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Effect of heat treatment on forage quality of bio-fortified orange fleshed *Ipomea batatas* crop residues and roots

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Post-harvest management of sweet potatoes (SP) crop residues preserves nutrients, deactivates inhibitor compounds and improves rumen degradation. The aim of the study was to determine effects of drying crop residues and heating roots on forage value of a bio-fortified orange fleshed sweet potato (OFSP) variety in South Africa. The crop was harvested at maturity and roots separated from crop residues. Roots were washed, sliced and divided into three portions as SP_{roots} that were frozen at -4°C for 4 weeks, SP_{70}- oven dried at 70ºC for 8 days and SP_{80} -80ºC for 7 days. Aboveground crop residue were separated into portions of vines and leaves ($SPVL_f$) and leaves and petioles only (SPL_f). A subsample of each portion was air dried for 7 days ($SPVL_d$ and SPL_d, respectively). Chemical composition and *in sacco* organic matter disappearance were determined. Crude protein (CP) was higher (P<0.05) in SPL_d (24.9% CP DM) compared to fresh material with 6.5%. Neutral detergent fibre (NDF) and insoluble CP (NDFICP) were higher after drying, non-fibre carbohydrates (NFC) declined and vitamin A declined. Effective degradability (ED) was higher than for Lucerne hay and differed between $SPVL_d$ and SPL_d 77.6% and 81.3% at kp=0.05; respectively. The SP_{roots} were low in CP, ether extracts and fibre; had higher NFC (77% DM) and gross energy (4.1 Mcal/kg DM) compared to SP_{70} and SP_{80}. The SP_{80} roots had the least NFC (P<0.01) and highest amount of fibre. Calcium, phosphorus and vitamin A were negligible post heating. Rate of degradation (c h^{-1}) and ED was highest with SP_{80} (0.22 and 91.3%; kp=0.03) and lowest with SP_{roots} (0.135 and 81.7%). Drying OFSP crop residues and heating roots affected nutrient profiles however, forage degradability improved.

Key words: Sweet potato, vines and leaves, vitamin A, rumen degradation, non-structural carbohydrates.

INTRODUCTION

Sweet potato are an important food security crop especially in rural areas (Xu et al., 2015; Mohanraj and Sivasankar, 2014; Sun et al., 2014a). Ruminant livestock scavenge on crop residues. Roots of orange-fleshed

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varieties are particularly important due to the high levels of carotenoids (up to 9980 ug/100 g and 14187 IU vitamin A) (Ellong et al., 2014; Allen et al., 2012; Laurie, 2010) and phytochemicals, mostly coumarins, flavonoids, phenolic acids (Jung et al., 2011). Starch content of fresh roots ranges between 20-64% (Senanayake et al., 2013) and sugars constitute up to 10% of dry matter (DM) (Nafeesa et al., 2012; Lewthwaite et al., 2010; Kohyama and Nishinari, 1992) hence the high energy density reported by Ellong et al. (2014). Sucrose is the main sugar, while glucose and fructose are present in lower concentration (Bonte and Picha, 2000). Sweet potatoes are also notable for the high content of minerals (K, P, Ca, Mg, Fe, Mn, and Cu) and vitamins mainly vitamin B, C and E (USDA NAL, 2015; Mohanraj and Sivasankar, 2014), however, crude protein content of roots is low (Bovell-Benjamin, 2007). Leaves and vines have high levels of proteins, polyphenols and micronutrients (Phesatcha et al., 2013; Peters, 2008). Walter and Purcell (1986) indicated that about 60% of leaf nitrogen is true protein. The polyphenols are important elements in boosting immune system function (Zhi-feng et al., 2016; Xi et al., 2015; Sun et al., 2014a, b). The feeding of fresh crop residues and roots to animals affects nutrient use efficiency as some varieties contain trypsin and amylase inhibitors (Rekha and Padmaja, 2002). Maeshima et al. (1985) indicated that sporamin, a 25-kDa storage protein, which makes up 80% of total sweet potato protein is a trypsin inhibitor and resistant to gastric digestion. Traditional preservation methods such as air-drying, baking and powdering, cooking, steaming and fermentation change plant physiochemical properties, deactivate inhibitors (Yadang et al., 2013; Ahmed et al., 2010; Kirana and Padmaja, 2003) and inactivate spoilage enzymes. Senanayake et al. (2013), Zhang and Corke (2001), and Lin (1989) confirmed that heating was effective against trypsin inhibitors; while Bradhury et al. (1992), Colonna et al. (1992) and Walter et al. (1976) noted that heat increased hydrolysed starch to maltose increasing its digestibility. Processing, however, destroy carotenes, lowers amino acid, mostly lysine bioavailability and reducing sugars (Walter and Purcell, 1986) and affects antioxidant activity. Frye et al. (1948) reported that substitution of maize by dehydrated sweet potato did not affect milk production of dairy cows hence processing is crucial. As feed costs escalate, sweet potato will play a major role as source of energy, micronutrients and antioxidants. Characterization of plant nutrient changes that occur because of post-harvest processing affect forage value. Threshold limits for most crop residues are undefined and that is detrimental to quality. This study examined compositional change in nutrients in a new bio-fortified orange-fleshed sweet potato (OFSP) and degradation potential of components post preservation. The cultivar Bophelo, assessed in this study was developed at the Agriculture Research Council South Africa; bio-fortification program aimed at combating vitamin A deficiency in South Africa. The crop residues have potential in supplementing micronutrients.

MATERIALS AND METHODS

The experiment was conducted at the Animal Production Institute, Agricultural Research Council, South Africa, latitude 25° 53' 63" S and longitude 28° 10' 90". Roots and forage vines and leaves of the orange-fleshed sweet potato variety *Bophelo* were harvested at crop maturity.

Postharvest treatment of roots: Damaged roots (not fit for the human market) were selected and cleaned using tap water and cut into 2 cm discs using a potato cutter. The SP discs were subdivided and allocated to three treatments in a complete randomized design as SP_{70}-oven drying at 70°C for 7 days; SP_{80}-oven drying at 80°C for 7 days and SP_{roots}- grated and frozen at -4°C. Oven dried samples (SP_{70} and SP_{80}) were milled through a 3 mm screen to yield SP70 and SP_{80} flour, respectively. The flour was packed and refrigerated at -4°C pending chemical analysis.

Postharvest treatment of leaves and vines: Above ground crop residues, (leaves, petioles and vines were collected immediately after harvesting. The material was separated manual into two portions of leaves and petioles only (SPL) and leaves, petioles and vines (SPVL). Each portion was further subdivided into two portions for either air-drying ($_d$) or no drying –control ($_f$). The treatments were SPL_d and $SPVL_d$ (air-drying); SPL_f and $SPVL_f$ (control). The SPL_d and $SPVL_d$ samples were air dried under shade for 10 days, turned over daily and then milled through a 3 mm screen. The milled samples were stored in moisture resistant bags at room temperature.

Chemical analysis

Fresh and dried forage and roots were assessed for dry matter (DM), ash and ether extracts (EE) according to AOAC (2002) procedures (Methods 934.01, 942.05 and 920.37, respectively). Ash corrected neutral detergent fibre (aNDF, AOAC Method 2002.04), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991). Cellulose and hemicellulose were estimated using equations of Van Soest et al. (1991). Crude protein (CP) was determined using the Kjeldahl Method (AOAC 2000, procedure 954.01). The NDF insoluble CP (NDFICP) and ADF insoluble CP were determined on ADF and aNDF residue using the Kjeldahl procedure. Non-fibre carbohydrates were calculated as NFC= [100- ((NDF - NDFCP) + %CP + %Fat + Ash)]. Vitamin A content was determined as described by Manz and Philipp (1981). Phosphorus content was determined according to AOAC (1984) and calcium as determined using procedures of Giron (1973). Gross energy was determined using the MC-1000 Modular bomb calorimeter. *In Sacco,* degradation of the dried crop residues (SPL_d, $SPVL_d$) was compared to that of Lucerne (*Medicago sativa*) hay (CP 14%; fat 2%, Ash 6%, NDF 49% and ADF 36% DM). Triplicate samples of 4.6 g DM were added into ANKOM nylon bags (53 µm and 10 cm*6 cm) and incubated in two rumen fistulated dairy cows for 0, 2, 4, 6, 18 and 30 h. The trial was repeated twice. Two triplicate sets of each sample were washed in cold water to determine solubility at 0 h. At termination, bags were washed with running water, oven dried at 100°C for 12 h and ashed at 550°C for 8 h to determine organic matter disappearance (OMD).

I*n Sacco* degradation of SP_{roots}, SP_{70} and SP_{80} was determined using the ANKOM procedure described above. About 4.6 g DM of

Table 1. Nutrient composition of fresh sweet potato roots (SP_{roots}) and roots oven-dried at 70 and 80°C (SP_{70} and SP_{80}).

Nutrient composition	SP_{roots}	SP_{70}	SP_{80}	Pooled StDev
Dry matter	28.9[b]	92.1[a]	93.4[a]	0.12
Organic matter (%DM)	96.2	94.1	94.3	0.23
Neutral detergent fiber (aNDF)	12.2[c]	23.4[b]	32.3[a]	2.25
Acid detergent fiber (ADF)	4.8[b]	6.8[a]	8.6[a]	0.91
Lignin	0.8[b]	1.5[a]	2.6[a]	0.54
Hemicellulose	3.4[c]	15.1[b]	23.7[a]	2.26
Cellulose	4.0[b]	5.4[a]	5.9[a]	0.99
Crude protein (CP)	5.8[a]	4.3[b]	4.5[b]	0.34
Ether extracts	1.2	1.0	1.1	0.04
NDF Insoluble CP	0.03[b]	1.1[a]	0.4[a]	0.17
ADF Insoluble CP	0.04	0.1	0.1	0.05
Non-fiber carbohydrates	77.0[a]	66.5[b]	56.7[c]	6.32
Calcium	1.3[a]	0.2[b]	0.2[b]	0.01
Phosphorus	1.6 [a]	0.2[b]	0.2[b]	0.01
Vitamin A (mg/100 g)	2.6[a]	0.05[b]	0.05[b]	0.01
Gross energy (Mcal/kg DM)	4.1[a]	3.7[b]	3.6[b]	0.02

a: ash corrected fibre, StDev=Standard deviation, [a, b, c] Means in the same row with different superscripts are significantly different at P<0.05.

SP_{70} and SP_{80} and 16 g (fresh weight) of SP_{roots} was weighed and added to nylon bags. The samples were incubated *In Sacco* for 0, 2, 4, 6, 18 and 30 h. Degradability coefficients were calculated in SAS (2010) using Ørskov and McDonald (1979): P= a*(1-exp (-b*(time-c). 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 values (ED %) were calculated according to Ørskov et al. (1980): ED =a+[bc/(c+kp)] with fractional rumen outflow rates (kp) of 3, 5 and 8% h^{-1}.

Statistics

Analysis of variance (ANOVA) was done using the General Linear Model procedures in SAS (SAS, 2010) to determine differences in chemical composition and *In Sacco* degradability characteristics. Means were separated using Tukey's test and significant differences declared at P<0.05.

RESULTS AND DISCUSSION

Nutrient composition of sweet potato roots

Table 1 shows chemical composition of fresh and oven-dried roots. Fresh roots (SP_{roots}) had low dry matter content, crude protein (CP) was 5.8% DM and NDFICP and ADFICP were negligible. Heat drying of roots reduced CP by 25% and increased fibre bound proteins. Increasing heating temperature from 70 to 80°C did not affect CP content. Walter and Purcell (1986) reported that drying destroyed plant proteins as heat beyond 46°C breaks hydrogen bonds causing amino acids coagulate and form enzyme resistant bonds, which reduce protein supply in animal diets. Moist heating sweet potato roots at high temperatures is effective against trypsin inhibitors (Ahmed et al., 2010; Zhang et al., 2001; Bradbury et al., 1992) however, root proteins and cellular structures are destroyed. The roots in this study were heated for several days to extrude all water and became rubbery in texture, which confirmed that cellular structures were damaged. Ether extracts were less than 1.5% DM, which is typical of root crops. Non-fibre carbohydrates (NFC) constituted a high proportion of SP_{roots}, and structural carbohydrates (SC) were low. Heat treatment, however, increased content of neutral detergent fibre (NDF) by 10 and 20% units in SP_{70} and SP_{80}, respectively. The reduction in NFC was associated with increase in cellulose and hemicellulose, which are structural carbohydrates. Available fibre (carbohydrate fraction B) was 84.3% of aNDF DM in SP_{roots} and 80% for both SP_{70} and SP_{80}. Unavailable fibre (carbohydrate fraction C) in SP_{roots} and heated roots ranged between 15 and 19.3% DM. Calcium, phosphorous ASs and vitamin A were higher in SP_{roots} and less than 1% DM in SP flours. Energy density was highest in SP_{roots} and less after heating. Observations in this study are similar to the findings of Bradbury and Holloway (1988) who noted 119% decline in starch with associated increase in maltose and dietary fibre, decline in Ca.

Nutrient composition air-dried leaves and vines

Table 2 shows the chemical composition of sweet potato crop residues (greens). Ash was high and ether extracts

Table 2. Nutrient composition of fresh and air dried orange fleshed sweet potato vines and leaves ($SPVL_f$ and $SPVL_d$) and (SPL_f, SPL_d).

Nutrient composition	Sweet potato leaves			Sweet potato leaves and vines		
	SPL_f	SPL_d	Pooled StDev	$SPVL_f$	$SPVL_d$	Pooled StDev
Dry matter	16.4[b]	88.6[a]	1.19	12.8[b]	96.5[b]	0.54
Organic matter	87.1[a]	80.7[b]	1.50	87.0	86.6	0.14
Neutral detergent fiber (aNDF)	12.6[b]	31.9[a]	0.40	13.4[b]	49.1[a]	3.40
Acid detergent fiber (ADF)	8.5[b]	13.8[a]	1.44	9.6	13.4	2.21
Lignin (%DM)	1.7[b]	4.0[a]	0.28	1.1[b]	10.2[a]	0.88
Hemicellulose	4.1[b]	18.1[a]	1.20	3.8[b]	35.7[a]	1.85
Cellulose	6.5[b]	9.8[a]	0.78	8.4[b]	3.2[a]	1.23
Crude protein (CP)	6.5[b]	24.9[a]	1.33	19.2[a]	11.4[b]	0.12
Ether extracts	1.2	1.3	0.02	1.9	1.8	0.05
NDF Insoluble CP	0.1[b]	1.2[a]	0.03	2.6[b]	4.6[a]	0.48
ADF Insoluble CP	0.1[b]	1.3[a]	0.01	1.4[b]	4.4[a]	0.07
Non-fiber carbohydrates	68.1[a]	23.8[b]	8.96	55.1[a]	28.3[b]	4.53
Calcium	0.41[b]	1.42[a]	0.042	0.33[b]	1.54[a]	0.541
Phosphorus	0.61[a]	0.32[b]	0.111	0.09[b]	2.41[a]	0.122
Vitamin A (mg/100 g)	0.08	-	-	0.11	0.09	0.003
Gross energy (Mcal/kg DM)	1.6[b]	3.4[a]	0.19	0.5[b]	3.6[a]	0.04

- Not detected; a: ash corrected fibre, StDev=Standard deviation, [a, b, c] Means in the same row with different superscripts are significantly different at $P<0.05$.

were low (less than 2% DM), similar to levels in roots. Crude protein content of SPL_f was 6.5%, which increased three-fold to 24.9% DM after drying. Levels of CP were even higher in $SPVL_f$; however, the concentration declined 30% after drying. Zhang and Corke (2001) also noted that SP greens contained more protein than the roots and Van Soest (1994) stated that leaf proteins are mostly soluble cytoplasmic and chloroplast protein and therefore of higher value than root proteins. Cell wall proteins (extensions) are low in concentration. Although drying concentrated leaf CP, amounts of NDFICP and ADFICP increased 10 fold. The increase in insoluble CP was a result of protein precipitation to indigestible Maillard products. Becker and Yu (2013), Meade et al. (2005) and Mauron (1990) noted that processing permanently denatures proteins. The preservation of leaves by air-drying may actually improve the value of SP residues as dietary source of protein for livestock. Denatured and precipitated proteins bypass rumen fermentation and are available as unaltered true protein for peptic digestion in the lower gut of ruminants. The $SPVL_d$ material was however, lower in CP and this variance requires further investigation.

Fresh materials (SPL_f and $SPVL_f$) were lower in fibre components compared to the dried samples and aNDF was less than 50% DM. Drying resulted in loss of NFC. The NDF residue consist mostly of the insoluble matrix fiber composed of cellulose, hemicellulose with variable degradability levels and lignin, which is indigestible. Sweet potato forage therefore has low impact on physical fill and physically effective fiber is lower compared to cereal crop residues and by-product feedstuffs. Sweet potato forage is therefore useful in lowering diet NDF to acceptable range of 35-45% DM in dairy cattle (NRC, 2001). Although cellulose and hemicellulose were increased by drying, these fractions are slowly degraded in the rumen and completely degraded when unlignified (Mertens, 1994). However, lignin content of $SPVL_d$ was high, which entailed that 24% DM was indigestible fiber. Lignification of structural carbohydrates lowers accessibility of microbes to primary cell walls reducing digestion (Engels, 1989). Dominguez (1992) also found high levels of fibre content in dried SP forages.

The ash content of leaves and vines was high, over 100 g/kg DM (Table 2), possibly due to residual soil as the crop is a creeper. Calcium and phosphorus of fresh forage was less than 1% DM as also noted by Senanayake et al. (2013). Leaves, vines and roots of the β carotene -fortified OFSP are high in vitamin A (Laurie, 2010), however, fresh materials in this study had low content of vitamin A and none was detected in the dried materials as also reported by van Hal (2000). Bechoff (2010) indicated that vitamin A breaks down rapidly after harvesting and is destroyed by mild heat.

In sacco degradation of heat dried SP flours

Organic matter disappearance and fermentation rates and effective degradability of SP flours, are illustrated in

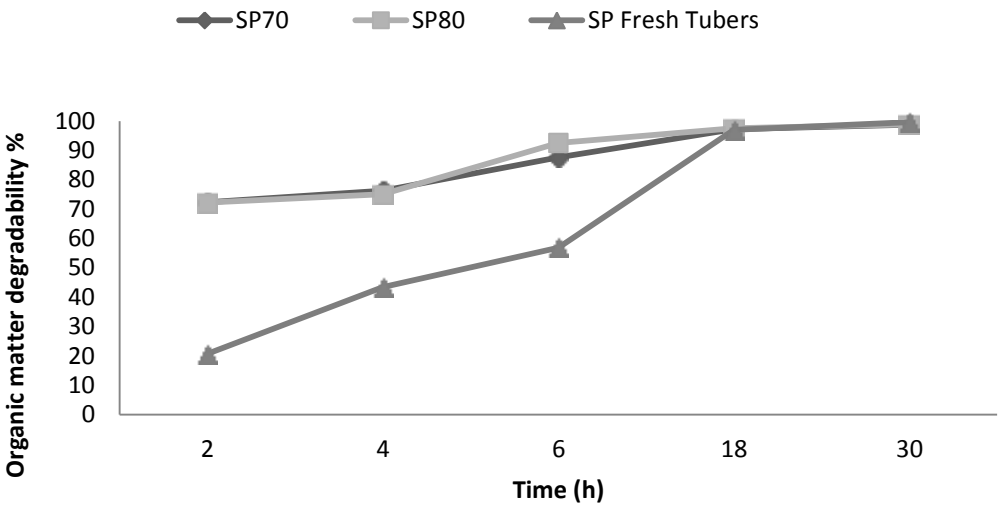

Figure 1. Organic matter disappearance of heat dried and fresh sweet potato roots.

Table 3. Degradation characteristics, effective degradability (ED) of fresh roots (SP_{roots}) and oven heated roots (SP_{70} and SP_{80}).

Parameter	SP_{roots}	SP_{70}	SP_{80}	SEM
Degradation characteristics				
a^1(%)	4.2^b	40.7^a	47.1^a	1.49
b^2 (%)	95.3^a	56.4^b	50.2^b	2.17
$a+b^3$(%)	99.5	97.0	97.3	3.29
C^4(h^{-1})	0.135^c	0.181^b	0.220^a	0.005
Effective degradability ED (%)				
kp=0.03	82.2^b	89.1^a	91.3^a	0.89
kp=0.05	73.3^b	84.8^a	88.0^a	0.94
kp =0.08	63.6^b	79.8^a	83.9^a	1.11

SEM=Standard error of the mean; 1, 2, 3, 4- constants in: P=a*(1-exp(-b*(time-c))); a-rapidly degraded fraction + b-insoluble fraction but potentially degraded; c = rate of degradation of "b"; Kp: passage rate in the rumen

^{a,b,c} Means in the same row with different superscripts are significantly different at P<0.05.

Figure 1 and Table 3. Within 4 and 6 h, 75 and 80% of OM in SP_{70} and SP_{80} had disappeared compared to 44 and 50%, respectively, in SP fresh roots. The slow rumen fermentation of fresh roots indicates the carbohydrates were less soluble or resistant to digestion compared to SP_{70} and SP_{80} carbohydrates as noted by Senanayake et al. (2013). However, all roots degraded completely by 18 h. Effective degradability was higher for the SP_{70} and SP_{80} compared to SP_{roots}, which averaged 90% (kp = 0.03). Raw starch is highly resistant to enzymatic hydrolysis, which could explain the lower rate of degradation during the first 6 h of SP_{roots} incubation. Heats breaks starch increasing digestibility of amylopectin and amylose by microbial enzymes. At 60-90°C of starch is gelatinized and is easily hydrolysed by α and β amylase. Non-fibre carbohydrates were high in the roots, compared to the content in flours. Robertson and Van Soest (1981) stated that carbohydrates are the major source of energy for rumen microbes. The growth of rumen microbes is therefore proportional to the amount of fermentable carbohydrates. Russell et al. (1992) reported that non-structural bacteria are predominant in the rumen of lactating dairy cattle that consume diets high in NFC. Aldrich et al. (1993) also reported that 36% NFC increased rumen bacterial nitrogen outflow. Sweet potato flour and roots were high in fermentable carbohydrates; comparable to barley and maize. The later cereal grains are widely utilized as dietary energy supplements for both monogastric and ruminant livestock. A large proportion of cell wall material was available fibre, which

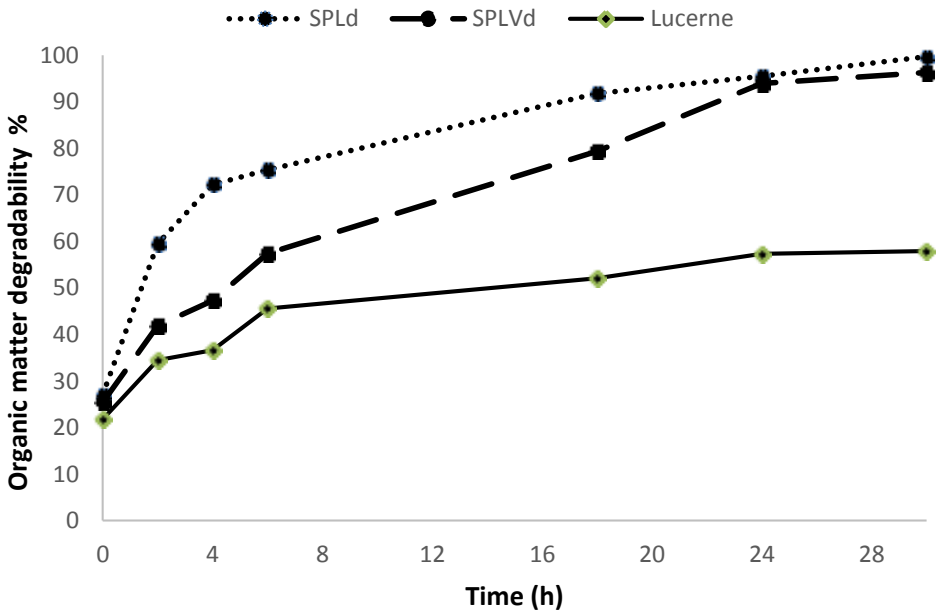

Figure 2. Organic matter disappearance of air-dried sweet potato forage and Lucerne hay.

Table 4. *In Sacco* degradation, rate and effective degradability (ED) of air-dried sweet potato forage (SPL_d and $SPVL_d$) and Lucerne hay.

Parameter	$SPVL_d$	SPL_d	Lucerne hay	SEM
Degradation characteristics				
a^1 (%)	30.7[a]	33.7[a]	21.0[b]	1.48
b^2 (%)	68.2[a]	67.4[a]	37.3[b]	2.33
$a+b^3$ (%)	98.9[a]	96.1[a]	58.3[b]	1.20
C^4(h^{-1})	0.11[a]	0.12[a]	0.04[b]	0.023
Effective degradability (%)				
kp=0.03	84.3[a]	87.6[a]	43.2[b]	0.73
kp=0.05	77.6[b]	81.3[a]	38.5[c]	0.74
kp =0.08	70.2[b]	74.1[a]	34.2[c]	0.88

SEM=Standard error of the mean; 1, 2, 3, 4- constants in: P=a*(1-exp(-b*(time-c))); a-rapidly degraded fraction + b-insoluble fraction but potentially degraded; c = rate of degradation of "b"; Kp: passage rate in the rumen. [a, b,c] Means in the same row with different superscripts are significantly different at P<0.05.

explains the rapid *in Sacco* disappearance of the roots. A greater proportion of SP carbohydrates are fermented to propionate, a precursor for glucose synthesis. The utilization of SP as substitute to cereals in diets of high performance animals would therefore optimize rumen degradation as available carbohydrates stimulate microbial growth. Lower inclusion levels would minimise lactic acid production. Lactic acid lowers rumen pH, inhibit bacteria such as *Megasphaera elsdenii* and *Selenomonads* (Russell et al., 1992; Van Soest, 1994) and promote gram-negative bacteria such as *Bacteriodes* (Bauman and Foster, 1956). The rapid degradation of heat-processed roots indicate that heating improved digestion of the carbohydrates. It is highly unlikely that the carbohydrates would bypass the rumen.

In Sacco degradation of air dried leaves and vines

Organic matter disappearance and fermentation rates and effective degradability of dried SP vines and leaves and Lucerne hay are illustrated in Figure 2 and Table 4. Early rumen organic matter disappearance of air dried SP forage was exponential (Figure 2). There were

differences (P<0.01) in OMD and ED of SPL_d and $SPVL_d$ (Table 4). Within four hrs of incubation, organic matter disappearance of SPL_d was twofold that of Lucerne hay. Effective degradability (ED) was higher than for Lucerne hay and differed between $SPVL_d$ and SPL_d 77.6% and 81.3% (kp=0.05 and 0.08); respectively. By 18 hrs, 92% of SPLd OM had disappeared. The dried leaves and vines ($SPVL_d$) also fermented rapidly but at a slower pace compared to SPL_d, however there were no differences in kinetics (a, b and c). The lower fermentation of $SPVL_d$ could be associated with the low content of CP and NFC content and higher lignin compared to SPL_d. The amino acid profile of sweet potato is equivalent to that of Lucerne. However, nutritional value of Lucerne deteriorates rapidly with maturity. Low physical fill effect of SP promotes higher forage intake animals increasing intake of protein and soluble carbohydrates. Smit (2015) observed that early lactation dairy cows preferentially consumed fresh vines and leaves relative to concentrate feed and Lucerne hay which confirms recommendations for inclusion in diets of monogastric animals (Dominiguez, 1992) and higher supplementation in ruminant diets (Kariuki et al., 1998). Copeland (1947) also noted that dried sweet potatoes could substitute corn but vitamin A in milk fat was less than that of corn fed cows.

Conclusion

This study provides insights on nutrient value of fresh sweet potato roots, root flour, and leaves and vines of a new bio-fortified variety, Bophelo, following preservation using traditional methods. Bophela is widely propagated on communal area farms and the crop residues are potential forage for ruminants. Conventional heating of roots affected both structural and non-structural nutrient fractions and rumen degradation was improved. Sweet potato forage contributes to energy, protein and micronutrient requirements with dried root flour supplying readily available carbohydrates. The dried leaves and vines contributed mostly to the slowly degradable fractions. However, vitamin A supplementation is necessary as the dry forage is deficient. As animal feed costs escalate, alternative forage such as sweet potato will increasingly play a critical role in livestock nutrition.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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