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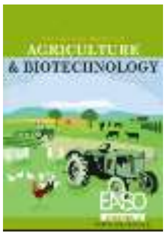

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Original Article

Optimizing Energy and Protein Contents in A Leucaena (*Leucaena leucocephala lam.*) Leaf-Based Concentrate for Dairy Goats Fed Napier Grass (*Pennisetum purpureum schumach*) Basal Diet in Kenya

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Concentrate Supplementation, Dairy Goats, Feed Intake, Leucaena Leaf Hay, Milk Yield, Napier Grass.

ABSTRACT

Dairy goats provide food and financial security through their milk and meat. The main basal diet for confined dairy goats in Kenya is Napier grass (Pennisetum purpureum Schumach). However, optimal milk production is hampered by the high cost of protein and energy supplements that are required while feeding the grass. The protein supplement affordability is of greater limitation among farmers, therefore use of protein-rich forages in a supplement can lower the concentrate cost. Information on the optimal protein and energy inclusion levels in a forage-based concentrate for dairy goats is hardly available in Kenya. A study was therefore conducted whereby Leucaena (Leucaena leucocephala Lam.) leaf hay was used as the main protein source in four concentrates formulated with crude protein (CP) content (gkg^{-1}) and metabolizable energy (ME) levels ($MJkg^{-1}$), respectively, of: 135, 12; 160, 10; 185, 8; and 210, 6; respectively. A fifth supplement was formulated, representing the commonly used cattle dairy meal (160 g $CPkg^{-1}$ DM and 10 MJ $MEkg^{-1}$ DM, respectively), using commercial sunflower seedcake as a protein source. The concentrates were fed at 300 gday-1 to lactating Toggenburg dairy goats on Napier grass basal diet, in a 5 x 5 Latin square design. The total dry matter intake by the goats was 1.059-1.128 kg DM/goat day^{-1}, with milk production of 221.3-285.5 mL/goat day^{-1}. It was concluded that the appropriate CP and ME levels in the Leucaena-based concentrate are 135 gkg^{-1} DM and 12 $MJkg^{-1}$ DM, respectively. It was recommended that other protein-rich forages be explored.

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INTRODUCTION

Dairy goats provide food and financial security among many smallholder farmers, through high quality milk for direct consumption, in addition to meat from culled stock. They require less feeds per unit (Leketa *et al*., 2019), hence they are more resilient to climate change. However, poor nutrition in terms of low-quality feeds, and high prices of commercial concentrates hinders optimal milk production in dairy goats (Leketa *et al*., 2019). Kahi & Wasike (2019) observed that livestock productivity can be increased three-fold by improving feeding to meet the nutritional requirements of the animals.

In Kenya, the demand for dairy goats (Kinyanjui *et al*., 2008; Mbindyo *et al*., 2018) and goat milk (FAO, 2011; Ogola *et al*., 2010) is high. However, inadequacy of dairy goat feeds, especially during the dry season (Mbindyo *et al*, 2018), and high cost of concentrates (Mburu *et al*., 2014; Ogola *et al*., 2010), has been a challenge. The Napier grass (*Pennisetum purpureum* Schum.) is widely used as a basal diet by smallholder dairy farmers in Kenya (Kariuki, 1998; Wambugu *et al*., 2011). However, it is not adequate for dairy goats' maintenance (Njarui *et al*., 2003), and therefore requires supplementation with energy and a protein source to achieve enhanced milk production (Economides, 2014; Leng *et al*., 2020). A 30 kg goat gaining 8 gd^{-1} and producing 2 L milk requires a concentrate with 162.0 g crude protein (CP) and 12.0 MJ metabolizable energy (ME) per kg DM (NRC, 1981). However, these estimates are based on equations using temperate pastures, and may not apply to tropical pastures or browse forages (NRC, 2007). Therefore, levels that may show the interaction between energy and protein in the tropics may be of interest. Supplementation aims at using small amounts of nitrogen and energy from a concentrate to increase roughage and energy intake without substituting much of the forage (Economides, 2014). It is, however, noted that there is no standard concentrate for dairy goats in the Sub-Saharan Africa (Kahi & Wasike, 2019), and feeding recommendations for dairy goats are adapted from or assumed to be similar to those for sheep or dairy cattle (NRC, 2007).

Regarding the cost of concentrates, protein sources are scarce and therefore protein is more expensive than energy, hence protein is a major limitation to animal production (Hennessy, 1980; Migwi *et al*., 2013; Preston, 1995). Locally available protein-rich forages are more affordable and can reduce the cost of feeding (FAO, 2011; Leketa *et al*., 2019), while cereal grain milling by-products like maize bran (FAO, 2011) or maize germ can be used as supplements for energy. Multi-purpose fodder trees have wide spread availability on most farms, are easy to access by farmers, and tend to have low N degradability in the rumen (Patra *et al*., 2002) thus providing more bypass protein to the animal. Use of fodder tree legumes for protein would also reduce methane gas emission due to the lower cell wall content of legume forage compared to grass (Peyraud *et al*., 2009), and mitigate feed shortage as the trees maintain their levels of protein during the dry season (Franzel *et al*., 2003; Oppong *et al*., 2008) when grasses and other herbaceous plants are dry

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(Lefroy *et al*., 1992). This would enhance goat resilience to climate change.

Leucaena (*Leucaena leucocephala* Lam.) is a vigorous, drought-tolerant and high-yielding legume that is extensively grown in many parts of the tropics as a forage crop (Ghosh & Bandyopadhyay, 2007; Zakayo *et al*., 2000). It is the most common protein-rich forage among dairy goat keepers in Kenya. However, it contains mimosine, a toxic amino acid (Ghosh & Bandyopadhyay, 2007; Hegarty *et al*., 1976), though a diet with less than 30% Leucaena meal has no health problems in ruminants (Ter Meulen *et al*., 1979). Leucaena leaves also contain condensed tannins (CT) at 0.43%, which can reduce protein digestibility but also protect protein from degradation in the rumen of ruminants, making it available in the small intestines (Ghosh & Bandyopadhyay, 2007). Diets containing CT at low concentration of 20-40 gkg^{-1} DM are beneficial through decreased degradation of dietary protein in the rumen (Waghorn *et al*., 1990), and diets with up to 5% tannins have no deleterious effects on intake or diet digestibility (Barry & McNabb, 1999). However, there is no information on the appropriate energy and protein inclusion levels in a dairy goats' concentrate incorporating Leucaena leaf as the protein source and the associated goats' performance in Kenya. The objective of this study, therefore, was to determine the optimal inclusion levels of CP and ME in a supplement concentrate formulated based on hay from Leucaena and maize products for lactating Toggenburg dairy goats (TDG) fed Napier grass basal forage in Kenya.

MATERIALS AND METHODS

Site

The study was carried out at the Kenya Agricultural and Livestock Research Organization (KALRO) at Naivasha, Nakuru County between March and August 2021. The area is located at 1900 meters asl. longitude of 36°22' E, and latitude of 0°40' S. The mean annual rainfall is 653 mm, mean monthly day and night temperatures of 26 and 8°C, respectively, and a relative humidity of 60-75% (Jaetzold *et al*., 2006a). The Napier grass basal forage was grown at the site and used for the feeding trial, maintained under the KALRO's Pivot Irrigation System.

The supplementary legume, Leucaena (*Leucaena leucocephala*) hay, was sourced from Kwa Muthike market area in Machakos County. The area is located at 1091 meters asl. longitude of 37°15'50" East, and latitude of 0°48'44" South (Jaetzold *et al*., 2006b). The mean annual rainfall and temperature ranges for the area are 22.4-205.7 mm and 16-24°C, respectively, and a relative humidity of 68% (Jaetzold *et al*., 2006b).

Animals

Fifteen lactating Toggenburg dairy goats (TDG) in mid lactation with an average age of 2.59 years and mean live weight of 32.9 ± 5.66 kg, producing an average of 869.2 mL milk per day and in lactation numbers 1 to 3 were selected from a dairy goat flock kept under free grazing in the morning and zero-grazing systems in the afternoon (semi-zero grazing system) at KALRO-Naivasha. They were divided into three groups of five and were blocked based on their liveweight. Five goats in each group were allocated to five treatments (three goats per treatment) at random. The goats were kept under the zero-grazing system, and housed individually in well-ventilated feeding stalls with a common roof. The goats were dewormed with 5 mL Albefas® each at the start of the experiment to control endo-parasites. They were sprayed weekly with Ectomin® acaricide to control ecto-parasites. They were weighed weekly before feeding. All experimental procedures were in accordance with the Animal Ethics guidelines of the Institutional Review Committee (IRC) (2013), Institute of Primate Research (IPR), Kenya.

Diets

Four concentrate supplements were formulated based on hay from Leucaena (*Leucaena leucocephala*) as a protein source, and maize germ as an energy source. A fifth supplement was constituted using sunflower seedcake as the

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protein source instead of the legume, and it represented the commercially used dairy meal for feeding dairy cattle. The constituted supplements had different metabolizable energy (ME) and crude protein (CP) combination levels, ranging from 6 to 12 MJkg^{-1} DM ME and 135 to 210 gkg^{-1} DM CP. Whole grain maize meal was used to boost the energy (Diet 2) while ground maize cobs (Briggs, 1999) (Diets 1, 3, 5) and rice husks (Diet 4) were used to lower the energy levels, as was necessary. The five concentrates were fed to the 15 lactating TDG consuming a Napier grass (*Pennisetum purpureum*) basal diet for 98 days after an adaptation period of 21 days. Data were collected on feed intake and milk yield for 70 days, after which fecal collection was done for 10 days in metabolic cages. The total change-over period was 28 days. The goats were fed on a particular concentrate for 14 days before a change-over period of seven days. The experiment was arranged as a 5x5 Cross over Latin Square design consisting of five diets with three animals (replicates) per treatment. The treatment diets fed were as follows:

T1: Basal diet of Napier grass *ad libitum* + 300 g Sunflower cake-based concentrate (160 g CP, 10 MJ ME kg^{-1} DM) (control)

T2: Basal + 300 g Leucaena hay-based concentrate (LBC) (135 g CP, 12 MJ ME kg^{-1} DM)

T3: Basal + 300 g LBC (185 g CP, 8 MJ ME kg^{-1} DM)

T4: Basal + 300 g LBC (210 g CP, 6 MJ ME kg^{-1} DM)

T5: Basal + 300 g LBC (160 g CP, 10 MJ ME kg^{-1} DM).

Napier grass was cut at 5 cm above the ground level (Lounglawan *et al*., 2014). Leucaena branches were hand-harvested by cutting and the branches spread out on a canvas to dry under the sun for about three days. The branches were turned at four-hour intervals to enhance the drying process. The branches were then shaken for the leaflets to fall off. The stemmy parts were removed by hand sorting, and the dry leaflets put into sisal twine gunny bags and stored in a roofed well-ventilated house, on timber raised to about 1 m high until feed compounding. Maize meal, maize germ, and sunflower seedcake were purchased from the Utafiti feed mill at KALRO-Naivasha. Rice husks were sourced from Mwea in Kirinyaga County while maize cobs were sourced from Nyandarua County. Feed compounding was done manually at the Utafiti feed mill. Before feed compounding, maize cobs and Leucaena hay were ground using a hammer mill at the Utafiti feed mill. Goats were fed minerals *ad libitum* in form of 2-kg mineral blocks. The minerals were purchased from a local stockist at Naivasha town. Clean water was provided *ad libitum* to each goat using 10-litre plastic buckets. During the change-over period, the daily feed for the goats was Napier grass basal diet *ad libitum* and 200 g dairy meal concentrate from the Utafiti feed mill.

Formulation of CP and ME contents of the constituted concentrates was based on nutritive value parameters of the constituent feed ingredients derived from the proximate (AOAC, 1999) and fibre analysis (Van Soest *et al*., 1991) procedures. Gross Energy (GE) analysis using a bomb calorimeter was done for roughage feed ingredients for use in ME calculation. The ME contents for the constituent feed ingredients were estimated using the equations prescribed by CSIRO (2007) for concentrates, and by MingMing *et al*. (2016) for roughages. The concentrate composition for the various diets were as follows: T1: Maize germ (24.30%), maize cobs (35.87%), sunflower seedcake (39.82%); T2: Maize meal (55.43%), maize germ (12.27%), Leucaena leaf hay (32.27%); T3: Maize germ (10.79%), maize cobs (22.70%), Leucaena leaf hay (66.48%); T4: Rice husks (15.19%), Leucaena leaf hay (84.41%); and T5: Maize germ (51.67%), maize cobs (8.36%), Leucaena leaf hay (39.97%).

Procedures and data collection

The goats were randomly allocated to treatment diets in each of the three groups ensuring that every group had all the five treatments. The goats

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were housed in well-ventilated individual 1.2 x 2.1 m roofed stalls having wooden slatted floor, raised 1 m above the ground. The stalls had also been fitted with feeding facilities (troughs). The goats were allocated into the stalls at random and fed with their respective treatment diets. Formulated concentrates were weighed using a digital weighing balance. The concentrates were put into 5-litre plastic containers cut open on one side, and placed in the feed troughs. The goats were fed the basal and supplement diets in two equal portions twice a day, at 0800 and 1400 h. The concentrate was offered preferentially before the animals were allowed to access the basal feed. Feed refusals for individual animals were collected every morning and weighed before fresh feed was offered. The amount of fresh Napier grass per feeding was about 3-5 kg, and was weighed using a suspension balance. The amount fed was adjusted based on a goat's intake during the previous three days to allow left overs to be about 20%. The Napier grass was chopped using a motorized chaff cutter, into pieces of 2 to 5 cm (Lukuyu, 2015; Moran, 2005) long. Goats were hand-milked twice a day, at 0800 and 1600 h.

After all the goats had been fed on all the five diets for two weeks each and data collected, two to three goats per treatment (three goats for diets one and two; two goats for diets three to five) were transferred into the 12 available metabolic cages, each measuring 0.53 x 1.24 m. The floor of a cage was raised to 0.71 m from the ground. Fecal pellets were collected at the end of a perforated aluminum sheet beneath the floor of the cage that allowed urine to pass through it. Fecal output per goat was collected into a 3-L plastic bucket and weighed using a digital weighing balance. Fecal collection was done for 10 consecutive days in the mornings and sampled for DM determination and ashing. Samples of 20% total fecal output (Mui *et al*., 2002) were put into khaki bags of size 2 and dried at 60ºC for 24 hours and ground at the KALRO Naivasha Laboratory. The samples were ground to pass through a 1 mm sieve (Zaklouta *et al*., 2011) and put into fresh khaki paper bags (size No. 2), and analyzed for nutritive value at Egerton University laboratories. Dry matter (DM) and ash contents were determined using AOAC (1999) procedures. Apparent dry matter digestibility (DMD) was calculated as the difference between total dry matter intake (TDMI) and total fecal output (TFO) on dry matter basis as a percent of the TDMI. Organic matter digestibility (OMD) was calculated as the difference between total organic matter intake (TOMI) and the total OM output in feces, as a percent of the TOMI. Both the DMD and OMD were then expressed in grams per kilogram. Data were recorded on milk yield, feed intake, and body weights.

Sampling and nutrient analysis

Nutrient chemical composition analyses before feed compounding as well as analysis of feed left overs were done at KALRO-Naivasha and Egerton University laboratory facilities. The feeds and left overs were sampled weekly during the experimental period. They were dried at 60ºC, and a subsample taken for DM and ash analyses. The remaining subsample was ground through a 1-mm sieve and stored for analyses of nutritive properties. The samples were then bulked per feed at the end of the experiment and a single sample taken. Maize germ, maize cobs, rice husks and sunflower seedcake purchased were sampled for DM and chemical analysis before supplement compounding.

The dry matter (DM), ash and nitrogen (N) (Kjeldahl-N) contents of Napier feed and refusals and the compounded concentrates were determined using AOAC (1999) procedures, at KALRO-Naivasha. DM was determined by drying the samples at 105ºC for 48 hr. Crude protein (CP) of ingredients, feeds and fecal samples was calculated as Kjeldahl N x 6.25 (Biancarosa *et al*., 2017). Neutral and acid detergent fibres (NDF and ADF), and acid detergent lignin (ADL) were determined according to the procedure of Van Soest *et al*. (1991). Gross Energy analysis for roughages was done using a bomb calorimeter at Egerton University laboratories. The metabolizable energy (ME) of the concentrate feed ingredients and the compounded concentrates were estimated using the proximate (AOAC, 1999) and fibre analysis

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(Van Soest *et al*., 1991) results from KALRO-Naivasha, and the equations prescribed by CSIRO (2007) for concentrates and by MingMing *et al*. (2016) for roughages:

(i) ME ($MJkg^{-1}$ DM) = 11.78 + 0.0654CP+ $0.066EE^2$ – (0.0414 EE * CF) – 0.11Ash% (CSIRO, 2007) for concentrates, and

(ii) ME ($MJkg^{-1}$ DM) = 6.943-0.101NDF+0.704GE–0.101ADF+0.138OM+0.032CP% (MingMing *et al*., 2016) for roughages,

where:

ME = the Metabolizable energy ($MJkg^{-1}$ DM)

CP = the Crude protein %

EE = the Ether extracts %

CF = the Crude fibre %

GE = the Gross energy ($MJkg^{-1}$ DM)

NDF = the Neutral detergent fibre%

ADF = the Acid detergent fibre%

OM = the Organic matter %.

Statistical analysis

Data were stored in Ms Excel files and subjected to analysis of variance (ANOVA), using the General linear model (GLM) procedures of Statistical Analysis System (SAS, 2004). The Cross over Latin Square Design Model was used to analyze data on the effect of treatments on feed intake, digestibility and milk yield. The model is shown below.

$$X_{ijkl} = \mu + \alpha_i + \beta_j + \rho_k + \tau_l + \varepsilon_{ijklm}$$

where:

X_{ijkl} = the dependent variable

μ = Overall mean

α_i = Effect of the i^{th} row or subject (animal) where 1 = {1, 2, 3, 4, 5}

β_j = Effect of the j^{th} column or order (period) where j = {1, 2, 3, 4, 5}

ρ_k = Effect of the k^{th} replicate where k = {1, 2, 3}

τ_l = Effect of the l^{th} treatment (concentrate levels) where 1 = {1, 2, 3, 4, 5}

ε_{ijklm} = Random error effect.

Treatment means were separated using the least significant difference (LSD) (Williams & Abdi, 2010) and significance difference determined at P<0.05.

RESULTS

Feeds chemical composition

The chemical composition of feed ingredients and compounded feed supplements used are shown in Table I.

Napier grass basal diet had a crude protein (CP) content above 7% (70g kg^{-1} DM), the minimum required for effective rumen function (Minson, 1981). The CP content of Leucaena hay was within the 189.0-275.7 gkg^{-1} DM reported by Ghosh & Bandyopadhyay (2007), but higher than the 220.3 gkg^{-1} DM reported by Garcia *et al*. (1996), and lower than the 340 gkg^{-1} DM reported by Ter Maulen *et al*. (1979) and 292.0 gkg^{-1} DM reported by Sethi & Kulkarni (2016) for Leucaena leaf meal. The CP, CF and ash contents of rice husks were higher than the 310, 350 and 175 gkg^{-1} DM, respectively, reported by Partama *et al*. (2019) but the fat (EE) content was lower than the 27 gkg^{-1} DM reported by the same authors. The mean NDF content for the treatment diets were 551.9, 562.8, 564.1, 592.4 and 603.8 gkg^{-1} DM for T1, T2, T3, T4 and T5, respectively.

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Table I: Chemical composition of feed ingredients, compounded concentrates and Napier grass used

Sample	Parameter								
	GE ($MJkg^{-1}$ DM)	DM (gkg^{-1})	DM basis (gkg^{-1})						
			Ash	CP	CF	EE	NDF	ADF	ADL
Napier grass	15.08	167.2	183.0	110.2	298.6	31.0	596.7	393.0	24.6
Leucaena hay	16.45	912.9	199.5	241.2	114.9	41.6	360.1	193.0	109.4
Sunflower seedcake	-	942.5	71.1	278.5	239.0	112.1	417.4	213.1	93.5
Maize meal	-	905.1	19.7	77.3	21.1	53.7	202.5	26.7	9.6
Maize germ	-	917.2	47.9	114.5	56.8	121.1	234.2	75.2	12.1
Maize cobs	17.20	930.6	25.7	56.4	350.8	0.7	824.4	414.5	39.0
Rice husks	14.15	923.9	246.2	37.9	449.5	8.0	712.2	554.0	161.3
T1 concentrate	-	915.6	87.7	153.9	174.5	73.8	406.2	240.7	60.1
T2 concentrate	-	901.1	107.9	146.2	66.3	71.3	446.0	102.9	50.7
T3 concentrate	-	908.1	203.4	177.0	118.7	63.1	416.1	202.4	100.9
T4 concentrate	-	905.8	172.3	222.2	142.7	30.1	541.8	242.0	118.0
T5 concentrate	-	908.8	174.3	160.4	76.7	85.5	392.4	136.8	71.7

DM – Dry matter; CP - Crude protein; CF - Crude fibre; EE – Ether extracts; NDF - Neutral detergent fibre; ADF - Acid detergent fibre; ADL - Acid detergent lignin; GE – Gross energy

Feed intake, digestibility, and milk production

The average dry matter feed intake of the goats, milk production, and feed digestibility are shown in Table II.

The basal DM intake (DMI) was highest (P<0.05) for T4, that had a concentrate with rice husks. The basal DMI was similar for T2, T3 and T5 and lowest (P<0.05) for T1 that had no Leucaena. The amount of concentrate DM offered by the respective supplements were 274.68, 270.33, 272.43, 271.74 and 272.64 g for T1, T2, T3, T4 and T5, respectively. The concentrate DM intake was similar and higher for T1, T2 and T5 where energy (ME) was 10 or 12 $MJkg^{-1}$ DM, but decreased (P<0.05) for T3 and T4 with decreasing ME level below 10 $MJkg^{-1}$ DM. The proportion of the concentrate DM consumed was 91.4, 94.0, 70.1, 29.8 and 96.5% of what was offered for T1, T2, T3, T4 and T5, respectively.

Table II: Average dry matter intake, milk production and diet digestibility for dairy goats fed Napier grass basal diet and supplemented with 300 g of various concentrate treatments.

Treatment (Diets)	Basal DMI (kg day^{-1})	Concentrate DMI (kg day^{-1})	Total DMI (kg day^{-1})	Milk production (mL day^{-1})	DMD (gkg^{-1})	OMD (gkg^{-1})
T1	0.816^{a}	0.251^{c}	1.067^{a}	243.7^{b}	615^{ab}	671^{ab}
T2	0.874^{b}	0.254^{c}	1.128^{b}	285.5^{d}	656^{b}	690^{b}
T3	0.868^{b}	0.191^{b}	1.059^{a}	257.3^{bc}	626^{ab}	657^{ab}
T4	0.952^{c}	0.081^{a}	1.059^{a}	221.3^{a}	601^{a}	636^{a}
T5	0.856^{b}	0.263^{c}	1.121^{b}	275.8^{cd}	656^{b}	686^{b}
LSD	0.0381	0.0140	0.0384	21.01	43.4	38.6

LSD – least significant difference between means; DM – Dry matter; DMI – Dry matter intake; DMD – Dry matter digestibility; OMD – Organic matter digestibility;
^{abcd} - Means bearing different superscripts within a column are significantly different (P<0.05)

The total DM intake (TDMI) was higher (P<0.05) for T2 and T5 than for the other diets. The total proportions of Leucaena in the diets consumed on DM basis were 0, 6.72, 10.95, 5.89 and 8.56% for T1, T2, T3, T4 and T5, respectively. The total DM intake by the goats as a percentage of live body weight were 3.24, 3.43, 3.22, 3.22 and 3.41% for T1, T2, T3, T4 and T5, respectively.

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Milk production was higher ($P<0.05$) for T2 whose supplement had more energy (12 MJ kg^{-1} DM) and lower CP (135 gkg^{-1} DM) but the production was similar to that of T5. In both cases (T2 and T5), Leucaena substituted sunflower seedcake that was used in the supplement for T1. The lowest ($P<0.05$) milk production was in T4. The DM digestibility of the diets was higher ($P<0.05$) for T2 and T5 than T4. Leucaena had little effect on DM digestibility as a source of protein (T2-T5) compared to sunflower seedcake (T1). OM digestibility was higher than DM digestibility but treatments followed a similar trend as for DM digestibility.

DISCUSSION

Feeds chemical composition

The CP content of Napier grass of 110.2 gkg^{-1} DM was within the range of 60-120 gkg^{-1} DM reported by Anindo & Potter (1994) and Muia *et al*. (2000); and the 20.0-270.0 gkg^{-1} DM reported by Skerman & Riveros (1990) for tropical grasses but higher than the mean CP content of 106.0 gkg^{-1} DM reported by the same authors. The Napier CP content was higher than the 66.3 gkg^{-1} DM reported by Njarui *et al*. (2003) and the 52-95 gkg^{-1} DM reported by Kariuki (1998). The CP content of the grass was well above the 7% CP minimum needed for effective rumen function (70.0 gkg^{-1} DM) (Minson, 1981), but below the 113.0 and 120.0 gkg^{-1} DM needed for ruminant growth and lactation, respectively (ARC, 1984). The NDF content of Napier grass was within the 500-600 gkg^{-1} DM characterized as moderate quality (Van Soest, 1982). The grass had an ADL content below the 60 gkg^{-1} DM level above which digestibility is negatively affected (Van Soest, 1982). The sunflower seedcake and Leucaena had CP contents higher than 240 gkg^{-1} DM, indicating their suitability as protein supplements. Though the Napier grass had high CP content favorable for ruminant microbial growth, grasses alone are inadequate for dairy goats' maintenance (Njarui *et al*., 2003; Yates & Panggabean, 1988), due to their high fibre content, poor digestibility (Njarui *et al*., 2003), and low protein content when mature (Minson, 1988). Together with the crop residues, grasses generally require supplementation with high protein forages such as legumes, or concentrates when fed so as to improve on digestibility and intake of the basal forage.

Feed intake

The basal DM intake was highest ($P<0.05$) for T4, that had a concentrate with rice husks which almost represented 0 g concentrate, as goats consumed very little of it. High consumption of basal diet DM is expected when there is no supplementation. The basal DMI was lowest ($P<0.05$) for T1 that had no Leucaena, indicating the value of a forage legume to stimulate basal DM intake. The consumption of 70.1 and 29.8% of the concentrate DM for T3 and T4, respectively, compared to over 90% for the other treatments shows that where the ME content was less than 10 $MJkg^{-1}$ DM (T3 and T4), the voluntary intake of the concentrate was also low. This agreed with the observation by NRC (2007) that DM intake decreases when the ME of a diet is below 12 $MJkg^{-1}$ DM but in this case, it was when it was below 10 $MJkg^{-1}$ DM. These treatments (T3 and T4) also had the lowest total DM intake (TDMI) though not significantly ($P>0.05$) different from T1.

For the higher ($P<0.05$) TDMI in T2 and T5 compared to T1, T3 and T4, the concentrates for T2 and T5 had over 50% maize meal, therefore the goats under these may have consumed higher amounts of energy from the concentrates which provided readily fermentable organic matter (FOM), leading to increased feed intake and volatile fatty acids (VFA) energy, thereby increasing the efficiency of microbial protein synthesis in the rumen (NRC, 2007). The improved efficiency of microbial protein synthesis led to greater supply of post-ruminal protein (Leng *et al*., 2020; NRC, 2007) to the goats, for an improved protein to energy (P:E) ratio of absorbed nutrients (Leng *et al*., 2020; Migwi *et al*., 2013). This has an effect of further increasing the feed intake (Migwi *et al*., 2013; NRC, 2007). It is noted that where Leucaena forage substituted the commercial sunflower seedcake, it was possible to use a lower CP level

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(135 vs 160 gkg^{-1} DM) and achieve similar TDMI as long as the ME is at least 10 MJkg^{-1} DM (T2 vs T5). This was because Leucaena mainly influenced positively the basal DMI, even when ME levels of the concentrate were similar (T1 vs T5), where TDMI improved ($P<0.05$) by 5.1% for T5 compared to T1. Use of the lower CP of 135 gkg^{-1} DM would reduce the cost of protein supplementation. The low TDMI by the goats under T3 and T4, was most likely caused by the inadequate supply of energy for rumen microbes to utilize the protein from both the Napier grass and concentrate, as the concentrate ME level was less than 10 MJkg^{-1} DM.

The low TDMI under T1 compared to T2 and T5 despite a ME of 10 MJkg^{-1} DM could have been due to the absence of the positive attributes from Leucaena which was missing in the diet. Leucaena has the benefits of better supply of minerals required by rumen microorganisms, especially the easily degraded soluble N that provides a valuable source of ammonia (Leng *et al*., 2020), and also a better amino acid profile of its protein that is similar to that of soya bean and fish meal (Leketa *et al*, 2019; Ter Maulen *et al*., 1979). The DM digestibility of the diets was higher ($P<0.05$) for T2 and T5 than T4 whose supplement had rice husks. Rice husks have low digestibility and affect the efficiency of ration use, unless injected with cellulolytic enzymes to hydrolyze the cellulose in them (Partama *et al*., 2019). These husks also contain high levels of silica which reduce digestibility.

In general, due to the low soluble carbohydrates in the DM of tropical grasses (Hennessy, 1980; Leng *et al*., 2020) and their high degree of lignification (Migwi *et al*., 2013), the Napier grass basal diet had low FOM which not only lowered the efficiency of microbial protein synthesis but also led to overall decrease in VFA energy absorbed by animals (NRC, 2007), and as a result, low voluntary feed intake (Preston, 1995) for all the treatments. Furthermore, the mean NDF content of the diets of 551.9-603.8 gkg^{-1} DM was considered to be too high for dairy goats, as the optimum dietary NDF proportion for maximum DMI is 350 gkg^{-1} DM (West *et al*., 1997). Goats are generally regarded as intermediate or mixed foragers (Shipley, 1999), selecting higher proportion of browse that are high in cell contents compared to cell wall that constitutes a greater proportion of DM in grasses (NRC, 2007) and preferred by larger ruminants like bovines, that are bulk feeders and can handle high fibrous diets.

The low TDMI levels of 1.06 to 1.13 kg translated to a DM intake of 3.2 to 3.4% of the goats' live body weights, compared to the potential of 7% body weight for dairy goats (Devendra & Burns, 1970; Steel, 1996). This low TDMI and therefore low milk productivity across all the treatments (diets) indicated that there was a deficiency in critical nutrients in the diets (Leng *et al*., 2020), limiting their capacity to supply the right amounts and balance of the nutrients required for milk production (Preston, 1995). Therefore, the available feeds were inefficiently utilized (Leng *et al*., 2020), which in turn led to low voluntary intake (Migwi *et al*., 2013). The nutrients absorbed from high fibre forages are reported to be imbalanced in ratios of protein: energy (P:E) and glucogenic: acetogenic substrates (Preston, 1995; Migwi *et al*., 2013; Leng *et al*., 2020), leading to inefficient utilization of acetate at tissue metabolism level (Leng *et al*., 2020; Migwi *et al*., 2013). This is in spite of the fact that acetate accounts for nearly 60-70% of VFA energy absorbed from the gut of ruminants (Leng *et al*., 2020; Migwi *et al*., 2013). The inefficient metabolism of acetate leads to heat increment and heat stress in an animal and may depress feed intake especially in the tropical environment (Leng, 1990; Leng *et al*., 2020; Migwi *et al*., 2013; Preston, 1995). Therefore, supplementing nutrients (amino acids) at both the rumen and tissue metabolism levels is important to ensure an appropriate protein to energy ratio in the nutrients absorbed in the gut for optimal efficiency of feed utilization, and minimizes wasteful disposal of absorbed acetate as heat increment (Preston, 1995). High heat increment in ruminants especially, under tropical condition is further exacerbated by the global warming thus compromising productivity.

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The total proportion of Leucaena in the diets consumed of 0 to 11% on DM basis was low, implying that there was no effect of mimosine toxicity or tannins protection of nutrients as bypass protein. Furthermore, there were no adverse effects observed in the goats, and DM digestibility of the diets was not adversely affected by the presence or absence of Leucaena. It is noted that small quantities of tree forages provide no bypass protein due to their fast degradation (Leng *et al*., 2020).

Milk yield

Milk production was higher for T2 (285.5 mL day^{-1}) whose supplement had more energy and lower CP but the production was similar to that of T5 (275.8 mL day^{-1}). In both cases (T2 and T5), Leucaena substituted sunflower seedcake in the supplement used in T1. As with TDMI, substituting the commercial sunflower seedcake (T1) with Leucaena forage (T2) allowed the use of a lower CP level (135 vs 160 gkg^{-1} DM) and achieve higher milk production (285.5 vs 243.7 mL) by 17.2%, though the level of energy, which is cheaper than protein, was raised. This was consistent with observation by Semenye *et al*. (1992) that a lactating dairy goat requires a supplement diet that has a CP content of 120 gkg^{-1} DM. This implies an overall reduction in the cost of protein supplementation.

The lowest mean milk production was recorded under T4 (221.3 mL day^{-1}), which was almost equivalent to what would be observed when there is no protein and energy supplementation. For the same CP and ME contents, goats on the diet with Leucaena as the source of protein produced 13.2% more milk (T5, 275.8 mL) than the goats on the diet with sunflower seedcake (T1, 243.7 mL). This could have been due to the positive effects of Leucaena such as being rich in minerals and a balanced amino acid profile (Leketa *et al*, 2019; Ter Maulen *et al*., 1979). The concentrate in T5 also had a higher proportion of energy-rich maize products (51.7 vs 24.3% for T1) and therefore more dietary starch, which enhances more production of propionate in the rumen (Otaru *et al*., 2020). Propionate is a precursor of the glucose formed in the liver and sometimes also in kidneys, some of which can be converted to galactose, with the two sugars being used for lactose synthesis in the mammary glands, which triggers a greater volume of milk (Otaru *et al*., 2020). For T1, there could have been insufficient glucogenic compounds to provide glucose for lactose synthesis (NRC, 2007; Preston, 1995), following a higher acetate to propionate ratio (A/P ratio) in comparison to T5. The high A/P ratio leads to low efficiency of using ME for milk production (NRC, 2007).

For all the treatments, the mean NDF contents of 551.9 - 603.8 gkg^{-1} DM were quite high, hence milk production was less than optimal, as high NDF content in a diet can decrease milk yield (West *et al*., 1997). However, the generally low milk production was also based on the low initial milk production (less than 1.0 L d^{-1}) by the goats that were under semi-zero grazing system before the feeding trial, and a high proportion of primiparous goats (60%) which produce less milk. Generally, the low milk productivity of ruminants in the tropical regions relative to their production potential is mainly attributed to the imbalanced nature of nutrients arising from digested forages that are available especially, when not adequately supplemented (Leng *et al*., 2020). Environmental factors such as the harsh climatic conditions (Leng *et al*., 2020), and genotype (Clark *et al*., 2017) or genetic quality of the goats also play a major role. Supplementation of diets for lactating goats should therefore aim to correct imbalances of nutrients for milk production (Preston, 1995), including bypass protein. Therefore, there is the need to lay emphasis on the nutrition and breeding aspects of the dairy goats in Kenya so as to improve their production performance.

CONCLUSION

It was concluded that when using *Leucaena leucocephala* as the protein source in lactating goats' supplementary concentrate and Napier grass as the basal diet, the appropriate CP and ME levels in the supplement are 135 gkg^{-1} DM and 12 MJkg^{-1} DM, respectively, and the supplement produced is superior to the commercial dairy

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meal. It was recommended that besides Leucaena, other protein-rich forages, especially those that are popular with farmers for dairy goats feeding, be explored for a wider diversity of what farmers can use.

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