AN EVALUATION OF THE EFFECTS OF TWO DIFFERENT INOCULANTS ON THE QUALITY OF POTATO HASH SILAGE FOR GROWER PIGS

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AN EVALUATION OF THE EFFECTS OF TWO DIFFERENT INOCULANTS ON THE QUALITY OF POTATO HASH SILAGE FOR GROWER PIGS

By

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DECLARATION AND COPYRIGHT

I, Ronald Thomas Sylvester, identity number [redacted], student number 208066187, declare that, this dissertation: **An Evaluation of the effects of two different inoculants on the quality of potato hash silage for grower pigs,** submitted to the Central University of Technology, Free State, for the degree MAGISTER TECHNOLOGIAE: AGRICULTURE, is my own independent work; and that all sources used and quoted have been duly acknowledged by means of complete references; and comply with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology; and has not been submitted before to any institution by myself or any other person, in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification. I also disclaim this dissertation in the favour of the Central University of Technology, Free State.

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DEDICATION

I dedicate this work to the extended and caring Mokgwamme and Mogoregi families; mother Sylvia Mokgwamme, Rebecca and Elliot Mokgwamme. Thank you for encouraging and supporting me. To my cousins, Tumi Mokgwamme, Tshepo Mokgwamme, Biki Letshwenyo, Palesa Mogoregi and Gosetsemang Mokgwamme, as well as my loving wife Maureen Masogo and my baby Tsholofelo Thomas, you are my inspiration, thank you for your support.

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ABBREVIATIONS	DESCRIPTION
%	percent
°C	degrees Celsius
ADF	acid detergent fibre
ADFI	average daily feed intake
ADG	average daily gain
ANOVA	Analysis of Variance
ARC	Agricultural Research Council
AA	acetic acid
BA	butyric acid
BF	Bonsilage Forte
BFPHS	Bonsilage Forte treated potato hash silage
BW	body weight
Ca	calcium
Cfu	colony forming unit
Cont	control
CO_2	carbon dioxide
CP	crude protein
CV%,	coefficient of variance %
DCP	digestible crude protein
DE	digestible energy
DM	dry matter
DMI	dry matter intake
EE	ether extract
FCR	feed conversion ratio
FW	final weights
FFS	full fat soya
g	gram
GE	gross energy
Gen	gender

Gly	glycerol
h	hour
HCl	hydrochloric acid
HClO4	perchloric acid
IW	initial weights
kg	kilogram
L	litre
LA	lactic acid
LAB	lactic acid bacteria
LFLBPHS	Lalsil Fresh LB treated potato hash silage
MJ	mega joule
NDF	neutral detergent fibre
NH_3	ammonia-nitrogen
OM	organic matter
P	phosphorus
PA	propionic acid
PHS	potato hash silage
SEM	standard error of means
SOC	soya oil cake
Supp	pig supplement
TDN	total digestible nutrients
TMR	total mixed ration
TN	total nitrogen
Trt	treatment
UNPHS	untreated potato hash silage
VFA	volatile fatty acid
Vs	versus
WB	wheat bran
WSC	water soluble carbohydrate
Wt	weight

GENERAL ABSTRACT OF THE STUDY

This study evaluated the effects of two bacterial inoculants on the fermentation quality and aerobic stability of ensiled potato hash (PH) and on digestibility, growth performance and carcass characteristics of growing pigs fed the ensiled PH. In the first experiment, 700 grams of PH, was mixed with 300g wheat bran (as is basis) and ensiled in 1.5 litre anaerobic jars. The mixture had a dry matter (DM) of 41.3 g/kg, 78.05 g/kg DM of water-soluble carbohydrates (WSC) and a pH of 6.87 at day 0 and was treated with *Bonsilage forte,* BF, a heterofermentative LAB, *Lalsil Fresh* lactobacillus bachneri*,* LFLB, a homofermentative LAB or without LAB inoculant (control). Triplicate samples per treatment were collected on days 0, 3, 10, 21 and 45 post-ensiling and analysed for DM, WSC, pH, lactic acid (LA), acetic acid (AA), butyric acid (BA), propionic acid (PA) and ammonia-N. On day 45, the silage was subjected to aerobic exposure for 5 days and CO_2 production was measured. In the second and third experiments, potato hash-wheat bran mixtures of 7:3 ratio were produced and ensiled in 210 litre drums that were kept at a 25^0C environment. The second experiment involved an apparent nutrients digestibility study using 30 female (Large White x Landrace crossbred) pigs (30 ± 2 kg live weight), which were selected and housed individually. A cross-over design was applied with two periods and 30 animals fed 10 diets. Three pigs were given one diet per period. The diets were: commercial feed (control); 20, 40, and 60% dietary inclusion of potato hash silage (untreated potato hash silage, UPHS; Lalsil Fresh treated potato hash silage, LFLBPHS, and Bonsilage forte treated potato hash silage, BFPHS). Each experimental period lasted for eleven days with seven days being for adaptation to each diet and four days for collection of faeces before crossing over to the next treatment. Pigs were fed twice per day at 8:00 and 15:00, with the daily allowance equally divided between the two meals. Faecal samples were weighed and 10% of the total collection was taken and kept in a freezer at -18^0C. Prior to chemical analysis, individual samples of faeces were thawed and pooled for pigs within periods. Water was made available at all times

through drinking nipples. The third experiment was a pig growth study using sixty-four crossbred pigs (Large White x Landrace) consisting of 32 males and 32 females (30.4±2.3kg live weight). The pigs were randomly allocated to four diets in a 4 x 2 (treatment x sex) factorial experiment in a completely randomised design. The diets contained up to 40% potato hash silage (PHS) and were: control (commercial diet - no silage), UPHS, BFPHS and LFLBPHS. Each experimental unit consisted of two pigs and each treatment was replicated 8 times. Pigs were fed on one of the four diets until they reached a slaughtering weight of 60 kg. Warm carcass weights were determined immediately after slaughter. After an overnight chill storage at 4.3^0C, cold carcass weights were determined. Carcass length was taken on hanging carcasses by measuring from the pelvic bone to the first thoracic vertebra, using a measuring tape. Backfat thickness was also taken on cold carcass at P2 (45 mm from midsection) between the 3^{rd} and 4^{th} rib on the left side of the pigs. Drip loss was also calculated for hanging carcasses by determining the weight loss after the overnight chill. Results from experiment 1 showed that both inoculants (LFLB and BF) reduced ($P<0.05$) the silage pH while increasing the LA content of silage compared to the control. The concentrations of propionic acid, butyric acid and ammonia-N were not affected by inoculation. When exposed to air, BF and LFLB reduced ($P<0.05$) CO_2 production compared to the control. Results of the second experiment showed that daily intakes of organic matter (OM), crude protein (CP), ether extract (EE), acid detergent fibre (ADF), neutral detergent fibre(NDF), and gross energy (GE) were different ($P<0.05$) between diets. There were no differences ($P<0.05$) in digestibility of DM, EE, and DE among the treatments. However, diets containing 60% PHS had lower ($P<0.05$) NDF and ADF digestibility compared to diets containing less PHS. Furthermore, pigs on the control diet had higher ($P<0.05$) final body weight, average daily gain (ADG) and better feed conversion ratio (FCR) compared to those fed on other diets. Results of the third experiment showed that, pigs that were fed the control diet had higher ($P<0.05$) slaughter weight than pigs that were fed on diets containing PHS. There were no differences ($P>0.05$) on warm and carcass weight between diets containing PHS. Control had higher ($P<0.05$) dressing percentage than the other treatments. Drip loss percentage, backfat

thickness, gastrointestinal tract (GIT), lungs and heart did not differ (P<0.05) between treatments. The effects of gender was not significant within treatments on slaughter weight, warm and cold carcass weights, dressing percentage, carcass length, backfat thickness, drip loss, GIT, lungs and heart. There were no gender by diet interactions (P>0.05) on warm carcass weights, cold carcass weights, drip loss percentage, carcass length, backfat, intergastral, lungs and heart. However, gender by diet interaction (P<0.05) occured on slaughter weight and dressing percentage. It was concluded that, inoculation improved both the fermentation and aerobic stability of PHS. Furthermore, there was no advantage in using LAB inoculants in ensiling potato hash on the growth performance or meat characteristics of growing pigs. However, further work is needed to evaluate the effects of higher dietary inclusion levels (> 60 %) of PHS on pig growth and reproductive performance.

Keywords: carcass traits, digestibility, growth performance, heterofermentative, homofermentative, Potato hash, silage

CHAPTER 1

1. BACKGROUND AND OVERVIEW OF THE STUDY

1.1 INTRODUCTION

Valuable studies have been conducted to determine the possibility of using non-conventional agro-industrial by-products in animal diets such as wheat middlings (Van Lunen *et al*., 1989; Han *et al*., 1998), canary seeds (Thacker, 2003), peas, sweet potato leaves, potato waste and rice bran, to mention just a few.

In the South African context, the use of agricultural by-products generated by the food industry could be of prime importance in the attempt to make more affordable feed resources available to resource-poor livestock farmers, especially pig farmers who at the moment keep different breeds of pigs, such as Kolbroek, Duroc, Landrace, Large White and their crosses. The products of industrial potato processing are a potential feed resource which could replace or be included in traditional pig diets which are mostly based on maize and soybean. The fact that potato waste is produced during the processing of chips (Schieber *et al*., 2001), makes this possible feed alternative plausible and may benefit resource-poor pig farmers with a significant decrease in feed costs, which accounts for 80% of pork production costs (Fialho *et al*., 1995). Other benefits would include the reduction of environmental pollution problems (Rahnema & Borton, 2000), and overall improvement of economic productivity by making use of local resources and creation of jobs.

Potato hash is a by-product that is generated during the production of chips and snacks in the food processing industries in South Africa. The by-product contains potato slices and relatively small amounts of yellow maize and fats. It is low in dry matter (15.5%) and is usually discarded without further use (Edwards *et al*., 1986). Interestingly, monogastric animals such as pigs cannot make effective use of potato materials unless they have been heated sufficiently to denature the starch and inactivate the proteolytic enzyme inhibitors (Nicholson *et al*., 1998). Limited data is currently available on the nutritional composition and effect of potato hash on livestock performance. Nkosi *et al.* (2010), evaluated various methods (e.g. ensiling) for treating the potato hash to make it more suitable for animal feeds. The researchers reported that quality silage can be produced by mixing potato hash with wheat bran as absorbent, and treated with microbial inoculants.

Ensilage is essentially the use of controlled fermentation to preserve a crop or material of high moisture by creating anaerobic conditions (McDonald *et al*., 1991). The primary goal of making silage is to maximise the preservation of original nutrients in the forage crop for feeding at a later date (Muck & Kung, 1997). Unfortunately, fermentation in the silo is a largely uncontrolled process, because, it leads to a lesser preservation of nutrients. (Bolsen, 1995). In order to assist in the fermentation process, various additives have been used to improve nutrient composition and energy recovery in the silage, often with subsequent improvements in animal performance (Dennis, 1992; Kung & Muck, 1997).

Silage additives support the fermentation process of the lactic acid bacteria (LAB) in order to produce well preserved silage (Henderson, 1993). These are mainly classified into two groups: stimulants and inhibitors. Fermentation stimulants include LAB and carbohydrate sources such as: glucose, sucrose, molasses, cassava, potatoes and cereals (Kung & Muck, 1997), while the fermentation inhibitors are normally acids and other chemical products. These additive groups are used to control fermentation and act either by encouraging lactic acid fermentation or by inhibiting microbial growth. A basic requirement for all additives is that, they should be non-toxic to humans and animals, and must have no adverse effect on animal performance (McDonald *et al*., 1991).

Fermentation stimulants can be classified into homofermentative and heterofermentative inoculants. Homofermenters are more energy efficient than heterofermenters. During homofermentation, each molecule of glucose produces two molecules of lactic acid, yielding high dry matter recovery and little energy loss from the silage (McDonald *et al*., 1991). Lactic acid is also a strong acid, it reducse silage pH more than other acids. Final silage pH is higher when fermentation is dominated by heterofermenters rather than homofermenters. For each molecule of glucose used in heterofermentation, one molecule of lactic acid, one of acetic acid or ethanol, and one molecule of carbon dioxide are produced. Carbon dioxide leaves the silage as a gas, resulting in DM loss.

Bacterial populations are highly variable across plants and fields, depending on plant and environmental conditions. Adding homofermentative microbial inoculants helps to reduce pH quickly, inhibiting the action of other bacteria and preserving plant proteins. Rapid pH drop and low final pH can inhibit the clostridial bacteria that produce butyric acid. Usually less acetic acid, butyric acid, and ethanol are produced during homofermentation, which improves DM recovery by 2-3% compared to heterofermentative fermentation. Moreover, homofermentative inoculants can improve animal performance by 3 to 5%, from research trials (Kung & Muck, 1997). However, the disadvantage with homofermentative inoculants is that the increase lactic acid concentration can make the silage and other normally low-pH silages more susceptible to heating during feed-out (reduced aerobic stability).

Lactobacillus buchneri is the main heterofermentative lactic bacteria used in silage inoculants. These bacteria convert LA to acetic acid and other products. Acetic acid is a good inhibitor of yeasts and moulds that cause heating and spoilage of silages, thus acetic acid improve bunk life or aerobic stability of silage. Compared to homofermentative inoculants, DM losses are 1 to 2% higher, digestibility is not affected by *L. buchneri*, and aerobic stability is consistently improved in silages and high moisture corn. However, *L. buchneri* inoculants do not appear to improve animal performance beyond that expected from keeping silage cool in the feed bunk (long bunk life). In this study Lalsil fresh LAB was used as heterofermentative and Bonsilage forte was used as homofermentative.

1.2 MOTIVATION FOR THE STUDY

Animal feed makes up the major cost in animal products. Pig feed usually contains feed ingredients such as maize, sorghum, oats, wheat, barley, and milling by-products (Fanatico, 1998). Maize is the well known and most commonly used energy or grain source in pig nutrition, but its cost is increasing because of competition with man and also its increased demand in bioethanol production. Alternative energy sources are either too expensive or have high fibre levels. Potato hash-a by-product of the potato food producing industry-is available in South Africa as an animal feed. An estimated amount of 50 ton per day is produced (Nkosi *et al*., 2010) and farmers are collecting it for free. However, if animals do not consume it within a short period of time, it gets mouldy and becomes useless as animal feed. Ensiling can be considered as an efficient way of preserving potato hash (PH). There is, however, an increasing awareness of the nutritional value of PH as an animal feed due to a great deal of research being done on its nutritional value.

Making silage from PH is of particular importance to small pig producers in South Africa. This is because; potato hash silage can substantially reduce the cost of feed. A major concern that reduces livestock productivity under resource poor farmers in South Africa, is the high cost of animal feed. Consequently, one of the challenges faced by resource-poor farmers is to find alternative feed sources that are of high feeding value and affordable. The study aimed at evaluating various by-products that could serve as a solution, potato hash silage was the proposed solution.

1.3 PROBLEM STATEMENT

Feeding concentrates that include cereal grains has been a common practice under commercial systems. Notwithstanding, this practice is hardly possible under smallholder systems due to lack of funds for the purchase of such commodities. Animal feed is a derived demand, and any change in the demand for animal products will therefore lead to changes in the demand for different animal feed rations (Taljaard, 2003). With the current rise in feed prices coupled with the escalating inflation rates in South Africa, the affordability of conventional feeds has gone beyond the reach of small-scale farmers (Briedenhann, 2008). The availability of agro-industry by-products seems to be a better option for solving such a problem. A by-product feedstuff is by definition a secondary product obtained during harvesting or processing of a principal commodity and as valuable as animal feed (Grasser *et al*., 1995). The amount of by-product that is produced (5-50% of the raw product) in an industry depends on several variables, including the type and quantity of raw product and the method of processing (Kajikawa, 1996). A large proportion of the by-product may be culls, trimmings, or raw product which is inferior in some way and unfit for packing. These by-products may still contain substantial amounts of nutrients and might make an excellent animal feed if further processed to a suitable and easily handled animal feed source. Reports from Kajikawa (1996) show that some by-products have specific properties that are lacking in grains, and their combinations can provide a diet with a range of nutrients that could not be supplied by grain or forage alone.

Fadel (1999) indicated that, potato by-products are amongst the agro-industry by-products that constitute 65% of the one billion metric tons of world dry matter tonnage of by-products. The use of agro-industrial by-products as animal feed has been a common practice for decades in Vietnam (Ngu & Ledin, 2005) and industrialised nations where millions of tons are produced each year (Khan & Atreja, 2005). Furthermore, Okine (2007) projected future increases in the production of by-products in developing countries. Feeding food by-products to livestock has two important advantages, namely; a reduction of the seemingly over-dependence of livestock on grains that can be consumed by humans (Bampidis & Robinson, 2006), and the elimination of costs of waste disposal through nutrient cycling of the by-products from numerous urban sources (Rogerson, 2003).

Some food processing by-products such as sugar beet pulp have been frequently included in livestock diets with success while others are not consistently used because of uncertainty regarding their availability, palatability or intake and the risk of toxic substances (Esteban *et al*., 2007).

One of the main drawbacks of using agro-industry by-products in the formulation of animal feeds is that, their composition may be extremely variable depending on the area and period of production, (Esteban *et al*., 2007). Another drawback is the inherent bulkiness and high moisture content in by-products that make handling difficult and favour microbial contamination (Garcia *et al*., 2006). This increases the cost of transportation of the waste, and may limit its use as feed even if it is given out free of charge at the processing factory. Whether this cost outweighs the benefits depends on the feed value of the product, the relative price of other feeds, and the difficulty of disposing of the by-product in other ways. Although by-product mixtures can be incorporated in intensive animal production systems, they are used to the best advantage during the dry season when feed is in short supply; thus, they can provide for maintenance and low levels of production until pastures start growing again.

It is worth noting that, these feed resources are sometimes of a low quality, containing low crude protein and higher fibre than optimal, for sustaining adequate intake and digestibility. Animals consuming poor quality forages often fail to obtain sufficient nutrients from the diet to meet maintenance requirements (Gertenbach & Dugmore, 2004). In contrast, studies from India (Khan & Atreja, 2005) and Vietnam (Ngu & Ledin, 2005) have proven that agro-industry by-products can be excellent unconventional feedstuffs for monogastrics. Furthermore, Kajikawa (1996) reported that the benefits of using by-products by small-scale farmers are not only to lower feed costs, but to increase animal production as well. Mekasha *et al*. (2002) report brewery wastes such as *Tela atella* and *Katicala atella* to have the potential to be used as protein and energy supplements to low quality based diets under smallholder livestock production systems.

A large number of food processing factories in South Africa are situated in Gauteng and are dependent upon agriculture for raw materials such as; sunflower seeds, peanuts, potatoes and maize. This has led to the availability of agro-industrial by-products resulting from food processing and packing houses, which have not been exploited commercially (e.g. by-products from the Tshwane and Johannesburg fresh produce markets, potato hash from Simba), and is seen as an option to mitigate feed flow problems. These two major fresh produce markets handle 32% (Johannesburg) and 16% (Tshwane) of all fresh produce marketed through formal channels, which are the highest of all markets in the country. In addition, simba is producing potato by-products which are used either as compost or dumped without any potential or value added use. These food processors are faced with a by-product disposal dilemma, which could be both an economic and an environmental problem. The regular use of these wastes as animal feed in the urban and peri-urban livestock keeping systems may reduce the problems of waste disposal. However, their successful use as animal feed should take into account their feed value (Okereke *et al*., 2008), and should increase the efficiency with which they can be used. According to Okine (2007), the rising costs and the decreasing availability of raw materials, coupled with a growing concern for environmental pollution, have led to a growth on the recovery, recycling and upgrading of by-products. This is particularly true for the food processing industries in which by-products, residues and wastes can be recovered and often recycled to higher value and useful products. The South African government does not allow food processors to simply discard these by-products. Consequently, they are sometimes distributed free or at a small charge. Therefore, the importance of using livestock, especially pigs, as consumers of these by-products cannot be over-emphasised. Alternative methods that are environmentally safe have to be made available for improving the digestibility of the large quantities of locally available low quality forages that are required in intensive livestock production systems.

Small scale livestock farmers residing in Gauteng have the advantage of a constant flow of agro-industry by-products that are mostly wasted in dumping areas. It is however possible that, these by-products could be used effectively by smallholder livestock farmers as part of traditional feeding systems if economic methods could be identified to treat them. The South African Legislation Act (Act 36 of 1947) does not permit the use of such wastes in animal nutrition without proper treatment. Most small-scale farmers have not yet internalised safety procedures applicable in terms of the regulations, requirements and guidelines on the use of these resources, as stipulated in the Act. This is because, these farmers prefer to utilise forage resources in the form available to them (Chin, 2002) thus, making their production unsafe. Some of the by-products can be used as direct feeds for livestock or as components in the feed industries. Discarded green leafy vegetables were found to be rich in protein and minerals (Dung, 2001), which can be beneficial to livestock when used as supplements. However, the researchers reported the presence of saponins and trypsin inhibitors (anti-nutritional factors), as well as indigestible fibre which may limit their utilisation in pig nutrition. Feeding untreated waste products to livestock may also cause some metabolic disorders such as blockage in the uptake of iodine especially with unprocessed *brasiccas* (Gertenbach & Dugmore, 2004), and such practices are therefore forbidden by the South African Legislation Act (Act 36 of 1947). In addition, the presence of herbicide and pesticide residues from vegetable wastes (Ngu & Ledin, 2005) restrict their dietary inclusion. This was evident in a study by Schnell *et al.* (1997) whereby, *benomyl* residues were detected on beef samples from animals fed apple pomace or pear pomace, which may cause serious illness to human beings. Pregnant goats that were fed poorly fermented silage produced from contaminated crops, were reported to produce insufficient milk to support their kids; high levels of cadmium were also reported (Telford *et al*., 1984).

Silage making has been long practiced in South Africa, mostly by the commercial sector, using high quality crops such as maize, and cultivated pastures. This production method relies on heavy equipment both to dig storage pits and to compress the forage, putting it beyond the reach of the smallholder farmers. Therefore, special ensiling technology should be developed for such farmers, to meet their needs and for economic feasibility. This technology should be adapted to the farmers through the provincial extension programmes. Fortunately, there are methods such as the small-scale silage bag method (whereby forages are stored in large bags made from polythene), and the big drums (210 litre drum) which can offer a better solution to the smallholder farmers. Plastic bags and drums are relatively cheap and ensiling can be done manually by a few workers. The bag or drum units can be used individually according to feeding requirements. Ashbell *et al*. (2001) confirm good silage from forages ensiled in small plastic bags (10-20 kg), which can be used by smallholder farmers in South Africa. This technology is also common among smallholder farmers in the south eastern areas of Asia (Chin, 2002). The researcher cites important roles played by silage to smallholder farmers as:

1. feed reserve for future utilisation: some farmers in South Africa use silage as a method for fodder conservation to overcome feed shortage in the dry season. This practice is very rare amongst subsistence farmers due to lack of knowledge, finance, labour, etc;
2. routine feed to increase productivity of animals: silage is also routinely fed to increase productivity of high producing animals (e.g. beef and dairy cattle) by providing nutrients necessary to nutritionally balance existing diets. Many commercial operations in South Africa produce and feed maize silage to animals. However, producing maize for silage purposes is a difficult option to be chosen by the subsistence farmers. This is because, maize is grown solely for home consumption. Moreover, the lack of land for the cultivation of maize is another factor limiting subsistence farmers in producing high quality silage. A study by Argel *et al.* (2000) has shown that, expensive concentrates can be replaced with *Cratylia* silage without affecting animal performance, and can be an economically viable option for smallholder farmers
3. a means to utilise excess growth of pasture for better management and utilisation: ensiling is a good option for the utilisation of the excess forage if stocking density is not increased and hay making,(particularly during the rainy period), is also not practical;
4. a way of storing and enabling extended use of potentially unstable material: ensiling enables the storage of forage resources that are perishable and unstable which, unless dehydrated or ensiled, can only be for immediate or at most very short term use. Since many of these resources have high moisture contents, sun-curing is difficult especially in the tropical wet areas and artificial drying may be costly or unavailable.

1.4 PRIMARY OBJECTIVE

The primary objective of this study was to determine the effect of inoculating either Lalsil Fresh LB® or Bonsilage forte® inoculants to potato hash on silage quality and the performance of grower pigs fed the silage.

1.5 SPECIFIC OBJECTIVES

The specific objectives were to:

- evaluate the fermentation quality and aerobic stability of potato hash silage treated with either Lalsil Fresh LB® or Bonsilage forte® as inoculants;
- evaluate growth performance (average daily gain, feed intake, and feed conversion ratio) and digestibility of grower pigs fed potato hash ensiled without inoculants or with Lalsil Fresh LB® or with Bonsilage forte® as inoculants;
- compare carcass traits of pigs fed potato hash ensiled without inoculants, or ensiled with either Lalsil Fresh LB® or with Bonsilage forte®.

1.6 HYPOTHESES

Hypothesis 1: There is no difference in the quality of silage produced without inoculants or with either Lalsil Fresh LB® or Bonsilage forte® as inoculants.

Hypothesis 2: There is no difference in performance of pigs fed a diet made up of either ensiled potato hash-based diet or the maize-soybean diet.

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CHAPTER 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

Ensilage has become an increasingly important method of feed conservation. In many countries, more forage is conserved as silage than hay (Wyss, 2004). There is a growth in the use of conserved forage used as silage due to the escalating costs of feed concentrates throughout the world. There is also the need to preserve quality plant material, only available in certain times of the year, for use during winter and drought seasons. The quality of silage depends greatly on the type of fermentation that takes place and the plant material ensiled. The degree to which the fermentation processes can be controlled thus plays a pivotal role in the quality control of silage (Wyss, 2003). The concept of extraneous treatment for the improvement of aerobic stability in silage is referred to as inoculation. Most of the inoculants that are available contain selected strains of homofermentative lactic acid bacteria (LAB) (Weinberg *et al.*, 1995). Many reports have shown the advantages of such inoculants as reviewed by Weinberg *et al.* (1993), Henderson *et al.* (1993), and Spoelstra (1991). However, studies under laboratory conditions (Weinberg *et al.*, 1993) indicate that, the addition of LAB inoculants impair the aerobic stability of silage of mature cereal crops (wheat, sorghum, maize). The explanation of this phenomenon is that, under anaerobic conditions, the homofermentative LAB inoculants produce mainly lactic acid, which can serve as a substrate for lactase-assimilating yeasts upon aerobic exposure (Weinberg *et al.*, 1995). More studies (Driehuis *et al.*, 1997) however, show that Lactobacillus buchneri improves aerobic stability of whole crop maize through the production of acetic and propionic acids, while the level of lactic acid is reduced.

The optimum pH for silage preservation is between 3.5 and 4.0 (McDonald *et al*. 1991). The harmful bacterial action which gives rise to the formation of butyric acid or the breakdown of protein to undesirable products is completely inhibited at a pH of or below 4. In all processes of ensiling there are losses of dry matter. These losses may be partially accounted for by such volatile materials as carbon dioxide, hydrogen, methane, and ammonia, which are the result of bacterial action and of plant cell respiration. Drainage from the silos carries with it a portion of the soluble material. The addition of preservatives is not only an attempt to make a more palatable feed but also to reduce these common losses to a minimum with special emphasis on the loss of volatile materials. It will be seen, therefore, that in order to minimise these losses, the fodder must be stored compactly so as to exclude as much air as possible. Cell respiration is thereby reduced. The mass of silage must also be acidified to stop undesirable bacterial activity. The use of preservatives at present has the sole objective of increasing the acidity of the mass. McDonald *et al*. (1991) states: "The loss in the ordinary process of silage varies from 25 – 35% of starch equivalent, according to the container used and general quality of the final product. The loss of digestible crude protein may be as high as 40%, particularly in stacks or clamps, but may be as low as 10% in some of the best silage made in a suitable container".

Silage fermentation is a dynamic process that is affected by a variety of factors. Research on silage and silage additives has been conducted for many years. Silage additives have been classified into various categories that generally include 1) stimulants of fermentation (microbial inoculants, enzymes, fermentable substrates), 2) inhibitors of fermentation (acids, other preservatives), and 3) nutrient additives (ammonia and urea). In order for a silage additive to be useful, it must increase DM (nutrient) recovery, improve animal performance (milk [quantity and/or composition], weight gain, body condition, reproduction), or decrease heating and moulding during storage and feed-out.

Bolsen *et al*. (1992) reported that in 19 studies conducted at Kansas State University with corn silage, inoculated silages had 1.3 percentage unit higher DM recoveries, supported by 1.8% more efficient gains, and produced 51 units more gain per ton of crop ensiled with beef cattle. Similar results were found with treated sorghum silages. In certain instances, significant animal responses have been observed with inoculation although there was little effect on traditional end-products of fermentation (Gordon, 1989; Kung *et al*., 1993). These data would suggest that, there may be unidentified components in inoculated silages that are responsible for improved animal performance. When compared to untreated silages, silages treated with adequate numbers of a viable LAB should be lower in pH, acetic acid, butyric acid and ammonia-N but higher in lactic acid content. In a review of the literature between 1990 and 1995, Muck and Kung (1997) reported that microbial inoculation lowered pH, improved the lactic acetic ratio, and lowered ammonia-nitrogen content in more than 60% of studies. Furthermore, dry matter recovery was improved by more than 35% and bunk life improved in about 30% of the studies. Dry matter digestibility was also improved in about one third of the cases. Microbial inoculation usually has little or no effect on the fibre content of silages because most lactic acid bacteria contain little or no ability to degrade plant cell walls. Decreases in fibre content may be due to partial acid hydrolysis of hemicellulose. Some data suggests that certain microbial inoculants can increase fibre digestion (Rice *et al*., 1990).

2.2 ENSILING PROCESS

2.2.1 Essentials for good silage

From a practical point of view, the three most important things that must occur in order to make good silage are 1) the rapid removal of air, 2) the rapid production of lactic acid that results in a rapid drop in pH, and 3) continued exclusion of air from the silage mass during storage and feed-out (McDonald *et al*., 1991). Rapid removal of air is important because it prevents the growth of unwanted aerobic bacteria, yeasts and moulds that compete with beneficial bacteria for substrates (Bolsen *et al*., 1996). If air is not removed quickly, high temperatures and prolonged heating are commonly observed. Air can be eliminated by wilting material to recommended dry matter (DM) for the specific crop and storage structure. Air must be removed before optimal fermentation can take place. Once air is removed, fermentation begins (Ashbell *et al*., 2001).

A quick reduction in silage pH helps to limit the breakdown of protein in the silo by inactivating plant proteases. In addition, a rapid decrease in pH will inhibit the growth of undesirable anaerobic microorganisms such as enterobacteria and clostridia (Kung *et al*., 1998). Eventually, continued production of lactic acid and a decrease in pH inhibits growth of all bacteria. The use of lactic acid may also prove invaluable in promoting pig intestinal health.

Silage can spoil rapidly if exposed to air during storage and feed-out. The most efficient way is to store the material in a hermetically sealed container. Under these conditions, the oxygen trapped in the herbage is rapidly removed by respiratory enzymes in the plant. Lactic acid bacteria (LAB) utilize water-soluble carbohydrates to produce lactic acid, the primary acid, responsible for decreasing the pH in silage (McDonald *et al*., 1991). In addition, a rapid decrease in pH will inhibit the growth of undesirable anaerobic microorganisms such as; enterobacteria and clostridia (Kung *et al*., 1998). Eventually, continued production of lactic acid and a decrease in pH inhibits growth of all bacteria. In general, good silage will remain stable, and not change in composition or temperature once air is eliminated and it has achieved a low pH. This is why filling silos quickly and sealing of silos immediately after filling is so important. Silage can spoil rapidly if exposed to air during storage and feed-out.

2.2.2 Effects of microbiological agents on silage

A common misconception is that, moulds are responsible for spoilage of silage when it is exposed to air. However, yeasts (not moulds) are the primary microorganisms that cause aerobic spoilage and heating (Rooke & Kafilzadeh, 1994). When exposed to air, yeast metabolises lactic acid that causes the pH of the silage to increase, thus allowing bacteria that were inhibited by low pH to grow and further spoil the mass. The dry matter content of the forage can also have major effects on the ensiling process via a number of different mechanisms.

Firstly, drier silages do not pack well and thus make it difficult to exclude all of the air from the forage mass. Secondly, as the dry matter content increases, growth of lactic acid bacteria is curtailed and the rate and extent of fermentation is reduced, since acidification occurs at a slower rate and the amount of total acid produced is less. Thirdly, undesirable bacteria called clostridia tend to thrive in very wet silages and can result in excessive protein degradation, dry matter (DM) loss, and production of toxins (Rooke & Kafilzadeh, 1994). Where weather permits, wilting forage above 30-35% DM prior to ensiling, can reduce the incidence of clostridia because, these organisms are not very osmotolerant (Dawson, 1994). Many end products are commonly produced during the fermentation process but many of these end products are associated with less than desirable fermentations. Of the several types of acids produced during the fermentation process, lactic acid is the strongest (10 times stronger than the other acids) and preferred end product of silage fermentation. In fact, homolactic acid fermentation that produces only lactic acid would be the desirable fermentation because of the resultant high energy and dry matter recoveries (Gordon, 1989; Kung *et al*., 1993).

2.2.3 The use of silage inoculants

Silage inoculants can be classified into various categories that generally include:

- stimulants of fermentation (microbial inoculants, enzymes, fermentable substrates);
- inhibitors of fermentation (acids and other preservatives); and
- nutrient additives (ammonia and urea).

Silage inoculants (additives) have been developed over years to improve the nutritive value of silages, reduce some risks during the ensiling process, with subsequent improvement in animal performance (Kung *et al.*, 1993)). Silage additives are used as fermentation stimulants, fermentation inhibitors, aerobic deterioration inhibitors, nutrients and absorbents (McDonald *et al*., 1991). Ensiling a low dry matter content (±23%) corn silage without additives was found to be unsuccessful, and chemical additives were then used to improve its fermentation (Juracek *et al*., 2008). Chemical additives, such as formic and other strong acids, are used and gradually being substituted by biological additives which are less dangerous and less corrosive to equipment (Muhlbach, 1999).

Although the main objective in using inoculants is to ensure that the lactic acid bacteria dominates the fermentation process, thus producing well-preserved silage, attention is also paid to methods of reducing ensiling losses and improving the aerobic stability of silages during the feeding phase. Inoculants which contain homolactic acid bacteria have shown to improve silage fermentation, but often reduce aerobic stability, (Muck & Kung, 1997; Rust *et al*., 1989) because, the production of anti-fungal compounds (e.g. acetic acid) is usually decreased (Muck & Kung, 1997). In contrast, *Lactobacillus buchneri*, a heterofermentative LAB, has improved the aerobic stability of silages (Muck & Kung, 1997) via the accumulation of acetic acid (Ranjit *et al.,* 1998). Lactic acid bacteria regularly associated with silage are members of the genera *Lactobacillus, Pediococcus, Leuconostoc, Enterococcus, Lactococcus* and *Streptococcus*. All LAB are facultative aerobes, but some have preference for anaerobic conditions. Therefore, adding of homofermentative LAB to a crop at ensiling will ensure that sufficient viable LAB are present (Khan & Atreja, 2005), and may also adversely affect the aerobic stability of the silage (Rust *et al.,* 1989). Various chemical additives such as propionic acid-based additives (Kung *et al*., 1998) have been used to prevent silage spoilage when silage is exposed to air, thus enhancing the aerobic stability of silages. However, their hazardous nature halts their usage, as they pose serious health problems to human beings (Gwayumba, 1997).

In order for a silage additive to be useful, it must increase DM (nutrient) recovery, improve animal performance, and decrease heating and moulding during storage and feed-out (Kung *et al*, 1993). Changes in fermentation end products without quantifiable improvement in one or more of these categories, will be questionable. Although additives may aid the preservation of forage, they cannot compensate for poor ensiling practices. The use of an additive should always be associated with good ensiling management. Corn/grass should be cut at the correct stage of maturity, dry matter and chop length; the silo must be rapidly filled and well consolidated. Following these practices will improve the ensiling techniques and increase the effectiveness of an additive or reduce the need for one. The use of an additive based on its effect during ensiling and livestock performance must be evaluated, as well as cost and return on investment.

2.2.4 Types of silage additives

Many different silage inoculants are available and are used for different reasons. Inoculants are used to improve the nutrient composition of silage, reduce storage losses by promoting rapid fermentation, reduce fermentation losses by limiting the extent of fermentation, and by improving the bunk life of silage (increase aerobic stability).

a) Non-Protein Nitrogen (NPN)

Urea and ammonia can be added to silage to increase its crude protein (CP) content. Urea usually has 280% CP whereas ammonia has about 512% CP. Therefore, relatively small additions of these compounds can markedly increase the CP content of silage. Corn silage is extremely low in CP (average 8%, DM basis), whereas hay crop silage may contain more than 20% CP. The benefit of adding NPN to corn silage includes increasing the CP content by 2-6% units. Ammoniated or urea-treated corn silage usually has CP concentration of 12-13% (DM basis). This can result in substantial savings by reducing the need for protein supplementation. Ammoniating hay crop silage does not increase its CP content greatly because, hay crop silages generally have relatively high concentrations of CP and the amount of ammonia added is low (0.6 – 0.7kg/tonne). Another benefit of adding NPN to silage crops is that, it reduces plant protein destruction during fermentation. During normal fermentation much of the plant protein is broken down into amino acids or small peptides. These compounds are degraded rapidly in the rumen when ruminants are fed the silages. Protecting plant proteins from breakdown during ensiling, increases the amount of undegradable or by-pass protein in the silage (Kung *et al.*, 1993). This procedure could be very advantageous with high quality grass or alfalfa silages.

b) Feedstuffs

Feeds such as corn, small grains and molasses can be added to forage at the time of ensiling. Addition of grain to corn silage is not useful, but adding it to hay crop silage has two benefits. Firstly, adding grain to crop silage increases the energy content of the silage. This will reduce the amount of supplemental grain that has to be fed. If silage is to be the main or only feed offered, then adding some grain to the forage at ensiling will make it a more complete diet. Secondly, adding grain to forage will increase the DM content of the silage. Hay crops that are not wilted sufficiently prior to ensiling can cause seepage and result in an undesirable fermentation (Umesiobi, 2000). Added grain may also make wet silage easier to unload from the silo. Molasses have been used as a silage additive for many years. Molasses, unlike grain, provide fermentable carbohydrate; therefore, molasses addition can improve the fermentation of some hay crop forages. Adding molasses at 61kg/wet tonne of hay crop silage (approximately 455 DM) usually increases fermentation noticeably and results in good quality silage. Molasses should not be added to wet silage (<35% DM) because of increased seepage losses. There is no benefit to adding molasses to corn silage.

c) Minerals

Minerals such as calcium, phosphorus, sulphur and magnesium have been added to forage at the time of ensiling. Usually, these have either no effect on fermentation or act as buffers resulting in higher pH silage. The only reason for adding minerals at the time of ensiling is if the silage is to be the only feed offered to the animals. Addition of minerals will make the silage more nutritionally complete. If concentrates are going to be supplemented, it will be better to add the minerals to the concentrate mix.

d) Acids

Acids are added to forage at ensiling to cause an immediate drop in pH, or to increase its bunk life. Formic and mineral acids (sulphuric and hydrochloric) added at 3 – 6kg/wet tonne will reduce pH quickly and greatly limit fermentation losses of protein and carbohydrates. These acids are extremely caustic and hazardous to use. Propionic acid is weaker than formic and mineral acids, but can be a useful additive for silage. Adding 7kg/wet tonne of hay crop silage increases its bunk life and reduces surface moulding. Low DM silage needs more propionic acid than drier silage.

e) Microbial inoculants

Inoculants are added to forage to increase the number of desirable bacteria present at the time of ensiling. Corn plants at harvest contains 500 000 – 2 million lactic acid bacteria/gram. Most commercial inoculants when applied at recommended rates, add about 100 000 LAB/g. Therefore, the relative increase in LAB due to inoculation ranges from 5 – 10%. Generally, there are fewer LAB on hay crops than on corn plants prior to ensiling. Hay crops can have less than 10 000 LAB/g to more than 1 000 000 LAB/g wet forage. Factors affecting the number of indigenous LAB include; forage species, environmental temperature, and wilting period. Forages that are cut during cool temperatures and have a short wilting period generally have low indigenous LAB populations.

2.2.5 Factors affecting silage fermentation

Several factors have shown to influence the course and outcome of silage fermentation and, in keeping with the aspects of silage considered so far, the accumulated information relates mostly to forage crop silage (Woolford, 1984). It can be seen that there are two overriding features of any silage which will affect fermentation. The first is the nature of the raw material being ensiled and the second relates to the ensiling conditions imposed by the silage-maker.

a) Chemical composition of the ensiled material

This aspect will have a dominating influence on fermentation in conventional silage. In the case of forage crops, chemical composition will be influenced by the weather, growth conditions, level of fertiliser applied, and the maturity of the material at harvest. Weather could have a significant effect on silage fermentation by virtue of its effects on water-soluble carbohydrates in grass or corn. Green crops harvested following cool dry weather tend to have the highest sugar content, and this is positively correlated to the lactic acid content of the resultant silage. In the case of corn, high plant density can delay the peak in sugar content and therefore this factor, combined with the time of harvest, could influence fermentation. The nature of the fermentable substrates or its sources may also influence the fermentation process.

b) Water soluble carbohydrates in crops

One of the main factors influencing the ensilability of a crop is the concentration of WSC in that particular crop. In temperate forages, the WSC comprise mainly monosaccharides glucose and fructose, the disaccharide sucrose, and the polysaccharide fructan. Since these occur as free sugars, they provide substrate for LAB at the earliest stages of ensiling. Both sucrose and fructans are available for lactic acid bacteria later on, since they must go through acid hydrolysis to become available as monosaccharides. Water-soluble carbohydrate development in forage plants might constrain the ensilability of whole crop cereal since the dough stage of growth is considered as the most desirable stage at which to harvest cereal for silage making (McDonald *et al.*, 1991). Ashbell and Weinberg (1992) suggested that the optimal harvesting time of whole crop cereal considering the yield, feeding value and ensilability to be between early and late dough stage. Normally a minimum of 6 – 12% crop WSC are required for proper silage fermentation. It is therefore important to understand the factors that will influence the WSC content of the forage.

c) Crop dry matter

The crop dry matter content can vary considerably depending on the weather. The DM content is an important factor influencing the microbial population and activity in the ensiled crop (McDonald *et al.*, 1991). Water content and availability in the crop are essential for microbial activity during the ensiling process. Clostridia are generally more sensitive to reduced water availability than lactic acid bacteria. This can be tested by wilting of forage which reduces the DM concentration and hence the water availability in the crop.

d) Buffering capacity of the crop

The buffering capacity of plants determines the ability to resist a pH drop down to 4.0. Most of the buffering properties of forages are attributed to the anions (organic acid salts, nitrates, and sulphates). Buffering capacity can be increased during the ensiling process by the production of various organic acids. The concentration of the buffering compound in plants is usually reduced with advancing stage of growth. Legumes possess high buffering capacity whilst grasses and cereals have relatively low capabilities. Nitrogen fertilisation increases the buffering capacity of a crop.

2.2.6 Use of silage in tropical livestock production

Large-scale intensive systems of ruminant production are relatively new to tropical and subtropical zones. Although traditional systems of feeding were often intensive, utilising hand-harvested forages and crop by-products, it is only recently that herds are being aggregated together in large-scale production units. This has been made possible by improvements in pasture and forage crop technology, or the availability of crop by-products from centralised processing facilities.

Silage has played an uneven role in these developments. There has been a tendency to equate the role of silage in these systems with that to be found in temperate zones, and consequently much of the attention has been on the

harvesting and storage of excess growth in the growing season for subsequent feeding during the dry season. The results of this practice have generally been disappointing. More recently, attention has focused on the ensiling of special-purpose crops, using these to increase productivity of the land, and this approach shows more promise. Ensiling has also been a convenient way of storing some wet by-products, such as pineapple skins and brewers' grains. In feedlot operations, there has been an increase in the amount of silage, particularly maize, in the diets of beef and dairy cattle. High quality silages are capable of supporting the high levels of animal production demanded in such operations, often cost lower than grains, enable higher productivity from land, and maintain a more stable rumen environment.
For a silage-making system to be considered successful for smallholder farmers in the country, it must:

- have low investment costs
- be reliable and repeatable
- use uncomplicated technology
- use locally sourced equipment and consumables
- give rapid and significant returns on investments
- be safe to use.

Over the past 20 years, there have been major advances in the technology of making and feeding silage. Much of this development has occurred in temperate zones, and there is need for further research in tropical zones, in areas such as manipulation of microbial fermentation and the development of grass and legume crop silage. In general, however, the technology is adequate, and the difficulties are in integrating silage into profitable feeding systems. Many small-scale farmers in and around Gauteng are learning the technology of making silage and feeding it to their livestock. The Animal Production Institute of the Agricultural Research Council (ARC) in Pretoria has been spear heading this development. Workshops and training have been organised for livestock farmers and some pilot projects on the feeding of maize and potato hash silage have been carried out. Students from Tshwane

University of Technology (TUT) also visited the institute and learned about silage making techniques.

2.3 POTATOES AND THEIR BY-PRODUCTS AS FEED RESOURCES FOR PIGS

Monogastric animals such as pigs cannot make effective use of potato material unless it has been heated sufficiently to denature the starch and inactivate proteolytic enzyme inhibitors (Dung, 2001; Dominguez, 1992).

The major component of potato peel is an insoluble biopolyester, the suberin, which is considered to be utilisable by animals. Its crude protein content ranges from 12 to 17% of the dry matter which is also comprised in the same interval (Nicholson *et al.,* 1998; Van Lunen *et al.*, 1989) and is a more valuable source of protein than the whole tuber (9 to 12.3% of dry matter) (McDonald *et al.*, 2002). However, as it has a very small quantity or no methionine, a supplementation is necessary, while its lysine content is twice as high as the amount found in maize (McDonald *et al.*, 1991). A study by Van Lunen *et al* (1989) reported that, the addition of potato waste improved the digestibility of the diet when it was included into maize or barley-based diets compared to maize and barley diets as shown in Table 2.1.

Table 2.1: Digestibility (%) by pigs fed diets containing potato steam peel and maize or barley (adapted from Van Lunen *et al.,* 1989)

	Grain variety					
	Corn			Barley		
SPI	0%	20%	40%	0%	20%	40%
DM (g/kg)	86.6 ±0.4	86.8 ±0.8	87.1 ± 0.3	76.2 ± 1.0	79.2±0.6	80.2±1.0
CP (g/kg)	76.8 ±2.1	78.5± 1.3	77.5± 1.5	66.3 ±2.3	68.3 2.1	68.8±0.9
GE (MJ/kg)	85.9 ± 0.6	85.9 ± 0.7	85.3 ± 0.4	74.4± 0.9	7.3±0.8	78.2±0.9
DE (g/kg)	3365 ± 84	3373± 62	3363± 55	2889±65	3020 ± 80	3070±34
DP (g/kg)	6.9 ± 0.2	7.7 ± 0.1	8.3± 0.2	7.4 ± 0.3	7.9 ±0.2	8.3± 0.1

SPI = Steam peel inclusion, DM =Dry matter, CP = Crude protein, GE = Gross energy, DE = Digestible energy, DP = Digestible protein

2.3.1 The composition and nutritive value of whole potatoes

The potential of a feedstuff for animals can be evaluated on the basis of its chemical composition, which traditionally comprises the content of moisture, ash, crude protein (CP), ether extract (EE), nitrogen-free extract and crude fibre (CF). In developing countries, feeds for pigs at the farm level are normally poor in protein but high in fibre content. Potatoes are available farm products that have high crude fibre contents (Dominguez & Ly, 1997).

Starch is the main constituent in potatoes and has been shown to be highly digestible in pigs whether raw or cooked (Wyss, 2003). The crude protein content of whole potato is about 9% of dry matter, and 90% of this can be accounted for as amino acid nitrogen. However, it has also been shown that raw potatoes are unpalatable to pigs (Whittemore & Taylor, 1976) and their inclusion in diets reduces intake. Monogastric animals such as pigs cannot make effective use of potato material unless it has been heated sufficiently to denature the starch and inactive proteolytic enzyme inhibitors (Dung, 2001).

2.4 FACTORS AFFECTING DIGESTIBILITY OF POTATOES

2.4.1 Digestibility

Feeds for animals are mainly organic materials which have to be broken down into simple components in the digestive tract before they can pass through the mucous membrane of the alimentary canal into the blood and lymph. The former process is called "digestion" and the passing of digested nutrients through the mucous membrane is called "absorption". The digestion processes are grouped into mechanical, chemical and microbial. The mechanical activities are mastication and the muscular contractions of the alimentary tract. The chemical action occurs by the secretion of enzymes. In pigs, the mechanical and chemical digestive processes mainly occur in the front parts of the digestive tract, while the microbial processes happen mainly in the large intestine by the action of microorganisms.

The value of feed to animals can be determined by the changes in the amounts of the nutrients made available through the digestion and absorption processes in the digestive tract.

a) Total tract digestibility

Measuring the digestibility of feed for all species of animals is based on the input of feed and output of faeces. Normally, in a digestibility trial, male pigs are preferred to females because it is easier to separate faeces and urine (McDonald *et al*., 1995). Nutrient digestibility of any given feed can be calculated as follows:

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

In a traditional digestibility trial, the feed under investigation is given to the animal in a known amount and the output of faeces is collected and measured. However, special methods can be used for measuring digestibility, such as the indicator method. The indicator should not be toxic, should not affect the animal physiology and should not affect gastrointestinal tract secretion, digestion, or absorption. Most importantly the indicator should not be absorbed or metabolised within the gastrointestinal tract. Another important point concerning the indicator is that, it must be distributed evenly throughout the feed. Indicators used for digestibility studies include acid insoluble ash (silica) or indigestible acid-detergent fibre as an internal marker, or an added chemical, such as chromium oxide (Cr_2O_3) as an external marker.

b) Ileal digestibility and cannulation techniques

Determination of ileal digestibility provides more detailed information on the utilisation of a feed than total tract digestibility. In monogastrics, the main site of absorption of nutrients is the small intestine. The undigested food is excreted in the faeces. However, not all the faeces are undigested food residues. Parts of the faeces are enzymes and other substances that are secreted into the gut, as well as microbes produced in the gut. This leads to an underestimation of the food actually absorbed by the animal. Total tract digestibility is therefore not a good estimate of the food absorbed in the small intestine. Several methods have been developed to collect digesta from the terminal ileum. All the pigs are surgically fitted with cannulas in the gastrointestinal tract. Ileal cannulation techniques include; T-cannulas, ileo-caecal re-entrant cannulas, ileo-rectal shunt technique and post-valvular T-caecum cannulas (Laplace & Darcy-Vrillon, 1989).

2.4.2 Nutrient composition

Variations in nutrient composition are inherent characteristics of agricultural products. The natural condition and the occurrence of genetic improvement have contributed to a large variety of potato cultivars, with slight differences in the relative proportion of their nutrients. Other factors likely to modify the digestibility of nutrients in a given feed are the climate, soil, and harvesting period. For instance, high and low tannin sorghum is digested differently and causes definite patterns of digestibility of other nutrients of the diet in which they are included. By-product contents are also affected by many factors ranging from the processing, the methods and the composition of the source to the storage conditions. Haigh (1996) reports substantial fluctuations in the percentage of dry matter of the experimental feed.

2.4.3 Animal factors

The extent to which foods are digested depends on factors that are intrinsic to the animal, such as the species and biological factors. For example, pigs and poultry are less well equipped than ruminants for the degradation and use of fibrous structures although some Mediterranean breeds of pigs are known for their ability to tolerate and use high fibre levels (Freire *et al*., 1998). They also cannot make effective use of raw potatoes, which are suitable for inclusion in ruminant diets. This is attributed to the fact that they are single stomached animals. The digestibility of certain classes of nutrients seems to be affected by the body weight and age, although the differences are not always significant. However, the general trend is that larger animals digest energy and nutrients better than the younger ones (Leterme *et al.*, 2006).

2.4.4 Effect of dietary fibre on digestibility in pigs

Dietary carbohydrates constitute a major fraction of the diet for pigs and consist of mono-, di- and oligosaccharides and two broad classes of polysaccharides – starch and non-starch polysaccharides (Bach Knudsen & Jørgensen, 2001). Starch and disaccharides are mainly broken down by a combination of salivary, pancreatic and mucosal enzymes in the small intestine with the end products (glucose, galactose and fructose) absorbed into the portal vein. No enzymes in the small intestine of pigs can cleave the bondings in some oligosaccharides and non-starch polysaccharides. These carbohydrates can be broken down by microbial fermentation in the large intestine.

The end products of microbial fermentation of carbohydrates are short-chain fatty acids and lactic acid, which are absorbed by the animal. Factors that influence the breakdown of non-starch polysaccharides in the large intestine include the retention time, age and weight of the animal and the microbial composition. The term dietary fibre, in older literature, is used for crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF). According to Bach Knudsen (1997) and Souffrant (2001) dietary fibre is defined as a heterogenous mixture of structural and non-structural polysaccharides and lignin not digested by endogenous secretions by the pig, but efficiently by the microbial flora. Dietary fibre can be measured by either enzymatic-gravimetric or enzymatic-chemical methods (Bach Knudsen & Jørgensen, 2001; Bach Knudsen *et al.*, 1997). Dietary fibre is generally considered as a fraction with low energy content and in the pig causes regular peristaltic action that avoids the possibility of constipation (Wenk, 2001).

In growing pigs, digestibility coefficients of dietary fibre average 0.4-0.5 but they range from around zero in high lignin and water-insoluble dietary fibre sources (e.g. wheat straw) to 0.8-0.9 in fibre sources with high pectin or water-soluble dietary fibre levels (e.g. sugar beet pulp or soybean hulls)

(Noblet & Le Goff, 2001). The digestibility of dietary fibre is lower in young animals than in adult animals and the negative effects of dietary fibre on the digestibility of energy and nutrients are highest in young animals (Bach Knudsen & Jørgensen, 2001). Chabeauti *et al.* (1991) found that in diets with similar amounts of non-starch polysaccharides, plant cell walls from sugar beet pulp and soya bean hull diets were highly digestible (0.69 and 0.74 for total non-starch polysaccharides, respectively) while those from wheat bran and wheat straw diets were low (0.51 and 0.30 for total non-starch polysaccharides, respectively). Similar results were also given by Freire *et al.* (2000) and Galassi *et al.* (2004). Therefore, it is not only the level of dietary fibre that is important, but also the type or source of fibre plays a significant role in digestion and absorption.

2.4.5 Particle size

The digestive capacity is limited to some extent to the size of feed particles. Dietary particle size affects the digestibility of nutrients particularly the amino-acids (Wondra *et al.*, 1995, cited by Fastinger & Mahan, 2003) although lysine is an exception. Coarse structures are less digestible and indeed it was suggested that reducing the particle size of corn from 1200 to 400 µm in adult pig diets, improved the digestibility of dry matter and energy (Wondra *et al.,* cited by Fastinger & Mahan 2003). An average particle size between 600 to 700 µm is generally recommended for most pig diets.

2.4.6 Anti-nutritive factors

Tubers are known to be particularly rich in anti-nutritive factors. For instance, cassava contains cyanogenic glucosides and tannins which lower the protein digestibility by forming inaccessible tannins-protein complexes. Yams are a great reservoir of trypsin inhibitors and co-alkaloids solanidine and chaconine which are toxic for animals are concentrated in potato peels (Schieber *et al.*, 2001; McDonald *et al.*, 2002). Moreover, some proteolytic enzyme inhibitors that reduce the digestibility of potato proteins or those of other feed ingredients in the diet are found throughout the potato tuber as well as in the peel, according to Schieber *et al.* (2001). A common method to alleviate this problem is to apply heat as these components are heat labile. In fact there is some evidence that cooking potatoes prior to feeding, improves their digestibility (Nicholson *et al.*, 1998; McDonald *et al.*, 2002; Cheeke, 2005), which is reported to be similar to that of maize.

2.4.7 Growth performance of pigs fed by-product silage

There were no significant differences in performance between pigs fed a traditional diet and the diets with ensiled shrimp by-products Protein sources (Rahnema & Borton, 2000). Perez (1995) reported that fish silage could replace 50 % of the protein from fish meal in pig diets without any negative effects on daily weight gain. In Vietnam, Le Van Lien *et al,* (1996) studied the nutritional value of fermented shrimp heads and concluded that shrimp head silage could replace 75 % of the fish meal.

Rahnema & Borton (2000) obtained poor Pig performance, with growth rates of 320-350 g/day, and feed conversion of 3.8-4.5 kg feed/kg liveweight gain. However, these values are fairly typical for pig performance on small-holdings in central Vietnam, where crossbred local pigs normally attain a slaughter weight of 70 to 80 kg live weight in 10 to 12 months, with a FCR of 4.5 to 5.5 kg feed/kg LWG (Nguyen Thi Loc 1996). The low genetic potential of the local Vietnamese pigs makes them less sensitive to the feed protein quality. However, other studies with improved pigs have shown that, high growth rates can be expected with both crab meal and fish silage. This indicates that, shrimp by-product silage could replace groundnut cake and also other protein feeds as a protein source for feeding both local and improved pigs under farm conditions in Vietnam.

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CHAPTER 3

EVALUATING THE EFFECT OF LALSIL FRESH LB® AND BONSILAGE FORTE® AS INOCULANTS ON THE QUALITY AND AEROBIC STABILITY OF POTATO HASH SILAGE

Abstract

This study evaluated the effects of bacterial inoculants on the fermentation quality and aerobic stability of ensiled potato hash. Potato hash, was mixed at 700 g, with 300 g wheat bran (as is basis) to produce silage. The mixture was treated with homofermentative LAB inoculant (*Bonsilage forte,* BF), heterofermentative LAB (*Lalsil Fresh LB,* LFLB) and without LAB inoculant (control). The mixtures were ensiled in 1.5 L anaerobic jars and kept at 25^0C room temperature. Triplicate samples per treatment were collected on days 0, 3, 10, 21 and 45 post-ensiling and analysed for dry matter (DM), water soluble carbohydrates (WSC), pH, lactic acid, acetic acid, butyric acid, propionic acid and ammonia-N. On day 45, silage was subjected to aerobic exposure for 5 days and CO_2 production was measured. Results from this study showed that, both inoculants reduced ($P<0.05$) the pH while increasing the lactic acid content of silage compared to the control. The concentrations of propionic acid, butyric acid and ammonia-N were not affected by inoculation. When exposed to air, BF and LFLB reduced ($P<0.05$) CO_2 production compared to the control. It can be concluded that, inoculation improved both the fermentation and aerobic stability of potato hash silage. Further work is needed to determine the effect of inoculating potato hash silage on the growth and reproductive performance of animals.

Keywords: Potato hash, homofermentative and heterofermentative LAB inoculants, silage quality

3.1 INTRODUCTION

Techniques for the conservation of feed are numerous and include, among others, drying, salting, sweetening, freezing, radiation and ensiling. Due to the fact that the small-scale livestock farmers in the Gauteng Province lack facilities for storing feeds, ensiling of feeds in drums or plastic bags may be a better option. Preservation of feeds by ensiling, has been practised for many centuries. Silage is defined as the material produced by the controlled fermentation of a crop of high moisture (McDonald *et al*., 1991).

The main objective of silage making is to preserve the nutritive and energy value of the raw plant until it can be fed to animals, and it has been reported to increase the acceptability of most by-products (McDonald *et al*., 1991). Potato hash, a by-product from the production of snacks and chips at Simba (Isando, Kempton Park, South Africa), contains a dry matter (DM) of 150 g/kg, starch of 700 g/kg DM, metabolizable energy (ME) of 11.2 MJ kg DM, crude protein (CP) of 105 g/kg DM, and a crude fibre of 58.5 g/kg DM (Nkosi, 2009). Its daily availability varies according to season, normally with 10 to 15 tons per day in summer and 2 to 5 tons per day in winter. Storage life and use of fresh potato is limited; therefore, ensiling offers the best and cheapest conserving method. Potatoes and their by-products are low in water soluble carbohydrates (WSC), low in concentration of lactic acid and do not ensile well (O'Kiely *et al*., 2002). Most vegetable by-products are subjected to washing, blanching, freezing or treatment with caustic chemicals that sometimes damage the normal lactic acid bacteria present in the material (Ashbell, 2003), which necessitates the use of bacterial inoculants or additives during the ensiling of by-products (Gwayumba, 1997).

Ensiling corn of 23% DM without additives was found to be unsuccessful, and chemical additives were therefore used to improve its fermentation (Juracek *et al*., 2008). Chemical additives are used, but because they are dangerous in handling and application, and also affect the environment and are corrosive to equipment (Wilkinson, 2005), they are gradually being substituted by biological additives. This has necessitated a search for alternative biological sources that are safe and easy to use for improving the silage making process (Gwayumba, 1997). Adding inoculants such as *Rhizopus oryzae* (R) and *Amylomyces rouxii* (A) to potato pulp at ensiling has been reported to reduced the pH and increased both lactic acid and acetic acid of the silage (Okine *et al*., 2007). In present study, a heterofermentative LAB inoculant, *Lalsil Fresh* Lactobacillus bachneri and a homofermentative LAB inoculant, *Bonsilage Forte,* were used as inoculants. The objective of this study was to determine the effect of adding *Bonsilage Forte* and *Lalsil Fresh LB* on the fermentation dynamics and the aerobic stability of the potato hash silage.

3.2 MATERIALS AND METHODS

3.2.1 Silage production

Potato hash (Figure 3.1) was collected from Simba (Pty) Ltd (Isando) in Kempton Park South Africa and brought to the Animal Production Institute (API) atIrene for chemical analysis, silage making, animal growth and digestibility studies. Mixtures of 700 g/kg potato hash and 300 g/kg wheat bran were produced to achieve at least a 400 g/kg DM. A heterofermentative LAB inoculant, *Lalsil Fresh LB* (*Lactobacillus buchneri* NCIMB 40788, Lallemand SAS, France) was applied at a rate of 2 litres per ton of freshly mixed potato hash (5 g of inoculant was dissolved in 2 litres of water, 4 hours before application) to obtain at least 6 x 10^5 cfu/g fresh material.

A homofermentative LAB inoculant, *Bonsilage Forte* (Schaumann, Agri Austria GmbH, Brunn am Gebirge, Austria) contains strains of *Lactobacillus paracasei* (DSM 16245), *Lactobacillus lactis* (NCIMB 30160) and *Pediococcus acidilactici* (DSM 16243). The inoculant was applied at a rate of 2 l per ton of freshly mixed potato hash (5 g of inoculant was dissolved in 2 l of water, 4 h before application) to provide at least 2.5 x 10^5 cfu/g of fresh material. In order to ensure the same amount of moisture as in the treated potato hash, the untreated silage (UNPHS) was sprayed with 2 l of water per ton of fresh material. Treatments were: Untreated potato hash silage (UNPHS), *Bonsilage Forte* potato hash silage (BFPHS) and *Lalsil Fresh LB* potato hash silage

(LFLBPHS). The application rates of the inoculants were in accordance with the level of LAB in the inoculants as specified by the manufacturers.

Figure 3.1: Fresh potato hash

The treatments were compacted in 210 l drums lined with a plastic bag and tightly sealed for animal feeding and 1.5 l glass jars for laboratory study, respectively. After 3 months of ensiling, drums were opened and triplicate samples were collected (before diet formulation) and analysed for DM, pH, lactic acid (LA), volatile fatty acids (VFAs) and ammonia-N (NH_3-N). Furthermore, aerobic stability (Figure 3.3) was determined by exposing silage to air in day 90 for 5 d (30°C) and CO_2 production was determined as described by Ashbell *et al*. (1991).

Table 3.1 Chemical composition of potato hash (% DM)

Parameter	Potato hash
DM%	15.5
OM %	95.69
CP%	10.49
CF%	5.85
NDF %	36.96
ADF %	16.25
ADL %	5.32
Fat %	10.97
Starch %	70.38
ME MJ/kg DM	11.16
IVOMD %	82.48

Dry matter (DM), Organic matter (OM), Crude protein (CP), Crude fibre (CF), Acidic detergent fibre (ADF) Neutral detergent fibre (NDF)

3.2.2 Chemical analyses

On day 0, triplicate samples were collected for subsequent chemical analysis. Three jars were opened per treatment on days 3, 7, 21, 45 and 90, for determination of pH, DM, crude protein (CP), ether extract (EE), metabolisable energy (ME), neutral detergent fibre (NDF), acid detergent fibre (ADF), ash, water-soluble carbohydrates (WSC), lactic acid (LA), ammonia-N (NH_3N) and volatile fatty acids (VFA). A 40 g sample from each jar was collected and mixed with 300 ml of distilled water in a stomacher bag (Figure 3.2), homogenised and left at 10^0C for 24 h. It was then homogenised for 1 minute and filtered through a Whatman No. 4 filter paper (G.I.C. Scientific, Midrand, South Africa) and the extract was used for determination of pH, WSC, VFA and LA.

Figure 3.2: A 40 g silage sample in a stomacher

The pH of the samples was determined by an electrode method. The WSC were determined by the phenol-sulphuric acid method according to Dubois *et al.* (1956) and lactic acid was determined by the colorimetric method of Barker and Summerson (1941) as modified by Pryce (1969). The VFA were determined with a Varian 3300 FID Detector gas chromatograph (Varian Associates, Inc., Palo Alto, CA, USA) by the procedure of Suzuki and Lund (1980). Ammonia-N was determined by distillation using a Buchi 342 apparatus and a Metrohm 655 Dosimat with an E526 titrator according to AOAC (ID 941.04, 1990). This is based on the method of Pearson and Muslemuddin (1968) for determining volatile nitrogen. Dry matter of the fresh material and silages was determined by drying the samples at 60^0C until a constant mass was achieved following the procedure of AOAC (ID 934.01, 1990). Following equilibration with atmospheric air, the samples were weighed, composited and ground to pass through a 1 mm sieve using a Willey mill and analysed for neutral detergent fibre (NDF) and acid detergent fibre (ADF) according to the method of Van Soest *et al*., (1991). Analyses for DM (ID 934.01), CP (ID 968.06), ash (ID 942.05) and ether extract (ID 920.39) were done according to the procedure of AOAC (1990), metabolisable energy (ME) using the gas production technique of Pienaar (1994).

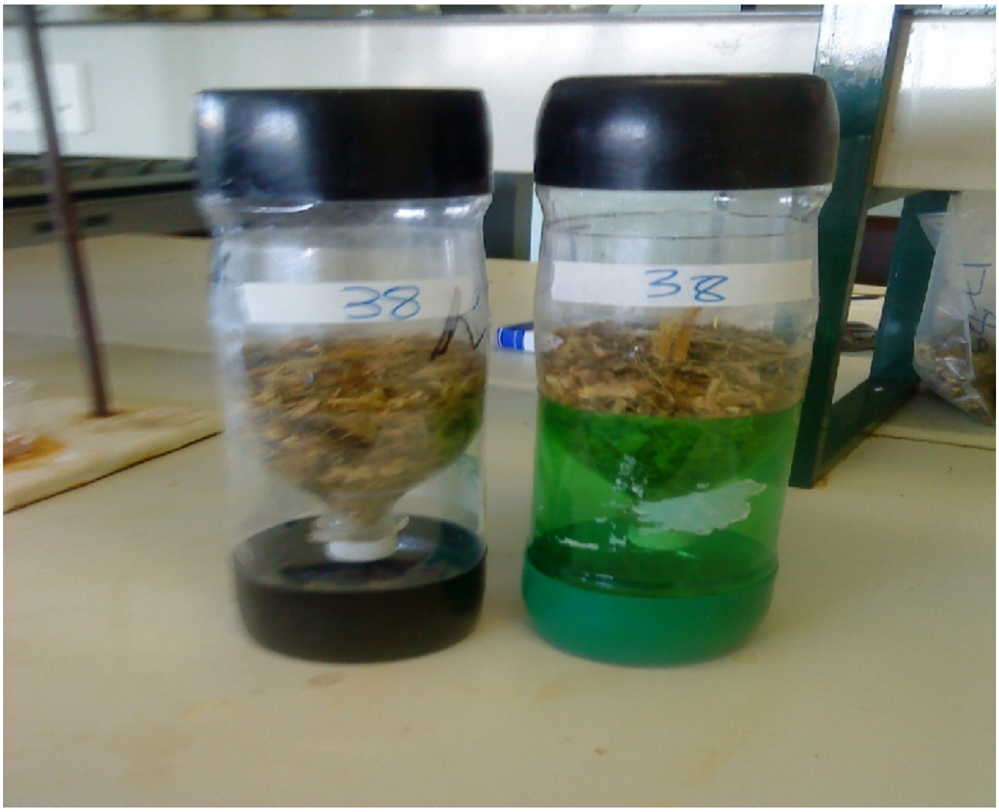

Figure 3.3: Aerobic stability test in 2-litre polyethylene terephtalate bottles

3.2.3 Statistical analysis

Data were analysed using the statistical analysis program, GenStat (2000). Differences between the treatments means were tested by ANOVA. The data were tested for normality and homogeneous treatment variances, and significance was declared at 5% probability level.

3.3 RESULTS

The results of the effect of treatments (UNPHS, BFPHS and LFLBPHS) on the fermentation and aerobic stability of potato hash are shown in Table 3.2. The inoculation of potato hash with either *Bonsilage Forte* or *Lalsil Fresh LB* reduced (P<0.05) the pH of the silage compared to the UPHS. There was no difference (P>0.05) among treatments on water-soluble carbohydrates (WSC) levels. Lactic acid production was higher (P<0.05) in BFPHS and LFLBPHS silages after 90 days of ensilage.

Table 3.2 Fermentation characteristics of potato hash silage treated with or without *LAB inoculants*

Variables	Pre-ensiled	Treatments			P-value	SEM
		UPHS	BFPHS	LFLBPHS		
DM g/kg	412.9	451.4[a]	385.8[b]	399.3[b]	<.001	2.19
pH	6.86	4.58[a]	4.25[b]	4.25[b]	0.03	0.03
WSC g/kg DM	78.05	39.30	35.51	36.32	0.26	3.65
LA g/kg DM	-	40.87[b]	52.94[a]	52.95[a]	0.05	1.40
AA g/kg DM	-	2.35[a]	2.49[a]	2.16[b]	0.04	0.18
PA g/kg DM	-	0.02	0.02	0.01	0.05	0.003
BA g/kg	-	0.05	0.05	0.04	0.12	0.011
NH_3- N (% TN)	-	0.08	0.09	0.09	0.47	0.008
CO_2 g/kg DM	-	3.01[a]	1.65[b]	0.76[b]	0.05	0.26

[a,b] Means with different letters in a row differ significantly (P<0.05); Cont=Control; BFPHS= Bonsilage Forte;LFLBPHS = *Lalsil Fresh LB* WSC = Water-soluble carbohydrates; LA= Lactic acid; AA= Acetic acid; PA= Propionic acid; BA= Butyric acid; NH_3= Ammonia-N and CO_2= Carbon dioxide

The UPHS and BFPHS had higher (P<0.05) acetic acid and propionic acid than the LFLBPHS silage, and there were no differences (P>0.05) among the treatments on butyric acid production. There were also no differences (P>0.05) in the production of ammonia-N between the treatments. Inoculation reduced (P<0.05) CO_2 production to 1.7 g/kg compared to 3.01 g/kg in the UPHS.

3.4 DISCUSSION

In the present experiment, LFLB and BF were used as inoculants to improve both the fermentation and the aerobic stability of the silage. Successful ensiling can be achieved when LAB dominates the fermentation and expels the activity of undesirable organisms. Silage inoculants are used to stimulate lactic acid fermentation, accelerating the decrease of pH, and thus improving silage preservation (McDonald *et al*. 1991). According to McDonald *et al*. (1991) and Okereke *et al*. (2008) silage with a pH that falls within a range of

3.8 – 4.2 is considered well preserved. Those of LFLB and BF fell within this range, an indication that they were well preserved. This corroborated well with Okine (2007) who observed a reduced pH with *Lactobacillus plantarum* inoculation on potato pulp.

Water-soluble carbohydrates are regarded as food for LAB during fermentation (McDonald, 1981), and lower amounts may restrict the fermentation process. Generally, a high level of WSC in the silage indicates higher nutritional quality, especially when the silage is the major component of the diet (Wilkinson, 2005). According to Yang *et al.* (2001), a concentration of > 70 g/kg DM of WSC is sufficient to achieve a silage pH of less than 4.5. The WSC of potato hash mixture at pre-ensiling was 78 g/kg DM which was sufficient for good fermentation. Furthermore, good silage is characterised by a lactic acid concentration of between 80 – 120 g/kg DM (Meeske *et al*., 1999). The lactic acid concentration in the present study was lower than that of Brzoska and Sala (1997), who recorded lactic acid of 68 – 129.5 g/kg DM in potato silages, which is higher than that of the present study. The reason is that, larger amounts of potato hash (70% fresh material) were used, while that used by these researchers was 35% fresh material. However, the lactic acid concentrations of the silages in the present study were below the recommended minimum of 80 g/kg DM but the silages were well preserved in terms of recommended pH values.

Inoculation of LFLB and BF to potato hash for 90 days reduced the pH and increased the level of acetic acid in the silages, which is an indication of well preserved silages (McDonald *et al*. 1991). Such a trend was also observed by Okine (2007), where potato pulp was ensiled with *Rhizopus oryzae* for 50 days. Acetic acid is derived mainly from the action of heterofermentative LAB and enterobacteriaceae on sugars, although some may also be formed from citrate, malate and amino acid degradation (Wilkinson, 2005). The UPHS and BFPHS had higher acetic acid and butyric acid relative to the LFLBPHS. It has been reported that, poorly preserved silage is associated with high levels of VFA, especially butyric acid arising from protein metabolism (McDonald *et al*. 1991). However, the silages produced propionic acid lower than the 0.3%

recommended by Kung and Shaver (2001). An amount of less than 1% propionic acid is acceptable in silages (Kung & Shaver, 2001) and the potato hash silages fell within this range. Inoculation reduced the ammonia-N production in the silages. The presence of ammonia in silage is the residual product of microbial proteolytic activity, and does impair the nutritive value of forages (McDonald, 1981). Such a role is an indicator of favourable fermentation in the silage (McDonald *et al*., 1991) which helps to preserve the nutritive value of the feed. This is in agreement with findings from studies by Kamra and Srivastava (1992) and Piltz *et al*. (1999).

Acetic acid has an anti-fungal activity against spoilage microorganisms, and is often used as an indicator for aerobic stability of silage (Weinberg & Muck, 1996). According to Weissbach (1996) an amount of > 8 g/kg DM of acetic acid is required to stabilise the silage during aerobic exposure

Carbon dioxide production is an indicator for aerobic stability in silage when exposed to air. The inoculants reduced ($P<0.05$) CO_2 production of potato hash silage compared to the control, indications of improved aerobic stability of the silages.

3.5 CONCLUSION

It was concluded that Bonsilage Forte and Lalsil Fresh can be used as silage inoculants to improve the aerobic stability and fermentation of potato hash silage. Further work is needed to determine the effect of LAB inoculated potato hash silage on the growth performance of pigs.

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CHAPTER 4

EFFECTS OF DIFFERENT DIETARY INCLUSION LEVELS OF ENSILED POTATO HASH ON NUTRIENT DIGESTIBILITY IN PIGS

Abstract

The study evaluated the digestibility of potato hash silage (PHS) using thirty crossbred sows (± 30 kg live weight) that were housed individually. Diets containing 20, 40 and 60% PHS (untreated PHS, lalsil fresh LB treated PHS and bonsilage forte treated PHS) were formulated and fed *ad libitum* in a cross-over design (3 sows per diet per period). A commercial diet (0% silage) was used as a control. Experimental period took eleven days (seven days adaptation and four days faecal collection). Intake of organic matter (OM), crude protein (CP), ether extract (EE), fibre and gross energy (GE) was higher ($P<0.05$) in the control compared to diets containing silages. Digestibility of dry matter (DM), EE, and GE was not ($P>0.05$) affected by treatmet. However, 60% PHS reduced ($P<0.05$) the digestibility of fibre compared to other inclusion levels. It was concluded that 60% PHS did not improve nutrient digestibility in grower pigs.

Keywords: Silage, Potato hash, grower pigs, digestibility

4.1 INTRODUCTION

While by-products have been successfully fed to animals for decades, other by-products are not consistently used because of the uncertainty in terms of availability, poor handling characteristics, storage properties, variation in nutrient composition, palatability or intake, and risk of toxic residues. However, supplementation of diets in monogastrics with conventional by-products is hindered by competition with ruminant animals and low availability of feed processing plants relative to the growing livestock population (Nelson *et al*., 2000). Pig feeds are no exception because they require diet of high protein and energy levels in their diets which makes feed costs even higher compared to those of ruminants. Pigs have several important functions for rural households, the major one being the fact that they generate much needed cash income through market sales (Peters, 1998).

In the South African context, the use of agricultural by-products generated by the food industry could be of prime importance in the attempt to make more resources available to resource-poor farmers. The products of industrial potato processing are potential sources to replace or to be included in traditional pig diets which are mostly based on maize and soybean. The fact that potato hash is available in large quantities during peak periods, makes this concept plausible and may benefit the resource-poor pig farmers by reducing significant feed costs, which accounts for nearly 75% of the production costs (Fialho *et al.*, 1995). Other benefits in using these wastes for animal nutrition will include the reduction of environmental pollution risks,.

Potato hash, a by-product that is produced during the production of chips and snacks in the food processing industries in South Africa, contains potato slices and relatively small amounts of yellow maize and fats. It is low in dry matter (15.5%) which makes it costly to transport, and is normally dumped without further use (Nkosi, 2009). The heterogeneous nature of potato hash makes it difficult to be included in formulated rations, while lack of information on its composition and nutritive value, as well as on the levels acceptable for use in animal diets, may also limit its use. Moreover, monogastric animals such as pigs cannot make effective use of potato material, unless it has been heated sufficiently to denature the starch and inactivate proteolytic enzyme inhibitors (Dominguez, 1992; Dung, 2001). No data is currently available on the nutritional composition and effect of potato hash on digestibility of pigs. However, some work has been done on the suitability of the whole potato as pig feed (Mora *et al.,* 1992) as well as on potato steam peels. The objective of the present study was to assess the nutritive value and digestibility of diets based on the different inclusion levels of potato hash silage.

4.2 MATERIALS AND METHODS

Total mixed rations (TMR) that contained potato hash silage treated with one of Lalsil Fresh LB®, BF inoculants or without inoculants, were formulated and as shown in Table 4.1. A fourth treatment, commercial diet, was formulated and used as a reference treatment.

4.2.1 Dietary treatment

The diets were supplied *ad libitum* and water was made available at all times through drinking nipples. The treatments were: commercial feed; 20, 40, and 60% untreated potato hash silage; 20, 40, and 60% Lalsil Fresh LB potato hash silage and 20, 40, and 60% Bonsilage Forte potato hash silage. These diets were randomly allocated to the 30 pigs.

4.2.2. Experimental design

Thirty female (Large White x Landrace crossbred) pigs of the same litter at Agricultural Research Council (ARC) breeding stock, were selected with an average weight of 30 $\pm$ 2 kg. Pigs were housed individually at room temperature. A cross-over design was used with two periods and 30 animals representing the rows and columns respectively. Three pigs were given one diet per period. Each experimental period lasted for eleven days.

Table 4.1: Formulation of experimental diets containing different inclusion levels of potato hash silage

	Inclusion level			
Ingredients (%)	0%	20%	40%	60%
Maize	48.53	50.70	30	20
WB	6.01	-	7.5	-
SMOC	-	5.24	-	-
Oil cake	12	-	2	-
FFS	11	6	9	9
Molasses	4.5	9	-	-
Lime	0.5	0.6	1.3	1.3
Salt	0.3	0.4	0.4	0.39
Lysine	1.5	1.5	1.5	1.5
Met	1.5	1.5	1.5	1.5
MCP	1.76	1.5	0.58	0.36
Silage	-	20	40.82	60
Oil	4	-	5	5
Gly	5	5		0.5
Supp	0.4	0.4	0.4	0.4
	Calculated composition			
Parameter	Control	20%	40%	60%
DM (%)	85.6	76.6	70.06	60.83
OM (%)	96.81	96.48	95.37	94.50
CP (%)	14.9	14.3	15.54	15.68
EE (%)	2.39	1.17	1.78	1.76
Fibre (%)	4.97	5.37	10.00	12.13
DE (MJ/kg DM)	14.0	14.1	15.69	16.59

20% (UNPHS, LFLBPHS and BFPHS), 40% (UNPHS, LFLBPHS and BFPHS), 60% (UNPHS, LFLBPHS and BFPHS); WB = Wheat Bran; SMOC = Soya oil cake meal; Oil cake = Sunflower oil cake meal; FFS = Full Fat Soya; Met = Methionine; MCP= Monocalcium phosphate; Oil = Sunflower Oil, Gly = Glycerol; Supp = Pig supplement. DM = Dry Matter; CP = CrudeProtein; EE = Ether extract; OM = Organic matter.

A seven day adaptation to each diet was given and faecal collection lasted four days before crossing over to the next treatment. Faeces were collected every 24 hours from day eight to day eleven. Pigs were fed twice per day at 8:00 and 15:00, with the daily allowance divided equally between the two meals. Feed refusals and spillages were recorded, and were used to correct the feed intake.

4.2.3. Sample collection

Faeces were collected from individual animals, for four days. Samples were weighed and 10% of the total collection was taken and kept in a freezer at -18^{o}C. Prior to chemical analysis, individual samples of faeces were thawed and pooled within pigs and periods.

4.2.4. Chemical analysis

Faecal samples was dried at 60^{o}C for 24 h and milled through a 1mm screen before analysis. All analyses were performed on dried samples. Dry matter (DM), Organic matter (OM) and crude protein (CP, N x 6.25) were determined according to (AOAC, 1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to the method of Van Soest *et al*., (1991).

4.2.5. Digestibility determination

Total tract digestibility coefficients for DM, OM, CP and EE were applied to each diet by daily collection of the total faeces after each dropping during a four-day period. The differences between the amount of nutrients consumed and excreted in the faeces were measured. The animals were kept in a pen where the feed intake and composition were recorded and was characterised by the total collection of the faeces. The amount of nutrients consumed by the animal was estimated by a prior chemical analysis of the feed. The difference between the amounts of nutrients consumed and excreted in the faeces was the quantity digested and absorbed. The coefficient of apparent digestibility was determined by the relation:

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

4.2.6 Statistical analysis

Digestibility coefficients of dry matter, crude protein, crude fibre and gross energy were calculated and compared across the treatments using the statistical analysis program GenStat (2000). Differences between the treatments means was tested by ANOVA, and significance were declared at 5% probability level.

4.3. RESULTS

The chemical composition of the experimental diets is given in Table 4.2. Higher dietary inclusion level (60%) of PHS increased the fiber (ADF and NDF) content of the diet. However, energy content of the diets was not affected (P>0.05) by the inclusion levels. Data on the intake and nutrient digestibility of the diets are shown in Table 4.3 and 4.4 respectively. Pigs that were fed control diet had higher DMI, OMI and CPI (P<0.05) than those fed the other diets. However, at the 20% inclusion level, pigs on the UPHS diet consumed more (P<0.05) than those on the LFLBPHS and BFPHS diets, but this effect did not occur on the 40 and 60% inclusion levels.The control, 40% and 60% PHS inclusion levels had higher (P<0.05) EE intake than pigs that were fed in 20%. Diets containing 40% inoculated PHS had higher (P<0.05) ADF intake than the rest of the diets. The control had a lower (P>0.05) NDF intake than the rest of the treatments. There were however, no differences (P>0.05) in NDF intake among the silages at 40% and 60% inclusion levels. However, pigs that were fed these PHS levels had lower (P>0.05) DE intake compared to those fed on control diet.

The digestibility of DM, DE and EE did not differ amongst the treatments at all PHS inclusion levels (Table 4.4). However, the control had higher (P<0.05) OM digestibility than the rest of the diets. Pigs on 20% (UNPHS, LFLBPHS and BFPHS) diets digested OM better (P<0.05) than pigs that were fed 40% and 60% inclusion levels of the same treatments. The control had higher (P<0.05) CP, ADF and NDF digestibility than the rest of the treatments. However, 20% inclusion of potato hash had a better (P<0.05) CP digestibility than the 40% and 60% inclusion levels. Pigs that were fed the 20% PHS inclusion level had higher (P<0.05) NDF digestibility than those fed on the 40% and 60% inclusion levels. However, silage treatements did not differ (P>0.05) in the NDF digestability at 40 and 60% inclusion levels.

Table 4.2 Chemical compositions (DM %) of the experimental diets

	Variables (%)						
Trt	DM%	OM	CP	EE	ADF	NDF	DE MJ/ kg DM
Cont	87.8	98.5	9.3	5.15	4.32	12.56	18.5
UN 20%	73.92	96.57	10.32	6.01	6.18	21.19	17.6
LAL 20%	75.12	95.98	11.23	6.38	8.4	22.69	18.08
BF 20%	77.56	95.89	12.68	6.66	7.02	23.16	17.92
UN 40%	74.66	94.1	14.02	11.48	9.3	25.82	18
LAL 40%	72.45	93.15	15.64	11.72	11.2	25.71	18.1
BMF 40%	78.66	93.17	16.08	12.22	10.98	27.63	17.92
UN 60%	65.25	90.29	16.52	13.92	13.86	28.2	18.24
LAL 60%	63.63	90.17	20.66	17.67	13.45	29.42	18.05
BF 60%	63.63	90.97	21.89	20.83	14.75	31.39	17.89

Cont =control, UNPHS = untreated potato hash silage, LFPHS= Lalsil fresh treated potato hash silage, BFPHS Bonsilage Forte potato hash silage. SEM= standard error of means; CV %= coefficient of variance %. DM=dry matter; OM= Organic matter; CP= Crude protein; CF= Crude fibre; EE= Ether extract ADF= Acid detergent fibre; NDF= Neutral detergent fibre

Table 4.3 Mean daily feed intake (g/kg DM) of experimental diets by pigs

		Treatments											
		20%			40%			60%					
Parameters	Cont	UNPHS	Lal	BF	UNPHS	Lal	BF	UNPHS	Lal	BF	P-V	SEM	CV%
DM (g/kg)	2779[a]	2350.7[b]	2203.5[c]	2206.6[c]	1945.3[d]	1956.2[d]	194.7[d]	1225.9[e]	1165[e]	1093.2[e]	0.005	64.92	8.4
OM (g/kg)	2489[a]	2270[b]	2115[b]	2115.9[b]	1830.5[c]	1822.2[c]	1811.8[c]	11079[d]	1050.5[d]	994.5[d]	0.005	65.6	8.6
CP (g/kg)	437.5[a]	242.6[c]	247.5[c]	279.8[c]	272.7[c]	305.9[b]	312.7[b]	202.5[d]	240.7[c]	239.3[c]	0.005	4.99	8.4
EE (g/kg)	254.3[a]	141.3[b]	140.6[b]	147[b]	223.3[a]	229.3[a]	237.6[a]	170.7[b]	205.9[a]	227.7[a]	0.005	5.56	8.3
ADF (g/kg)	101.5[d]	145.3[c]	185.1[b]	154.9[c]	180.9[b]	219.1[a]	213.5[a]	169.9[b]	156.7[b]	161.2[b]	0.005	3.63	2.1
NDF (g/kg)	158.5[c]	498.1[a]	499.9[a]	511[a]	502.3[a]	502.9[a]	537.3[a]	345.7[b]	342.7[b]	343.1[b]	0.005	11.29	8.6
DE (MJ/kg)	514.2[a]	433.1[b]	414.3[bc]	379.1[cd]	371[d]	361.8[d]	289.9[e]	276.3[e]	276.2[e]	274.3[e]	0.001	0.28	8.4

[a,b] Means with different letters in a row differ significantly ($p<0.05$); Cont =control, Un = untreated potato hash silage, LF= Lalsil Fresh LB potato hash silage, BF= Bonsilage Forte potato hash silage. SEM= standard error of means; CV %= coefficient of variance %. DM=dry matter; CP=crude protein; ; OM= Organic matter; CP= Crude protein; CF= Crude fibre ; EE= Ether extract ADF= Acid detergent fibre ; NDF= Neutral detergent fibre

Table 4.4 Digestibility coefficients (%) of nutrients of different treatments of 20%, 40% and 60% of potato hash silage ensiled with or without inoculants

		Digestibility											
		20%			40%			60%					
Parameters	Cont	UNPHS	Lal	BF	UNPHS	Lal	BF	UNPHS	Lal	BF	P-V	SEM	CV%
DM %	99.20	95.02	97.09	97.75	95.21	95.88	95.98	95.95	94.78	94.14	0.48	0.32	2.0
OM %	94.9[a]	88.34[b]	87.09[b]	86.13[b]	85.95b[c]	83.44[c]	82.43[c]	81.58[c]	79.23[d]	78.89[d]	0.001	0.24	2.5
CP %	89.85[a]	77.17[b]	77.65[b]	77.55[b]	75.79b[c]	75.98[c]	75.20[c]	71.56[d]	70.89[d]	70.26[d]	0.001	0.35	2.4
EE %	99.5	96.10	95.85	94.22	96.50	96.87	96.30	88.16	87.64	88.08	0.03	0.29	2.8
ADF%	80.6[a]	78.76[b]	78.10[b]	78.04[b]	76.74[b]	75.50[b]	75.47[b]	59.02[c]	58.97[c]	58.35[c]	0.001	1.19	5.7
NDF%	77.2[a]	61.98[b]	61.55[b]	62.17[b]	58.90[c]	57.54[c]	57.13[c]	51.28[c]	50.32[c]	50.33[c]	0.001	1.55	3.9
DE %	96.11	96.96	97.13	95.39	95.05	95.72	95.93	96.76	95.89	95.41	0.66	0.82	2.1

[a,b] Means with different letters in a row differ significantly ($p<0.05$); Cont =control, UNPHS = untreated potato hash silage, LF= Lalsil Fresh potato hash silage, BF= Bonsilage Forte potato hash silage. SEM= standard error of means; CV %= coefficient of variance %. DM=dry matter; CP=crude protein; OM= CP=crude protein; EE= Ether extract ADF= Acid detergent fibre; NDF= Neutral detergent fibre

4.4 DISCUSSION

The commercial diet (Control) of the present study was formulated according to the recommendations of NRC (1993) for requirements of grower pigs. Dietary addition of 20%, 40% and 60% PHS resulted in changes in the chemical composition of those diets. An increase in the fibre content with PHS inclusion occurred, which reduced the digestibility of nutrients of the diets compared to control. The fibre fraction in a diet has the greatest influence on diet digestibility, and both the amount and chemical composition of the fibre are important (McDonald *et al.,* 1995). The variation in digestibility can be explained by differences in the chemical composition and level of water soluble and insoluble fibre contents (Noblet & Le Goff, 2001). Part of the dietary fibre can be digested before it reaches the end of the ileum (Graham *et al*., 1986; Jørgensen *et al*., 1996; Anderson and Lindberg, 1997; Phuc & Lindberg, 2000) while the main part is fermented by microorganisms in the hindgut, with a subsequent production of volatile fatty acids.

Increasing the inclusion level of PHS from 20% to 60% reduced the digestibility of nutrients, which is in agreement with reports from other studies (Dominguez, 1992; Close, 1993). Bach Knudsen and Hansen (1991) hinted that, the bulking nature of digesta and faeces are usually enhanced by dietary fibre in the pig, which probably resulted in higher rate of feed passage through the gastrointestinal tract that would have reduced nutrient digestibilities of the diets containing PHS. According to Phuc & Lindberg, (2000), digestibility of CP is depressed at around 2% units per 1% increase of crude fibre. Dominguez and Ly (1997) also found that the total digestibility of DM, CF and NDF decreased with increases of sweet potato vine (SPV) meal (100 and 200 g SPV meal/kg feed) in the diets.

Tor-Abbidye *et al.* (1990) reported no difference in DM and GE digestibility, but a significant decrease of CP digestibility when replacing maize with potato by-product meal in pig diets, which agrees with the findings of the present study. The inclusion of 40% - 60% PHS in the diet reduced the digestibility of

CP and OM. This can be explained by the increase in fibre content of the diets and is in agreement with other studies (Phuc & Lindberg, 2000; Lindberg & Andersson, 1998). A likely explanation for the reduced digestibility of protein and amino acids in fibre-rich diets is that, amino acids are bound to or encapsulated in the cell wall and that, fibre will stimulate secretion of endogenous nitrogen. Also, a high content of insoluble fibre in the digesta increases the peristaltic action of the gut, and therefore reduces the transit time, which may lead to an impaired digestibility. Jørgensen *et al*. (1996) reports that a high fibre diet (268 g crude fibre kg^{-1} DM) resulted in a five- to six-fold increase in the flow of digesta through the terminal ileum of growing pigs.

4.5 CONCLUSIONS

It was concluded that dietary inclusion of 60% PHS that was treated with or without LAB inoculants did not improve nutrient digestibility in grower pigs when compared to lower addition level (20% - 40%) PHS and the control diet.

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CHAPTER 5

THE GROWTH PERFORMANCE OF GROWER PIGS FED POTATO HASH ENSILED WITHOUT INOCULANTS OR WITH LALSIL FRESH LB® OR WITH BONSILAGE FORTE®

Abstract

Potato hash (150 DM g/kg) was mixed with wheat bran at a ratio of 7:3 on an as is basis, treated with either homofermentative LAB inoculant (BF® - *Bonsilage Forte®*), or heterofermentative LAB (LFLB®- *Lalsil Fresh LactoBacilli*) and also without LAB inoculant and ensiled in 210 l drums for 90 days. After 90 days of ensiling, samples were collected and analysed for chemical composition. Diets containing 40% potato hash silage (PHS) were formulated resulting in four treatments which were: control (commercial diet - no silage), untreated PHS, BF treated PHS and LFLB treated PHS. The diets were fed to 64 growing pigs (30.4±2.3 kg live weight) that were housed in pairs of the same gender, with each treatment replicated 8 times in a completely randomised block design. The pigs were fed *ad libitum*, and intake was measured daily with body weight being taken weekly until the end of the trial which lasted 8 weeks. The results showed that, the dry matter intake (DMI) of pigs that were fed on the control diet (1062 g/kg) was significantly higher ($P<0.05$) than that of pigs fed on diets that contained PHS respectively. Furthermore, pigs on the control diet had higher ($P<0.05$) final body weight, ADG and better FCR compared to those fed on other diets. There were no differences ($P>0.05$) in DMI, final body weight, ADG and FCR among the untreated, BF and LFLB diets. It can be concluded that, there was no advantage in using LAB inoculants in ensiling potato hash on the growth performance of growing pigs. Further work is needed to evaluate the effects of higher dietary inclusion levels (>40%) of ensiled potato hash on mature pigs for maintenance and reproductive performance.

Keywords: Potato hash, grower pigs, growth performance

5.1 INTRODUCTION

Feed costs account for 70 – 80% of total animal production costs and reducing feed expenses is very important (Okereke *et al*., 2008). With the current rise in feed prices, coupled with the escalating inflation rates in South Africa, the availability of conventional feeds will be difficult under small-scale production systems (Briedenhann, 2008). The availability of agro-industry by-products could be a better option in solving such a problem. The main challenge in the use of these by-products is the inability of pigs to effectively digest and utilise nutrients from diets derived from by-products, because of various anti-nutritional factors. Feeding food by-products to livestock has two important advantages, namely: diminishing the dependence of livestock on grains that can be consumed by humans (Bampidis & Robinson, 2006), and eliminating the costs of waste disposal through nutrient cycling of the by-products from numerous urban sources (Rogerson, 2003).

Potato hash, a by-product derived from the production of potato food, is available in the Gauteng Province of South Africa, and is currently dumped without any use. According to Nkosi (2009), this by-product contains a DM of 150 g/kg, 700 g/kg DM of starch, 11.16 MJ kg DM of ME, 105 g/kg DM of CP, and a crude fibre of 58.5 g/kg DM. Feeding this by-product to livestock in its fresh form is possible, but if it is not consumed in a short period of time by animals, it gets mouldy and quickly becomes useless for animal feeding.

A more sustainable method than dehydration for conserving high moisture by-products is to ensile them with absorbents such as poultry litter, hay, maize cobs and wheat bran, which will absorb the excess moisture in the by-product. Due to the fact that high moisture by-product may lack suitable amounts of sugar and lactic acid bacteria (LAB) for efficient fermentation, silage inoculants are used and have been reported to reduce silage pH, proteolysis and deamination (Okine *et al*., 2005).

Inoculated silages are expected to improve feed intake, dry matter digestibility (DMD) and organic matter digestibility (OMD), resulting in improved animal performance (Bolsen *et al.,* 1996). Following the digestibility experiment conducted in Chapter 4, it was imperative to evaluate the effect of dietary inclusion of potato hash silage ensiled with LAB inculants (LFLB or BF) and without inoculants on the growth performance of grower pigs. This is because, improvement in silage alone without demonstrable improvement in animal performance is of little value to livestock farmers (Gwayumba, 1997). The objective of this study was to evaluate the effects of feeding total mixed ration that contained potato hash silage, treated with or without bacterial inoculants on the growth performance of pigs.

5.2 MATERIALS AND METHODS

Potato hash was collected from Simba (Pty) Ltd (Isando) in Kempton Park and brought to the Agricultural Research Council (ARC) at Irene Institute for chemical analysis, silage making, animal growth and digestibility studies. Mixtures of 700 g/kg potato hash and 300 g/kg wheat bran were produced to achieve at least a 400 g/kg DM. A heterofermentative LAB inoculant, *Lalsil Fresh LB and* a homofermentative LAB inoculant, *Bonsilage Forte,* were applied as inoculants at a rate of 2 l per ton of freshly mixed potato hash. The mixtures were ensiled in sixteen 210 litre drums (Figure 5.1) with a packing density of 822 kg/ m^3 ± 33.5 per treatment and were stored at 29^0C.

After three months of ensiling, drums were opened and samples were collected (before the diets were formulated for a two-phase feeding experiment) and analysed for DM, pH, lactic acid (LA), volatile fatty acids (VFAs) and ammonia-N (NH_3-N). Total mixed rations (TMR) were formulated as shown in Table 5.1 (for phase 1 with inclusion level of 18%) and Table 5.2 (phase 2 with an inclusion level of 40%).

5.2.1 Animals and housing

Sixty-four crossbred pigs (Large White x Landrace) consisting of 32 males and 32 females (64 days old, ± 30 kg live weight) were selected from ARC breeding stock and used for the experiment. The experimental pigs were randomly allocated to four treatments in a 4 x 2 (treatment x sex) factorial experiment in a completely randomised design. Each experimental unit consisted of two pigs and each treatment was replicated 8 times, making 16 pigs, 8 boars and 8 gilts, per treatment. The experimental pigs were housed in a commercial type grower house. The pigs were fed on one of eight diets (four diets for the first phase of the experiment which lasted for four weeks and four diets for the second phase which also lasted for four weeks) until they reached an average slaughtering weight of 60 kg.

Figure 5.1: Potato hash ensiled in 210 litre drums

5.2.2 Dietary treatments

The diets were: 20% UNPHS, 20% LFLBPHS, 20% BFPHS and a dry mash diet (control) that was fed for the first four weeks of the experiment and 40% UNPHS, 40% LFLBPHS,40 % BFPHS and a dry mash diet (control) that was fed for four weeks of the second experiment. All diets were formulated to be isoenergetic and have similar crude protein content.

5.2.3 Data collection

The animals were weighed individually at the start of the trial and continued at weekly intervals until the end of the trial. Daily feed intake was measured by weighing the feed offered and refusals every morning. This data was used to determine the average daily gain (ADG), dry matter intake (DMI) and to calculate the feed conversion ratio (FCR). Feed was given *ad libitum* and water was available at all times through drinking nipples. Mortalities and morbidities were noted and all mortalities were subjected to post-mortem examination. Morbidities were diagnosed and the necessary treatments were done. At the end of the trial, animals were slaughtered and carcass weight and grading was used to calculate dressing percentage and assessment of change in grading was made.

5.2.4 Statistical analysis

Data was analysed using the statistical program GenStat (2000). Analysis of variance (ANOVA) was used to test for differences between treatments. Treatment means were separated using Fishers' protected least significant difference (LSD) at the 5% level of significance..

Table 5.1: Ingredients (%) and chemical compositions (DM %)) of diets used in phase 1 (20% potato hash silage)

	Treatments			
Ingredients %	Control	UNPHS	LFLBPHS	BFPHS
Maize	48.53	50.70	50.80	50.78
WB	6.01	-	-	-
SMOC		5.24	5.28	5.58
Sunflower oil	12	-	-	-
FFS	11	6	6	6
Molasses	4.5	9	9	8.8
Limestone	0.5	0.6	0.5	0.5
Salt	0.3	0.4	0.3	0.3
Lysine	1.5	1.5	1.5	1.5
Methionine	1.5	1.5	1.5	1.5
Monocalium	1.76	1.5	1.67	1.65
Silage	-	20	20	20
Sunflower oil	4	-	-	-
Glycerol	5	5	5	5
Pig supplement	0.4	0.4	0.4	0.4
Calculated composition				
Parameters	Control	UNPHS	LFLBPHS	BFPHS
Dry matter (%)	85.63	76.54	76.19	76.11
Protein (%)	15.0	14.06	14.05	14.05
Energy (MJ/kg DE)	14.00	14.06	14.10	14.09
Ether extract (%)	2.39	1.17	1.17	1.17
Fibre (%)	4.97	5.0	4.93	4.28
Ash (%)	3.19	3.44	3.18	3.18
Calcium (%)	0.84	0.86	0.82	0.81
Phosphorus	0.58	0.58	0.58	0.58

UNPHS = Untreated potato hash silage; BFPHS = Bonsilage Forte potato hash silage; LFLBPHS = Lalsil Fresh potato hash silage Fort; WB = Wheat bran; SOC = Soya oil cake; Oil = sunflower oil, FFS = Full fat soya, PHS = Potato hash silage

Table 5.2: Ingredients (%) and chemical compositions (DM %) of diets used in phase 2 (40% potato hash silage)

	Treatments			
Ingredients %	Control	UNPHS	LFLBPHS	BFPHS
Maize	40.33	30	30	30
WB	23.37	7.5	7.5	7.5
SMOC	13	2	2	2
FFS	7.5	9	9	9
Limestone	1.1	1.3	1.3	1.4
Salt	0.4	0.4	0.5	0.5
Lysine	1.5	1.5	1.5	1.5
Methionine	1.5	1.5	1.5	1.5
Monoclacium	0.90	0.58	0.56	0.54
Silage		40.82	40.76	40.66
Sunflower oil	8	5	5	5
Pig supplement	0.4	0.4	0.4	0.4
Calculated composition				
Parameters	Control	UNPHS	LFLBPHS	BFPHS
Dry matter (%)	85.63	70.06	69.43	69.19
Protein (%)	14.96	15.54	15.43	15.16
Energy (MJ/kg DE)	14.00	15.69	15.69	15.66
Ether extract (%)	2.39	1.78	1.80	1.80
Fibre (%)	4.97	10.00	9.79	8.29
Ash (%)	3.19	4.63	4.56	4.70
Calcium (%)	0.84	0.82	0.82	0.85
Phosphorus	0.58	0.58	0.57	0.58

UNPHS = Untreated potato hash silage; BFPSH = Bonsilage Forte potato hash silage; LFLBPHS = Lalsil Fresh potato hash silage; WB = Wheat bran; SOC = Soya oil cake; FFS = Full fat soya, PHS = Potato hash silage

5.3 RESULTS

Data on the growth performance of pigs in phase 1 is shown in Table 5.3. There were no differences (P >0.05) in the initial weight (IW), final weight (FW), and average daily feed intake (ADFI) between treatments. The pigs on the control diet had a better (P <0.05) FCR (2.9) and higher average daily gain (218g/d) compared to those fed on the other diets. Furthermore, the control had higher (P <0.05) DMI (0.48 kg/d) compared to the other diets.

No difference (P >0.05) existed between gender within treatments in terms of IW, FW, ADG, ADFI and DMI. There were no gender by diet interactions on growth performance parameters (P >0.05).

The growth performance for pigs in phase 2 is shown in Table 5.4. There were no differences (P >0.05) in the IW. The control had a higher (P <0.05) final weight (60.77 kg), ADG (323.7 /d), and lower FCR (2.2) compared to other treatments. However, LFLBPHS had a higher (P<0.05) DMI (0.605 kg/d) compared to control (0.542), UNPHS (0.591 kg/d), and BFPHS (0.531 kg/d).

No differences (P >0.05) in IW and ADFI between treatments occurred. There were also no differences (P >0.05) between gender within treatments in IW, FW, ADG, ADFI, DMI and FCR. However, boars on the control diet had a higher FCR (P> 0.05) than gilts in the same treatment. Female pigs on the UNPHS, LFLBPHS and BFPHS had a higher FCR (P> 0.05) than boars in the same treatment. There were no gender by diet interactions on growth performance parameters (P >0.05).

Table 5.3: Means for the growth performance of pigs in phase 1

	Treatments				P-value				
Parameters	Con	UNPHS	LFPHS	BFPHS	Trt	Gen	Trt*Gen	SEM	CV%
IW (kg)	30.44	30.94	29.01	29.93	0.52	0.77	0.64	0.11	8.8
FW kg)	42.65	39.90	38.94	36.92	0.11	0.91	0.79	1.58	11.3
ADG (g/d)	218.1[a]	159.9[ab]	177.3[b]	125.0[b]	0.01	0.62	0.62	18.63	31.0
ADFI (kg/d)	0.56	0.53	0.54	0.51	0.47	0.30	0.30	0.11	10.4
DMI (kg/d)	0.48[a]	0.40[b]	0.41[b]	0.4[b]	0.02	0.17	0.30	0.05	10.9
FCR	2.9[a]	3.4[b]	3.8[b]	4.4[b]	0.08	0.48	0.21	0.38	29.9

Means in the same row without superscripts do not differ (P< 0.05). Cont =control; UNPHS = untreated potato hash silage; LFPHS= Lalsil Fresh potato hash silage; BFPHS= Bonsilage Forte potato hash silage. Trt = Treatment; Gen = Gender; SEM= standard error of means; CV %= coefficient of variance %. IW= initial weights; FW= final weights; ADG= average daily gain; ADFI= average daily feed intake; DMI = dry matter intake; FCR= feed conversion ratio.

Table 5.4: Means for the growth performance of pigs in phase 2

	Treatments				P-value				
Parameters	Con	UNPHS	LFPHS	BFPHS	Trt	Gen	Trt*Gen	SEM	CV%
IW (kg)	42.62	39.90	38.94	36.92	0.12	0.22	0.35	4.47	11.3
FW (kg)	60.77[a]	52.48[b]	50.99 [b]	48.51 [b]	0.002	0.83	0.90	5.82	10.9
ADG (g/d)	323.7[a]	224.6[b]	215.2b	206.9[b]	<.001	0.69	0.89	34.23	14.1
ADFI (kg/d)	0.73	0.78	0.77	0.73	0.40	0.44	0.45	0.08	10.2
DMI (kg/d)	0.54[b]	0.59[ab]	0.61[a]	0.53[b]	0.04	0.41	0.43	0.06	10.2
FCR	2.2[a]	3.5[b]	3.7[b]	3.6[b]	<.001	0.82	0.62	0.45	13.5

Means in the same row without superscripts do not differ (P< 0.05). Cont =control; UNPHS = untreated potato hash silage; LFPHS= Lalsil Fresh potato hash silage; BFPHS = Bonsilage Forte potato hash silage. Trt = Treatment; Gen = Gender; SEM= standard error of means; CV %= coefficient of variance %. IW= initial weights; FW= final weights; ADG= average daily gain; ADFI= average daily feed intake; DMI = dry matter intake; FCR= feed conversion ratio.

5.4 DISCUSSION

Silage inoculants are used to improved DM (nutrient) recovery and animal performance (Kung *et al.*, 1993) through an improvement in silage fermentation. In this study the addition of *Lalsil Fresh* and *Bonsilage Forte* as inoculants did not improve daily gain, feed intake or feed efficiency compared to untreated silage. Moreover, Kim *et al*. (2006) report that, the growth performance of growing/finishing pigs fed diet consisting of 5% fermented persimmon shell diet was lower than those fed on concentrate, which supported the results of the present study.

Pig performance was rather poor in the present experiment, with growth rates of 224.6 - 206.9 g/day, and feed conversion of 3.5 - 3.7 kg feed/kg liveweight gain. However, (Rahnema *et al.,* 1998) reported a reduced GE intake when pigs were fed 15% or 20 % potato chips scraps diet. Further, Rahnema and Borton (2000) reported a reduced DMI and ADG when pigs were fed potato chips scraps diet. Manfredini *et al*. (1993) fed pigs (43 to 155 kg live weight) sweet potato chips and reported no significant difference in ADG or Feed. Gain ratio; similar results were reported by Muirhead (1995), where 33% of barley was replaced with dehydrated potato by-products in the diet of growing pigs. The reduced DM intake in the diets containing PHS could be due to their bulkiness, as well as high fibre content of these feeds compared to the control. In addition, the control diet had higher DM content and lower fibre content compared to those containing PHS. Similarly, Just (1984) reported a high DMI in pigs fed high DM and low fibre content diet, compared to those fed on low DM and high fibre diets. In contrast, Shimizawa *et al.,*(2007) did not obtain a difference in feed intake between pigs that were fed either on a concentrate or total mixed potato silage.

The high fibre in potato hash could at least partially account for the increase in the bulking characteristics of the digesta (Metz 1985, cited by Dominguez & Ly, 1997). These results are in agreement with those of Kyriazakis and Emmans (1995), who reported that the voluntary feed intake in pigs is largely governed by the bulkiness of the diet. Ly (2002) reported that dry matter intake decreased in diets containing cassava foliage silage due to its bulkiness. Dominguez (1990) reported that, dietary substituting of 25 and 50% of soybean meal with sweet potato foliage decreased the DM intake of grower pigs. However, in the present study, LFLBPHS had a higher DMI. This could be due to the nutrient density of the diet.

Phuc (2000) reported that the feed intake by grower pigs was lower in diets containing potato vine silage compared to control. The poorer responses in ADG and FCR when PHS was included in the diet, could be related to the lower digestibility of nutrients. Fuller and Chamberlain (1982) (cited by Dominguez 1992) hinted out that, the amino acid content of sweet potato roots and SPV were somewhat deficient in total sulphur amino acids and lysine compared to the ideal protein. In addition, replacing the basal diet with sweet potato meal or sweet potato silage was partly at the expense of maize and, according to Wu (1980, cited by Yeh, 1982), the digestible and net energy of potato by-products are only 91 and 79% respectively, of those of maize. Manfredini *et al.* (1993) concluded that the use of sweet potato root chips in heavy pig production, as a substitute for maize meal at 40% level, decreased daily gain and feed efficiency. Tor-Agbidye *et al.* (1990) concluded that pigs fed sweet potato by-product meal and soybean meal grew more slowly and had poorer feed efficiency than those fed a maize-soybean meal diet, and suggested that this probably was due to the low digestible energy, methionine and threonine contents of the experimental diets.

Dominguez (1990) summarised previous studies with sweet potato root chips and concluded that, half the maize could be substituted (about 40% sweet potato root chips in the diet) without affecting pig growth rate and feed conversion. There is support for this recommendation on the basis of the similarity in performance of pigs fed the basal diet, and the diets with 40% of sweet potato meal or 40% sweet potato silage during Period 2 (50 to 70 kg live weight). However, this result is confounded with the possible effects of adaptation to the high fibre levels, as a consequence of exposure to the sweet potato diets. Peters *et al.* (2005) obtained a growth rate of 454 g/d in pigs fed diets containing 30% sweet potato root silage, which is comparable to the results obtained in the present study in pigs fed on diets containing the PHS.

5.5 CONCLUSION

The present study showed that, pigs that were fed on diets containing PHS that was treated with or without inoculants, had a lower ADG and higher FCR than those fed on commercial diets. It was concluded that, dietary inclusion of PHS did not improve pig performance when compared to the control. Furthermore, the effects of LAB inoculants on pig performance were not significant in this study. Thus, work that will evaluate the effects of similar dietary inclusion levels of ensiled potato hash on breeding pigs and on reproductive performance may be warranted. This is because the age of the pigs plays a major role when feeding ensiled potato hash diets.

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CHAPTER 6

THE EFFECTS OF DIETARY ADDITION OF POTATO HASH SILAGE ON CARCASS TRAITS OF GROWER PIGS

Abstract

An experiment was conducted to assess carcass traits of cross-breed (Landrace X Large White) pigs fed potato hash silage (PHS) ensiled with or without bacterial inoculants. Thirty-two pigs, 16 males and 16 females (aged 130 days with average live weight of 56±4kg) that were fed on diets containing PHS, were slaughtered and carcass traits were evaluated. Pigs that were fed the control diet had higher (P<0.05) slaughter weight than those that were fed on diets containing PHS. There were no differences (P>0.05) on warm and cold carcass weights between diets containing PHS. Drip loss percentage, backfat thickness, gastrointestinal tract (GIT), lungs and heart weights did not differ between treatments (P>0.05). No gender differences (P>0.05) occured within treatments on all the carcass traits. Gender by diet interactions, (P <0.05) occurred on slaughter weight and dressing percentage. Furthermore, silage treatments did not differ on carcass characteristics. Further work that will evaluate the effects of LAB inoculated PHS on meat quality of porkers and baconers is warranted since the age of the pigs plays a major role in meat quality.

Keywords: Potato hash silage, grower pigs, meat characteristics

6.1 INTRODUCTION

In recent years, economic pressure on pig production has resulted in intensification of production methods in order to decrease production costs. As a consequence, animal health and welfare and environmentally friendly production have been pushed into the background. Furthermore, the production of lean carcasses to meet consumer demands for low-fat pork, has resulted in a substantial decrease of intramuscular fat levels and an increased concern that, eating quality may be consequently reduced (Cisneros *et al*., 1996). With every new feed, especially non-conventional feed types such as potato hash, the carcass traits and meat quality should be investigated.

Feeding by-products puts more emphasis on the production system to meet the demands of a specific consumer segment (Sundrum, 1998). Due to the extensive production system, there is doubt as to whether by-products can meet the demands of high carcass quality (Branscheid, 1996). There is, however, very little information on the impact of feeding potato hash silage on carcass characteristics of pigs. The objective of the present study was to evaluate the effects of potato hash silage ensiled with or without inoculants on carcass traits of grower pigs.

6.2 MATERIALS AND METHODS

Mixtures of 700 g/kg potato hash and 300 g/kg wheat bran were ensiled to achieve at least a 400 g/kg DM. A heterofermentative LAB inoculant, *Lalsil Fresh LB and* a homofermentative LAB inoculant, *Bonsilage Forte* were applied as inoculants at a rate of 2 l per ton of the mixture. After three months of ensiling, total mixed rations (TMR) were formulated as in chapter 5 and fed to grower pigs. After the growth study has been completed (Chapter 5), the pigs were slaughtered and carcass traits were evaluated under standard abattoir procedures.

6.2.1 Animals and housing

Thirty-two crossbred pigs (Large White x Landrace) consisting of 16 males and 16 females (aged 130 days with average weight of 56±4kg) that were used for growth performance trials (Chapter 5) were used for this study. Pigs were fed a control diet (commercial feed), 40% untreated potato hash silage (UPHS), 40% potato silage ensiled with either Lalsil Fresh (LFPHS) or Bonsilage Forte (BFPHS). The pigs were fed on one of four diets until reaching slaughter weight of 60 kg.

6.2.2 Pre-slaughter activities

The pigs were weighed 24 hours prior to slaughtering. They were transported simultaneously in the early hours (7:30) of the morning to the ARC–Irene abattoir where they were provided with fresh drinking water, kept calm and then slaughtered. At the abattoir, standard pre-slaughtering procedures were followed.

6.2.3 Slaughtering

The pigs were electrically stunned with an electrical stunner set at 220 V and 1.8 A with a current flow for 6 seconds. Electrical stunner electrodes were positioned at the base of each ear. Exsanguination followed within 10 seconds after stunning. The pigs were dehaired in the dehairing machine following scalding at 63ºC and the remaining hairs were removed with a gas flame.

6.2.4 Post-slaughter activities

After slaughtering, standard abattoir post-slaughtering procedures were followed. Warm carcass weights were determined immediately after slaughter. After an overnight chill storage at an average temperature of 4.3ºC, cold carcass weights were determined. Carcass length was taken on hanging carcasses by measuring from the pelvic bone to the first thoracic vertebra using a measuring tape. Backfat thickness (Figure 6.1) was also taken on cold carcass at P2 (45 mm from midsection) between the 3rd and 4th rib on the left side of the pigs using a calliper. Drip loss was also calculated for hanging carcasses by determining the weight loss after the overnight chill, and was calculated using the following formula:

$$\text{Drip loss} = \frac{\text{Warm carcass} - \text{cold carcass}}{\text{Warm carcass}} \times 100$$

Dressing percentage was also determined using the following formula:

$$\text{Dressing \%} = \frac{\text{Warm carcass weight}}{\text{Live weight}} \times 100$$

6.2.5 Statistical analysis

Data was analysed using the statistical program GenStat (2000). Analysis of variance (ANOVA) was used to test for differences between treatments. Treatment means were separated using Fishers' protected least significant difference (LSD) and significance was declared at 5% leve.

Figure 6.1: Backfat thickness taken on hanging carcasses

6.3 RESULTS

Data for the means of carcass traits is shown in Table 6.1. Pigs that were fed the control diet had higher (P<0.05) slaughter weight and dressing % than pigs that were fed on diets containing PHS fed. There were no differences (P>0.05) on warm and cold carcass weight between the PHS treatments (UNPHS, BFPHS and LFLBPHS). However, drip loss percentage, backfat thickness, GIT, lungs and heart did not differ (P>0.05) between treatments. No gender differences (P >0.05) occurred between treatments in all carcass traits. There were no (P >0.05) gender by diet interactions on warm carcass weights, cold carcass weights, drip loss percentage, carcass length, backfat, lung weights and heart weights. However, gender by diet interactions were observed ($P < 0.05$) on slaughter weight and dressing percent. Boars that were fed the control diet had heavier ($P<0.05$) carcasses than the sows on the same diet. Similar trend occurred in the diet containing LFLBPHS. Also boars that were fed UNPHS had more weight ($P<0.05$) than the sows that were fed UNPHS. However, sows that were fed BFPHS weighed more ($P<0.05$) than the boars that were fed BFPHS. Boars that were fed the control and BFPHS had a higher ($P<0.05$) dressing % than the sows. Sows that were fed LFLBPHS had a lower ($P<0.05$) dressing percentage that boars that were fed LFLBPHS.

6.4 DISCUSSION

Dressing percentage for pigs consuming diets containing 40% PHS ensiled with or without inoculants decreased ($P<0.05$) as compared to those that were fed the control diet. This is in agreement with the results obtained by Borton and Rahnema (1998), where there were no differences in carcass traits of pigs fed potato chip scraps. Also, Scipioni and Martelli (2001) found no differences in carcass traits of pigs fed 10% and 20% sugar beet pulp diets. Hang (1998), reports that, the inclusion of 5% ensiled cassava leaves in the diet of growing pigs did not affect carcass traits. High-fibre from potato hash silage diets negatively affected warm carcass weights and dressing percentages of the pigs. This was probably due to the increased weight of the gastrointestinal tract. Similar results were found in studies where pigs were fed high-fibre diets (Jorgensen *et al.,* 1996). The results in the current study are in agreement with those of Partanen *et al.* (2002),, who also found that, back fat thickness and carcass lean were not affected by fibre level in the diet.

However, Jin *et al*. (2003) reports that the feeding of sweet potato stem silage increased the crude ash content of pork. Kim *et al*. (2006), who experimented by feeding the Berkshire breed of pigs with fermented persimmon shell diet, reports that the fermented persimmon shell diet reduced the moisture content and increased the crude fat of pork. In the results of the present study, the intake of potato hash silage was found to affect the chemical composition of carcass traits, which is similar to the report of Kim *et al*. (2006a).

6.5 CONCLUSION

It was concluded that, dietary inclusion of PHS that was treated with or without LAB inoculants did not improve carcass traits when compared to the control. Furthermore, the effects of LAB inoculants on meat traits was not significant in this study and therefore further work that will evaluate the effects of inoculants on meat quality of porkers and baconers is warranted since age of the pigs plays a major role on meat quality.

TABLE: 6.1 Effects of dietary inclusion of 40% potato hash silage on the carcass quality of grower pigs

	Treatments				Gender								P-value			SEM	CV%
	Combine				Boars				Sow								
Parameters	Cont	Un	LF	BF	Cont	Un	LF	BF	Cont	Un	LF	BF	TRT	Gen	TRT*Gen		
SW(kg)	65.1[a]	53.9[b]	53.6[b]	52.3[b]	68.1	56.3	55.4	50.3	62.2	51.5	51.8	54.2	<.001	0.05	0.04	1.2	6.2
WCW (kg)	54.8[a]	41.1[b]	42.5[b]	39.85[b]	56.4	43.2	43.7	39.1	53.2	39.1	41.3	40.6	<.001	0.16	0.52	1.4	8.9
CCW (kg)	53.5[a]	41.4[b]	40.2[b]	38.7[b]	55.0	42.2	42.6	38.1	52.0	38.2	40.2	39.35	<.001	0.14	0.53	1.3	8.6
Drip %	2.3	2.3	2.5	2.9	2.4	2.3	2.4	2.6	2.2	2.2	2.6	3.1	0.07	0.59	0.52	1.9	17.8
Dressing%	84.1[a]	76.4[b]	74.0[c]	73.0[c]	82.6	76.9	71.9	76.0	85.6	75.9	76.2	70.0	<.001	0.92	<.001	0.7	2.4
CL (mm)	70.7[a]	69.4[a]	68.8[a]	66.2[b]	71.8	68.0	67.1	68.8	69.6	70.8	65.2	68.8	0.01	0.74	0.19	0.9	3.7
BF (cm)	11.6	11.3	9.9	9.6	11.5	11.0	8.9	8.0	11.8	11.5	10.8	11.3	0.37	0.15	0.68	0.9	26.0
GIT (kg)	6.5	6.7	5.7	6.8	6.9	6.4	6.0	7.5	6.0	7.0	6.1	5.5	0.32	0.25	0.49	0.4	19.5
L and H (kg)	2.5	2.3	2.1	2.0	2.7	2.1	2.1	2.1	2.2	2.4	2.2	1.8	0.06	0.40	0.19	0.1	15.7

Means in the same rows without superscripts do not differ ($p \leq 0.05$), SEM= standard error of means; CV %= coefficient of variance %. Cont =control, Un = untreated potato hash silage, LF= Lalsil treated potato hash silage, BF potato hash silage. SW= Slaughter weight, WCW= warm carcass weights; CCW= cold carcass weights; Dressing %= dressing percentage; CL= carcass length; BF= back fat; Drip %= drip loss percentage.

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CHAPTER 7

7.1 GENERAL CONCLUSION

The results of this study demonstrated that ensiling potato hash with inoculants improved aerobic stability and fermentation of potato hash silage. However, dietary addition of those silages did not improve the growth performance, nutrient digestibility and carcass quality of grower pigs compared to the commercial diet. In addition, dietary addition of PHS increased the fibre content while reducing the DM content of the diets.

Potato hash is available as an animal feed. An estimated amount of 50 tones per day is produced and dumped without being used, which also causes environment problems. Farmers can collect the potato hash for free and ensile it without inoculants and feed it to their boars, sows and finisher grower. This will save cost of production for small-scale pig farmers.

Work that will evaluate the effects of higher (> 60%) dietary inclusion levels of PHS with or without inoculation on reproductive performance of pigs may be warranted, since the age of the pigs plays a major role when feeding PHS diets to grower pigs.

7.2 RECOMMENDATIONS

- Although the PHS used in the present study did not improve pig performance compared to the commercial diet, it has a potential as alternative feed for resource-poor pig farmers.

- It is further recommended that, PHS may be included in diets at the 20% level without adverse effects on the digestibility of nutrients. The higher the inclusion level of silage, the higher the fibre level; which negatively affects pig performance.

- Use of LAB inoculants, preferably Lalsil Fresh LB, is also recommended since it improved the fermentation and stability of PHS.

- Resource poor pig farmers can feed their boars, dry and pregnant sows and finisher growers on PHS, since they can utilise high fibre diets.