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The potential of replacing conventional dairy supplements with forage legume-based diets in Zimbabwe's smallholder dairy sector

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The effect of replacing commercial supplements with isoenergetic and isonitrogenous velvet bean-, cowpea- and lablab-based supplements on milk yield, milk quality and economic returns in smallholder crossbred dairy cows was investigated in the 2013 and 2014 dry seasons. Using 3 × 3 Latin square designs, nine multiparous Red Dane, Guernsey and Holstein-Friesian crosses in mid-lactation (130 ± 19 d) were offered forage legume-based supplements for 63 d at 0.5 kg per litre of milk produced. Milk quantity and quality were significantly ($P < 0.05$) different among supplements in both seasons. Cows fed commercial supplements had higher milk yield than cows fed forage legume supplements. Milk fat content was significantly ($p < 0.05$) higher in cows fed lablab-based supplements than cows fed other supplements. Milk protein, total solids and lactose content of cows fed commercial supplements was significantly ($p < 0.05$) higher than those fed forage legume-based supplements, although protein content was similar to cows fed lablab-based supplements. Dietary gross margins were higher for cows fed velvet bean- and lablab-based supplements by 17% and 16.5%, respectively. Based on supplement, production costs per litre of milk was higher by 28% and 23% using commercial supplements compared to velvet bean and lablab supplements, respectively.

Keywords: forage legumes, smallholder dairy, Zimbabwe

Introduction

Several authors have projected an increase in demand for food and food products with an increase in population by 2050 (Thornton and Herrero 2010; Gerber et al. 2013; Ross et al. 2014). Smallholder farmers in Zimbabwe currently contribute only 1–2% to national milk production (Chinogaramombe et al. 2008; Manyawu et al. 2013). This leaves a huge gap where the current national annual milk demand in Zimbabwe is 120 million litres against a current annual milk production of 56 million litres (Department of Livestock Production and Development 2014). Therefore, there is scope for smallholder farmers to improve productivity to meet this demand and invariably improve rural household income and livelihoods through inclusion in local and regional value chains.

Various authors have documented the shrinkage of the dairy sector in Zimbabwe and the declining trend in milk production from 262 million litres (1990), through 187 million litres (2000) to 37 million litres (2009) owing to a number of challenges (Department of Livestock Production and Development 2011; Osman 2014). Challenges limiting dairy development in Zimbabwe's smallholder dairy sector include herd size and herd productivity decline, poor genetic quality and access, high disease prevalence, poor management

practices and lack of skilled personnel, and poor quality and high cost of feed (Ngongoni et al. 2006).

Nutrition remains one of the major constraints to smallholder dairy production. Several authors (Moran 2005; Mapiye et al. 2007; Mapekula et al. 2009; Madzimure et al. 2011) concur that lack of protein, especially during the dry season, limits smallholder dairy performance. According to Oleredi and Ajay (2005) and Chinogaramombe et al. (2008), low nutritive value of available feed resources and resultant reduced efficiency of utilisation account for the reduced dairy performance. Work by Murungweni et al. (2004) has demonstrated that forage legumes such as *Mucuna pruriens* var. *utilis* (velvet bean), *Vigna unguiculata* (cowpea) and *Lablab purpureus* (lablab) can potentially replace commercial concentrates in dairy diets.

Strategies to improve smallholder dairy productivity and market competitiveness are underpinned by increasing milk quality and quantity via efficient feed utilisation and availability at a considerably lower cost. Arriaga-Jordán et al. (2002) and García-Martínez et al. (2009) reported in Mexico that small-scale farmers have acknowledged the need for better and sustainable feeding strategies to improve the performance of their herds. Gusha et al. (2013) allude to the

fact that farm income can be optimised by utilising low-cost and more available feed resources whilst maintaining the quantity and quality of milk produced. Livestock genetic and feed manipulation to improve dairy performance can be a viable option to meet the growing milk demand.

Conventional feed meals and protein supplements, such as sunflower, groundnut and cottonseed cakes or meals, are not readily available and are generally expensive (Chinogaramombe et al. 2008). Use of these conventional protein sources by smallholder dairy farmers coupled with other dairy production constraints limits their viability. Therefore, the use of forage legumes, such as velvet bean, cowpea, lablab, and browse legumes, such as acacia (*Senegalia* and *Vachellia*), *Calliandra* and *Leucaena* tree species, which are adaptable to subhumid and semi-arid tropical regions, could present a viable alternative (Chakeredza et al. 2008; Chinogaramombe et al. 2008; Volpelli et al. 2010). Velvet bean and lablab, which have relatively high crude protein (CP) contents ranging from 16% to 19% and are low in fibre, can supplement low-quality roughages to improve productivity of ruminants (Gwanzura et al. 2012). Work by Mashanda (2014) demonstrates the use of velvet bean and cowpea forage legumes to replace commercial concentrate and reduce the production cost of milk by 20%.

The present study is based on the premise that during the drier months of the year, communal rangelands in Zimbabwe, which form the bulk of the feed resource for smallholder farmers, are characterised by poor feed quality and quantity, culminating in smallholder farmers supplementing with commercial supplements. Smallholder dairy farmers often lack capital to purchase commercial dairy supplements resulting in a reduction in milk production during this period. The study was therefore carried out (1) to evaluate the feasibility and effect of replacing commercial dairy supplements with on-farm produced forage-legume supplements on milk quality and quantity and (2) to assess the feed-based economic viability of replacing commercial supplements with forage-legume supplements in smallholder dairy systems. The study aimed to evaluate the feasibility of utilising forage legumes in smallholder-produced on-farm supplements.

Materials and methods

Study area

The study was conducted in Zimbabwe's Goromonzi (17°29' S, 31°29' E) and Murehwa (17°24' S, 31°35' E) districts, 54 km and 70 km north-east of the capital city, Harare, respectively. Murehwa and Goromonzi districts are in the subhumid agro-ecological region 2b. Agro-ecological region 2b, which covers 15% of Zimbabwe, is characterised by an average annual rainfall of 750–1 000 mm with 16–18 rainy pentads per season. The rains are confined to summer, received from October to April, whereas the rest of the year is dry. Temperatures range from 10 °C minimum in June–July to 35 °C maximum in October–November (Hove et al. 2003). The soils are generally well-drained, highly leached, coarse-grained sand derived from granite. The soils are inherently infertile, classified as fersiallitic with very low soil organic carbon, phosphorus, sulphur and nitrogen (Nyamapfene 1991). Studies have indicated that up to 63% of the soils in this region are generally acidic (pH < 4.5) reducing availability of most macronutrients, falling below the critical marginal threshold of 20–30 ppm nitrogen, 15–30 ppm phosphorus and 0.1–0.2 mg per 100 g potassium (Mugwira and Nyamangara 1998). The net effect is limited crop productivity where smallholder farmers cannot afford corrective measures.

Treatment diets

Four isonitrogenous and isoenergetic diets containing 16% CP and 12 MJ kg⁻¹ metabolisable energy (ME) (Table 1) were fed to crossbred dairy cows on-farm in the Goromonzi and Murehwa districts of Zimbabwe in a two-step 3 × 3 Latin square design. Isonitrogenous and isoenergetic diets are those that have the same amount of dietary nitrogen and energy, respectively. The diets consisted of a commercial supplement, a velvet bean (*Mucuna pruriens* var. *utilis*) based diet, a cowpea (*Vigna unguiculata* 'CBC3') based diet and a lablab (*Lablab purpureus* 'Highworth') based diet. Lablab and cowpea hay in the diets was made by cutting forage at the booting or early flowering stage, drying for 3–5 d then bailing. The velvet bean diet also consisted of pods and seeds, as velvet bean is a prolific

Table 1: Treatment diets fed to dairy crossbred animals in the Goromonzi and Murehwa districts, Zimbabwe

Ingredient	Velvet bean diet		Lablab diet		Cowpea diet		Commercial diet	
	%	Cost (US\$ kg ⁻¹)	%	Cost (US\$ kg ⁻¹)	%	Cost (US\$ kg ⁻¹)	%	Cost (US\$ kg ⁻¹)
Maize grain	25	0.10	36	0.14	20	0.08	–	–
Lablab hay	–	–	43	0.06	–	–	–	–
Soybean meal	–	–	20	0.12	21	0.13	–	–
Velvet bean grain	44	0.11	–	–	–	–	–	–
Velvet bean pods with grain	30	0.08	–	–	–	–	–	–
Cowpea hay	–	–	–	–	50	0.12	–	–
Veld hay	–	–	–	–	5	0.03	–	–
Maize stover	–	–	–	–	4	0.03	–	–
Vitamin premix	1	0.01	1	0.01	1	0.01	–	–
16% Dairy meal (Pastulak)	–	–	–	–	–	–	100	0.44
Cost per kg (US\$)		0.30		0.33		0.40		0.44
Dry matter (%)		88.9		88		89		89
Crude protein (%)		16.01		16.02		15.9		16
Crude fibre (%)		12.09		13.8		13.5		12
Metabolisable energy (MJ kg ⁻¹) (%)		12.09		12.07		12.04		12.00

seed producer, with recordings of over 1.5 t ha⁻¹ (Maasdorp et al. 2004). The CP content range of lablab hay, cowpea hay, velvet bean seeds and velvet bean pods with seed was 11–12%, 13–15%, 20–22% and 15–16%, respectively.

Experimental design

Three Red Dane, three Guernsey and three Holstein-Friesian crossbred dairy cows, in mid-lactation (130 ± 19 d) in the second trimester of pregnancy and average body condition score of 2.5, were each fed the experimental diets in two experiments. In experiment 1, velvet bean, cowpea and commercial diets were fed to three dairy cows in a trial involving a 3 × 3 Latin square design. In experiment 2, six dairy cows were each fed velvet bean, lablab and commercial diets in a trial involving a double 3 × 3 Latin square. Each animal was housed in a 3 m × 5 m holding pen. Animals were given diets at 0.5 kg per litre of milk produced, fed in the morning and evening during milking time by dividing the daily allowance in to two equal parts (Gusha et al. 2013). Adjustment of the given diet was made weekly based on milk yield for each cow. In addition, each animal was given 3 kg maize silage daily. Maize stover and fresh clean water was given to each animal *ad libitum*. The duration of the experiment was 63 d, divided into three experimental periods. The first 14 d were the adaptation period to the diet followed by 7 d of data collection on the same diet. The animals were treated for internal and external parasites before the experiment commenced.

The 3 × 3 Latin square design

A 3 × 3 Latin square design consists of three columns, three rows and three treatments, hence three explained sources of variability are defined (Kaps and Lamberson 2004). Each column and each row are a complete block of all treatments. In experiment 1, it consisted of three animals A, B and C (columns), fed three diets T₁, T₂ and T₃ (treatments) consecutively over three feeding periods 1, 2 and 3 (rows). Each animal received all treatments in consecutive periods. Precision is increased in an experiment through a simultaneous set of several Latin squares, as done in experiment 2 (Kaps and Lamberson 2004), as is illustrated in Figure 1. A Latin square design is used in on-farm trials to indicate animal responses to different treatments using repeated measures through multiple time periods, where animal numbers are limited (Quinn and Keough 2002).

Data collection and analytical procedure

Feed

Voluntary feed intake was computed as the difference between treatment diet quantity provided to the animal and quantity of feed refusal daily. Feed samples were collected at the beginning and at the end of each 21-day feeding period. Feed samples were dried in a forced air oven at 65 °C for 48 h to determine dry matter (DM) content. Chemical analysis was undertaken after grinding samples through a 1 mm sieve. Crude protein content in the feed was analysed by the Kjeldahl method (AOAC 1995). Crude fibre was determined according to Goering and van Soest (1970). Energy was determined by the bomb calorimetric method (AOAC 1995).

The ingredient composition, diet chemical composition and cost per kilogram of the diets were as shown in Table 1.

The feed ingredient cost for maize, soyabean meal, 16% Dairymeal (Pastulak) and vitamin premix was determined using prevailing market prices in Zimbabwe (current price as at July 2013 for experiment 1 and as at July 2014 for experiment 2). The ingredient cost of the respective forage-legume hays, grain, veld hay and maize stover was computed using actual production cost estimates from the farmers who produced the ingredients (production costs as at July 2013 for experiment 1 and as at July 2014 for experiment 2). The figures for an ingredient obtained from different farmers were averaged into a single figure proportionally by weight.

Milk yield and quality

Cows were hand-milked twice per day at 06:00 and 15:00. Each individual cow's daily milk yield was measured using a calibrated milk jar and recorded on milk weight sheets. Milk samples (20 mL) were collected daily during the seven-day data collection period by proportional pooling of morning and evening milking, and stored in sample bottles containing Bromopol (2-bromo-2-nitropropane-1,3-diol + natamycin) preservative tablets to prevent spoilage before chemical analysis. Milk samples were analysed for protein, butterfat, lactose and total solids. Milk sampling was done following the procedures of Oliver et al. (2004). A Bentley DairySpec Combi 300 machine was used to analyse the milk for protein, butterfat, lactose and total solids.

Single Latin square				Double Latin square										
Rows (periods)		Columns (animals)		Square 1			Square 2							
		A	B	C	Columns (animals)			Columns (animals)						
1		T ₁	T ₂	T ₃	Rows (periods)	A	B	C	A	B	C			
2		T ₃	T ₁	T ₂		T ₁	T ₃	T ₂				T ₂	T ₃	T ₁
3		T ₂	T ₃	T ₁		T ₃	T ₂	T ₁				T ₂	T ₁	T ₃

A, B and C are the three different animals fed three different diets (T₁, T₂ and T₃) over three consecutive feeding periods (1, 2 and 3)

Figure 1: Single and double Latin square designs

Dietary cost benefit analysis

Dietary gross margin (DGM) was calculated as the difference between total income and dietary component cost of producing the diet. The DGM was computed using the following model as applied by Mburu et al. (2007) and Pengelly et al. (2004):

$$\text{DGM} = \text{MP} \times \text{MV} - \text{FQ} \times \text{FC}$$

where DGM represents dietary gross margin, MP represents the price of milk (US\$) per kilogram, MV represents the amount of milk produced by feeding a particular treatment diet, FQ represents the calculated amount of a particular treatment diet consumed to produce MV, and FC represents the cost per kilogram of producing a particular treatment diet.

Cost of producing 1 kg of feed consisted of the sum cost of the dietary components and did not include other variable costs such as labour. The cost of producing 1 kg of milk is expressed as 'dietary' cost as it does not account for other variable costs such as veterinary cost, *ad-libitum* basal stover, silage, labour costs and costs associated with dry cows and heifers.

Statistical analysis

A repeated measures analysis of variance (ANOVA) was used to examine the effect of treatment, feeding period and animal on milk yield and milk composition using the General Linear Model procedure of the Statistical Analysis System software (SAS Institute 2012). Treatment means were compared using the Predicted Difference (pdiff) statistic (SAS Institute 2012). The model used was

$$Y_{ijk} = \mu + T_i + P_j + C_k + e_{ijk}$$

where Y_{ijk} represents the (observation) response variable (Milk yield, protein, milk fat, lactose and total solids), μ is the overall mean/experimental mean, T_i is the treatment effect where i is a particular treatment, P_j is the feeding period where j is a particular feeding period, C_k is the effect of animal where k is a particular animal, and e_{ijk} is the random residual with a distribution of $N \sim (0, \sigma^2 E)$.

Results

Diet intake

There was no significant difference in diet intake ($P > 0.05$). The cows consumed the daily ration, which was divided into two equal portions, without any significant refusals (Table 2). However, it was noted that the animals on the velvet bean diet took longer to finish the diet during the first few days in the adaptation phase, which was recorded as refusals. The cows then readily consumed the diet thereafter. The calculated velvet bean grain intake was 1.32 kg d⁻¹.

Milk yield and composition

Significant differences in milk yield were observed across all diets. Specifically, milk yield was observed to be significantly greater compared to other diets ($P < 0.05$) for cows on a commercial diet and least on a cowpea diet in the two experiments (Tables 3 and 4), while cows on a lablab diet

produced more milk than those on a velvet bean diet. There was a difference of more than 1 L in average daily milk yield between the highest-yielding diet (commercial diet) and the least-yielding diet (cowpea diet).

There were significant differences ($P < 0.05$) in milk composition across the diets. Milk fat was observed to be significantly highest ($P < 0.05$) in milk from cows fed a lablab diet and least in milk from cows fed a velvet bean diet. It can be noted that milk fat from cows fed a cowpea diet did not significantly differ to milk fat from cows fed a commercial diet, and was significantly higher than in milk from cows fed a velvet bean diet (Table 3). Milk protein did not significantly differ in milk from cows fed a commercial diet and those fed a lablab diet (Table 4), but was significantly higher than that of the other two treatments ($P < 0.05$). Within the forage diets, milk protein from cows fed a lablab diet was not significantly higher than milk protein from cows fed a velvet bean diet, but was significantly higher than that from cows fed a cowpea diet. Lactose content was significantly ($P < 0.05$) different among all treatment diets.

Table 2: Diet intake for dairy crossbred cows fed commercial, velvet bean and lablab diets in Goromonzi and Murehwa districts, Zimbabwe. Values within a column followed by different superscripts are significantly different at $P < 0.05$

Treatment	Feed provided (kg ⁻¹ d)	Refusals (kg ⁻¹ d)		Feed intake (kg ⁻¹ d)
		Adaptation	Data collection period	
Commercial diet ($n = 9$)	3.2 ^a	0.0 ^a	0.0 ^a	3.2 ^a
Lablab diet ($n = 6$)	3.1 ^a	0.0 ^a	0.0 ^a	3.1 ^a
Velvet bean diet ($n = 9$)	3.1 ^a	0.1 ^a	0.0 ^a	3.1 ^a
Cowpea diet ($n = 3$)	3.0 ^a	0.0 ^a	0.0 ^a	3.0 ^a
Standard error	0.001			0.001

Table 3: Experiment 1: Milk yield and composition for dairy crossbred cows fed commercial, velvet bean and cowpea diets (each $n = 3$) in Goromonzi and Murehwa districts, Zimbabwe. Values within a column followed by different superscripts are significantly different at $P < 0.05$

Treatment	Milk yield (kg cow ⁻¹ d ⁻¹)	Protein (%)	Milk fat (%)	Lactose (%)	Total solids (%)
Commercial diet	6.7 ^a	1.99 ^a	2.65 ^a	3.12 ^a	8.81 ^a
Velvet bean diet	6.1 ^b	1.82 ^b	1.92 ^b	2.72 ^b	7.37 ^b
Cowpea diet	5.6 ^c	1.67 ^c	2.60 ^a	2.56 ^c	7.47 ^b
Standard error	0.318	0.009	0.024	0.017	0.046

Table 4: Experiment 2: Milk yield and composition for dairy crossbred cows fed commercial, lablab and velvet bean diets (each $n = 6$) in Goromonzi and Murehwa districts, Zimbabwe. Values within a column followed by different superscripts are significantly different at $P < 0.05$

Treatment	Milk yield (kg cow ⁻¹ d ⁻¹)	Protein (%)	Milk fat (%)	Lactose (%)	Total solids (%)
Commercial diet	6.8 ^a	2.04 ^a	2.72 ^a	3.14 ^a	8.94 ^a
Lablab diet	6.4 ^b	2.01 ^b	2.97 ^b	3.08 ^b	7.58 ^b
Velvet bean diet	6.2 ^c	1.85 ^c	1.98 ^c	2.96 ^c	7.44 ^b
Standard error	0.176	0.006	0.026	0.005	0.048

Highest milk lactose content was observed in milk from cows fed a commercial diet and least in milk from cows fed a cowpea diet. Total solids were observed to be significantly ($P < 0.05$) highest in milk from cows fed a commercial diet than in milk from the other diets. However, the total solids in milk from the forage legume diets was observed to be similar in both experiments (Tables 3 and 4)

Milk yield was observed to be influenced by breed. Holstein-Friesian crossbred cows produced significantly higher milk yield than Red Dane and Guernsey crossbreds. There was an increase in milk yield as the experiment progressed (period). The cows also improved slightly in body condition score, improving by 0.5 grade points on average (Table 5).

Economic returns

Compared with the cowpea and commercial diet, the daily and monthly dietary gross income margins were higher for cows fed a velvet bean and lablab diet by 17% and 16.5%, respectively. It follows that the dietary cost to produce 1 L of milk is higher and almost equivalent from cows fed a cowpea diet and a commercial diet by 28% and 23%, respectively, compared with velvet bean and lablab diet-fed cows (Table 6). While the cowpea diet consumed was less (2.8 kg d^{-1}) than the other forage diets (lablab 3.20 kg d^{-1} and velvet bean 3.05 kg d^{-1}), it was noted that it was still more expensive.

Discussion

Intake

No difference in voluntary feed intake of the diets was

observed. Diet intake is affected by anti-nutritional factors (ANFs), CP level and form (Madzimure et al. 2011). Velvet bean, lablab and cowpea contain ANFs that include tannins, phytic acid, saponins, cyanogenic glycosides, lectins and L-Dopa (in velvet bean only), which limit feed intake (Mapiye et al. 2006, 2007; Tuleun et al. 2008; Fathima et al. 2010). However, the study results indicate that inclusion of forage legumes in the diets did not have an effect on intake, which could have been a result of the low daily dietary inclusion quantities. Topps and Oliver (1993) report that besides the laxative effect observed if consumption levels of forage legume grain exceed 2 kg d^{-1} in cattle, no intake effect was observed. In this study, the average total dietary feed was 3 kg d^{-1} , translating to a calculated velvet bean grain intake of 1.32 kg d^{-1} .

Lazzarini et al. (2009), cited in Gusha et al. (2013), indicate that CP levels of below 6–8% depress appetite and voluntary feed intake. In the present study the dietary CP level was 16%, which further explains the intake pattern. The form in which forage is fed influences intake. According to Madzimure et al. (2011) tannin-rich feeds can be eaten in large quantities like any other non-tannin feed when dry rather than fresh. Drying of forages reduces the solubility of tannins, thereby affecting their ability to precipitate salivary proteins to cause an unpalatable astringent taste (Waghorn 2008). Tannin-rich forages used in the diets in this study are in the dried form, which might also explain the insignificant difference in intake of the diets. However, it was noted that cows initially took longer to finish the velvet bean diet. This could be due to the astringent taste that is associated with velvet bean due to tannin presence. However, the cows readily consumed the diet after a few days of adaptation.

Table 5: Comparison of milk yield and body condition score across breeds and period for dairy crossbred cows fed commercial, velvet bean, cowpea and lablab diets in Goromonzi and Murehwa districts, Zimbabwe. Values within a column followed by different superscripts are significantly different at $P < 0.05$

Breed	Period 1		Period 2		Period 3		Average milk yield (kg)
	Body condition score	Average milk yield (kg)	Body condition score	Average milk yield (kg)	Body condition score	Average milk yield (kg)	
Holstein-Friesian cross ($n = 3$)	2.0	7.2 ^a	2.0	7.6 ^a	2.5	7.8 ^a	7.6 ^a
Red Dane cross ($n = 4$)	2.0	5.7 ^b	2.0	5.9 ^b	2.0	6.4 ^b	6.0 ^b
Guernsey cross ($n = 2$)	2.5	4.7 ^c	2.5	5.1 ^c	2.5	5.5 ^c	5.1 ^c
Standard error		0.882		0.667		0.577	0.577

Table 6: Economic analysis for dairy crossbred cows fed commercial, lablab, velvet bean and cowpea diets in Goromonzi and Murehwa districts, Zimbabwe

Component	Commercial diet	Lablab diet	Velvet bean diet	Cowpea diet
Milk yield ($\text{kg cow}^{-1} \text{ d}^{-1}$)	6.7	6.4	6.1	5.6
Milk income per day (US\$)	2.81	2.69	2.56	2.35
Calculated diet offered per day (kg^a)	3.35	3.20	3.05	2.80
Diet cost per day ^b	1.41	1.06	0.92	1.12
Dietary net income per day (US\$)	1.40	1.63	1.64	1.23
Dietary net income per 30 days (US\$)	42.00	48.90	49.20	36.90
Dietary cost to produce 1 L milk ^c	0.21	0.16	0.15	0.20

^a Calculated diet offered per day was calculated at 0.5 kg L^{-1} milk produced in the previous week

^b Diet cost is constituted of component feed elements costs excluding other costs such as labour

^c Dietary cost to produce 1 L milk does not account for other variable costs, such as veterinary, *ad-libitum* basal stover, water, silage, labour and costs associated with dry cows and heifers

Milk yield and composition

Holstein-Friesian crossbred animals gave a consistently higher milk yield across the periods when compared with Red Dane and Guernsey crossbreds (Table 5). This is consistent with literature where Holstein-Friesian were bred for high milk yields compared with Guernsey and Red Dane, which have lower milk yields with higher protein and fat content (Ngongoni et al. 2006). However, the average milk yield of all animals in the trial was lower than their breed yield potential. Costa et al. (2005) reported an average of 6.3 L d⁻¹ milk yield for Holstein-Zebu crossed cows fed diets with graded levels of coffee pulp in Brazil. Madzimure et al. (2011) and Mashanda (2014) attribute the low milk yield in their studies to poor body condition, which is consistent with this study where the body condition of the animals was 2–2.5 on average (Table 5). Table 4 indicates that the animals seemed to improve in body condition slightly as the study period progressed, but the cows remained in the poor body condition score-band of 2–3. Wattiaux (2005) and Mapekula et al. (2009) concur that cows that have poor body condition have reduced milk production due to lack of adequate reserves to mobilise for milk production. Ngongoni et al. (2006) states that in low-resource and low-input production systems, such as those prevalent in the smallholder sector, dairy cows perform below their genetic potential.

An increase in milk yield was observed as the experiment progressed. According to Heck et al., (2009), milk yield and quality is not only influenced by breed and feeding system, but also by physiological factors such as age and stage of lactation. Machuwe (2010) concurs that milk yield and quality is influenced by stage of lactation, parity, size of animal, feed construct, level of feeding and the body condition. Padekar and Bhoite (2002) cite that milk yield gradually increases post-partum and peaks at mid-lactation and gradually decreases towards parturition due to nutritional demands of the growing foetus. This is consistent with the study results (Table 5) where milk yield is increasing with period.

Several authors agree that milk yield tends to be affected by dietary protein content, which affects the amount of protein and energy available for milk synthesis (Ngongoni et al. 2009; Barde et al. 2010; Chakoma 2012). However, despite the diets in this study being isonitrogenous and isoenergetic, there were significant differences in milk yield. Differences in milk yield might be attributed to other dietary factors in the feeds that include ANFs. Work by Gwanzura et al. (2012) indicated that velvet bean has higher concentrations of both condensed and hydrolysable tannins than lablab, cowpea and sorghum. However, the study results indicate that average milk yield from cows fed a cowpea diet was lower than average milk from cows fed a velvet bean diet. Ayala-Burgos et al. (2003) and Iyayi and Taiwo (2003) reported that velvet bean is an excellent source of fermentable nitrogen and energy to rumen microorganisms and compares favourably to soybean amino acid and mineral profile. Given the low daily intake levels of velvet bean (1.32 kg d⁻¹), the anti-nutritional effect of L-Dopa and tannins might have been significantly reduced in masking an effect on fermentable nitrogen and energy levels. This could explain why cows fed a velvet bean diet gave higher milk

yields than those fed a cowpea diet. Work by Buwu (2014) indicated that lablab-based diets had higher *in vitro* organic matter and dry matter digestibility than velvet bean-based diets. This could explain how cows fed a lablab diet produced higher milk yields than those fed a velvet bean diet. In contrast, Murungweni et al. (2004) demonstrated that the use of a lablab hay supplement resulted in milk yield increases slightly less than those obtained through the use of velvet bean. Mapiye et al. (2007) explains this variability by differences in agronomic and edaphic factors that affect the nutrient quality of the forages.

Milk from cows fed a commercial diet and lablab-based diet was significantly higher in milk protein than from cows fed velvet bean- and cowpea-based diets. According to Hulár and Brand (1993), increasing forage content of diets increases milk fat and suppresses milk protein. This could explain the higher milk protein in milk from cows fed a commercial diet than those on forage-based diets. Ayala-Burgos et al. (2003) reported that when forage legumes, such as velvet bean, are used in stock-feed, the grain is readily available in the rumen hence can be considered an excellent source of fermentable nitrogen to the rumen microorganisms. However, ANFs present in velvet bean seeds, such as trypsin and chymotrypsin inhibitors, reduce protein digestibility and induce pancreatic hypertrophy and hyperplasia (Kumar 1991). This could further explain the lower milk protein from cows fed a velvet bean-based diet compared with a lablab-based diet that contained hay.

Fat content is affected by the acetate to propionate ratio. Milk fat was significantly different across all diets, with milk from cows on a velvet bean diet being the lowest and on a lablab diet being the highest. Milk fat content is influenced by fat, grain content and neutral detergent fibre content in the diet (Jenkins and McGuire 2006; Rutkowska et al. 2012). High grain content depresses milk fat due to inadequate rumen production of acetate and butyrate for the synthesis of milk fat. Jenkins and McGuire (2006) further explain that propionate from grain stimulates insulin concentration, which redirects metabolites away from mammary tissue. This can explain the low milk fat from cows fed a velvet bean-based diet in this study that is high in velvet bean seeds. High neutral detergent fibre from hay-rich diets stimulates high milk fat percentage. Increasing forage content of diets increases milk fat and suppresses milk protein, which is consistent with the results in this study (Tables 3 and 4) where milk fat from cows fed forage-based diets was comparable to milk fat from cows fed a commercial diet.

According to Jenkins and McGuire (2006), lactose is not affected by dietary variances except in extreme cases. Lactose content is affected by physiological variability of the animal, nutritional status, stage of lactation, season of the year, age and quantity of milk produced. Significant differences were observed in the lactose content of milk in this study. Differences observed could have resulted from significant differences in milk quantities observed in this study. However, Kittivachra et al. (2007) indicate that lactose is to some extent affected by nutrition. Kittivachra et al. (2007) further indicate that lactose synthesis seems to be supported by high-fibre diets through manipulation of the propionate–acetate balance.

As milk total solids is a culmination of milk fat, lactose and protein, total solids vary depending on the predominant factor affected of these three. Holmes and Wilson (1984) indicate that total solids follow protein and fat trends as affected by stage of lactation implying milk quantity. In this study milk from cows fed forage-based diets had lower total solids than milk from cows fed a commercial diet.

Tables 3 and 4 indicate lower milk composition content than observed in other studies (Volpelli et al. 2010; Gussha et al. 2013). This is consistent with Machuwe (2010) who cites that milk yield and quality is influenced by level of feeding and the body condition. Cows with poor body condition produce lower milk yields with inferior quality. Lactating cows that consume less than 3% of their body weight in feed DM often produce low milk yield with low milk component percentages. In most smallholder farming areas, during the drier months of the year, there is poor feed quantity and quality. This may explain the poor body condition score and related milk yields and composition.

Economic returns

Velvet bean- and lablab-based diets have significantly higher dietary net income and lower production costs per litre of milk produced than a commercial diet. This is due to the lower cost of producing these forage-based diets. Similar results have been observed by several authors (Murungweni et al. 2004; Mupenzi et al. 2009; Olafadehan and Adewumi 2010; Chakoma 2012; Omer et al. 2012; Gussha et al. 2013). These authors concur that cheap high-nitrogen sources can improve the economic profitability of smallholder dairy. According to Gussha et al. (2013) farmers who reduce use of commercially prepared supplements improve their income by nearly 50%. Murungweni (2004) concurs by indicating that using ley legumes has been shown to increase profits by over 300% in smallholder dairy systems.

In smallholder dairy systems, where feed costs account for 70% of production costs, feed is the major factor limiting viability. During the feed gap in the drier months of the year, when feed quantity and quality is poor, it becomes necessary to supplement. Supplementing using commercial supplements, which are more than 20% higher in cost, reduces smallholder dairy viability. Forage legumes not only reduce feed costs significantly, but have good agronomic attributes suitable for smallholder farming systems, which include soil amelioration properties. Lablab and velvet bean are adapted and suitable for production in Zimbabwe at the smallholder farming system level. The present study indicated an improvement in the body condition score as well as an increase in milk yield across all diets, as the experiment progressed. This demonstrates the potential of forage legumes to contribute to livestock production in the smallholder dairy sector. Forage legumes have the potential to contribute to smallholder dairy productivity at a reduced cost, contributing to viability and availability of quality supplements during the drier months of the year, which usually coincide with poor feed quantity and quality. The contribution of smallholder dairy to household income and economic food security can potentially be improved through sustainable feeding strategies that enhance performance of smallholder dairy systems.

Conclusion

Use of forages can be a cost-effective feed-level intervention to optimise income in small-scale dairy systems by reducing the cost of producing each litre of milk. Use of low-cost farm-produced forages as alternative feed for resource-poor smallholder farmers enhances the economic viability of the dairy business.

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