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Sweet potato (*Ipomoea batatas*) vine silage: a cost-effective supplement for milk production in smallholder dairy-farming systems of East Africa?

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Abstract

Context. Dairy production in East Africa is dominated by smallholder production systems, but is dogged by suboptimal milk production mediated by poor nutrition. Grain-based concentrates can be used to make the energy and protein deficits in rain-fed systems, but this strategy faces several hurdles. For livestock production systems to be sustainable, it is important that less human-edible food is fed to animals and sweet potato can serve both as a source of human food (tuber) and animal feed (vines). Smallholder scale-appropriate technology has been used to allow feed preservation of the perishable sweet potato vines for use throughout the year.

Aims. We assessed the efficacy of sweet potato vine silage plus wheat bran (SPVSWB) as a supplement to maintain milk production at a lower cost than that of grain-based commercial dairy concentrate (CDC).

Methods. Multiparous Holstein–Friesian cattle (n = 12) were given a basal diet of Napier grass (*Pennisetum purpureum* cv. *South Africa*), *ad libitum*, plus a fixed amount of either SPVSWB or CDC, (designed to be both iso-nitrogenous and iso-caloric) during late (LL) and early (EL) lactations.

Key results. Daily milk yield was lower for SPVSWB than for CDC groups, although comparable (not significant), in both LL (6.2 vs 7.5 L/day) and EL (14.2 vs 16.0 L/day); however, the lower cost of production for SPVSWB (23.2 vs 48.7 KES/kg DM) ensured that margins on milk income over feed (per cow per day) were greater for SPVSWB in both periods. (LL: 71 vs 14.5; and EL: 426 vs 400 KES/day). The lower intake for SPVSWB than for CDC is most probably due to high neutral detergent fibre content in the supplement and the lower milk production, owing to either, or both, of lower energy and protein intake.

Conclusions. It is suggested that some reformulation of SPVS, replacing in part or in whole the Napier grass with rejected sweet potato tubers, will decrease the neutral detergent fibre content, increase the metabolisable energy content, reducing the need for additional wheat bran and may, thereby, enhance the production response to equate with that of CDC.

Implications. It is clear that, despite SPVSWB eliciting lower milk production (LL 6.2 and EL14.2 L/day) than does CDC (LL 7.5 and EL 16.0 L/day), SPVSWB is a cost-effective, accessible alternative to grain-based supplementation in small-holder dairy-farming systems of Kenya.

Additional keywords: economic, evaluation, feed preservation, non-conventional feed, rain-fed system, tropical agriculture.

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Introduction

Dairy production is dominated by smallholder producers (farmers) and is essential to the livelihoods of more than 1 billion poor people in Africa and Asia (McDermott *et al*. 2010). The sector plays a large role in the agricultural gross domestic product (GDP) of Kenya where it contributes 14% of agricultural GDP and 3.5% of total GDP (Wambugu *et al*. 2011). The importance of the dairy sector may further increase due to increasing demand for meat and milk, a situation driven by population growth, urbanisation and increased purchasing power. This offers market opportunities in the smallholder dairy value chain (Thorpe *et al*. 2000). In Kenya, per capita annual milk consumption is predicted to double within two decades from ~110 L in 2009, to 220 L by the Year 2030 (MoLD 2010). To meet this demand, the dairy sector in Kenya will need to approximately triple the production, to 12.76 billion L, over the next two decades till 2030 (MoLD 2010). However, smallholder dairy systems are characterised by suboptimal milk production through a combination of low daily milk yields (2–8 kg/day), short lactations (6–8 months) and long inter-calving intervals (18–24 months; Mayberry *et al*. 2017). The situation is exacerbated by the dairy cows' need for a high plane of nutrition so as to perform to capacity, and the difficulties associated in securing suitable feed resources in a tropical, rain-fed production environment (Devendra and Leng 2011) Tropical (C4) grasses, frequently poorly managed and fed in conjunction with cereal crop residues, will not support and sustain effective production when fed alone (Tolera and Sundstøl 2000); thus, supplementary feeding is needed to improve dairy productivity in smallholder systems. Grain-based concentrates can supply needed energy plus protein and other essential nutrients (Tolera *et al*. 2000); however, in Kenya and other sub-Saharan countries, they are expensive and are often of substandard quality (Lukuyu *et al*. 2011). Indeed, some developing countries, including Kenya and Tanzania, have shortages of cereal grains even for human consumption (Tefera 2012), raising the ethical dilemma of feeding human-edible grains to ruminants in a resource-constrained environment (Ertl *et al*. 2015).

This creates both the opportunity and the challenge to find and use alternative feed resources that are locally available and fall outside of the conventional human-consumption food chain (Apata and Babalola 2012). By-products of cereal processing, such as maize germ and wheat bran, can provide a partial solution to the problem, but are also in high demand and, thus, their availability is often limited. Ideally, to make them truly accessible to farmers, production of supplements should be integrated into the existing smallholder production systems without substitution or competition for land and other resources. This can be achieved by growing crops with both food and feed value in these farming systems (Tolera and Sundstøl 2000). Sweet potato is one such crop that can serve both as a source of human food (tuber) and animal feed (vines: sweet potato vines; SPV) and the cost of production of vines is much lower than that of cereal crops, especially when the value of the tuber is taken into account (Apata and Babalola 2012). The potential of SPV as livestock feed has been demonstrated (Phuc 2000), having a high protein content (16–23%) and low fibre (26%). The production potential of most varieties ranges from 3 to 4 t DM/ha, and from 4.3 to 6 t DM/ha of tubers and vines respectively (Khalid *et al*. 2013). The vines of some high-yielding varieties can be harvested up to three times per year, with a yield of up to 125 t/ha of fresh biomass (~16 t DM; Lam 2016). Vines of sweet potato have been fed fresh to goats (Megersa *et al*. 2013) and sheep (Olorunnisomo 2007) with a good effect, but a significant limitation of SPV as a source of ruminant feed is that the vines are available only once or twice a year, during each harvest cycle, and are highly perishable due to their high moisture content (up to 86.7%; Lam 2016). Additionally, times of availability do not generally coincide with times of scarcity of other feeds, i.e. from August to February (Lukuyu *et al*. 2012*b*).

Ensiling is a well recognised and established method for preservation of high moisture-content feeds and there are considerable economic advantages in making high-quality feed available at times when there is a shortage of fresh feed. Therefore, ensiling of SPV would be a potential technology option of feed preservation (as silage) to be used in periods of scarcity under smallholder systems. The International Potato Center, in conjunction with the International Livestock Research Institute and the University of Nairobi, has developed a smallholder scale-appropriate method of making SPV silage (SPVS), producing batches of 350–500 kg of SPV, requiring minimal mechanisation and little capital investment (Lukuyu *et al*. 2012*a*). The technology uses a plastic silage tube with a customised drainage system for removing excess liquid from the silage tube (limiting losses through spoilage).

We hypothesised that we could maintain milk production at a lower cost by replacing commercial dairy concentrate (CDC) with a mixture of SPVS and wheat bran (SPVSWB), in a typical East African dairy system where lactating dairy cows are fed a basal diet of Napier grass (NG; *Pennisetum purpureum* cv. South Africa) *ad libitum*. Furthermore, in smallholder-farmer situations, use of grain supplements can be both practically and economically problematic due to its lack of availability, variable quality and high cost (Megersa *et al*. 2013). By contrast, SPVS is a cheap and readily available source of energy and protein for ruminant feeding for smallholder farming systems. Therefore, the objectives of the present study were (1) to assess the effect of supplementing lactating dairy cows with SPVSWB on milk production and dry-matter intake, and (2) to examine the economic impacts of SPVSWB supplementation compared with conventional CDC supplementation.

Materials and methods

Experimental animals

The experimental protocol was reviewed and approved by the Biosafety Animal Use and Ethics Committee, University of Nairobi, Kenya (Protocol No. FVM 142 BAUEC/2018/161). Multiparous Holstein–Friesian cows in mid- to late lactation ($n = 12$; age = 48–96 months; liveweight = 422 ± 9.4 kg (mean ± s.e.); parity = 2.83 ± 0.24 (mean ± s.e.)) were selected from the herd at the Kenya Agricultural and Livestock Research Organisation (KALRO) at Kakamega research station (0°17′N, 34°45′E; annual rainfall 1971 mm; elevation 1535 m asl; MoLD 2010). The experiment was conducted from September 2016 to June 2017. Animals were assigned to equal treatment groups (CDC or SPVSWB) matched for parity and milk production. Prior to selection, the animals had grazed only on unimproved pasture without supplementation, and, consequently, milk production had been low (4.2 ± 0.1 kg/day). After selection, animals were housed in individual pens (2.4 m × 4.8 m) in a zero-grazing unit at the KALRO (Kakamega) campus. They were drenched with an anthelminthic (Levamisole Hydrochloride, Norbrook Ltd, Nairobi, Kenya), washed with an acaricide (Amitraz 125 g, EC, Coopers Ltd, Nairobi, Kenya), and ear tagged as part of standard induction procedures before commencing the trial. The trial was conducted in two distinct tranches, namely, late lactation (LL), commencing ~126 days before the estimated parturition, and an early lactation (EL), commencing 14 days postpartum. Each tranche consisted of a feeding period of 70 days, including a 14-day adaption period. Cows in LL were dried off 56 days before the expected calving date. During the dry period, animals were fed on NG *ad libitum* and then put on an increased plane of nutrition of 4 kg CDC/cow.day for 28 days before they were expected to calve.

Experimental design

The experiment was conducted using a completely randomised design.

Feeds and feeding

Napier grass cultivation

The NG was established at 14-day intervals over 56 days in four plots of ~0.5 ha each, so that all grass could be harvested and fed at a similar stage of maturity throughout the trial. Land was ploughed and harrowed before the onset of the long rains (March 2016). Three-node canes were planted with a spacing of 0.5 m between canes and 1.0 m between rows at the onset of rains and fertilised with 40 kg/ha of di-ammonium phosphate fertiliser. Grass was harvested daily (after 42 days) and once a section was completely harvested, it was manually weeded, and top-dressed with 50 kg/ha of calcium ammonium nitrate (NH_4NO_3 + $CaCO_3$ ($MgCO_3$)). Once harvested, NG was chaffed in a two-roller engine-driven chaff cutter (Model # J-56 Jawala Singh & Sons, Coraya, Punjab, India), and spread to wilt for 1 day before feeding.

Sweet potato cultivation

Three dual-purpose varieties of sweet potato (*Ipomea batatas*; cv.: Kenspot 1, SPK 013 and SPK 117) were planted on an area of 0.65 ha for each plot. Similar to NG cultivation, the plots were ploughed and harrowed in March 2016, before the onset of the rains. Pre-emergence herbicide (Lumax 537.5 SE, Syngenta, Nairobi, Kenya) was sprayed 1 week before planting at a rate of 4 L/ha. Cuttings (length 0.3 m) were obtained from disease-free breeding plots at KALRO and planted with 1.0-m row-to-row distance and 0.2-m plant-to-plant distance, and plots were weeded 42 days after the crop establishment, but there were no other management practices, including fertilising, pest control or irrigation.

Ensiling sweet potato vines

Endeavouring to produce results that would be applicable (adoptable) under the conditions that are experienced by smallholders, SPV was ensiled using the technique developed by The International Potato Center (Lukuyu *et al*. 2012*a*). The process and equipment used to produce SPVS has been described in detail elsewhere (Goopy and Odongo 2017). Briefly, the SPV from the three varieties were harvested at 150 days after crop was planted, spread and left to wilt for 1 day under sunlight, then chopped separately down to 20–30 mm in length (using the same chaff cutter as used for NG). The vines from the three varieties were then weighed separately and mixed in equal portions (w/w) by hand on a tarpaulin, then mixed with 10% (w/w) fresh chopped NG and 5% (w/w) of wheat bran. The silo was constructed from 1000-gauge silage tube of 2.5-m length and 1.0 m in diameter (Asami Ltd, Nairobi, Kenya). The tube was tied at one end, then folded inside out and held in place by a custom-made, hinged drum (length 1.2 m and diameter 0.86 m). The base of the silage tube held a perforated flexible rubber tube (length 2.3 m and diameter 25.0 mm), formed into a circle by using a 40-mm-outside-diameter pipe with an attached T-piece. The mixture was manually compacted in layers of ~8 kg and molasses was diluted with water (1 : 1 v/v) and sprayed onto each layer until the silo was deemed full at ~1.8-m height. The remaining tubing tied very tightly to seal the silo and, thus, exclude the air present inside. The top of the silo was weighted using large stones to promote compaction during fermentation, later the compacting drum was removed, and the filled silo anchored. Twenty-three silos were produced for each tranche and the SPVS was deemed to be ready to feed after 30 days.

Experimental diets, feeding and data collection

All cows received a basal diet of chaffed NG, initially offered at 10% of liveweight (LW) on a fresh-weight basis, with half of the NG being offered at 0830 hours after collection of orts from the previous day, and the balance at 1530 hours, with unrestricted access to water. The treatment groups received either a supplement designed to be representative of a CDC (300 g/kg WB, 320 g/kg maize 213 germ, 200 g/kg wheat pollard, 110 g/kg cotton seed cake and 70 g/kg sunflower seed cake) at 7 kg/day), or a mixture of SPVS and wheat bran (WB) at a ratio of 2 : 1 w/w (fresh-weight basis; SPVSWB) fed at 18 kg/day. Both treatments were designed to be iso-caloric (11.0 MJ ME/kg DM) and iso-nitrogenous containing 16.0% crude protein (CP). Feed and refusals were recorded on a daily basis, subsamples were taken for the last 28 days of the (56 days) measurement periods, and the basal diet was adjusted weekly to allow for 10% refusals. Animals were milked by hand twice a day (0600 hours and 1500 hours) and the individual milk production was recorded daily. LW was recorded weekly with a digital platform weighing scale (model: PS 1500 MS, HD, Highland scales Ltd, Nairobi, Kenya). Feed and refusals were dried at 55°C for 24 h before grinding, then, ground material was sieved through a 1-mm-screen with a hammer mill (model: MF 10 basic Microfine grinder IKA, Staufen, Baden-Württemberg, Germany) and stored in air-tight bottles at –4°C. All samples were analysed according to standard analytical procedures.

True DM was determined by drying samples at 105°C for 3 days, ash was determined by combustion in a muffle furnace at 600°C for 2 h. Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined with a fibre analyser, and total N content was determined by micro Kjeldahl, with selenium tablets being used as a catalyst (AFIA 2014).

Energy-requirement and -intake calculations

Energy balances for each period were calculated by estimating energy requirements for each animal on the basis of mean LW, change in mean LW and mean daily milk yield in each period. Metabolisable energy (ME) contents of the experimental diets (NG, SPVSWB, CDC) were calculated in MJ/kg of DM by using equations appropriate to the feed type from the laboratory methods manual of the Australian Feed Industry Association (AFIA 2014), as follows;

$$\%\,\mathrm{DMD}\,(\mathrm{DM\ digestibility}) = 83.58 - 0.824 \times \mathrm{ADF} + 2.626 \times \mathrm{N}$$

$$\%\,\mathrm{DOMD}\,(\mathrm{dry\ organic-matter\ digestibility}) = 2.11 + 0.961 \times \mathrm{DMD}.$$

$$\mathrm{NG} = 0.203 \times \mathrm{DMD}\,(\%) - 3.001$$

$$\mathrm{SPVS} = 0.16 \times \mathrm{DOMD}\,(\%)$$

$$\mathrm{CDC\ and\ WB} = 0.858 + 0.138 \times \mathrm{DOMD}\,(\%) + 0.272 \times \mathrm{EE}\,(\%)$$

where ME is metabolisable energy (MJ/kg DM), EE is the ether extract (g/kg DM) determined by Method number 1.14R (AFIA 2014).

Metabolisable energy (ME) content of SPVSWB was determined arithmetically from the ME content of the constituent feeds (SPVS and WB).

Metabolic energy expenditure was calculated using equations from Nutrient Requirements of Domestic Ruminants (CSIRO 2007), as follows:

$$\mathrm{MERTOTAL}\,(\mathrm{MJ/day}) = \mathrm{MERM} + \mathrm{MERG/L} + \mathrm{MERL}$$

where MERM is the energy requirement for maintenance, MERG/L is the energy requirement for LW change, and MERL is the energy requirement for lactation.

The energy requirement for maintaining core temperature was not considered as the daily temperature range at the experimental site was in the thermo-neutral zone for adult cattle (CSIRO 2007, #280). The energy requirement for gestation was not specifically considered, being implicitly captured in LW change.

Economic analysis

Feed cost as a function of milk production (gross margin, GM) was calculated as follows:

$$\mathrm{GM} = [(\mathrm{ML} \times \mathrm{MP}) - (\mathrm{FC})]/\mathrm{ML}$$

where GM is in Kenyan shillings, ML is milk produced (L/cow.day), MP is market milk price (calculated as the average price offered by the three largest commercial processors during the study period), and FC is the average cost of feed consumed per day during the measurement period (as calculated below). The cost of CDC was calculated as the cost of all ingredients, plus milling and transportation, divided by the total amount (kg) of concentrate produced:

$$\mathrm{C} = (\mathrm{IC} + \mathrm{MC} + \mathrm{TC})/\mathrm{TP}$$

where C is the cost of CDC in Kenyan shillings, IC is the cost of ingredients, MC is milling cost of ingredients, TC is the transport cost, and TP is the total amount of concentrate produced (kg).

The cost of SPVSWB was calculated as the cost of purchasing WB plus all the costs involved in producing SPVS, divided by the total production (kg), while the cost of SPVS was calculated as all the cost involved in vine and silage production, divided by total silage production. The cost of NG production was calculated as the cost of establishment, cultivation and harvesting, divided by the total harvested material (fodder) over the experiment. All costings and calculations are given in Table S1, available as Supplementary material to this paper.

Statistical analyses

Parity and LW pre- and post-trial were examined using Student's *t*-tests. Treatment effects on intake and daily milk yield (DMY) were analysed using R 3.0.3 (R Development Core Team, Vienna, Austria). Treatment and (lactation) period effects were compared using two-way ANOVA. Differences between means were compared by the least square-means method and the level of significance was determined at 0.05.

Economic variables were compared by examining calculated means from production data.

Statistical model

$$Y_{ij} = \mu + L_i + T_j + \mathrm{LT}_{ij} + E_{ij},$$

where Y_{ij} = milk yield, μ = overall mean, L_i = the effect of lactation stage, T_j = the treatment effect, LT_{ij} = the interaction of treatment and lactation stage, E_{ij} = the error term.

Results

There were no differences between SPVSWB and CDC treatment groups in LW ($P = 0.41$) or parity ($P = 0.18$) either at the commencement or end of the treatment periods. However, there were clear differences in DMY both between treatments and the treatment periods ($P < 0.001$; Table 1).

Daily milk yield was much lower in LL than in EL for both treatment groups and was lower for SPVSWB than for CDC in both periods but by similar amounts (1.3 vs 1.9 kg/day; Table 1). However, there was no interaction effect between treatment and the stage of lactation ($P = 0.75$). LW change for SPVSWB in EL was significantly ($P < 0.05$) different from both treatment groups in LL, while DM intake (DMI) was lower for SPVSWB than CDC in both LL and EL. As animals always consumed their allocated supplement, decreased intake indicated substitution of the NG basal diet (DM: 213.9 g/kg; CP: 79.1 g/kg DM; NDF 615.7 g/kg DM; ME: 7.4 MJ/kg DM) in favour of the supplements, resulting in an improvement of ME and CP in both treatment groups during the EL period. The SPVSWB was approximately half of the DM content of CDC, with twice as much NDF and ADF on a DM basis, although being similar, but lower (not significantly), in CP and ME content (Table 2).

Table 1. Daily milk yield (DMY kg/day), average weekly liveweight change (ΔLW), daily feed intake (as fed), DM intake (DMI), crude-protein intake (CPI) and neutral detergent-fibre intake (NDFI) of dairy cows fed *ad libitum* basal diet of Napier grass and supplemented with fixed levels of either commercial dairy concentrate (CDC) or sweet potato vine silage plus wheat bran (SPVSWB)

Means in the same row followed by the same letter are not significantly different (at P = 0.05)

Parameter	Late lactation		Early lactation		s.e.m.	*P*-value
	CDC	SPVSWB	CDC	SPVSWB		
DMY (kg/day)	7.50a	6.18b	16.04c	14.16d	0.160	<0.001
ΔLW (kg)	3.14a	3.30a	0.38ab	–1.42b	0.702	<0.001
Intake as fed (kg)	42.0ab	49.3b	39.8a	40.2a	9.78	0.004
DMI (kg)	13.53 a	11.34a	12.97a	11.07b	0.390	0.003
CPI (kg)	1.53a	1.45ab	1.48ab	1.35b	0.032	0.010
NDFI (kg)	5.97ab	6.40a	5.62ab	5.01b	0.249	0.002

Table 2. Composition (g/kg DM) of commercial dairy concentrate (CDC), sweet potato vine silage (SPVS), wheat bran (WB) and SPVS plus WB (2 : 1 w/w, SPVSWB)

CDC and SPWSWB were fed a principal supplement to lactating Friesian cows fed a basal diet of Napier grass. ADF, acid detergent fibre; CP, crude protein; ME, metabolisable energy; NDF, neutral detergent fibre. Means in the same row followed by the same letter are not significantly different (at P = 0.05)

Parameter	CDC	SPVS	WB	SPVSWB	s.e.m.	*P*-value
DM (g/kg)	868.2a	240.2c	870.0a	450.1b	0.80	<0.001
Ash (g/kg)	69.4b	112.0a	56.1b	93.4b	6.72	<0.001
CP (g/kg)	153.6a	171.0a	74.2b	137.3a	10.51	<0.001
NDF (g/kg)	227.9b	427.0a	352.0c	402.0c	13.35	<0.001
ADF (g/kg)	119.0b	294.0a	226.3b	271.4a	10.40	<0.001
ME (MJ/kg DM)	12.5a	9.7b	11.8a	11.1a	0.20	<0.001

There was no difference (P > 0.05) between the offered basal diet and refusals of either treatment in DM (P = 0.47), ash (P = 0.48) or NDF (P = 0.37); however, the trend showed lower CP (P = 0.09) and higher ADF (P = 0.10) concentrations in the refusals, suggesting that there may have been some limited selection of the basal diet (Table 3).

Calculated energy intake and expenditure for all treatment groups indicated that both groups were in significant energy surplus in late lactation and that this surplus was similar for both diets (Table 4), which is consistent with the observed weight gains for both groups during the same period (Table 1). Similarly, both CDC and SPVSWB were in a slightly negative energy balance during early lactation, mediated by reduced energy intake and, thus, greatly increased DMY (Table 4).

The cost of producing NG solely on the basis of the input prices was much lower (0.77 Kenyan shilling (KES)/kg fresh weight) than the cost of both supplements. The cost of producing CDC was approximately four times higher than the cost of producing SPVSWB (42.27 vs 10.95 KES/kg). This was, in turn, reflected in the average daily cost of feeding with CDC being higher than the cost of feeding with SPVSWB in both lactation periods (LL: 323 vs 221 KES/head.day; and EL: 321 vs 217 KES/head.day). While the higher milk production observed in the CDC group resulted in greater revenue, the situation was quite different when considering the gross margins (milk revenue/cost of feed). In both LL and EL, the margins were greater for the SPVSWB, both on a per cow basis (58 vs 14.5 and 420 vs 400 KES/day respectively) and per litre of milk produced (9.4 vs 2.0 and 29.7 vs 25 KES/L respectively).

Table 3. Composition (g/kg DM) of the Napier grass basal diet and refusals from Friesian cows supplemented with a fixed level of either commercial dairy concentrate (CDC) or sweet potato vine plus wheat bran (SPVSWB)

ADF, acid detergent fibre; CP, crude protein; NDF, neutral detergent fibre. Means in the same row followed by the same letter are not significantly different (at P = 0.05)

Parameter	As fed	Refusals CDC	Refusals SPVSWB	s.e.m.	*P*-value
DM (g/kg)	213.9a	281.6a	283.9a	13.44	0.47
Ash	105.2a	94.3a	100.8a	6.25	0.48
CP	79.1a	69.6a	70.7a	3.04	0.09
NDF	615.7a	622.3a	631.6a	7.82	0.37
ADF	414.5a	432.9a	431.7a	6.45	0.10

Discussion

Although it was not the focus of the present trial, it is worth mentioning that both treatment groups responded positively in terms of DMY to the introduction of the supplement, as compared with their pre-induction when consuming pasture alone. However, in both LL and EL

Table 4. Mean metabolisable-energy (ME) intake (MJ/day) and metabolisable-energy requirement (MJ/day) for maintenance, liveweight change (ΔLW) and lactation of dairy cows fed *ad libitum* basal diet of Napier grass plus a supplement of either commercial dairy concentrate (CDC) or sweet potato vine silage plus wheat bran (SPVSWB)

Means in the same row with different fresh weight (kg). Means in the same row followed by the same letter are not significantly different (at P = 0.05)

Item	Late lactation		Early lactation		s.e.m.	*P*-value
	CDC	SPVSWB	CDC	SPVSWB		
ME intake (MJ/day)	131.3a	123.3a	127.1a	109.8b	3.05	<0.001
ME expenditure (MJ/day)						
Maintenance	43.6	43.2	42.0	40.2		
Lactation	40.4	32.2	86.2	76.3		
ΔLW	18.2	17.7	2.9	–1.6		
Total	102.2a	94.1a	131.1b	115.4ab	4.48	0.002
ME balance (MJ/day)	29.1a	29.2a	–4.0b	–5.7b	1.43	<0.001

periods, DMY was 17% and 13% lower for the SPVSWB group than for the CDC group. The cause(s) of this lower response was not immediately clear, and the possible etiologies are considered below. Results showed that there were large differences in the quantum of response between LL and EL. Davison and Elliott (1993), in reviewing several trials, highlighted the differences in response to supplementation of animals in early, mid- and late lactation, so our results were unsurprising in this respect, but their s study also points to a significant limitation in the present work, namely, that due to resource and logistical constraints, we were not able to measure intakes and DMY during mid-lactation. If it had been possible to do so, this would have been likely to add further insights into the efficacy of feeding SPVSWB as an alternative feed to CDC. The diminished production response could be due to lower feed conversion efficiency observed in the late lactation (Wachirapakorn *et al*. 2016), but is also consistent with the animals' need to divert energy to the growing fetus and supporting organs (CSIRO 2007). Energy and protein intake are the key determinants of milk production and inadequate supply of these nutrients can lead to cows losing weight in early lactation due to mobilisation of body reserves for milk protein and fat synthesis (Sutter and Beever 2000). Such weight losses by lactating dairy cows are attributed to imbalances between nutritive value of feed and daily requirements of the animal at a given level of milk production (Etela *et al*. 2008). In the present study, animals were limit-fed in both periods (LL and EL), but SPVSWB animals consumed smaller amounts of feed on a DM basis than did CDC animals (Table 1) in both periods. The calculated energy intakes and expenditures of the groups provided further insight into this situation. In LL, the difference between the treatment groups in ME intake was equivalent to the difference in ME requirement for DMY, indicating that the decreased DMY for SPVSWB is directly attributable to the difference in ME intake between the groups. In EL, reduced DMY accounts for only 10 of the calculated 17 MJ ME, but, to this, the difference in energy expenditure due to LW change (~4 MJ), might also be added. Thus, while they were not determined experimentally, the energy-balance calculations suggest that the observed differences in DMY between the groups in both LL and EL are largely attributable to reduced ME intake.

Dry-matter intake (DMI) is fundamentally important in the nutrition of the lactating cows because it determines the amount of nutrients available for milk production and, so, it appeared in the present study that reduced DMY in the SPVSWB group is most likely attributable to a reduction in voluntary feed intake. In turn, intake may be constrained by several factors acting alone or in combination. NDF content is highly correlated with voluntary intake of forages (Allen 1996). High NDF content has been reported to reduce voluntary intake in cattle (Gwayumba *et al*. 2002) and NDF concentration is suggested to be the best single chemical predictor of DMI by ruminants (Waldo 1986). While our base feed NG itself is high in NDF, and this was held more or less constant across treatment groups, the SPVSWB contained 75% more NDF than did the CDC and, while provision of adequate NDF is important for milk yield in dairy cattle, the NDF content of both diets was well in excess of the 27% posited as producing maximum milk yield (Seymour *et al*. 2005).

In feed with a lower ME content, intake may also be correlated with limitations to gut fill and, in turn, rate of rumen clearance (Kubkomawa *et al*. 2013). The high moisture content found in silage has been implicated in the reduction of voluntary intake (Gwayumba *et al*. 2002). Moreover, DMI of NG by cattle has been shown to increase by 15% following wilting (Grant *et al*. 1974); however, other researchers (Thomas *et al*. 1961; Clancy *et al*. 1977) have disputed the relevance of moisture content in governing or limiting intake. Thus, while SPVSWB had approximately four times the moisture content of CDC, it is unclear whether the high moisture content of SPVSWB may have limited intake *per se*. Intake may also be governed by the rate of rumen clearance (Bosch and Bruining 1995) and the higher intake observed for CDC in the present study might be attributable to the faster rate of fermentation of grain than for SPVSWB; however, assessing this observation was beyond the scope of the present study.

Distinct from the energy intake, a potentially important determinant of milk production is the quantity and quality of protein (Clark and Davis 1980), which was provided through the experimental diets in the present study. Rumen protein degradability is one of the most important qualitative factors in determining the value of tropical feeds and SPV are reported to have rumen protein degradation as high as 722.1 g/kg CP (Kabi *et al*. 2005). Protein degradability also determines the supply of N to rumen microbes; however, once the amount of protein degraded in the rumen exceeds microbial needs, the balance is lost as NH_3 and ultimately as urea (Colmenero and Broderick 2006). Feeding untreated silages causes high protein degradation in the rumen (Setälä *et al*. 1984) and the relative lack of rumen undegraded protein in SPVSWB may have negatively influenced the DMY, although the beneficial effects of rumen undegraded protein (Alstrup *et al*. 2014) on milk production have not been unequivocally demonstrated (Santos *et al.* 1998).

The CP content of NG used in the present study (7.9%) was low, but comparable to 7.6% CP of the NG used by smallholder farmers in the tropics (Wouters 1987). Even so, this is less than the minimum dietary CP requirement for milk production from dairy cows (Muia *et al*. 1999), even when allowing for the limited selectivity displayed, which might have increased the CP content of the basal diet consumed to as high as 9%. The SPVS had a CP content of 17.1%, making this a suitable supplement for feeding lactating cows. Supporting this, a survey by Gunderson *et al*. (1998) indicated that dairy animals require a dietary CP content of 16.1–18.9% for optimal milk production; thus, the combination of either supplement with the basal diet of NG (~13.5% CP) was unlikely to support more than modest milk production. A further consideration was that while the low ME content of SPVS (9.7 MJ/kg DM) necessitated its combining with another feed to increase the ME content to the targeted 11 MJ/kg (Colmenero and Broderick 2006), this had the effect in the resulting supplement (SPVSWB) of having ME and CP similar to those in CDC (as intended; Table 2). Thus, it appears less likely that differences in energy or protein content contributed to the observed lower DMY in animals fed the SPVSWB supplement.

Despite the lower DMY of the SPVSWB group in both periods (LL and EL), the margins for milk revenue over feed costs were considerably greater than for CDC (7.4KES/L and 4.2KES/L for LL and EL respectively). However, it is stressed that the higher (calculated) margins do not represent a claim to profitability. There are many other elements that need to be considered when determining whether a feeding strategy is likely to be profitable such as return to capital, farm labour and opportunity costs; however, other elements were not considered here. Likewise, the price received for milk as well as the cost of producing feed will likely vary in other areas; thus, the findings here cannot be assumed to be quantitatively translated to other regions or situations.

Conclusions

Supplementation with SPVSWB can support moderate milk production at a lower cost in smallholder dairy-farming systems than does conventional grain-based supplementation, and this might also be a strategy for profitably fattening ruminants in these situations. However, there are limitations and challenges. If the energy density of SPVS can be improved, possibly by substituting unsalable sweet potato tubers for NG when making the silage, this will also reduce the need for WB. In turn, this will increase the CP content and lower the cost of silage production. These small changes have the potential to further improve the production potential of SPVS, but further investigation is needed.

Conflicts of interest

The authors declare no conflicts of interest.

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