Effects of Sweet Potato Forage Meals on Protein and Energy Supply, Beta-Carotene and Blood Glucose Content of Dairy Cattle Milk

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Christiaan Jacobus Smit

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Supervisor: Dr F.V Nherera-Chokuda

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Declaration

Student number:45106754

I declare that "Effects of Sweet Potato Forage Meals on Protein and Energy Supply, Beta-Carotene and Blood Glucose Content of Dairy Cattle Milk" is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

_____ 14/04/15

SIGNATURE DATE

Mr CJ Smit

Abstract

Forage of beta-carotene-fortified orange-fleshed sweet potato is essential for alleviation cattle malnutrition. The study aims were to determine effects of supplementing sweet potato (SP) roots and sun dried forage on degradation of dietary legumes, intake and milk yield in dairy cattle. Mature SP roots were oven dried and forage vines and leaves (V&L) sun dried. Lactating dairy were supplied meals with total mixed ration (TMR) constituting varying levels of sweet potato forage and concentrate. The SP flour was rapidly and completely degraded *In Sacco* while degradability of V&L was comparable to that of Lucerne hay. Rumen degradation of Lucerne was reduced when the legume was incubated proximal to SP. Substitution of TMR with fresh SP forage and flour meal increased degradability of diets. Glucose post-feeding was increased ($P<0.05$) by SP roots but no change in milk yield. Orange-fleshed SP forage is recommended for improving energy supply in lactating cow diets.

Keywords: Metabolizable Energy, Nutrient Intake, Dehydrated Roots

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CHAPTER 1

Introduction

In Sub-Saharan Africa, the rapid increase in the human population is resulting in an increasing demand for food and livestock products. Most rural households suffer food and health insecurity due to limited opportunities for income generation. High levels of child malnutrition reflect the imbalances in nutrition. One in 3 children in Southern Africa has a low vitamin A status (Leighton, 2007). Worldwide, 33% of children younger than 5 years suffer from a vitamin A deficiency (WHO, 2009). Vitamin A enhances immunity against infectious diseases such as measles, malaria and diarrhoea.

Potential staple crops for the Sub-Saharan environment include the orange-fleshed sweet potato *(Ipomea batatas L. Lam)* which is rich in beta (β)-carotene, a precursor for vitamin A (Pfeiffer, & McClafferty, 2007; Burri, 2011; Wenhold *et al* 2012;). In light of millennium goals for food and health security, the International Potato Centre launched the Sweet Potato Bio-Fortification Programme to improve human nutrition through the consumption of orange-fleshed roots. Coupled with forage feeding milking cattle to produce milk high in vitamin A, the Bio-Fortification Programme would accelerate the achievement of the above-mentioned millennium goals. Children are particularly prone to vitamin deficiencies and hence their diets should be augmented through increased consumption of vitamin A enriched milk.

In Sub-Saharan Africa, sweet potatoes *(Ipomea batatas)* are grown primarily by small-scale livestock farmers as a dual-purpose crop (Faber, & Wenhold, 2007; Laurie, 2010) because of its drought tolerance. The vines are underutilised as livestock feed (Orodho, 1990). Sweet potato (SP) tubers grow underground, generally in the top 25 cm of soil although some of the roots produce elongated starchy tubers. Tubers range in flesh colour from cream to yellow, purple or orange, are high in soluble carbohydrates, minerals and vitamins, and have a low fibre content.

White- or cream–fleshed sweet potatoes are abundant but have little or no pro-vitamin A which counteracts the risk of blindness. Additional benefits of augmenting diets with coloured SP include deep colouring of milk and milk products by β-carotene to reduce the use of colorants in the industrial processing of foods and dairy products.

The cost of cropping home grown forage such as sweet potatoes is low compared to the cost of purchasing feeds, and it is possible to limit feeding costs to less than 45% of gross income from livestock (Sipiorski, 2013). Peters (2008) reported increased milk output in dairy cows fed SP vines. Feeding dehydrated tubers of orange-fleshed varieties increased the vitamin A and β-carotene content of milk (Woolfe, 1992; Phesatcha, & Wanapat, 2013). Rondon *et al*. (1989) however found lower weight gains for lambs grazing

sweet potato leaves, suggesting that other bioactive compounds such as trypsin inhibitors may play a role in exacerbating protein deficiencies in cattle on low nutrient diets.

There is a lack of scientific data on the forage nutrient value of the new varieties of SP currently being propagated by the Agricultural Research Council, Vegetable and Ornamental Plant Institute (ARC-VOPI) for the purpose of enhancing the vitamin A status of vulnerable groups. Even more inadequate is research on the effects of dehydrated and fresh ungraded roots as a potential energy booster for lactating dairy cattle or other milking cattle. The orange-fleshed sweet potato (OFSP) is considered to be an excellent new source of natural health-promoting compounds such as β-carotene (Bovell-Benjamin, 2007).

Study aim

The aim of this study were to determine the forage value of orange fleshed sweet potato (OFSP) for improving energy and protein nutrition, milk yield from milking cattle in the subtropics.

Objectives

1. To determine the nutrient profiles of mature fresh and dried leaves and vines, forage grade roots and heat processed root flours of a new bio-fortified OFSP variety.
2. To determine effects of incubating heat processed OFSP forage components on rumen disappearance of Lucerne hay.
3. To determine diet composition and dry matter intake of fresh OFSP forages and dried vines and leaves and milled dehydrated roots supplemented to lactating dairy cows.
4. To determine rumen degradability of flours derived from dried vines and leaves and milled dehydrated roots supplemented to lactating dairy cows.
5. To determine milk production and blood glucose and β-carotene in lactating dairy cattle supplemented with OFSP flours.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

South Africa has a competitive cattle industry in terms of other countries but operates below potential. Production costs, drought and livestock diseases affect cattle farming and profitability nationally and internationally. Rural farmers in South Africa keep cattle for the dual purpose of having meat and milk. The number of cattle in South Africa is estimated at 13.8 million, including not only various international dairy and beef cattle breeds, but also indigenous breeds (Palmer & Ainslie, 2004). South Africa had an estimated 540,000 dairy cows in 2009 with an average herd size of 280 cows. Of these cows, 66% were Holsteins and 26% were Jersey cows (Lingnau, 2011). Ruminant livestock production is however seriously hampered by nutritional limitations associated with insufficient nutrient bases, climate change, the exorbitant cost of conventional feeds and competition for grains from humans and the bio-fuel industry. However, technological advancements in nutritional science continue to open up new possibilities for addressing the nutritional requirements of cattle. Non-conventional feeds are essential in mitigating the high feed costs associated with milk and meat production.

2.2 Nutritional requirements of dairy cattle

Nutrition is critical to livestock productivity. A balanced diet consists of water, energy, protein, minerals and vitamins, in proportions that vary based on animal, environmental and management factors. Dairy cows in particular require nutrient energy for maintenance, pregnancy, milk production and changes in body weight of adult cows (Moran, 2005). Carbohydrates are the primary source of energy in diets fed to dairy cattle, usually comprising 60-70% of the total diet. The function of carbohydrates is to provide energy for the rumen microbes to maintain the health of the gastrointestinal tract for optimum digestion (NRC, 2001).

Macro-minerals are important structural components of bone and other tissues, and serve as important constituents of body fluids. They play a vital role in the maintenance of acid-base balance, osmotic pressure, membrane electrical potential and nervous transmission (NRC, 2001). Foraging cattle are not able to meet all their mineral requirements hence the need to supplement these. Most plants do not contain sufficient available minerals, in particular phosphorus. Non-conventional feeds are often deficient since essential components are often lost during processing or edible components are removed for human consumption.

Other critical components are vitamins. Vitamins have multiple functions in the body including involvement in many metabolic pathways and immune cell function. Vitamin A (also called retinol) and is formed from beta (β)-carotene synthesised by most coloured plants such as carrots, pumpkins, Lucerne, orange-fleshed sweet potatoes (OFSP) and butternut. Vitamin A is required for the maintenance of a healthy epithelium as well as for good eyesight and tissue and bone formation. Subclinical deficiencies may occur in which clinical signs of the deficiency are not evident but performance or overall animal health is less than optimal. Dairy cattle require vitamins A, D, E and K. However, vitamins A and E are the only absolute dietary requirements as they are in short supply in processed plant material (NRC, 2001). Vitamin A is rapidly lost in the drying process. Deficiencies of vitamin A lead to poor eyesight and can also lead to mastitis infections due to an unhealthy epithelium. Vitamin A deficiency is a leading cause of stunting in South African children. Animal products rich in vitamin A are therefore essential.

2.3 Nutritional deficiencies in cattle

In lactating dairy cattle, a deficiency of energy results in a decline in milk yield and loss of body weight. Prolonged energy deficiency depresses the reproductive function of the cows. In cases of severe deficiencies of dietary energy, protein or both, placenta retention can occur because cows, already suffering the stress of parturition, lack the strength to expel the placenta immediately after birth (Maas, 1982). The prevalence of metabolic disorders is primarily linked to poor nutritional management, affecting herd immunity, productivity and profitability. Mineral deficiencies such as milk fever are associated with low blood calcium and paralysis in cows beyond first lactation. Cows in dry period are fed adequate calcium, but after calving, are lacking in calcium intake. Low energy supply is linked to ketosis. Feeding rations of concentrates and forage balanced with critical amino acids, vitamins and minerals is essential for the stabilisation of gastrointestinal bacterial flora in order to avoid acidosis and translocation of endotoxin in the bloodstream which predispose cows to laminitis.

2.4 The digestive tract of large ruminants

2.4.1 Ruminant stomachs

Ruminants have 4 stomachs – the reticulum, rumen, omasum and abomasum (Figure 2.1) - as an adaptation to their nutrition. The reticulum is the first stomach in a ruminant. The reticulum is separated from the rumen by a ridge of tissue. The lining has a raised honeycomb-like pattern, also covered with small papillae. Large particle feeds will stay in the reticulum and not pass on into the rumen until chewed into smaller particles.

The rumen is the largest stomach and can contain up to 100-120 kg of material. The temperature inside the rumen remains constant at around 39ºC which is suitable for the growth of a range of microbes needed for digestion (Lingnau, 2011). The fermentation of fibre in the rumen is a slow process and can take 20-48 hours because of the slow bacterial fermentation (Ishler *et al*.,1996). Bacteria, protozoa and fungi which are found in their billions are the basis for the fermentation process. Most of the groups of bacteria are specialised in polysaccharide hydrolysis and the fermentation of sugars resulting from the hydrolysis, and for this reason animals fed the same diet will have very similar microbe populations (Firkins & Yu, 2006). A cow spends as much as 35-40% of the day ruminating (Lingnau, 2011). Mature cattle spend little time chewing when eating. During rest periods, feed will be regurgitated for chewing to reduce particle size and for mixing with saliva. In the rumen, the microbes will digest the feed more readily if the particle size is reduced.

The microbes in the rumen ferment the glucose to obtain energy for growth and for the production of volatile fatty acids (VFA). The VFA cross the rumen wall and become the major source of energy for the cow (Dijkstra *et al*., 1993). Not all types of proteins are fully utilised by the microbes and some will pass out without dissolving. Dietary changes cause severe changes in the rumen microbe population structure (Lingnau, 2011). Starch feeds promote non-structural bacterial populations species such as *S. bovis* and *M. elsdinii*, methanogens and the production of propionate, while high fibre diets are utilised by structural bacteria such as *Fibrobacter succinogens*, *Ruminococcus flavefaciens*, *Bacterio succinogens* and *Butyrivibrio fibrisolvens*, and promote the production of acetate and butyrate (Fonty & Gouet, 1994). Ration balancing, which involves balancing energy and protein supplies, influences rumen pH and microbial protein synthesis (Lingnau, 2011).

The omasum, the third stomach of a ruminant (Figure 2.1), is smaller, with a capacity of 10 L. It has good absorption which allows for the recycling of water and minerals such as sodium and phosphorus.The abomasum is the last part of the stomach and functions in a similar way to a monogastric animal's stomach. Strong acid and digestive enzymes are secreted from the abomasum to digest unfermented feed particles and stop certain microbial fermentations and microbes that grow in the rumen (Lingnau, 2011).

Drastic changes in diet impact severely on papillae and rumen membranes and should be avoided. Rapid changes in dietary content affect fermentation patterns and interfere with fibre digestion. A new feed should be introduced to the cow gradually over a period of 14 days so that the populations of rumen microbes can adjust accordingly. Problems in the digestive tract like acidosis and depressed intake can then be avoided.

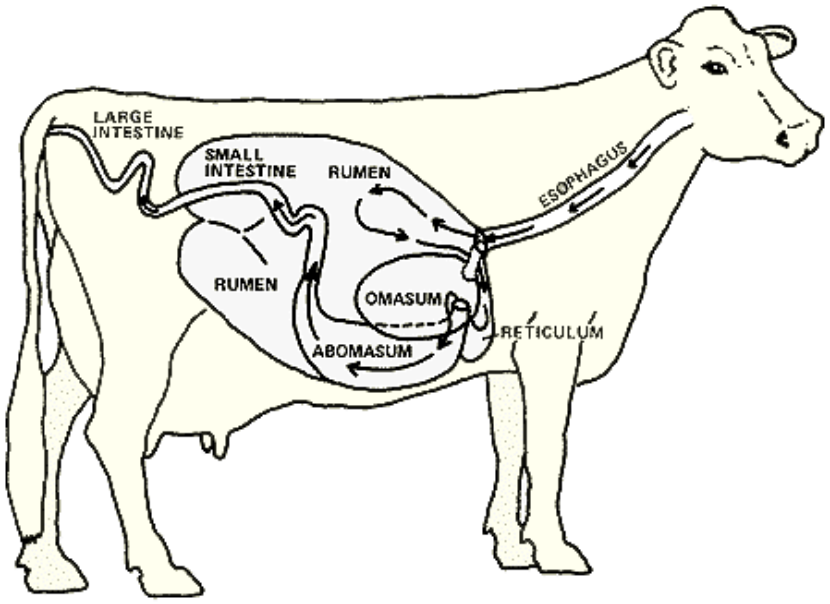

Figure 2.1 The ruminant digestive tract (Lingnau, 2011)

2.4.2 Digestion of energy feeds in the rumen

Carbohydrates are classified as simple or complex. Both forms are digested by rumen microbes which are then converted into volatile fatty acids (VFA) (Ishler et al., 1996). Dairy cows are sometimes fed large amounts of forages which then form acetic acid with propionic and butyric acids (NRC 2001, Lingnau, 2011.). Adding grain or ground forages to the diet will increase the proportion of amylolytic microbes (Tajima *et al*., 2000). Large amounts of starch are degraded, but this depends on the amount of starch fed and on how fast the materials were ingested and moved through the rumen. Of all feed sources, sugars are 100% digestible in the rumen (Lingnau, 2011). Forage feeds and non-conventional co–products are very low in sugar content which is why forage diets require energy supplementation. Sweet potato (SP) tubers are high in soluble carbohydrates and would therefore constitute good alternative energy feeds.

2.4.3 Protein and non-protein nitrogen utilisation in the rumen

Protein that undergoes fermentation is converted to ammonia, organic acids, amino acids and other products (Shirley, 1986). Rumen micro-organisms require ammonia for growth and synthesis of microbial protein (Lingnau, 2011). Rumen microbes convert the ammonia and organic acids into amino acids that are assembled into microbial protein (NRC, 2001). Most excess ammonia is absorbed from the rumen into the blood stream, but small amounts may pass into the lower digestive

tract and be absorbed there. Feed protein that escapes breakdown in the rumen as well as microbial protein pass to the abomasum and small intestine for digestion and absorption. Forages such as Lucerne and other legumes are rich sources of protein while grain type forages, for example maize, sweet potato vines and wheat chaff, are deficient in protein, especially at maturity.

2.5 Forage feeding in cattle

The production of cows fed on less nutritional forages will be lower than that of cows fed high quality forages with less concentrate supplement. The chemical composition of forage depends on plant characteristics and on harvesting and storage methods. In most cattle farming, animals harvest nutrients off the veld and subsist on crop residues, feedlots and, in the case of dairy cows in coastal areas, irrigated pastures. (Lingnau, 2011). All production systems are subject to variations and fluctuations in nutrient supply and costs. High levels of grass type grain crops, vegetables, protein crops and energy type crops are grown in and imported into South Africa. The utilisation and processing of crop residues and co-products are not clearly defined. Sweet potato forage utilisation in South Africa is not defined with the result that the residue is utilised in manure production when there are better opportunities in the feed industry.

2.5.1 Types of forages

Pasture grazing of dairy cows is mainly based on temperate grass species (Bargo *et al*., 2003) such as perennial ryegrass (*Lolium perenne*) under irrigation, which could form a useful basis for winter pastures (Van Oudtshoorn, 2004). Kikuyu grass is over-sown with annual ryegrass during autumn to improve the seasonal dry matter (DM) production of kikuyu pastures during spring (Botha *et al*., 2008). During early spring, ryegrass pastures are high in protein, and have low neutral detergent fibre (NDF) content and high digestibility (Wales *et al*., 2001). The metabolisable energy (ME) content of ryegrass is above 3.5 Mcal/kg DM from winter until the end of September, after which it falls markedly to concentrations of less than 2.5 Mcal/kg. It usually contains 18-24% dry matter (DM) content, 18-25% crude protein (CP) levels, 40-50% NDF fractions and 1.5-2.2 Mcal/kg DM of net energy (NE) (Bargo *et al*., 2003). Cows grazing on high quality ryegrass pasture in the springtime have a shortage of energy levels with the result that milk production will decrease during the feeding period (Fulkerson *et al*., 1998). These cows will consequently need extra supplementation for energy and protein (Schwarz *et al*., 1995; Penno *et al*., 2001).

Kikuyu (*Pennisetum cladestinum*) is the next best pasture-based grass for grazing dairy cows, but is restricted to certain areas because of its cold and drought intolerance (Marais, 2001). Sweet potato,

on the other hand, can survive in drought areas and is cold resistant. The dry matter content of kikuyu is highest during the summer and autumn seasons, and during the winter and summer seasons it consists of low DM content (Van der Colf *et al*., 2009). The energy content of kikuyu grass is a major limiting factor in the productivity of dairy cows.

2.5.2 Effects of season on quality and forage supply

Plants are seasonal and hence their nutritional value varies. During early growth, nutritional value is higher as a result of less lignification. Crop residues and hay tend to be lower in nutritional value due to the loss of nutrients with maturation. Seasonal cycles are linked to the cycles of sufficiency and deficit in livestock production that result in metabolic disorders. This is particularly the case with animals on rangelands. Usually, palatable species are selected in early season and the animals are then forced to graze the unpalatable forages later. Dependence on natural systems is only profitable when grazing management systems are in place and camps are rehabilitated. Failing this, crop residues and supplements should be provided to meet nutritional needs and prevent poor growth and performance.

Hydroponically sprouting systems can provide green fodder but may involve additional costs.

In Sub-Saharan Africa and South Africa, grasslands with palatable and unpalatable grasses are the most important available resource for the livestock of rural and smallholder farmers. Rural farmers are dependent on grassland for their livestock to produce meat, milk, hides and fleeces (Palmer & Ainslie, 2004).

Soybean foliage can be grazed but is not a satisfactory pasture for cattle as trampling damages the growing plant (Göhl, 1982). It can also be ensiled or dried to make hay. Soybean straw is a good source of roughage for cattle, fed as fresh or as ensiled material, since it has a protein content of 5-8% DM and a digestibility of 30–60%. Untreated straw has low palatability because of the hard stem and woody texture. Soybean hulls are rich in fibre and can be used for ruminants if mixed with low fibre contents such as maize or soybean meal.

South Africa mainly produces grain crops in the Highveld inland areas such as Mpumalanga. The residue is primarily used for feeding beef cattle during the winter months. There is extensive production of white variety sweet potatoes on commercial farms, but the vines and leaves are recycled as green manure and there are no formal value chains for utilising this type of fodder.

In countries such as India and Egypt cotton crop residues are sometimes used as cattle and sheep feed (Heuzé *et al*., 2012).

Due to the fluctuating market of raw materials for stock feed, the prices of grain crop residues are escalating and increasing the cost of meat and milk production. Larger concentrated animal feeding programmes are better able to absorb price shocks, but small to medium production systems have to gravitate toward lower input costs. There is an ongoing need for innovation in the selection and development of feed and forage bases. The sweet potato option is already being explored in east Africa, Asia, North America and Indonesia. With the up-scaling of CIP activities in Sub-Saharan Africa, there is opportunity to develop sweet potato residue into a formal fodder value chain. Nutritional evaluations incorporating data from sources such as FAO and Feedipedia databases are essential in the initial screening of non-conventional feeds.

Large tracts of land are cultivated under maize, wheat, soy, cotton and sweet potato in South Africa. Most residues are harvested and baled after the removal of grain and seed and then channeled through various fodder markets. Shortages of crop residues is an evident producers as rural farmers struggle to maintain animal conditions, rural farmers are mostly affected because of the poor resource base. Shortages of crop residues make it difficult for producers to maintain animal health. Communal farmers are particularly affected by the poor resource base. Imbalances in animal nutrition are often fueled by the inappropriate channeling of fodder as well as poor feed management, as evidenced by the underutilisation of sweet potato crop residues. There is large scale planting of white-fleshed sweet potato varieties but the residue is utilised mostly as manure. In rural sectors, the orange varieties are being propagated and the residues could meet micro-nutrient gaps that have a negative effect on the production of meat and milk in the livestock sector. There are currently no strategies in place for the utilisation of this forage source that is rich in soluble sugars and vitamin A. There are however limitations to the use of sweet potato forage and other crop residues, linked to the occurrence of secondary metabolites such as trypsin inhibitors that are also found in soybean.

2.6 Secondary compounds

The sweet potato contains trypsin inhibitors in the raw tuber. Protein digestion can be limited by trypsin inhibitor in the tubers. The protease inhibitors in plants and in animals are presented naturally in microorganisms, (Liener & Kakade,1969). The inhibitors play an important role by regulating and also controlling the endogenous proteases through acting as a protective agent against factors such as insect or microbial proteases (Ryan, 1989). Trypsin inhibitors (TI) were first isolated in 1945 in soybean (Liener, & Kakade,1969) and reported by Sohonnie & Bhandarker (1954) in sweet potato. Drying or cooking deactivates the trypsin inhibitors and thereby improves the nutritional value of the sweet potato as animal feed.

2.7 Sweet potato production in Africa

Most African household and smallholder farmers grow sweet potato varieties with white, cream or yellow flesh, all of which are low in provitamin A. Orange-fleshed sweet potato (OFSP) is rich in β-carotene which is converted to vitamin A by the human body. This variety is in fact one of the best sources of naturally bio-available β-carotene (Van Jaarsveld *et al*., 2005). Carey *et al*., (1999) compared different varieties of sweet potato ranging from white- to deep orange-fleshed, and showed that just a small quantity (70-100 g) of OFSP is needed to meet the daily provitamin A requirements of adults as compared to 9 kg of the white-fleshed variety.

Resisto is one of the very dark orange-fleshed sweet potatoes with 9980 µg/100g β-carotene when cooked (Van Jaarsveld *et al*., 2005). Laurie (2010) found that the cream-fleshed varieties, Blesbok (40.2 t/ha), Ndou (35.6 t/ha) and Monate (35.0 t/ha) had higher marketable yield than the orange-fleshed varieties. A total of 22 ARC lines, 2 land races, 4 local cultivars and 8 imported varieties were developed through the breeding program of the Agricultural Research Council (ARC) (Laurie & Van den Berg, 2002)

Laurie (2001) reported that in terms of the β-carotene content of 8 varieties and selections, Mafutha (a creamy orange-fleshed local variety) contained 1870 µg/100g β-carotene. The cream-fleshed varieties had negligible trans-β-carotene content. Blesbok and Monate contained less than 50 µg/100 g, and Ndou (with a slightly darker cream color) contained 134 µg/100g (Laurie, 2010).

Cultivated in more than 100 countries, sweet potato ranks third in the world root and tuber crop production after potato and cassava (FAOstat, 2008). World production has been estimated at 110 million tonnes per annum (FAOstat, 2008). Orange-fleshed sweet potato acreage and consumption has increased, now occupying an estimated 1-2% of land in the lake zone of Tanzania, 5-10% in Central Uganda, 10-15% in western Kenya and 15-20% in southern Mozambique (Tumwegamire *et al*., 2004). Mukherjee & Ilangantileke (2002) found that orange-fleshed sweet potato was promoted for production and consumption in south and west Asia.

2.8 Utilisation of orange-fleshed varieties

Varieties with β-carotene content above the minimum level for use in the crop-based programmes (5500 µg/100g) were Resisto, Khano, 2001-5-2, W-119, Beauregard and 1999-1-7 (Laurie, 2010). Impilo, Excel and Serolane (5109-5220 µg/100g trans-β-carotene) are useful for populations with mixed dietary sources of vitamin A.

2.9 Orange-fleshed sweet potato varieties

Figure 2.2 A selection of OFSP varieties (Photos: Dr SM Laurie, VOPI-ARC)

2.10 Sweet potato nutrients and chemistry

Woolfe (1992) described sweet potato tubers as an excellent energy source, with a good yield of carbohydrates per unit area. Carbohydrates make up approximately 80% of DM, comprising mainly starch (Figure 2.3) and sugars, with less pectins, hemicelluloses and cellulose (Woolfe, 1992; Bovell-Benjamin, 2007). Sweet potato contains low levels of glycemic which results in low digestibility of starch despite high levels of carbohydrates (ILSI, 2008). This is important in ruminants because high degradability in the rumen results in acidosis conditions. Starch is degraded to volatile fatty acids (VFA), primarily propionate, which are then converted to glucose as the energy source for cattle. There are two main types of bacteria in the rumen, structured and non-structured. Sweet potato supplies more energy, phosphorus, potassium and Vitamin B than other β-carotene rich vegetables (Kruger *et al*., 1998).

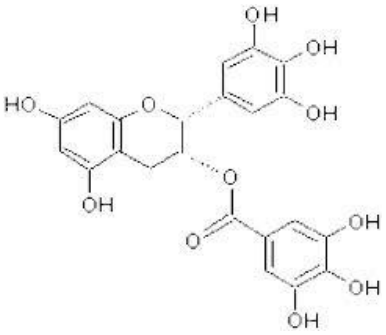

Figure 2.3 Structure of starch in SP (chemical) (Jeong, & Youl Kim, 2008).

2.11 Uses for human food

Within the commercial industry in South Africa, 1,000-1,500 tons of sweet potato are dehydrated per annum and the powder is used in instant soups and infant products. The residual flour of 650 processed tons is frozen (Laurie, 2004).

Beta-carotene rich sweet potato has also been added to products such as beef patties (Saleh & Ahmed, 1998) and noodles (Collins & Pangloli, 1997).

2.12 Sweet potato research with cattle and other animals

About 30% of the sweet potato production in developing countries is used for animal feed (An, L.V., 2004). Karachi & Dzowela (1988) reported that SP vines could be used as an alternative dry season supplementary feed for calves. Goats fed fresh SP had higher milk yields, milk protein, milk fat and total solids compared to goats fed *Sorghum vulgare* and chopped clitoria (*Clitoria ternate*) (Khalid *et al*., 2013). The intake of sugar cane was reduced by only 9% when SP forage was substituted. Rabbits on a diet of 50% sweet potato leaves (SPL) with a commercial rabbit concentrate had a

higher final body weight, total weight gain and daily weight gain, with variations of 25%, 75% and 100% depending on the ratio of SP leaves to the standard rabbit pellets. Abonyi *et al*. (2012) recommend a ratio of 50% SP leaves to 50% pelletised concentrate feed for weaned rabbits. Dominguez (1992) found that including fresh sweet potato vines with 10% of DM to a diet of cooked sweet potato roots and soya bean meal influenced the digestibility of nutrients in growing pigs. Farmers in China and the Philippines preferred to boil the sweet potato roots first and use it as a pig feed in order to improve the digestibility (Scott, 1992).

Oyenuga & Fetuga (1975) found that cooking sweet potato did not affect the utilisation of energy, but it did increase the digestibility of the nutrients. Wethli & Paris (1995) evaluated SP leaves as a feed to replace dried alfalfa in poultry feed, but the chickens grew approximately 20% slower than those fed the commercial control diet and showed 15% lower feed conversion compared to other treatments. Feeding Ross broiler chickens a finisher ration diet supplemented with 100g/kg DM dried SPL can be considered the optimum level of supplementation (Tamir & Tsega 2010). In a feeding trial with growing calves, Backer *et al*. (1980) found no differences in live weight gain between treatments with 100%, 75%, 50%, 25% and 0% tubers to SP forage supplemented with urea.

Orodho, & Wanambacha, (1993) found that when feeding growing calves less milk, *ad hoc* SP vines could partially replace the milk because the chemical composition, moisture content and digestibility of the vines are similar to those of milk. For dairy cows, Copeland (1947) found that dried sweet potatoes were 91% as valuable as corn for milk production, but that the butter from sweet potato-fed cows had low levels of vitamin A compared with corn fed cows. Briggs *et al*. (1947) found that with steers the digestibility of the nitrogen-free extract of sweet potatoes was higher than that of cottonseed. Kariuki *et al*. (1998) stated that feeding dairy cows a 100% ratio SP vines is not ideal for calving, and suggested a ratio of 50% vines to 50% Napier grass.

2.13 Harvesting and processing sweet potato

Various methods are used in rural and commercial farming to harvest sweet potatoes. The tubers can be ploughed up with a tractor and plough and then picked up by hand or mechanical picker. The leaves of sweet potatoes can be preserved by means of ensiling (Nguyen Thi Tinh *et al*., 2006; Lebot, 2009). The green and healthy parts of the leaves and vines can be chopped into 0.5 cm long pieces and laid in the sun to reduce the moisture content by 45%. The partly dried leaves can be mixed with 10% sweet potato root meal and 0.5% salt. The mixture can be placed in impermeable plastic bags and heavily pressed to remove most of the air from the mixture before carefully sealing the bags (Nguyen Thi Tinh *et al*., 2006).

2.14 Spoilage and health hazards

In hot climates, harvested sweet potato root tested in feed samples revealed the presence of ipomeanol, a mycotoxin found in mouldy sweet potatoes.

Tubers that are stored for long periods of time are more prone to mycotoxins, and at harvesting contamination by fungi and toxins can happen. *Fusarium sp., Penicillium sp.* and *Aspergillus sp.* are fungi that have been found in dried sweet potatoes in Camaroon (Ngoko *et al*., 2008). Sweet potato tubers that have mould can be infected by *Ceratocystis fimbriata* which produces a potent toxic alkaloid called ipomeamarone (Heuzé *et al*., 2012). Cattle that are sensitive to ipomeamarone can suffer from dyspnea, experiencing rapid breathing after one day of ingesting contaminated sweet potato tuber and being at risk of dying from asphyxia within a few days (Wilson, 1973). Woolfe (1992) stated that mice subjected to ipomoeamarone suffered severe kidney damages. Cattle feeding on sweet potatoes can develop severe dental decay caused by pH problems (MSU, 2010). The tubers also contain ipomoein which has laxative properties (Duke, 1983).

Sweet potatoes that are sprouting or sunburned can contain levels of glycoalkaloid toxins. The concentration of these toxins increases when the sprouts or peelings are exposed to light in warm, moist conditions. It is recommended that long sprouts be removed before feeding. Wilson *et al*. (1971) found that mouldy tubers can be toxic and lead to lung oedema in laboratory animals and cattle.

2.15 Potential as non-conventional feed

The foregoing overview of sweet potato forage research shows that there is great scope for exploring the utilisation of this forage in rations for milking cattle. There is a huge amount of crop residue that could be preserved and utilised in dairy cattle feeding to minimize feed costs and boost the vitamin A status of cattle. Poor post-harvest management impedes full utilisation. Management of trypsin inhibitors also needs to be considered as there may be complications due to protein binding. The up-scaling of orange-fleshed sweet potato production in rural Sub-Saharan Africa offers greater opportunities to harness the residues for livestock feeding and increasing vitamin A provision to humans via milk production.

2.16 Summary

The foregoing analyses indicate that forages play a critical role in the nutrition of ruminants. Cattle production systems such as dairy that require high investment in quality feeds for the production of milk should be prioritised for introducing the feeding of sweet potato tubers, vines and leaves while remaining cognisant of the possible negative effects as highlighted in the above discussion.

Organic compounds such as trypsin inhibitors may also serve a positive role in reducing protein loss during digestion. Since processing methods tend to deactivate inhibitors, the risk of nutrient loss to complexes is lowered. There is an opportunity to utilise abundant crop residues through sweet potato forage in communal systems where cattle suffer nutrient deficiency cycles.

In Sub-Saharan African countries, animals are primarily maintained on low quality forages as these are the only resources available. Further exploration of bio-fortified sweet potato residues as alternative forage for meat and milk animals should be considered.

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CHAPTER 3

Nutrient profiles and rumen degradation of leaves, vines, roots and flour of bio-fortified orange-fleshed sweet potato (*Ipomea batatas*)

Abstract

The low grade roots and forage greens of beta (β)-carotene-fortified orange-fleshed sweet potato (*Ipomea batatas*) are essential for improving the provision of energy and vitamin A. The roots are rich in fermentable carbohydrates and hence diets of waste roots, vines and leaves and leguminous forage would increase the supply of nutrients for cell metabolism. The aim of the study was to determine the nutrient value of the fresh dried tubers and forages and the effects of supplementing heat processed sweet potato (SP) forage on *In Sacco* degradation of Lucerne, a premium forage for dairy cattle. Mature sweet potato tubers were washed, sliced and dried in a conventional oven at 70º C and 80ºC for 7 days hours, and were milled to produce SP flour. The vines & leaves (V&L) were sun dried over 14 days and milled. Samples of Lucerne hay (3 g) were weighed into nylon bags (53 µm and 5 cm*3 cm) and inserted into larger nylon bags (53 µm and 10 cm*6 cm) containing either 5 g of SP flours, leaves or V&L to determine the influence of SP components on rumen disappearance of Lucerne. Drying altered the chemical composition of the SP tubers. Dry matter of fresh roots was 25%. Roots dried at 80ºC (SP 80) were high in neutral detergent fibre (NDF) 32% DM and at 70ºC (SP70) 23%, crude protein (CP) was 4.2% DM and 4.3% DM, with negligible indigestible protein. Dried V&L were richer in CP (11% CP DM however with 4% ADICP) and higher NDF, with relatively high OMD (b = 95%) and c (0.01%) compared to Lucerne. Organic matter degradability (OMD) of Lucerne incubated proximal to SP 70 was low, 54% at 30 hours compared to 64% when Lucerne was incubated with dried V&L and 58% when incubated alone. Incubating SP forages with Lucerne seemed to reduce degradability, pointing to possible interference with degradation of organic matter. The soluble carbohydrates in SP flours were rapidly fermented and fermented completely before 8 hours. Heat processed tubers would therefore be suitable for supplementing diets that are low in energy while vines would be useful as protein supplements. Vitamin A in sweet potato is lost rapidly at harvesting and therefore the forage should be fed fresh or external sources should be supplemented. Intake and digestion of diets of Lucerne and SP forage should be investigated and optimum supplementation levels determined.

3.1 Introduction

In view of the critical need to continuously improve sustainability of dairy cattle production systems, alternative forage feeds are increasingly playing a critical role in optimising production costs. Crop residues are a crucial component of ruminant production systems, and as new varieties of planted crops are developed, assessment of these materials as potential forage is inevitable. Sweet potato is among the priority research crops for Sub-Saharan Africa as it is a common crop with high production yields of both tubers and vines. It is commonly used for human consumption and the foliage as feed for livestock. The tubers have a high carbohydrate content while the leaves are rich in protein and both tubers and vines can be used as animal feed (Woolfe, 1992). The Vegetable and Ornamental Plant Institute (VOPI) of the Agricultural Research Council (ARC) in South Africa, among other international initiatives, is engaged in bio-fortification and multiplication of vegetative stock for propagation on smallholder farms to combat vitamin A deficiency and energy-related malnutrition. There is opportunity to utilise sweet potato greens and waste roots as livestock feed to increase vitamin A status in cattle and to improve the health and reproduction of ruminant livestock, especially milking animals. Energy balance and vitamin A are important in immune support and play a significant role in providing immunologic protection against viral, bacterial and protozoan infections in animals.

Lu *et al*., (2014) and Machpesh (2013) reported that even on commercial farms most cattle herds have sub-optimal vitamin A levels and this curtails metabolic functioning. Sweet potato supplies energy to rumen microbes but also contains protein inhibitors. Heating and drying processes have been shown to deactivate trypsin, but also reduce available protein. Adding SP forages to diets of moderate to high protein forage such as Lucerne may optimise rumen degradation processes by providing energy and possibly reducing protein loss to ammonia in the rumen. However, there is the possibility of inhibition of fermentation of other dietary components.

Study aim

The aim of the study was to determine the nutrient profiles and rumen metabolism of fresh and dried leaves, vines, roots and flour of a new bio-fortified orange-fleshed sweet potato variety grown on smallholder farms in South Africa.

Objectives

1. To determine the nutrient profiles of mature fresh and dried leaves and vines, forage grade roots, and heat processed root flours of a new bio-fortified orange-fleshed sweet potato variety.

2. To assess rumen degradation of sun dried and heat processed flour flours, orange-fleshed sweet potato forage components and standard grass and legume forage.

3. To determine the effects of incubating heat processed orange-fleshed sweet potato forage components on rumen disappearance of Lucerne hay.

3.2 Materials and methods

3.2.1 Study site

The experiment was conducted at the Animal Production Institute, Agricultural Research Council (ARC-API) Dairy Nutrition Section in Irene, south east Pretoria, GPS coordinates latitude 25º 53' 63" S and longitude 28º 10 90" E, altitude 1480 m. The estimated temperature range for Irene is 6.5°C to 25°C, the relative humidity is 79% and the average rainfall is 823 mm per annum.

3.2.2 Preparation of orange-fleshed sweet potato (OFSP) forage

The OFSP crop variety Bophelo was harvested at 120 days maturity from the Vegetable and Ornamental Plant Institute (VOPI) of the ARC unit in Roodeplaat, Pretoria. At harvesting, vines were separated from underground roots using sharp machetes and the greens were packed in aerated bags. Roots were dug mechanically and hand graded. Low grade roots and roots with undesirable physical characteristics were classified as ungraded and collected for the experiment. The roots were washed by hand after removing all spoilt material. A portion of the forages (leaves and vines) and the tubers were separately selected for immediate drying in a forced draft conventional oven at the Animal Production Institute (API) in Irene, Pretoria.

The cleaned roots were sliced to a thickness of 2 cm using sharp machetes and dried in a large conventional oven at 70°C (SP 70) and 80°C (SP 80) for 72 hours, representing two heat treatment levels for tubers. Zhang & Corke, (2001) recommended 80^{o}C to deactivate trypsin inhibitors in tubers. The adaptation to lower drying temperature was effected to minimise damage to organic compounds. Semi-dried material was placed on a clean concrete surface under shade for complete drying over 5 days. The dehydrated roots were milled in a hammer mill to pass through a 5 mm screen and then bagged. The leaves of OFSP were dried at API, Irene for 7-10 days on a clean concrete surface.

The leaves were turned daily for optimal drying and prevention of mould. The dried leaves (L) were collected and milled through a 5 mm screen and added to the vine and leaf (V&L) meal and used in feeding experiment and *in Sacco* trials within three months.

Sub-samples of all fresh material were collected, dried at 60 °C in a conventional oven for 5 days and preserved for dry matter and chemical analyses.

3.2.3 Chemical analysis

Dry matter of the feeds was determined according the Method AOAC (2002), AOAC Official Method Number 934.01; weighing 1 g samples into crucibles and drying them in the oven at 105ºC overnight. After drying, the crucibles were placed in a desiccator to cool at room temperature and then weighed. Ash content was determined according to AOAC International (2002), AOAC Official Method Number 942.05. Approximately 1 g of dried feed sample was weighed into a crucible and placed in the muffle furnace at 550ºC for 8 hours.

Neutral detergent fibre (NDF) was determined as described by Robertson & Van Soest (1981). Samples of approximately 1 g were weighed into F57 ANKOM filter bags and NDF solution was prepared. Samples were added as the solution started to boil and were boiled for 1 hour. After boiling, the samples were rinsed in boiling water 3 times, after which they were placed in acetone for 3 minutes and then air dried for 40 minutes. The samples were dried overnight at 105°C, cooled down in a desiccator for 30 minutes and weighed at room temperature.

The NDF residue was used to determine acid detergent fibre (ADF) as described by Robertson & Van Soest (1981). The samples were boiled in an ADF solution for 1 hour. After boiling, the samples were rinsed 3 times with boiling water for 3 minutes. The samples were covered with acetone for 3-5 minutes, then placed on a clean surface for 40 minutes to air dry before being dried in a forced air oven at 105°C overnight.

Acid detergent lignin (ADL) was determined by using the ADF residue as described Robertson & Van Soest (1981). A solution of 830 g distilled water and 2440 g sulphuric acid were mixed. Samples were placed in the solution for 3 hours. After boiling, the samples were rinsed 3 times with boiling water for 3 minutes. The samples were covered with acetone for 3-5 minutes then placed on a clean surface for 40 minutes to air dry before being dried in a forced-air oven at 105°C overnight.

Crude protein (CP) was determined according to the Kjeldahl Method AOAC International (2000), AOAC Official Method Number 954.01. NDF insoluble nitrogen and ADF insoluble nitrogen were determined by conducting a nitrogen analysis on the residue remaining after the NDF and ADF extractions were done. Ether Extract (EE) was determined according to AOAC International (2002), Official Method 920.37: Fat (Crude) or Ether Extract in Animal Feed. Vitamin A content was determined as described by Manz & Philipp (1981). The phosphorus content was determined

according to AOAC (1984). Calcium was determined as described by Giron (1973). Non-polar extracts (NPE), Hemi-cellulose and cellulose were determined according to Robertson & Van Soest (1981). Gross energy content of the feed was determined with the MC-1000 Modular Bomb Calorimeter. Magnesium, Sodium, Iron, Zinc and Copper were determined by the ARC, Analytical Laboratory in Irene.

3.2.4 *In Sacco* degradability

The *in sacco* technique was used to assess degradation of SP forage materials SP 70 flour, SP 80 flour, SP leaves (L) and SP vines and leaves (V&L). Clean Nylon and ANKOM bags were dried in a conventional oven at 60°C for 1 hour, cooled in a desiccator to room temperature (25°C), weighed and labelled. Samples of Lucerne hay (3 g) were weighed into nylon bag (53 µm and 5 cm*3 cm) and placed inside a larger nylon bag (53 µm and 10 cm*6 m) containing 5 g of the dried and milled SP flour and forage materials. A marble was place in the bag with the ingredients so that the Lucerne bag could submerge in contents of the outside bag.

Samples were incubated for 2, 4, 6, 18 and 30 hours in triplicate. After incubation, the bags were removed and placed in a bucket of cold water to stop all aerobic bacteria and enzyme activity. Thereafter the inner bags were removed and all the outside and inner bags were hand washed under running tap water until the water from the bags ran clear. The bags were dried in a 100°C oven for 12 hours after the samples had been washed. The samples were then placed in the desiccator to cool to room temperature (25°C) and were weighed to estimate the disappearance of organic matter (ODM). The ODM was measured as the loss of weight of the bag contents.

The fresh tubers were grated with skin and weighed at 10 g per bag before each set of incubation to maintain freshness. The incubation method and removal process as well as the estimation of ODM were done as with the other samples.

Estimation of potential degradability (b) and rates of degrade was done in Statistical Analysis Systems (SAS, 2010) using the Orskov & McDonald (1979)

$P= a + b\ (1-e^{ct})$

Where: P = proportion degraded at time "t"

a = rapidly degraded fraction

b = insoluble fraction but potentially degraded

c = rate of degradation of "b"

Effective degradability (ED; %) was calculated from the aforementioned parameters (a, b and c) assuming a fractional passage rate (kp) of 8%/h, using the McDonald (1981) model:

$$ED = a + b\left(c \Big/ (c + kp)\right)$$

3.3 Statistics

Data from chemical analyses were subjected to analysis of variance (ANOVA) for a one factor (Forage component/type) complete randomised design (CRD) in Minitab Statistical Software (Version 17, 2010). Mean differences were tested using Fishers LSD and significant differences declared at $P<0.05$. The Statistical Analysis System (SAS, 2010 Version 9.3) PROC NLIN and PROC Plot were used in generating degradability plots and ANOVA on fermentation kinetics data. All data was normally distributed and with equal variances.

The linear model used:

$$Y_i = \mu + \alpha_i + e_i$$

Where

Y_i= parameter considered

μ = overall mean

α_i = effect of the i^{the} diet/ingredient

e_i = error associated with each Y (residual random effect)

3.4 Results

3.4.1 Forage composition

Chemical profiles of SP flours are shown in Table 3.1. There were no variations in organic matter (OM) content. Crude protein (CP) was low (approximately 4%), as was fat (1%), which is typical of SP forage and roots. Content of NDF was 30% higher in SP 80 than in SP 70 and a similar pattern was reflected in ADF and lignin concentrations, although differences were not significant. Non-polar extracts (NPE) were inverse to fibre fractions. There was no difference in the calcium, phosphorous and vitamin A content of the SP flours. The energy density of fresh and dried root flours was high (4 Mcal/kg DM), qualifying SP roots as tropical energy feed.

3.4.2 Chemical composition of leaves

The nutrient profiles of sun dried SP leaves and fresh leaves are shown in Table 3.2. There were differences in the DM content as well as OM of the dried SP Leaves and fresh SP leaves. The content of ash was very high in dried forage (about 20%). The fibre fractions were higher in sun dried SP leaves compared to the fresh forage as expected. Both dried and fresh material were high in ash with relatively lower OM content. . The content of crude protein bound to ADF was elevated by drying the forage greens. Drying also resulted in lower content of the soluble components (NPE) and an increase in the proportion of ADF.

Table 3.1 Chemical composition of sweet potato flour derived from tubers dried at 70ºC and 80ºC

Sweet potato forages						
Parameters	**Unit**	**Fresh root**	**SP 70**	**SP 80**	**Pooled StDev**	**P Value**
		Mean	**Mean***			
Dry matter (DM)	% DM	28.9	92.1	93.4	0.12	0.555
Organic matter		96.2	94.1	94.3	0.23	0.481
Gross energy	Mcal/kg	4.1	3.7	3.6	-	-
Ash	% DM	3.8	5.9	5.7	0.23	0.481
Crude protein		5.8	4.3	4.5	0.34	0.655
Ether extracts		1.2	1.0	1.1	0.04	0.169
Neutral detergent fibre		12.2	23.4^{b}	32.3^{a}	2.25	0.023
Acid detergent fibre		4.8	6.8	8.6	0.91	0.121
Acid detergent lignin		0.8	1.5	2.6	0.54	0.110
NDFICP		trace	1.1	0.4	0.17	0.071
ADFICP		trace	0.08	0.06	0.05	0.789
Calcium	(g/kg DM)	1.3	0.2	0.2	0.01	0.423
Phosphorous	(g /kg DM)	1.6	0.2	0.2	0.00	-
Non-polar extracts (NPE)	% DM	87.8	79.6^{a}	67.7^{b}	4.20	0.026
Hemi-cellulose (WS)		3.4	15.1^{b}	23.7^{a}	2.26	0.010
Cellulose (AS)		4	4.4	5.8	0.99	0.149
Vitamin A	mg/100g	2.6	0.05	0.05	-	-

Mean* = Statistical comparisons applied to SP 70 and SP 80 only, SP=Sweet Potato, StDev=Standard deviation, NDFICP=Neutral detergent fibre insoluble crude protein, ADFICP=Acid detergent fibre insoluble crude protein, ^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.005.

Table 3. 2 Chemical composition of sun dried and fresh SP leaves

Feed ingredients					
Parameters	**Units**	**Fresh SP leaves Mean**	**Dried SP leaves Mean**	**Pooled StDev**	**P Value**
Dry matter (DM)	% DM	16.4[b]	88.6[a]	1.19	0.001
Organic matter		87.1[a]	80.7[b]	1.50	0.050
Ash		12.9[b]	19.3[a]	1.50	0.050
Neutral detergent fibre		12.6[b]	31.9[a]	0.40	0.001
Acid detergent fibre		8.5[b]	13.8[a]	1.44	0.011
Acid detergent lignin		1.7[b]	4.0[a]	0.28	0.003
Non-polar extracts (NPE)		87.4[a]	68.1[b]	0.40	0.001
Hemi-cellulose (WS)		4.1[b]	18.1[a]	1.20	0.001
Cellulose (AS)		6.5	8.0	0.78	0.081
Crude protein		6.5[b]	24.9[a]	1.33	0.001
Ether extracts		1.2[a]	1.3[a]	0.02	0.001
NDFICP		0.1[b]	1.2[a]	0.03	0.001
ADFICP		0.08[b]	1.3[a]	0.01	0.001
Calcium		0.39[b]	1.4a	0.04	0.023
Phosphorous		0.58	0.3	0.11	0.078
Magnesium		-	7.4	-	-
Sodium		-	1.4	-	-
Iron	mg/kg	110	2100.0	-	-
Zinc		3.1	31.9	-	-
Copper		0.04	14.7	-	-
Energy	Mcal/kg	1.6[b]	3.4[a]	0.19	0.001
Vitamin A	mg/100g	103(ug RE)*	0.09	-	-

SP=Sweet Potato, NDF-N=Neutral detergent fibre-nitrogen, ADF-N=Acid detergent fibre-nitrogen, StDev=Standard deviation, [a,b,c] Means in the same row with different superscripts are significantly different at P<0.005. [*] Wenhold *et al*., (2012),

3.4.3 Chemical composition of vines and leaves

The chemical profiles of fresh SP vines and leaves (V&L) and sun dried SP V&L are shown in Table 3.3. There were differences in the DM content of the two fresh forages. Levels of OM and ash content did not vary between the forage components. The fibre fractions between the two forages did vary. Higher levels in the sun dried leaves were evident at 49% compared to 13% DM in fresh materials, creating inverse relationship soluble components. The CP was very high in fresh

V&L but declined 30% with drying and CP bound to fibre increased sharply with sun drying, alluding to loss of protein structure. There were no changes in the ash concentration which remained over 10%. Minerals were concentrated by drying, particularly sodium.

Table 3.3 Chemical composition of fresh and sun dried vines and leaves

SP forage					
Parameters	**Units**	**Fresh V&L Mean**	**Dry V&L Mean**	**Pooled StDev**	**P Value**
Dry Matter (DM)	% DM	12.8[b]	96.5[a]	0.54	0.001
Organic Matter		87.0	86.6	0.14	0.053
Ash		13.0	13.4	0.14	0.053
Neutral detergent fibre		13.4[b]	49.1[a]	3.40	0.001
Acid detergent fibre		9.6	13.4	2.21	0.105
Acid detergent lignin		trace	10.2	-	-
Non polar extracts (NPE)		86.6[a]	50.9[b]	3.40	0.001
Hemi-cellulose (WS)		3.8[b]	35.7[a]	1.85	0.001
Cellulose (AS)		9.4[b]	21.9[a]	1.23	0.001
Crude Protein		19.2[a]	11.4[b]	0.12	0.001
Ether extracts		1.9	1.8	0.05	0.084
NDFICP		2.6[b]	4.6[a]	0.4827	0.050
ADFICP		1.4[b]	4.4[a]	0.065	0.001
Calcium		0.3	1.5	0.533	0.253
Phosphorous		0.06	2.4	0.115	0.801
Magnesium		0.1	6.0	0.015	0.14
Sodium		0.02[b]	2.8[a]	2.59	0.001
Iron	mg/kg	3150[a]	244.49[b]	162.9	0.003
Zinc		40.9[a]	22.5[b]	1.47	0.001
Copper		14.4	17.4	0.94	0.19
Energy	Mcal/kg	0.5[b]	3.6[a]	0.04	0.001
Vitamin A	mg/100g	trace	trace	-	-

SP=Sweet Potato, NDFICP=Neutral detergent fibre insoluble crude protein, ADF-N=Acid detergent fibre insoluble crude protein, StDev=Standard deviation, [a,b,c]Means in the same row with different superscripts are significantly different at P<0.005.

3.4.4 Rumen degradation of root flours and Lucerne

In Sacco degradability and fermentation kinetics of Lucerne incubated with heat dried SP flour is shown Table 3.4 (Appendix Table 6.1) and illustrated in Figure 3.1. Within 2 hours of incubation, approximately 37% of Lucerne hay (Luc) had been degraded. Although Lucerne incubated without flour degraded more at each time interval, there were no differences between the 3 treatments. Within 18 hours, 51% OM Luc (SP 80) degraded compared to Luc (SP 70) with 47% OM degradability. Differences were only noted at 6 hours when Luc (Luc) had 50% compared with 45% for Luc (SP 70).

Table 3.4 Effective degradability and Fermentation Kinetics of Lucerne incubated i*n Sacco* proximal to heat processed SP flour

Parameters	**Luc (Luc)**	**Luc (SP 70)**	**Luc (SP 80)**	**Pooled**	**P Value**
		Mean		**StDev**	
a	39.3	29.6	32.2	11.91	0.641
b	70.3	64.1	52.9	13.92	0.375
c	0.04	0.04	0.04	0.066	0.190
ED	71.0[a]	50.4[b]	73.3[a]	6.365	0.023

Luc (Luc)=Lucerne only, Luc (SP 70)=Lucerne in SP flour 70, Luc (SP 80)= Lucerne in SP flour 80, StDev=Standard deviation, ED=Effective degradability, a = rapidly degraded fraction, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", [a,b,c] Means in the same row with different superscripts are significantly different at P<0.005.

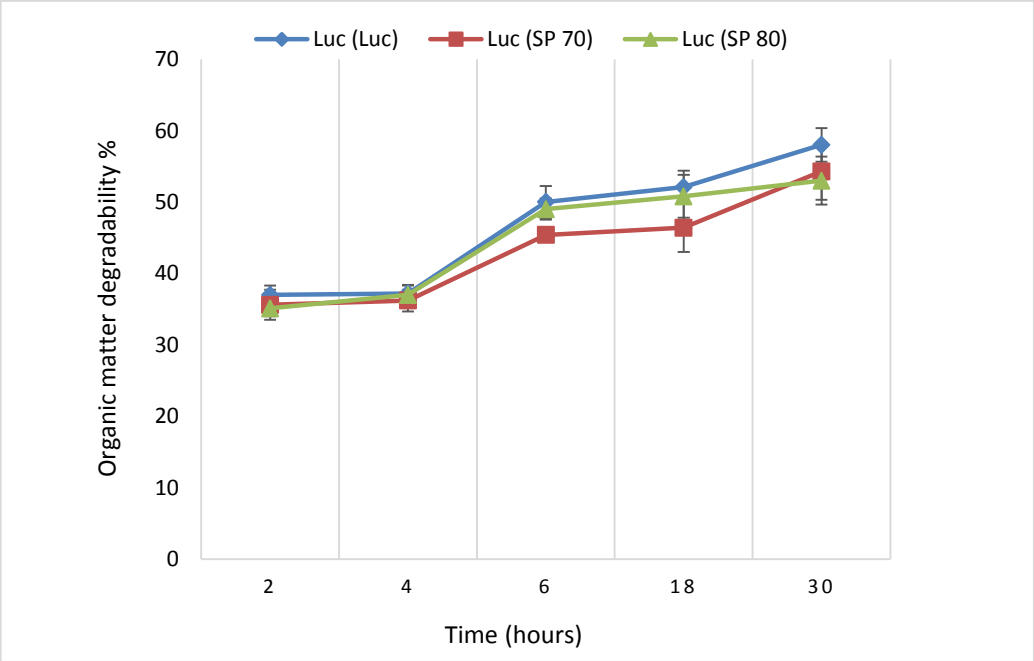

Figure 3.1 Organic matter degradability of Lucerne incubated proximal to sweet potato flours

3.4.5 Rumen degradation of sweet potato leaves and vines with Lucerne

Organic matter degradability and fermentation kinetics of Lucerne incubated proximal to SP forages and Eragrostis is shown in Table 3.5 (Appendix Table 6.2) and illustrated in Figure 3.2. Within 2 hours, 37% of organic matter was degraded. Differences in degradability occurred from 6 hours. Pure Lucerne (Luc (Luc)) had the highest levels of OMD at each level except at 30 hours when the Luc (SP V&L) had the highest OMD (64%). There was no difference between Luc (SPL) and pure Lucerne (Luc (Luc)). Lucerne incubated inside Eragrostis (Luc (Erg)) had consistently the least OMD. Organic matter degradability of Luc (SP L) was lower (57%) and Luc (SP V&L) higher (64%) at 30 hours.

Table 3.5 Effective degradability and fermentation kinetics of Lucerne incubated *in Sacco* proximal to sun dried SP forage

Parameters	Luc (SP L)	Luc (SP V&L)	Luc (Luc)	Luc (Erg)	Pooled StDev	P Value
	Mean					
a	69.3	39.6	39.3	43.4	13.02	0.329
b	94	78.4	70.3	49.9	14.7	0.098
c	0.022^{b}	0.045^{a}	0.03^{b}	0.019^{b}	0.057	0.002
ED	86.6^{a}	80.7^{a}	71.0^{a}	54.8^{b}	7.78	0.049

Luc (SP L)=Lucerne in SP leaves, Luc (SP V&L)=Lucerne in SP vines & leaves, Luc (Erg)=Lucerne in Eragrostis, StDev=Standard deviation, ED=Effective degradability, a = rapidly degraded fraction, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", ^{a,b,c}Means in the same row with different superscripts are significantly different at P<0.005.

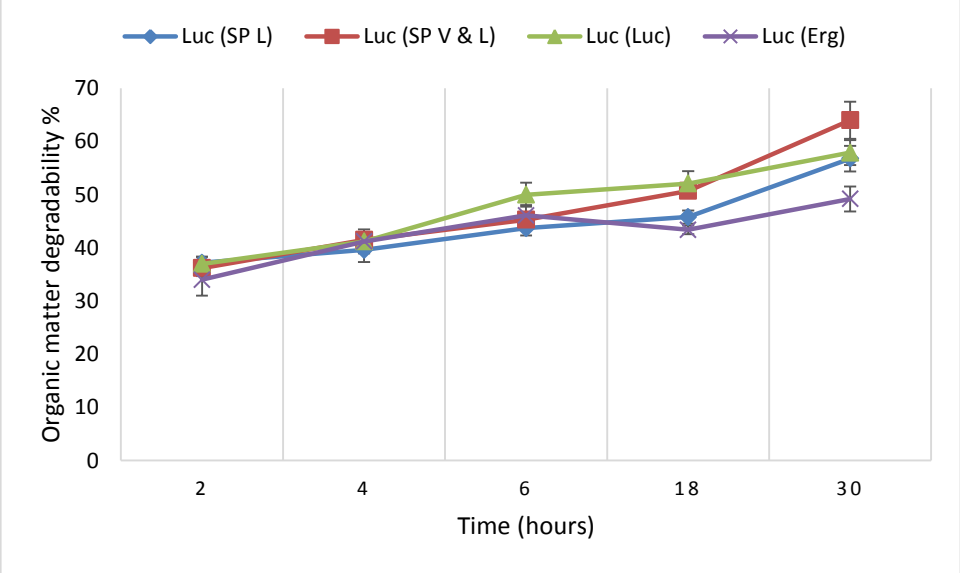

Figure 3.2 Organic matter degradability of sun dried sweet potato forages

3.4.6 Degradation of heat dried sweet potato flours and fresh tubers

The organic matter degradability and fermentation kinetics of heat processed SP flours and fresh tubers is shown in Table 3.7 (Appendix Table 6.3) and illustrated in Figure 3.3. Within 4 hours, 88 % of the SP 70 flour degraded compared to 79% OM degradability for SP 80. The degradability of the tubers was much lower compared to that of the flours. The tubers degraded more slowly up to 6

hours, but all components were completely degraded by 18 hours. There was no significant difference in a, b or c and effective degradability of fermentation kinetics of the flours.

Table 3.6 Fermentation kinetics and effective degradability of heat processed SP flours

Parameters	SP Flour 70	SP Flour 80	Pooled StDev	P Value
	Mean			
a	40.0	47.3	5.223	0.163
b	99.1	98.9	0.318	0.418
c	0.18	0.25	0.495	0.162
ED	99.8	99.6	9.76	0.157

SP=Sweet potato, StDev= Standard deviation, a = rapidly degraded fraction, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", ED=Effective degradability

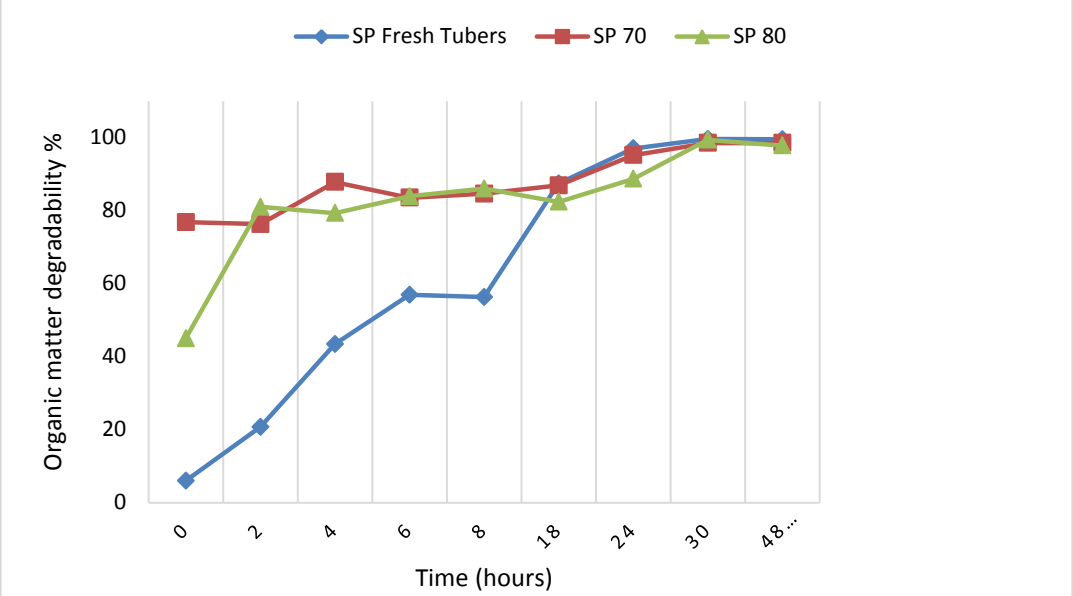

Figure 3.3 Organic matter degradability of heat processed sweet potato meal and fresh tubers

3.4.7 Degradability of SP forages compared to standard dairy forages in South Africa

In sacco organic matter degradability and fermentation kinetics of sun dried SP forages and the comparable common forages such as Eragrostis and Lucerne hay are shown in Table 3.8 (Appendix Table 6.4) and illustrated in Figure 3.4. Lucerne degraded faster than SP leaves, although at 18 and 30 hours the degradability of SP leaves was higher at 75% and 97% respectively (Figure xxxx). Between all the forages, Eragrostis showed the lowest degradability levels. There was no significant difference between the degradability levels of Lucerne and SP V&L at 4 and 30 hours of

incubation. Overall, OMD was highest with SP leaves, which was completely degraded by 30 hours followed by SP V&L and then Lucerne at 68%. Potential degradation (b), the rate (c) and ED of Eragrostis was low (P<0.01) relative to Lucerne and the SP forages. Although fermentation was high in Lucerne, ED, b, c and a of SP forage superceded (P<0.01) that of Lucerne forage (Table 3.7)

Table 3.7 Organic matter effective degradability and fermentation kinetics of sweet potato forages and standard forage (Lucerne and Eragrostis hay)

Parameters	Eragrostis	Lucerne	SP Leaves	SP V&L	Pooled StDev	P Value
	Mean					
a	25.0^{d}	49.2^{c}	84.9^{ab}	94.9^{a}	14.98	0.006
b	30.6^{c}	70.4^{b}	94.7^{a}	91.4^{a}	11.61	0.001
c	0.03	0.08	0.10	0.01	0.032	0.052
ED	32.6^{c}	85.7^{ab}	85.3^{ab}	91.6^{a}	6.58	0.000

SP=Sweet potato, SP V&L=Sweet potato vines & leaves, StDev=Standard deviation, a = rapidly degraded fraction, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", ED=Effective degradability, ^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.005.

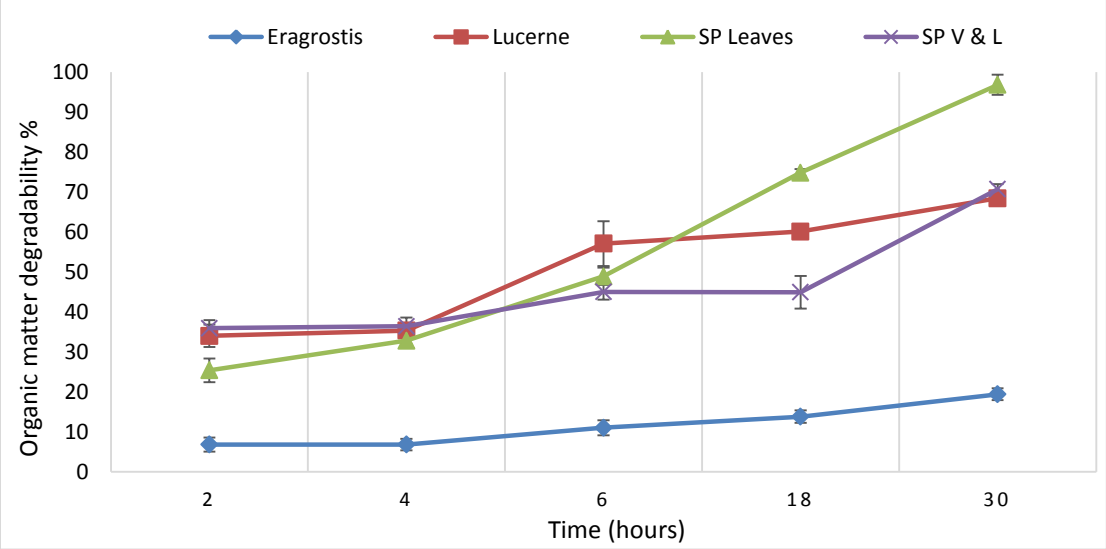

Figure 3.4 Organic matter degradability of sun dried sweet potato forage meal and standard forages

3.5 Discussion

3.5.1 Forage fibres and nutrients

Drying influenced the nutrient composition of SP flours and forage. Heat processing had little effect on protein fractions. Sun drying the vines and leaves however seemed to impact the protein quality of the fibre components. Lignin was relatively low and therefore could not have affected degradability as the feeds fermented even better than Lucerne, a prime forage with high CP and moderate levels of NDF. Sweet potato vines and leaves may therefore be a potential feed source to supply soluble components and highly degradable fibre when fed in conjunction with Eragrostis and other mature forages. Dominguez (1992) also found high levels of fibre content in dried SP forages. Sweet potato forage when fed whole would meet the minimum protein requirement in large ruminants (7.5%) but, unlike legume forages, it does not contain notable quantities of anti-nutritional factors. The high levels of non-fibre carbohydrates in SP flours contribute to the high energy density of the flours. However, heating tends to reduce and also change the nature of the storage proteins, possibly affecting their breakdown process.

Lucerne is a prime forage for lactating dairy, and SP leaves and vines could supply soluble nutrients equally as well as Lucerne. This is a very important advantage in light of the fact that, as the alternative forage is poor quality Eragrostis which slows down the breakdown of essential nutrients and can lead to malnourishment. Digestibility of dried forage was reduced by the high amount of fibre. With the low fibre content of the fresh SP forages the fermentation rate was higher compared to the dried SP forages with their higher fibre fractions. While drying and heat processing are recommended for deactivating SP protease inhibitors, negative interactions were still evident when Lucerne was incubated in close proximity to SP forages. Negative interactions of organic compounds in the new OFSP varieties may either exacerbate protein and energy deficiency of ruminants consuming low quality forage diets or be a cheaper biological strategy for increasing bypass protein and minimizing ruminal ammonia nitrogen losses.

3.5.2 Vitamin A

Vitamin A content was not detected in the SP vines and leaves. We can conclude that vitamin A breaks down rapidly after harvesting and during heat processing. Walter & Purcell 1986 found that heating the tubers reduced the amino acid content in the roots, an indicator that heating impacts other organic components. Flour made from sun dried roots under non-controlled drying conditions also resulted in insufficient provitamin A content (van Hal, 2000). Dehydrating tubers affects the internal cell structure which leads to higher losses of micronutrients such as provitamin A (Bechoff, 2010). To achieve a higher provitamin A content in the flour, improved techniques of drying are required. Loss of carotenoid from drying was reported by Bechoff (2010).

3.5.3 Rumen fermentation of sweet potato root flour

The fresh tubers did not degrade as much as the dried material during the 10 hours of incubation but they were also completely degraded which indicates that changes in carbohydrate structures are instigated by heating. The flours degraded rapidly indicating that they could be useful as an immediate remedy for animals with critical energy deficits and could be used as a substitute for glucose treatment. Rapid degradation in the rumen is cause for concern due to issues of acidosis, bloat, displaced abomasum and ketosis. Fermented sugars rapidly reduce rumen pH levels resulting in deficiency disorders such as laminitis. When there is no matching level of protein, the sugars are wasted. Heating the tubers to 70ºC is sufficient to preserving the integrity of the starch matrix and protein fractions. Excessive heating to 80ºC did not seem to provide any additional advantage in terms of fermentation, as all sugars were fermented.

Lin (1989) reported that heating at 100ºC for 15 minutes completely inactivated the original trypsin inhibitors in sweet potato root flour samples. Medium levels of trypsin inhibitors were found in the tubers (Bradbury et al., 1992) and these were still sufficient to decrease the protein digestibility in the diets (Dominguez, 1992). Zhang et al., 2001 reported that moist heat treatment at above 80°C was effective in deactivating trypsin inhibitor activity in the sweet potato.

3.6 Conclusion and recommendations

Sun dried sweet potato can be used as protein rich feed for dairy cows. Heat processing and sun drying the vines and leaves are important for preserving nutrients but tend to drastically reduce levels of essential micronutrients such vitamin A and macro-minerals. The SP leaves and vines and SP tubers have high nutrient profiles and all sweet potato forage components could be useful as a supplement to expensive forage such as Lucerne or to completely replace Eragrostis hay which tends to be overpriced in winter even though its nutrient levels are lower. Sweet potato forage is

available in winter and drying prolongs the period of utilisation. There are however valid concerns with regard to the effects of trypsin inhibitors. As noted in this study, sweet potato did tend to affect the digestion of Lucerne.

Further research is required to clearly define the interaction of major OFSP secondary compounds with nutrients of other dietary components in the rumen and post ruminally. Low cost processing methods that preserve vitamin A should also be evaluated, and studies on the effects of fresh forage and dried material on milk production in early lactation are needed. Crop residues of the bio-fortified OFSP contain essential nutrients of energy, protein and vitamin A that can be harnessed through appropriate post-harvest technology.

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CHAPTER 4

Intake, rumen degradability of sweet potato forage, energy balance and milk production in lactating Holsteins

Abstract

In view of the critical need to continuously assess nutrient requirements of dairy cattle and seek alternative forage feeds that optimize nutrient supply at relatively low cost, forage from new varieties of orange-fleshed sweet potatoes (OFSP) were evaluated. The aim of this study was to determine the effect of supplementing the dried flour and forages of the OFSP cultivar Bophelo to lactating dairy cows on dry matter intake, rumen degradability, metabolic energy and protein supply, beta-carotene, glucose levels and milk yield. The sweet potato (SP) flour was prepared by drying sliced tubers at 70ºC and milling. Vines and leaves (V&L) were sun dried and milled. Four diets were formulated using the total mixed ration (TMR) as (1) base diet + Eragrostis + Lucerne hay (control); (2) TMR + 15 kg fresh SP V&L + Eragrostis (defined as SP Fresh); (3) TMR + 20 kg fresh SP V&L + Eragrostis (defined as SP* Fresh) and (4) TMR + 0.5 kg SP flour + 0.5 kg dried SP V&L + Eragrostis (defined as SP Flour). Dry matter intake for the diets was similar except for the control diet. The control diet had a slightly higher neutral detergent fibre (NDF) intake level at 4% of body weight (BW) compared with the other diets at 3%. Dry matter degradability of OFSP forage components at 24 hours was 99% for SP* Fresh, 72% for SP Fresh and control, and 77% for SP Flour. All fresh SP V&L and SP Flour were selected within the first hour of feeding, an indicator of high palatability. No differences were shown in the beta-carotene levels of the various diets. Circulating glucose 1 hour post feeding showed higher levels in the diet supplemented with dried SP flour and dried SP V&L. Fasting glucose was similar in all treatments except for SP Flour. The cows supplemented with the dried flour and dried vines and leaves had the lowest milk yield, but this was related to milk level before treatments were imposed; there were no changes in milk production levels across diets.

4.1 Introduction

Sweet potato is the most common crop in Sub-Saharan countries, with high yield, palatability and crude protein content for supporting human nutrition. Sweet potato forage greens and low grade tubers are also essential as livestock feed. The roots of sweet potato are underutilised in South Africa, especially as animal feed. The vines are occasionally sun dried and fed to pigs and poultry but little is known about their nutritional value. Both sweet potato tubers and vines have high biomass yields. The high demand for animal products is a strain on conventional feed sources and leads to increases in stock feed costs. The utilisation of multiple forages and grain crops is therefore important for sustaining profitability in livestock businesses (Khalid *et al*., 2013). Since sweet potatoes are already grown in rural communities, it is prudent to optimise crop residues for nutritional support, particularly for the most vulnerable groups of milking cows. With inadequate nutritional supply in African countries, the major concerns are limiting livestock production.

The cultivation of orange-fleshed sweet potato (OFSP) is increasing in South African rural communities because the crop is rich in carbohydrate and vitamin A precursor (beta (β)-carotene). Plant material does not contain vitamin A but precursors, carotenes and carotenoids are present. Sunlight and air with high temperatures destroy the carotene content in the plant material. Vitamin A provides immunologic protection against viral, bacterial and protozoa factors. Orange-fleshed sweet potato has high levels of β-carotene which is a forerunner of Vitamin A (Woolfe, 1992) which can help alleviate post calving and negative energy levels in dairy cows. Heuzé *et al*., (2012) stated that in fresh forage and tubers, the energy was 18 (MJ/kg DM) and 17 (MJ/kg DM), fat was 5% DM and 1% DM, and NDF was 43% DM and 11% DM respectively. Trypsin inhibitors are mainly present in tubers and forage material. The composition however changes rapidly as harvested material spoils rapidly. Moulding and drying reduces the feed value.

Peters (2008) showed that in Rwanda, OFSP was instrumental in improving the milk production of dairy cows by approximately 1.5 L of milk per day. There were however no effects on milk yield and composition of vitamin A. The value of forage greens, sun dried materials and heat processed flour were evaluated as substitutes for proteinaceous forage and concentrate feeds in early lactation cattle. Several new bio-fortified varieties of OFSP are now being cultivated in rural South Africa and the forage value is undefined.

Study aim

The aim of the study is to determine the Intake, rumen degradability of sweet potato forages, energy balance and milk production in lactating Holsteins

Objectives

1. To determine dietary composition and dry matter intake of fresh sweet potato forages, dried vines and leaves and milled dehydrated roots supplemented to lactating dairy cows.

2. To determine rumen degradability of flours derived from dried vines and leaves and milled dehydrated roots supplemented to lactating dairy cows.

3. To determine milk production and blood glucose and β-carotene in lactating dairy cattle supplemented with sweet potato flours.

4.2 Materials and methods

4.2.1 Study site

The experiment was conducted at the Animal Production Institute, Agricultural Research Council (ARC-API) see chapter 3.

4.2.2 Preparation of orange-fleshed sweet potato forage

The orange-fleshed sweet potato (OFSP) crop variety Bophelo was harvested at 120 days maturity from the Vegetable and Ornamental Plant Institute (VOPI) of the ARC unit in Roodeplaat, north east Pretoria. At harvesting, vines were separated from underground roots using sharp machetes and the greens packed in aerated bags. Roots were dug mechanically and hand graded. Low grade roots and roots with undesirable physical characteristics were classified as ungraded and collected for the experiment. The roots were washed by hand after removing all spoilt material. A portion of the forages (vines and leaves) and the tubers were separately selected for immediate drying in a forced draft conventional oven at the Animal Production Institute (API) in Irene, Pretoria.

The cleaned roots were sliced to a thickness of 0.5 mm using sharp machetes and dried in a large conventional oven (50 kg capacity) at and 80°C for 72 hours due to the high moist content. Zhang & Corke., (2001) recommended 80^{o}C to deactivate trypsin inhibitors in tubers. Semi-dried material was placed on a clean concrete surface under shade for complete drying over 5 days. The dehydrated roots were milled in a hammer mill to pass through a 5mm screen to produce sweet potato flour (SP Flour) and then bagged. The leaves of OFSP were dried at API, Irene for 7-10 days on a clean concrete surface.

The leaves were turned daily for maximum drying and prevention of mould. The dried leaves were collected and milled through a 5 mm screen, and constituted the vine and leaf meal pending the feeding experiment and *in vitro* trials.

Sub-samples of all fresh material were collected, dried at 60ºC in a conventional oven and preserved for chemical analyses. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin in the forage was determined as described by Robertson & Van Soest (1981).

The fresh vines and leaves were placed under roofing at the trial house and watered daily to maintain moisture. Fresh forage was supplied every second day during the course of the trial.

4.2.3 Experimental animals

Multiparous early lactating Holstein dairy cows (7-90 days in milk - DIM) were used in the study. The 20 Holstein cows are resident at the ARC-API Irene and weighed between 500-600 kg. The dairy cows, including 4 with existing rumen cannula, were each randomly allocated to 4 dietary treatments in a complete randomised design (CRD). Diets were formulated to meet milk production of ± 30 L/cow/day using the Agriculture Modelling and Training System (AMTS) Dairy Cattle software (AMTS 2013).

4.2.4 Experimental design

Four supplementary feed ingredients incorporating different processed and raw components of OFSP were tested. The diets are defined in Table 4.1 with CP benched marked on the composition of the diet (Control) supplied to early lactating cows in the herd at the ARC. The control diet was low in CP and applied to a mixed herd of low and high milk producers. Table 4.2 shows the chemical composition of diets. Lucerne was harvested at bloom stage.

Table 4.1 Composition of orange-fleshed sweet potato dietary treatments

Treatment	Diet Supplement
Control	TMR & Eragrostis hay + Lucerne hay
SP Fresh	TMR & 15kg SP fresh vines & leaves + Eragrostis hay
SP* Fresh	TMR & 20kg SP fresh vines & leaves + Eragrostis hay
SP Flour	TMR & SP Flour + dried SP vines & leaves + Eragrostis hay

Components of the OFSP were fed as substitutes for Lucerne (*Medicago sativa*) hay and the total mixed ratio (TMR).

Table 4.2 Amounts (kg as fed) and chemical composition of diets

Parameters	Units	Control	SP Fresh	SP* Fresh	SP Flour
Total mixed ration		20	18	18	18
Eragrostis hay		10	10	10	10
Lucerne hay		8	-	-	8
Fresh SP V&L	**kg/cow/**	-	15	20	-
Dried SP V&L	**Day (As fed)**	-	-	-	0.5
Dries SP flour		-	-	-	0.5
Dry matter		92.2	65.7	60.4	92.1
Crude protein		13.4	13.2	12.9	13.1
Neutral detergent fibre	**%DM**	57.5	55.6	54.7	57.8
Acid detergent fibre		28.7	25.7	25.3	26.2
Non-fibre carbohydrates		44.3	45.1	45.2	37.0
% Forage NDF		87.5	87.4	87.5	90.8
Fat		4.0	4.3	4.2	3.7

DM=Dry matter, NDF=Neutral detergent fibre,, SP= sweet potato, SP V&L=sweet potato vines & leaves

4.2.5 Animal management

Twenty cows were selected and allocated to diets 7 days post parturition and housed in an animal experimental unit. Previous milk yield and body weight were used in balancing the allocations to diets. The cows were fed experimental diets for 28 days. Cows were fed individually and clean water was provided *ad libitum*. The cows were milked twice daily using an automatic machine and milk samples were collected during the last 7 days of the experiment. All animals in the study were kept according to regulated animal welfare standards and no sick animals were included in the trails. The feeding stations were cleaned with clean water on a daily basis after feeding. Samples of complete diets were collected for nutrient analyses. The cows were housed under roof at the Milk Production Unit at ARC. The trail house is divided into 2 rows of pens, with 8 pens in each row separated by a 5 m corridor to facilitate the storage of feed and hay bales. The pens had concrete flooring and uncovered surface, and with good drainage. Each pen was fitted with an *ad libitum* water trough that empties into the drain and a concrete feed trough. Rubber carpets were placed on the concrete flooring for cow comfort. The concrete was washed off every morning with clean water and the water troughs were also cleaned daily.

The ground part was cleaned with a rake and excess faeces and grass removed. The cows were milked twice a day at 06h00 and 16h00. Throughout the trail, proper milking procedures were adhered to so as to maintain udder health. The trail cows were milked first before the herd. After morning milking, the cows were fed individually at 07h00.

4.2.6 Blood collection

Blood samples were drawn from the coccygeal vein of each cow using an 18-gauge vacutainer needle and collected into a 10 ml Heparin Vacutainer (Green top). Samples were collected 3 hours after feeding at 09h00 on days 26, 27 and 28 of the trail. Blood plasma and serum were separated by centrifugation immediately after sampling at 3,000 ×g for 15 minutes at 20°C. The samples were frozen at −20°C until analysed for beta (β)-carotene. Glucose levels were tested using a Contour Glucose Meter and Contour TS test strips. Glucose was tested 1 hour before feeding and again 3 hours after feeding. The tip of the tail was pricked with a needle and pressure was applied until a drop of blood appeared which was dropped onto the tip of the glucose strip.

4.2.7 Analyses of beta-carotene

The β-carotene content of the whole blood samples was determined by using the hand-held portable spectrophotometer developed by Schweigert & Immig, (2007). The frozen plasma was left to warm up to room temperature (25ºC). Beta-carotene levels were determined using the iCheck™ procedure (BioAnalyt, GmbH, Germany). A serum sample of 0.4ml was injected into the iEx Carotene vial and the sample was shaken for 10 seconds. For the separation of the phases and the extraction of the carotenoids from the sample into the upper phase, the vial had to stand for 5 minutes. If the upper phase turns yellow, the sample contains carotenoids. The vial was inserted into the device and the carotenoids in the sample were measured.

Figure 4.1 Use of iCheck machine (Photo: Nadine Gibbins DSM Nutrition)

4.2.9 Degradation of lactating cow diets with Sweet potato flour and forage meals

The 4 diets and the sweet potato ingredients (leaves, vines, flour - fresh and dried) were assessed for *in vitro* degradability using the Daisy ANKOM system to determine fermentation kinetics of potential degradability (b) and rate of fermentation (c). The samples were weighed in at 1 g, heat sealed into ash free and nitrogen free filter bags and placed in the digestion vessels. The bag size was 57 microns and each bag was labelled with a material marker. The ANKOM Daisy apparatus contains four 4 L digestion vessels which slowly rotate in a digestion chamber at a constant temperature of 39ºC.

A solution containing distilled water, macro-mineral solution, buffer solution, tryptose, micro-mineral solution and rezasurin was prepared and warmed to approximately 39ºC in a water bath. Reducing solution containing distilled water, potassium hydroxide pellets, cysteine-HCL and sodium sulphite nonahydrate was prepared prior to rumen collection.

The solutions were prepared just before each digestion run by warming micro-mineral solutions and buffer solution in a water bath to 39ºC.

Rumen fluid were collected 2 hours after the morning feeding from each of the 4 cows fitted with rumen cannula and on dietary treatments. The rumen fluid and rumen particulate matter were processed through 2 layers of pre-warmed cheesecloth to remove any further particulate matter. Rumen fluid was then placed in a mixer and blended at low speed for 60 seconds with constant purging with CO2. The rumen fluid was then placed in a bottle with lid into a warm bath at 39ºC until used.

The samples were placed in the vessels for incubation at 39ºC for 0, 6, 18 and 30 hours respectively, each sample in triplicate. After incubation the samples were washed with tap water until the water was clear and then dried at 100ºC for 24 hours. After drying the samples were weighed and scraped out into porcelain crucibles that were labelled with a furnace-proof ink to be ashed for the purpose of estimating *in vitro* dry matter digestibility (IVDMD) and *in vitro* organic matter degradability (IVOMD).

Estimation of potential degradability (b) and rates of degradation was done in SAS using the Ørskov & McDonald (1979) method.

$P= a+b\ (1-e^{ct})$

Where: P = proportion degraded at time "t"

a = soluble fraction

b = insoluble fraction but potentially degraded

c = rate of degradation of "b"

4.2.10 Chemical analysis

Dry matter of the feeds was determined according the method AOAC (2002), AOAC Official Method Number 934.01. Samples of 1 g were weighed into crucibles and dried in the oven at 105ºC overnight. After drying the crucibles were placed in a desiccator to cool at room temperature and then weighed. Ash content was determined according to AOAC International (2002), AOAC Official Method 942.05. Approximately 1 g of dried feed sample was weighed into a crucible and placed in the muffle furnace at 550ºC for 8 hours. Crude Protein (CP) was determined according to the Kjeldahl method AOAC International (2000), AOAC Official Method Number 954.01.Neutral detergent fibre (NDF) was determined as described by Robertson & Van Soest (1981).

Approximately 1 g samples were weighed into F57 ANKOM filter bags and NDF solution, with samples added as the solution started boiling and then boiled for 1 hour. After boiling, the samples were rinsed 3 times in boiling water, then placed in acetone for 3 minutes and air dried for 40 minutes. The samples were dried overnight at 100ºC, cooled down in a desiccator for 30 minutes and weighed at room temperature.

4.3 Study limitations

The low CP content of the standard diet supplied to the mixed herd of high and low milk producers based on a commercial customized total mixed ration with low quality Lucerne and Eragrostis hay for this dairy herd was noted. The trial took place during the summer months when tick-borne diseases occur. Two cows were diagnosed with Anaplasmosis mid-trial. The cows were moved to the farm's hospital camp where they were treated with Forray, Alamycin, Kyro B + Liver and Rumis + Replensol with 20 L of water. One cow recovered well and responded to the treatment whereas the other cow died as a result of rumen stasis and high parasitic count.

Two more cows suffered from Babesiosis (Red Water). They were moved out of the trial and into the hospital camp for treatment. Although the incubation period was in the trial, the cows still consumed all the food, and milk production did not drop. The cows were treated with Alamycin, Forray, Finadyne and Kyro B + liver injectable. Rumix and Replensol were also given for energy and to keep the rumen activity going. (One cow died of the Babesiosis). A third cow got sick 3 days before sampling, contracting Mastitis in the left hind quarter. She stayed in the trial house but the trial was stopped and she received the normal feed. She was treated with Mastijet forte twice a day for 7 days. All data from sick animals was excluded. Sick cows were substituted to maintain four replicates per diet.

The cows did not like the yellowing leaves but still ate everything. The browned forage was rejected completely.

4.4 Statistics

All data was tested for normality and equality of variance. Data from the chemical analyses was subjected to analysis of variance (ANOVA) in Minitab Statistical Software (Version 17, 2010). Mean differences were tested using Fishers Least Squares Differences.

Data from the *in Sacco* feeding experiment and *in vitro* trials were analysed using analysis of variance procedures (ANOVA) in Statistical Analyses Systems (SAS Version 9.3, 2010). Body weight and initial milk were assessed as covariates and they were not significantly different.

Mean differences were tested using Fishers Least Squares Differences and significance declared at $P<0.05$. All data was normally distributed and with equal variances.

The linear model used:

$Y_i = \mu + \alpha_i + e_i$

Where

Y_i= parameter considered

μ = overall mean

α_i = effect of the i^{the} diet/ingredient

e_i = error associated with each Y (residual random effect)

4.5 Results

4.5.1 Dry matter intake

The results of the dietary intake on the 4 diets are shown in Table 4.3. Dry matter (DM), organic matter (OM), neutral detergent fibre (NDF) and acid detergent fibre (ADF) intakes on the diets compounded with OFSP forage were similar, except for the control diet which was higher in fibre. The intake of NDF in the control diet was about 61% of total feed intake and 3% of BW as compared to 53% and 2% BW in the OFSP augmented rations. The crude protein intakes were similar at 4 kg/day in rations where Lucerne was substituted by OFSP forage compared to the TMR ration at 5 kg CP DM intake/cow/day. Although DM intake was on average 8 kg less in the ration supplemented with SP flour, daily available metabolizable energy supply was 4% units higher than on the TMR diet.

Table 4.3 Intake of dry matter, crude protein and fibre by early lactating cows supplied total mixed ration and diets augmented with OFSP forage

Parameters	Control	SP Fresh	SP* Fresh	SP Flour
Dry matter intake kg/day	36.9	29.6	30.2	28.5
Organic matter intake kg/day	33.9	26.6	27.2	26.3
Crude protein intake kg/day	4.8	3.7	3.8	3.7
NDF intake kg/day	21.2	16.4	16.5	16.5
NDF intake (% BW)	3.5	2.7	2.8	2.8
Total ME avail. (Mcal/day)	64.3	65.1	66.7	68.1

NDF=Neutral detergent fibre, ME=Metabolizable energy, BW=Body weight

Table 4.4 shows the predicted supply of nutrients. All diets resulted in negative energy balance. The control was just adequate while the diet with fresh SP only was 6% short of energy requirement for early lactation. Protein was deficient in all rations, particularly the diets augmented with fresh SP V&L. The low NH3 also confirmed the protein deficiency. Calcium was adequate in the control (standard diet) and the diet supplemented with the SP flour. Phosphorus was critically low.

Table 4.4 ATMS Model estimates of nutrient balances in mature early lactating cows supplemented OFSP forage

Parameter	Control	SP Fresh	SP* Fresh	SP Flour
	% Required			
Metabolizable energy supply	99	94	97	97
Metabolizable protein supply	93	86	89	88
Ammonia Nitrogen (NH3-N) balance	113	90	90	110
Calcium	108	69	74	107
Phosphorus	74	59	59	68

SP=sweet potato

4.5.2 *In vitro* degradability of dietary forage components and sweet potato flours

The *in vitro* dry matter degradability, potential degradability (b) and the rate of degradation (c) of sun dried SP forages and standard dairy forages is shown in Table 4.5 and also (Appendix Table 6.5) and illustrated in Figure 4.2. Lucerne and SP vines and leaves (V&L) degraded significantly faster than SP leaves. The sweet potato leaves degradability levels were higher at 18 hours. At 24, 30 and 48 hours, the levels of degradability of Lucerne and SP leaves were higher than those of SP vines and leaves. Eragrostis degraded least.

Table 4.5 Potential degradability (b) and the rate of degradation (c) of sun dried SP forages and standard dairy forages

Parameters	Eragrostis	SP leaves	Lucerne	SP V&L	Pooled	P value	SP Flour	
	Mean				StDev		Mean	StDev
b	55.0	75.3	90.4	99.6	29.83	0.531	45.0	8.95
c	0.01	0.05	0.07	0.04	0.023	0.129	0.1	0.02

SP= Sweet potato, SP V&L=Sweet potato vines & leaves, StDev=Standard deviation, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", ^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.005.

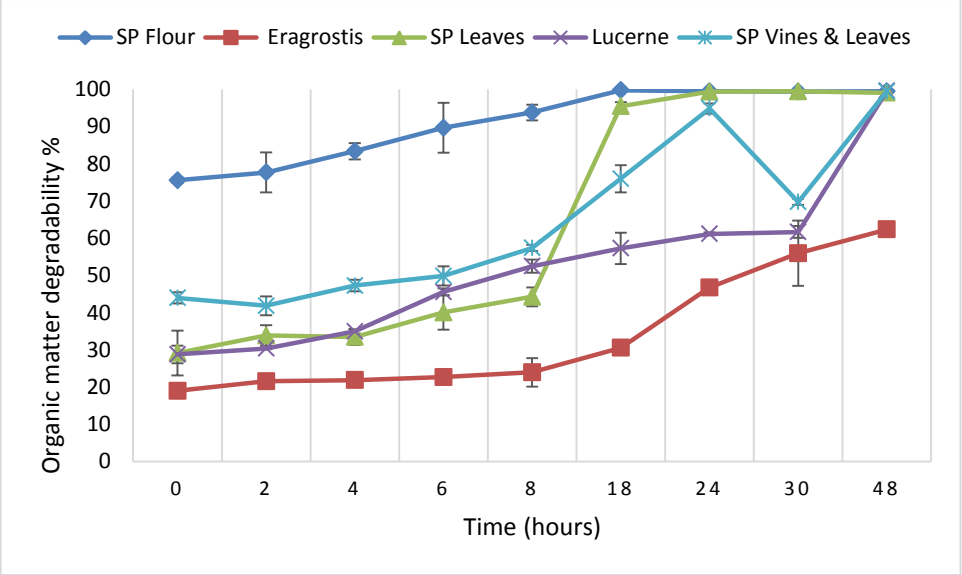

Figure 4.2 *In vitro* organic matter degradability of the SP forages and standard forages

In Sacco organic degradability of the SP* Fresh diet was highest (83% at 4 hours; P<0.001), compared to Control (63.2%), SP Flour (59.7%) and SP Fresh (38.8%). At 24 hours SP* Fresh was highest (90%; P<0.001) whilst the diet with less fresh SP forage remained lower 72%, 72% and 67% respectively.

4.5.3 Beta-carotene and glucose in the blood

The β-carotene and glucose levels in the blood of the 4 treatment cows are shown in Table 4.6. The β-carotene levels in the different treatments were not significantly different, but diets with fresh vines and leaves had much lower concentrations compared to the control and the diet with additional SP flour. Fasting metabolism showed no variation in glucose, indicating homeostatic control of this component. There were however differences in circulating glucose 1 hour post feeding, with highest levels in the diet with SP Flour. The control diet and SP Fresh had equal levels of glucose before feeding, as did diet SP* Fresh and diet SP Flour. Within the 4 hour period after feeding, the glucose levels stabilized. Pre-calving beta carotene levels were between 5.6 and 6.4 mg/L.

Table 4.6 Beta-carotene levels in the blood of the trial cow

Parameter	Units	Control	SP Fresh	SP* Fresh	SP Flour	Pooled StDev	P Value
		Mean					
β-carotene	mg/L	2.1	1.6	1.9	2.3	0.78	0.408
Glucose 06h00	mmol/L	2.4	2.4	2.7	2.7	0.41	0.447
Glucose 10h00		2.3^{bc}	2.5^{ab}	2.5^{ab}	2.8^{a}	0.19	0.002

[a,b,c] Means in the same row with different superscripts are significantly different at P<0.005, SP= sweet potato, StDev=Standard deviation

4.5.4 Milk production

The milk yields on the different diets are shown in Tables 4.7 and 4.8. Cows fed on control and SP* Fresh diet had similar milk yields. The diet SP Fresh maintained highest level of milk production similar to the pre-treatment period. Milk production did not change with changes in cow diets. Protein available for milk was low, and actual milk produced was limited by the protein supply. Energy seemed to be sufficient.

Table 4.7 Milk production within the treatments

Treatments	Pre-feeding (kg/day)	Post-feeding (kg/day)	Pooled StDev
	Mean	Mean	
Control	35.6	34.7	5.206
SP Fresh	36.8	37.7	7.249
SP* Fresh	35.6	34.9	7.300
SP Flour	28.2	29.4	3.254

SP=Sweet potato, StDev=Standard deviation P>0.05

Table 4.8 Milk yield (kg/day), energy allowable milk and protein allowable milk

Parameter	Control	SP Fresh	SP* Fresh	SP Flour	St dev	P value
	Mean					
Milk yield	34.7^{ab}	37.7^{a}	34.9^{ab}	29.4^{b}	4.2	0.035
Energy allowable milk	37.6	38.6	40.1	40.4	-	-
Protein allowable milk	33.6	32.9	34.7	33.8	-	-

[a,b,c] Means in the same row with different superscripts are significantly different at P<0.005, StDev=Standard deviation, SP= Sweet potato

Predicted energy and protein milk in AMTS, T. Tylutki (Oct. 2012)

4.6 Discussion

Lucerne's high dry matter content, protein and calcium make it a suitable forage (Heuzé *et al*., 2013) to augment sweet potato flours. Lucerne and Eragrostis have been primary sources of fibre. The hay tends to have high fibre fractions that slow down the degradation of the feed source. The recommended intake of NDF is less than 2%, especially in early lactation. The NDF fraction is slowly degradable so high intake may result in low supply of metabolic energy. Eragrostis had the least degradability and mature Lucerne is reported to have low OM digestibility and metabolisable energy (Heuzé *et al*., 2013). The diet energy concentration was therefore limited in the control diet, which is a standard formula on many dairy farms. Substituting Lucerne with SP forage resulted in lower fibre intake because SP is low in fibre content - 23% DM NDF and 7% DM ADF. The SP flour and Lucerne DMD were completely degraded as also reported by INRA, 2007.

Rapid rumen degradation of SP forage (flour, leaves and vines) is linked to the low levels of fibre fractions (NDF, ADF and lignin) and the availability of some sugars. Approximately 22% NDF is required in the diets of lactating dairy cattle. These diets were over 40% in NDF, although the SP forage supplied mostly digestible fibre. Sweet potato has a low dry matter content which may have influenced the fluidity in the rumen and passage rates of feed (laxative effect). The fact that SP flour is also degraded 100% is an added benefit in that small amounts are needed to boost energy supply for early lactation because most cows suffer metabolic imbalances such as acidocis, ketosis, metritis and retained placentas. Mixing the ingredients with high NDF degradability and those with low NDF degradability is a strategy for stabilising fibre digestion in lactating cattle. Sweet potato forages are not conventional forage and are rarely considered as a useful dietary component. These results show that producers practising mixed farming have an opportunity to harness nutrients from cheaper material that is normally recycled as compost.

With the rapid degradation of the SP flour, there is an opportunity to utilise this forage component as a replacement for expensive glucose as an energy booster in early lactation diets to avoid excessive loss of body condition. It can be used post calving to normalise and stabilise the cow's energy. The cows experience stress during the calving process and in case of a long birth, are also tired, so SP flour can be added to the milk for extra energy supplementation and colostrum ration given as an extra glucose supplement. The pregnant cows can be given a supplement of SP flour for 7 days before calving for energy build up for the birth process. Sweet potatoes are usually home grown and preserved low grade tubers would constitute a cheaper and easily available energy remedy for stressed transition cows.

The post-partum β-carotene was subclinical and required immediate intervention through supplementation with β-carotene concentrates. Parturition and early lactation nutrient demand drastically impacts vitamin A levels. Cows with blood values lower than 1.5 mg/L show a deficient β-carotene status and need a supplementation of 500 mg/L β-carotene (Schweigert & Immig 2007), or 300 mg per day when levels are between 1.5-3.5 mg/L (Machpesh, 2013). Standard dairy forages have β-carotene content ranging from 20 to 59 mg/kg for Lucerne and 9 to 18 mg/kg for Eragrostis hay (Machpesh, 2013). Fresh SP forage is rich in β-carotene but large amounts would be needed to meet daily requirements. SP is bulky and in early lactation cows are not able to eat to meet the levels required. De Ondarza & Engstrom 2009 found that supplementing with β-carotene had no effect on milk production. However, Chawla & Harjit, (2001) stated that the supplementation did increase milk production, and Arechiga *et al*., (1985) also found an increase in milk production as a result of supplementation. Cows supplemented 21 days pre-partum up to calving showed higher serum β-carotene levels (Kawashima *et al*. 2010). Plasma β-carotene levels in cattle fed on grass silage were higher than those fed on maize silage 7 days pre-partum. The levels declined at calving (2.15 mg/kg for grass silage and 0.98 mg/L for maize silage) (Calderón *et al*., 2007).

Milk production in early lactation was not affected by changes in cow diets. The high intake and high palatability of sweet potato heat processed flours and fresh forages suggest that the flours and forages have potential as animal supplementing feed sources. The cows on the SP flour diet consistently sought the SP forage and consumed it in one quick meal before moving to the concentrate and later the dry forages.

Glucose absorption directly from the gastro intestinal tract is little or nil, therefore ruminants rely primarily on gluconeogenesis to satisfy their glucose requirements (Macrae & Lobley 1986). In cases where the glucose supplied is deficient, an amount of dietary protein may be diverted to glucose production by decreasing the amount of amino acids that are normally available for protein deposition (Bareki, 2010). The SP flour is rich in soluble carbohydrates and provides readily available energy for microbial growth. An adult dairy cow in production with an average weight of 400-500 kg can consume 50-70 kg of sweet potato forages daily (Göhl, 1982). Guinea grass (*Megathyrsus maximus*) or sorghum silage can be fed to dairy cows in production supplemented with sweet potato forage (Ashiono *et al*., 2006; Etela *et al*., 2008; Etela *et al*., 2009). The supplementation with SP forages is lower in DM but higher in metabolisable energy that is utilised for milk production (Etela *et al*., 2008; Etela *et al*., 2009). However, this does not generally have a negative effect on the milk quality; the only effect is that it can contribute to lower levels of milk production. According to Lopez & Herrera., (1998);Etela *et al*., (2008); Etela *et al*., (2009) sweet potato forages do not compare with dried brewers' grains or cassava forage as a supplementation

for milk production, but they can help tremendously in saving production costs for emerging rural dairy farmers.

4.7 Conclusion

With the rapid degradation of the SP flour, there is opportunity to utilise this forage component as a replacement for expensive glucose when giving energy boosters in early lactation diets in order to avoid excessive loss of body condition. It can be used post calving to normalise and stabilise the cow's energy. The calves also experience stress during the calving process and in cases of a long birth are tired, so SP flour can be added to the milk for extra energy supplementation and colostrum ration given as an extra glucose supplement.

Animal feed costs are the largest component of total production costs and by utilizing the resources that are available to milk producers, especially smallholder farmers, production costs can be lowered by reducing feed expenses, and animal production can be improved. Additional benefits of an increase in β-carotene status have been noted. Large research scope exists to enhance the harnessing crop residues bio-fortified OFSP produced by rural smallholder farmers in South Africa. There is greater need for research in reducing nutrient losses to Maillard products during processing, assessing gut losses in transfer of β-carotene to milk, determining the laxative effects of diets high in fresh sweet potato forage and assessing the effects of such diets on water intake.

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CHAPTER 5

General conclusion and recommendations

Fresh and dried forage meals were readily degraded and therefore suitable forage for dairy cattle during early lactation. Drying at lower temperature preserved nutrients, although content of beta carotene was not determined post drying. Highly degradable forage supplies energy and minimizes utilisation of body reserves. There are no previous studies on the utilisation of flour from dried tubers for supplementing both energy and β-carotene, this study therefor represents a first insight into opportunities for standardising temperatures for drying tubers and also determining levels of supplementation. The supplementation level with flours need to be increased to make a significant impact on β-carotene supply, energy supply from tubers was not limiting. The SP forage (fresh, dry and flours) provided more energy relative to standard forages currently utilized in South Africa e.g. Eragrostis and Lucerne. Although levels of β-carotene are high in fresh materials, drying renders trypsin inhibitors inactive. It is therefore to include SP in diets with other high protein forages such as Lucerne without negatively affecting rumen degradation of other feed components. Since SP is also produced under dry land conditions the forage is a critical component of diets of dairy cattle raised under smallholder conditions. The forage provides both energy and β-carotene thereby minimizing nutritional deficiencies. The transfer of β-carotene to milk still needs further research. Farmers feeding low fibre and poor quality feeds can add SP leaves to augment protein, energy (glucose) and vitamin

Future studies can be conducted on full lactation periods with a larger number of animals to evaluate the milk yields as well as the milk quality, weight gain and metabolic disorders during calving periods. Further investigations on rumen metabolism of SP forage protein and sugar fractions are essential. More investigation can also be done of the natural drying processes and the effect of provitamin A and β-carotene content with longer storages periods.

6. Appendix

Table 6.1 Degradability of Lucerne incubated i*n Sacco* with heat processed SP flour meal

Organic matter degradability					
Incubation time	**Luc (Luc)**	**Luc (SP 70)**	**Luc (SP 80)**	**Pooled StDev**	**P Value**
		Mean			
02 hours	37.0	35.6	35.1	1.56	0.385
04 hours	37.2	36.2	37.0	1.87	0.277
06 hours	50.0[a]	45.4[b]	49.0[a]	1.397	0.028
18 hours	52.1	46.4	50.8	3.067	0.174
30 hours	58.0	54.3	53.0	3.319	0.244

Luc (Luc)=Lucerne only, Luc (SP 70)=Lucerne in SP flour 70, Luc (SP 80)= Lucerne in SP flour 80, StDev=Standard deviation, [a,b,c] Means in the same row with different superscripts are significantly different at P<0.005.

Table 6.2 Degradability of Lucerne incubated *in Sacco* with sun dried SP forage

Organic matter degradability of Lucerne in SP forage						
Incubation time	**Luc (SP L)**	**Luc (SP V&L)**	**Luc (Luc)**	**Luc (Erg)**	**Pooled StDev**	**P Value**
			Mean			
02 hours	37.2	36.2	37.0	34.0	1.873	0.227
04 hours	39.6	41.5	41.2	41.2	1.756	0.541
06 hours	43.7[b]	45.3[ab]	50.0[a]	46.1[ab]	1.670	0.027
18 hours	45.8[a]	50.7[a]	52.1[a]	46.4[a]	1.285	0.001
30 hours	56.8[b]	64.0[a]	57.9[b]	49.2[c]	2.732	0.004

Luc (SP L)=Lucerne in SP leaves, Luc (SP V&L)=Lucerne in SP vines & leaves, Luc (Erg)=Lucerne in Eragrostis, StDev=Standard deviation, ED=Effective degradability, [a,b,c] Means in the same row with different superscripts are significantly different at P<0.005.

Table 6.3 Organic matter degradability of heat processed SP flour flours and fresh tubers

Organic matter degradability					
Incubation time	**SP Fresh Tubers**	**SP 70**	**SP 80**	**Pooled StDev**	**P value**
	Mean				
02 hours	20.7^{c}	76.3^{ab}	81.0^{a}	1.486	0.000
04 hours	43.4^{c}	87.8^{a}	79.3^{ab}	3.414	0.000
06 hours	56.9^{c}	88.0^{a}	83.9^{ab}	2.370	0.000
18 hours	97.0^{a}	89.0^{ab}	82.4^{b}	3.34	0.022
30 hours	99.6	98.5	99.4	1.12	0.484

SP=Sweet potato, StDev=Standard deviation, ^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.005.

Table 6.4 Degradability of sweet potato forages and standard forage (Lucerne and Eragrostis hay)

Organic Matter Degradability of Forages						
Incubation time	**Eragrostis**	**Lucerne**	**SP Leaves**	**SP V&L**	**Pooled StDev**	**P Value**
	Mean					
02 hours	6.8^{ac}	34.0^{a}	25.4^{b}	35.9^{a}	2.49	0.000
04 hours	6.8^{c}	35.3^{a}	32.8^{ab}	36.4^{a}	1.50	0.000
06 hours	11.0^{c}	57.1^{a}	48.9^{b}	45.0^{b}	2.91	0.000
18 hours	13.8^{d}	60.1^{b}	74.8^{a}	44.9^{c}	2.39	0.000
30 hours	19.4^{c}	68.4^{b}	96.8^{a}	70.7^{b}	1.91	0.000

SP=Sweet potato, SP V&L=Sweet potato vines & leaves, StDev=Standard deviation, a = rapidly degraded fraction, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", ED=Effective degradability, ^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.005.

Table 6.5 *In vitro* organic matter degradability and fermentation kinetics of sun dried sweet potato forages and standard dairy forages

Organic Matter Degradability								
Incubation time	**Eragrostis**	**SP leaves**	**Lucerne**	**SP V&L**	**Pooled**	**P value**	**SP Flour**	
	Mean				**StDev**		**Mean**	**StDev**
00 hours	19.0[c]	29.2[b]	28.8[b]	44.0[a]	3.142	0.001	75.6	0.71
06 hours	22.7[c]	40.1[b]	45.6[a]	49.9[a]	2.756	0.004	89.7	6.74
18 hours	30.6[c]	95.5[a]	57.3[b]	76.0[a]	2.87	0.001	99.8	0.10
30 hours	56.0[c]	99.5[a]	61.7[b]	94.0[a]	3.69	0.001	100	0.00

SP= Sweet potato, SP V&L=Sweet potato vines & leaves, StDev=Standard deviation, b = insoluble fraction but potentially degraded, c = rate of degradation of "b", [a,b,c] Means in the same row with different superscripts are significantly different at $P<0.005$.