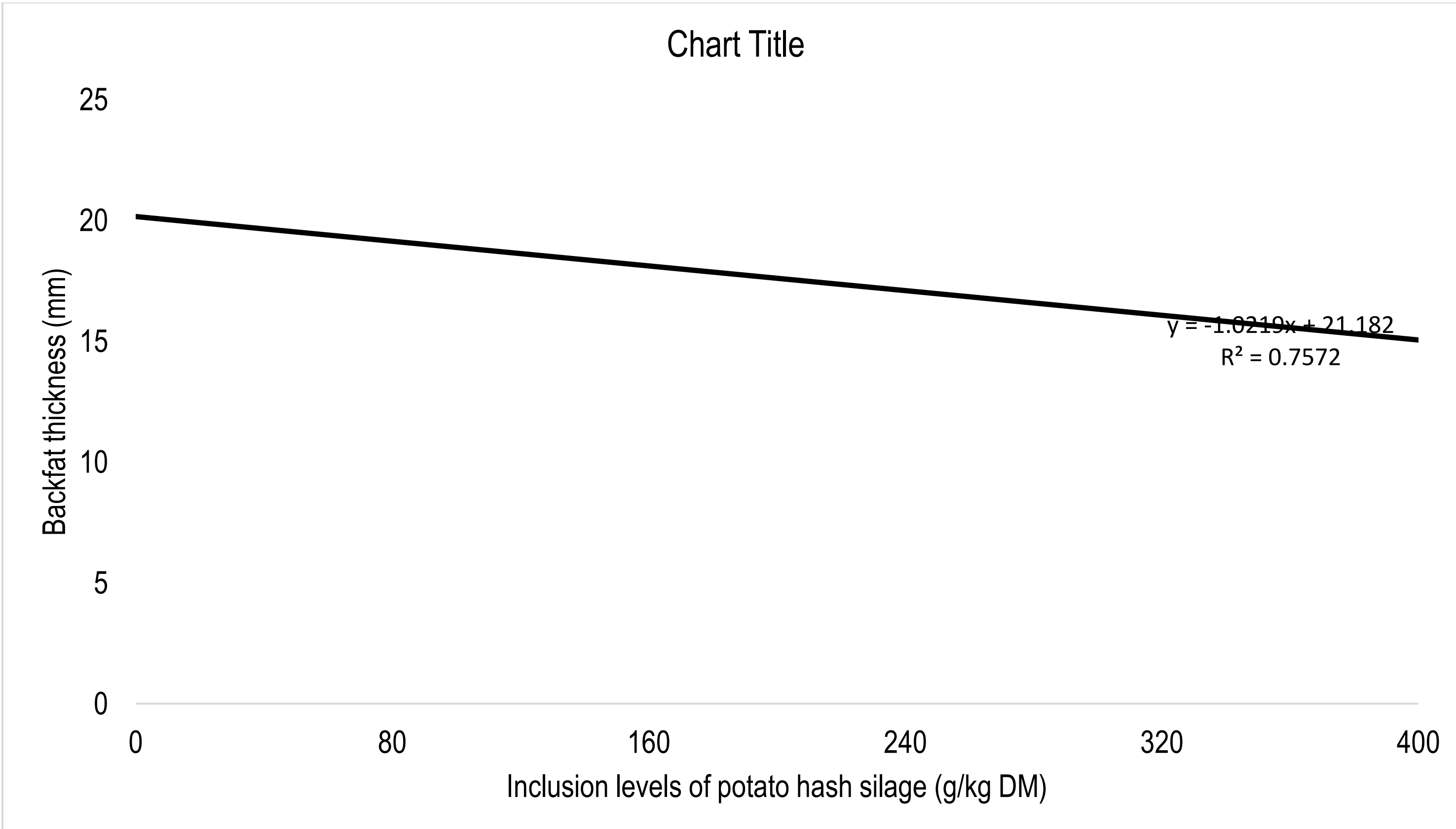

Figure 7. 1: Relationship between inclusion levels of potato hash silage and backfat thickness

The differences between findings could be due to different pig breeds used, agro-industrial by-products under investigation and variation in time of ensiling. A linear increase in dressing percentage implies that Windsnyer pigs were efficient at utilising diet containing ensiled potato hash. This also suggests diet containing potato hash silage may be beneficial to swine farmers who keep Windsnyer pigs. Cooler shrinkage is the weight loss that occurs as the carcass loses moisture during chilling. A negative quadratic relationship between cooler shrink and inclusion levels of potato hash silage is difficult to explain. A decrease in cooler shrink could be associated to genetically deposition of high fat on the carcass of Windsnyer pigs which have a direct impact on the cooler shrink. Carcasses with excessive amounts of fat are likely to have less cooler shrink than trimmer carcasses. The normal range of cooler shrink for Windsnyer pigs is, however, largely unknown. The negative linear relationship between carcass length and inclusion of ensiled potato hash is difficult to explain. Generally, Windsnyer pigs have short carcass stature (Kanengoni *et al*., 2017; Madzimure *et al*., 2017). Carcass length is influenced mostly by genetic selection instead of diet. Windsnyer pigs have a small frame size and stocky body that largely influence carcass length. Carcass length affects the weights of the most important pork cuts and determines the number of rashers of bacon obtained (Kanengoni *et al*., 2004). Pork shoulder is not considered as one of the leaner cuts of pork because it is high in saturated fat. A linear decrease in shoulder fat could be due to differences in slaughter weight of pigs.

A linear increase in DFT2 is related to the genotype of the pig. A linear decrease in DFT3 as potato hash silage increased could be due to fat from last rib of lumbar vertebrae is closer to backfat thickness that mostly affected by fibre inclusion levels. A linear reduction in backfat thickness with incremental levels of potato hash silage is likely to be due to the dietary fibre that reduces nutrient digestion and absorption of fatty acids. Fang *et al*. (2014) reported that high dietary fibre or resistant potato starch decreased lipogenesis in adipose tissue. The increase in water-holding capacity and swelling capacity of the diets with incremental levels of ensiled potato hash silage could have induced a durable satiety and inevitably lowered the energy intake, henceforth, suppressing nutrient availability to support fat deposition (Khanyile *et al*., 2017). A linear decrease in HQC could be that Windsnyer pigs have stocky bodies with small distribution of muscle and fat in hind legs. Quadratic increase in HCL is difficult to relate it to inclusion level of potato hash silage. It could, however, be related to the carcass length and weight of pigs. Inclusion of ensiled potato hash in diets, did not negatively affect HQWP, RWP and SWP. These primal pork cuts are of economic importance in South African pork production industry.

7.6 Conclusions

There was a positive relationship between inclusion levels of potato hash silage and warm carcass weight, cold carcass weight and dressing percentage. There was, however, no clear relationship between other carcass traits and primal pork cuts against ensiled potato hash silage. It is believed that most of carcass traits and primal pork cuts are largely related to the genetics of Windsnyer pigs instead of diet. Backfat thickness was negatively related to inclusion levels of ensiled potato hash silage.

7.7 References

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CHAPTER EIGHT: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 General discussion

Genetic diversity and adaptation to tropical circumstances can be important reasons to do research with Windsnyer pigs. Lack of information on the attributes of the slow-growing breeds, particularly the Windsnyer breed, makes it difficult to conserve, utilise and incorporate it in improvement schemes (Chimonyo *et al*., 2005). Windsnyer pigs utilise maize cob silage more efficient than imported breeds (Kanengoni *et al*., 2015). There is a need to search for other feed resources that are available in abundance to increase the availability of feed resources for Windsnyer pigs whilst promoting their conservation. There is a growing intrigue towards expanding availability of feedstuffs that are not edible by humans for pigs. The focus of interest has mostly shifted towards smallholder pig farmers who are not affording to purchase conventional feed resources. Climate change, for example, has messed up prices of feed ingredients, making non-conventional feeds become more important. Potato hash is highly available throughout the year and need to be utilise as feed for pigs. Utilising non-conventional fibrous feeds such as potato hash in feeding scheme for pigs improves the cleanliness of the environment, and contributes to employment creation.

Feed intake and growth performance of Windsnyer pigs fed progressive levels of potato hash silage was estimated (Chapter 3). It was hypothesised that inclusion of ensiled potato hash in Windsnyer pig diets improves growth performance up to an optimum inclusion level beyond which higher levels negatively affect average daily gain (ADG) and gain: feed (G\F) ratio. The feed intake increased at increasing rate and then started to increase at a decreasing rate until it reaches the maximum before decreasing. This is could be related to either bulkiness or palatability of potato hash silage. When feed is bulky, pigs consume more feed to meet nutrient requirement. High levels of potato hash silage spoil very rapid if pigs do not eat it and finish quickly, thus feed intake is limited. It is, therefore, difficult to single out one factor since preference studies were not conducted. Increasing levels of potato hash silage resulted to linear decrease in ADG and G\F ratio could be that during ensiling, micro-organisms did not sufficiently break down fibre from potato hash to facilitate energy absorption and utilisation. It is also possible that the maize cobs used as absorbent had a direct influence on utilisation of potato hash by pigs. The hypothesis tested was then rejected due to linear decrease ADG and G\F ratio.

In chapter 4, changes in nutritionally-related blood biochemistry of slow growing Windsnyer pigs fed on different levels of potato hash silage were determined. A hypothesis was that there is a positive linear relationship between nutritionally-related blood biochemistry of Windsnyer pigs and inclusion levels of potato hash silage. A linear increase in albumin concentration was observed. Increasing albumin concentration is related to poor palatability of increasing levels of potato hash silage that could lead to hunger or unsatisfied satiety. A positive quadratic relationship between potato hash silage and globulin difficult is to explain. Windsnyer pigs are characterised as being resistant to disease and parasites, which means they have high levels of globulin. Unpalatability of high levels of potato hash silage could frustrate pigs. This links with a linear increase in alkaline phosphatase. A hypothesis tested was not rejected because albumin and globulin concentrations increased with increasing levels of potato hash silage.

The objective of chapter 5 was to determine the relationship between incremental levels of potato hash silage against rate of digesta passage and nutrient utilisation in slow growing Windsnyer pigs. The hypothesis of the study was that as the inclusion levels of potato hash silage increase, the mean retention time and nutrient digestibility will reduced quadratically. A linear decrease in transit time (TT) could be due to increasing content of neutral detergent fibre (NDF) and acid detergent fibre (ADF) in potato hash silage. Potato hash silage has higher moisture content and hydrophilic polysaccharides that absorbs water and hold it in the lumen of the gut. By so doing, they give rise to faster passage rate of the digesta. A quadratic decrease in mean retention time as inclusion levels of potato hash silage increased could be due to low levels of water-soluble carbohydrates in potato hash (Nkosi and Meeske, 2010), which causes feed to be less viscous and rate of passage is shortened. A linear decrease in digestibility of dry matter (DM), organic matter (OM), crude protein (CP) and neutral detergent fibre (NDF) indicates that increasing levels of potato hash silage necessitates the use inoculants and additives to improve utilisation of potato hash silage. Since TT, MRT and digestibility of nutrients were reduced as inclusion levels of ensiled potato hash increased, the hypothesis was not rejected.

The objective of chapter 6 was to relate varying levels of potato hash silage to physicochemical properties of digesta in slow growing Windsnyer pig. A hypothesis tested was that there is positive change in physicochemical properties of the digesta of Windsnyer pigs when fed on increasing levels of potato hash silage. A quadratic increase of swelling capacity of digesta in the stomach of pigs when fed potato hash silage could be that potato hash silage has a high swelling capacity (4.85 mg/l), which directly affects swelling of digesta in the stomach. As diets contained increasing amount of potato hash silage increased, the swelling capacity of the digesta increased. A linear decrease in the capacity of swell of ileum digesta could be related to absorption of the liquids substances. The capacity of the feed particles to swell is, then, reduced. A linear decrease in water holding capacity in the stomach and proximal colon and a quadratic decrease in ileum and caecum was not anticipated. It was not clear whether or not ensiling and the use of absorbents, viscosity, particle size, digestibility, rate of passage and resistant starch content had direct or indirect influences on the water holding capacity of the digesta. A hypothesis tested was rejected due to the decrease in swelling capacity and water holding of the digesta as it passed through the gastrointestinal tract (GIT) in most compartments.

The objective of chapter 7 was to determine the response in carcass traits and primal cuts of pork from slow growing Windsnyer pigs fed on graded levels of potato hash silage. A hypothesis of the study was that the response in carcass traits and primal cuts of pork from slow-growing Windsnyer pigs is related in a positive linear fashion to the inclusion levels of potato hash silage. A linear increase in dressing percentage implies that diet containing potato hash silage may be beneficial to swine farmers who keeps Windsnyer pigs. A quadratic decrease in cooler shrink was difficult to explain. It could be associated to that Windsnyer pigs genetically deposit high fat on the carcass, which have a direct impact on the cooler shrink. Carcasses with excessive amounts of fat are likely to have less cooler shrink than trimmer carcasses. A linear reduction in backfat thickness with incremental levels of potato hash silage is likely to be due to the dietary fibre that reduces nutrient digestion and absorption of fatty acids. A hypothesis was rejected due to no changes in most of the primal pork cuts and a decrease in cooler shrink and backfat thickness.

8.2 Conclusions

Results from the present study showed that ensiled potato hash has a potential to be used as a feed resource for pigs. However, there is still need of enhancing fermentation of potato hash during ensiling to further improve its utilisation by pigs. Broken stick analysis were appropriate statistical tool to predict feed intake of Windsnyer pigs fed on increasing levels of potato hash silage. An increase in ADFI and decrease in ADG and G/F ratio demonstrates that Windsnyer pigs were consuming more potato hash silage but were not efficient in converting it to muscles. An increase in feed intake with inclusion levels of potato hash silage is ascribe to high water holding capacity and swelling capacity of potato hash silage. Increasing concentrations of nutritionally-related blood metabolites indicates that no damage liver and intestines of pigs fed on ensiled potato hash. This suggests that there were toxicities related to potato hash silage fed to Windsnyer pigs. A reduction in MRT induces low digestibility of nutrient when pigs were fed on potato hash silage. A reduction in TT, MRT and nutrient digestibility occurs because potato hash is fibrous and has a high content of indigestible material. Inclusion levels, water holding capacity and NDF of potato hash silage resulted to less MRT. Incorporation of different levels of potato hash silage induced variable physical properties that additively influence feed bulk and digesta properties along the gut. Changes in physicochemical characteristics of digesta along the gut were influenced by potato hash inclusion level. An increase in compartment weights was due to dietary fibre from potato hash silage. Variation in the swelling capacity and water holding capacity in different compartments indicates that patterns and processes happening in each gut compartment influences physicochemical properties of the digesta. The insignificant relationship between potato hash silage and primal pork cuts suggests that these cuts are associated with pig breed instead of inclusion levels. Backfat was the main carcass traits affected by inclusion levels of potato hash silage.

8.3 Recommendations

8.3.1 Practical recommendations

Environmental relevance of using potato hash is crucial when making use of this by-product as an alternative feed ingredient for smallholder pig production. There is, therefore, a need for concrete evidence on how feeding potato hash affects the environment. The cost benefit analysis of using potato hash has not been done making it difficult for farmers to recognise the economic benefits of using and processing the potato hash. Proper storage and room temperature management where PBPs are stored for feed are crucial to limit the synthesis of GAs. There is a need to teach farmers about innovative ways to preserve, process and improve the utilisation of potato hash. To maximise exploitation of ensiling method, challenges associated with them need to be identified and resolve.

8.3.2 Further research

Possible aspects that need further research include:

- Relationship between inclusion levels of potato hash silage as an antioxidant supplement and pork quality;
- Effect of ensiling on antioxidant capacity of potato hash;
- Relationship between potato hash silage and microbial population and activity of growing pigs;
- Relationship between potato hash silage and volatile fatty acids and nitrogen balance
- Comparison between liquid fermentation and silage on growth performance of pigs
- Comparison performance of slow-growing and fast growing breeds fed on potato hash silage.

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APPENDIX 1: METHODS THAT WERE USED TO MEASURE BLOOD METABOLITES IN PIGS

Method used to measure total protein

Biuret method was followed to measure serum total protein (Weicheselbaum, 1946). A violet-coloured compound was formed by allowing biuret reagent to complex with the peptide bonds of protein from the sample under alkaline condition. Sodium potassium titrate was used as an alkaline stabilizer, and potassium iodine was used to prevent auto-reduction of the copper sulphate. The amount of the violet complex formed was proportional to the increase in absorbance when measured bichromatically at 544 nm/692 nm.

Method used to measure uric acid

Uric acid was determined with urease kinetic ultraviolet method (Tietz, 1995).The procedure involves the hydrolysis of uric acid to produce ammonia and 91 carbon dioxide. The ammonia produced in the first reaction combines with α oxoglutarate and Nicotinamide adenine dinucleotide (NADH) in the presence of glutamate-dehydrogenase to yield glutamate and NAD+. The conversion of NADH chromophore to NAD+ product, measured at 340 nm/647 nm is proportional uric acid in the sample.

APPENDIX 2: ETHICAL CLEARANCE

ARC • LNR

Excellence in Research and Development

Date: 04 June 2016

Dear Cyprial,

Re: Ethical evaluation of the project entitled "Prediction of gut capacity using physicochemical properties of fibrous feeds and their effect on blood metabolite concentration, microbial activity and pork quality in indigenous and exotic pig genotypes".

Your application for the ethical evaluation of the project entitled "Prediction of gut capacity using physicochemical properties of fibrous feeds and their effect on blood metabolite concentration, microbial activity and pork quality in indigenous and exotic pig genotypes" has been finalized and approved. Its Ref no is **APIEC16/015**.

I would like to inform you that the project was evaluated and found to be ethically acceptable.

Please note that should any amendments or changes be made to the protocol, you are obliged to submit an application to the Ethics committee and that the protocol should be resubmitted for review annually.

Regards,

Dr. C. M. Pilane (Ph.D.)

Interim-Chairperson ARC-API Ethics Committee

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APPENDIX 3: PUBLICATION(S)

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Review article

A review of the utility of potato by-products as a feed resource for smallholder pig production

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ABSTRACT

The use of potato by-product (PBP) as alternative feed, particularly for smallholder pig farmers requires exploration. Potato by-products are abundantly available and considered as debris and yet they have potential to be valuable feed ingredients. Chemical and bulk properties of PBPs vary largely with processing and type of PBP generated. Ordinarily, they are good sources of energy, starch, partly fibre and have low levels of protein. Drawbacks of utilising PBPs are that they are bulky with high levels of moisture that make them prone to putrefaction if unused in a short period. It is, therefore, worthwhile to process PBPs as a strategy to prolong their shelf life, to fill the gaps of feed shortages throughout the year. This promotes their usage as source of dietary energy and fibre for pigs and will, in turn, solve disposal problems facing the food processing industry. The methods used to process and preserve PBPs should be appropriate for farmers to maintain low cost of production whilst ensuring both environmental and financial sustainability. There is inconsistent data on the influence of PBPs on pig performance. This could be because of the different processing methods used, inclusion levels and pig breeds. The information on nutritive value, bulk properties and the impact of PBPs on feed intake and growth performance of pigs is inconclusive. Processing and preservative methods such as boiling, liquid fermenting, sun drying and ensiling are likely to be compatible methods for smallholder pig farmers. These methods are inexpensive, easy to access and are appropriate for the financial standing of smallholder famers. To maximise exploitation of these methods, challenges associated with them need to be identified and resolved.

Contents

Abbreviations: PBPs, potato by-products; DM, dry matter; GAs, glycoalkaloids; NDF, neutral detergent fibre; WSC, water soluble carbohydrates; LAB, lactic acid bacteria; SID, standardized ileal digestibility.

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