

Effect of dried *Leucaena leucocephala* and *Manihot esculenta* supplementation leaves on feed intake, milk production, and milk composition of Holstein Friesian x Ankole crossbred cows

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Research Article

Keywords: Dairy cows, Democratic Republic of the Congo, Forage, Nutrient intake, Protein Supplements

Posted Date: January 31st, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2440834/v1>

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Abstract

This experiment was conducted to investigate the effect of dried *Leucaena* (*Leucaena leucocephala*) and cassava (*Manihot esculenta*) leaves on feed intake, milk production, and milk composition of Holstein Friesian x Ankole crossbred cows. Three cows in early lactation, with initial milk production of 4 ± 1.20 kg/day and 359 ± 24 kg average live body weight, were randomly assigned to the experimental diet in a 3x3 Latin square design. Three 15-day experimental periods were adopted (1 to 10-day: diet adaptation and 11 to 15-day: data collection). Cows were fed on a freshly chopped Guatemala grass diet supplemented with 1.25 kg DM of brewers' spent grain (control). The experimental diets were similar to the control diet differing in the presence of dried *Leucaena* or cassava leaves, both at the inclusion rate of 20% of the basal diet intake. Total dry matter intake, nutrient intake, milk production, and milk composition showed significant variation among treatments. Cows supplemented with dried cassava leaves had higher total dry matter intake and organic matter intake. *Leucaena* significantly increased ($p < 0.001$) daily milk production by 15% compared to cassava (3%). *Leucaena* had a higher milk fat content (38.44 g), while cassava and the control diet had higher milk protein (38.53 and 38.43 g), lactose (56.79 g and 56.111 g), and not-fat solids (102.41 g and 101.27 g). These results indicate that dried *Leucaena* and cassava leaves can be used as protein supplements for Guatemala grass basal diet for crossbred cows to improve milk production and quality.

Introduction

In the eastern Democratic Republic of the Congo (DRC), the integrated smallholder crop-livestock system is the dominant form of agricultural production (Maass et al., 2012). Its production is the primary source of food and income for rural households. Its expansion is thus desirable in alleviating poverty and enhancing food security. Smallholder dairying is particularly important as milk produced provides nutrients and income to the households. Despite its importance, feed quantity and quality are inadequate and rarely meet the nutrient requirements of lactating crossbred cows, especially during the dry season (Maleko et al., 2022). This is further exacerbated by the effects of rapid human population growth and the subsequent reduction in land available for pasture production, as well as climate change, negatively impacting pasture productivity shortage (Mugumaarhahama et al., 2021).

Consequently, inadequate nutrition of crossbred cows often culminates in substantial economic losses to the farmers due to low weight gain or milk production rates, poor body condition, reduced productive and reproductive performance, and susceptibility to pests and disease infestations Gebreyowhans and Zegeye, 2018). Alternative conventional supplements used by smallholder farmers, such as concentrates and agro-industrial by-products, are not readily available and, when available, are costly for most resource-poor smallholder farmers (Maass et al., 2012; Mutwedu et al., 2022). In response to this challenge, there is a need to provide alternative cheap-to-produce and locally available feed resources to supplement the feeds produced on smallholder farms.

Trees and shrubs are instrumental in delivering the triple-win strategy of enhancing livestock productivity, mitigating harsh climates in pastoral and agro-pastoral areas, and improving food security and rural livelihoods (Henry et al., 2018). This strategy is attributed to their multiple roles in contributing to the welfare of the cattle farming communities; and mitigating climate change through biological nitrogen fixation, carbon sequestration, and reduction of greenhouse gas emissions (Pello et al., 2021). Trees and shrubs are highly valued because of their high volume of biomass production, nutritional value, and adaptation to poor soil and harsh climatic conditions (Osuga et al., 2011, Barwani et al., 2022). Osuga et al. (2008) reported that tender shoots, leaves, pods, twigs, and fruits of trees and shrubs are rich in proteins, vitamins, and minerals compared to natural pastures. Integrating trees and shrubs into animal diets improves palatability, feed intake, digestibility, and lactation performance (Derero and Kitaw, 2018; Osuga et al., 2011). Although the benefits of trees and shrubs such as Leucaena (*Leucaena leucocephala* (Lam.) De Wit) and cassava (*Manihot esculenta* Grantz) are well known and used by smallholder farmers in the tropics (Franzel et al., 2014; Wanapat et al., 2003), the studies focusing on the utilisation of Leucaena and cassava as cattle feeds, notably in the eastern DRC context, remain a significant literature gap.

Leucaena is a plant that potentially improves soil fertility, introduced to eastern DRC 20 years ago. It is mostly used in soil fertility management as a source of green manure. The plant has the propriety of colonizing a wide range of soils due to its early year-round flowering and fruiting, abundant seed production, self-fertility, seed coat, and ability to regrow after burning or on being cut. These characteristics make the plant survive and multiply on farms, thus availing its resources all year round, which can be used in supplementing ruminants. Leucaena leaves are highly palatable, digestible (50–70%), and nutritious (22–40% of CP) (Katunga et al., 2014, Barwani et al., 2022). These good nutritional characteristics make the leaves suitable for supplementation in ruminant diets and have been shown to increase milk production, fat, and protein contents (De Angelis et al., 2021). Besides the Leucaena trees, cassava is also grown in the eastern DRC for its roots which constitute a staple food for more than 70% of the population, and its leaves are consumed throughout the year as a vegetable (Munyahali et al., 2017). However, for household consumption, most farmers (80%) cut only the young leaves without petiole to avoid fibrous stuff, leaving the other parts of the leaves as mulch or lost during root harvest (Munyahali et al., 2017). Wanapat et al. (2011) reported that cassava leaves at any stage of growth can still have good levels of protein (> 14%), vitamins, minerals, low condensed tannins (1.5–4%); and can be used as a source of nutrients to dairy animals after removing the hydrocyanic acid (HCN) content. However, the information about the nutritional and feeding characterisation of Leucaena and cassava leaves is inadequately addressed, which constitutes an obstacle to its utilisation in feeding the crossbred cows in the study region. Furthermore, scientifically generated information is useful in developing livestock feeds and feeding management policies. Therefore, this study investigated the effects of supplementing Guatemala grass with dried Leucaena and cassava leaves as nitrogen sources on feed intake, milk production, and milk composition of lactating Holstein Friesian x Ankole crossbred cows in the eastern DRC. The study findings would enable policymakers and farmers to design appropriate intervention strategies to improve livestock productivity and serve as a benchmark for future research.

Materials And Methods

Experimental animals, experimental design, and treatments

The experiment was conducted at the Catholic University of Bukavu research farm in Kabare, South-Kivu province, DRC. The study followed the national guidelines for the use and care of animals (license No: 55.00/99/IPPEL/SK/2021). Three lactating Holstein-Friesian x Ankole crossbred cows were randomly assigned to three dietary treatments in a 3 x 3 Latin square design. All cows had similar lactation characteristics, early lactation, third parity, average body weight (359 ± 24 kg), initial milk production (4 ± 1.2 kg/day), days-in milk (24 ± 9.02 days), and age were four years. The experiment lasted 45 days, divided into three 15-day experimental periods, which were periodized into 1 to 10-day (diets adaptation periods), and 11 to 15-day (data collection). Cows were fed on fresh Guatemala grass *ad libitum* and supplemented with 1.25 kg DM of fresh brewers' spent grain as a basal diet (control). All cows were supplemented with dried Leucaena or cassava leaves at the inclusion rate of 20% of basal diet intake. The supplement was offered twice daily after milking (at 8:00 a.m. and 4:00 p.m.). All cows were housed in well-ventilated stalls and fed individually. Cows had free access to freshwater and mineral licks (Mineral block containing 37.79% Sodium, 1.96% Calcium, 0.32% Magnesium, 0.105% Iron, 0.023% Zinc, 0.018% Copper, 0.015% Manganese, 0.0015% Cobalt, 0.00099% Iodine, and 0.00049% Selenium). Fresh brewers' spent grain was purchased every three days from Bralima company, Bukavu, DRC. Leucaena and cassava leaves were hand-harvested during the rainy season from smallholder farmers' fields in Uvira territory, South-Kivu province, DRC. Plant production conditions are fairly similar in most smallholder systems ensuring minimum variation in the characteristics of the harvested herbage. Generally, leaves from Leucaena regrowth of about four months old were cut and dried under the shade, while the cassava leaves came from plants about ten months old. The cassava leaves were harvested and dried in the sun for three days to reduce the hydrocyanic acid content (Wanapat et al., 2003). The dried leaves were put into sacks and stored properly for feeding. Guatemala grass regrowth of about five months old was collected from the Catholic University of Bukavu farm, chopped, and used in the experiment.

Data collection and chemical analysis

Feed offered and refusals were measured daily throughout the experimental period to determine daily dry matter intake. Leucaena, cassava, brewers' spent grain, and Guatemala grass was sampled daily throughout the experimental period, compounded, and then shade-dried for subsequent chemical analysis at the Animal Nutrition Laboratory of the Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. The samples were determined for dry matter (DM), ash, crude protein (CP), ether extract (EE), and crude fibre (CF) according to methods described by Abdulrazak and Fujihara (1999). Milk production (kg) was collected daily and weighed using a Camry scale (Camry company, China). Milk samples were composited daily from morning and afternoon milking, refrigerated in an ice-packed cooler, and then stored. The milk samples were then analysed for milk composition (fat, protein, lactose, solids not-fat content) at the Microbiology Laboratory of the Université Evangélique en Africa, Bukavu, DRC, using the Milk Analyser Lactostar 3510 (Funke Gerber, Germany).

Statistical analysis

Data on feed intake, milk production, and milk composition were analysed for two-way repeated measures analysis of variance (ANOVA) using R software for windows, version 4.1.3 (R Core Team, 2022). Significant treatment means were separated using Tukey's multiple comparisons test. The model used is presented below.

$$Y_{ijt} = \mu + C_i + P_j + T_t + \epsilon_{ijt}$$

where Y_{ijt} = $i \dots 3, j = 1 \dots 3, t = 1 \dots 3$; μ , overall mean; C_i , fixed cow effect; P_j fixed period effect; T_t , fixed treatment effect; ϵ_{ijt} random residua error.

Results

The results for the chemical composition of the feedstuff tested in this experiment are shown in Table 1. The organic matter content of the diets ranged from 78.5% in cassava to 87.2% in Leucaena. The crude protein content of Leucaena was at 30.1% of the DM, which was higher than that of cassava. Leucaena and Guatemala grass had respective crude fibre levels of 12.9% and 12.7%, which were higher than cassava at 9.5% of the dry matter. Guatemala grass had a CP content of 10.9% DM.

Table 1
Chemical composition (%) of the feedstuff used in the experiment

	Guatemala	Brewers' spent grain	Leucaena	Cassava
Dry matter	88.8	90.2	90.5	89.3
<i>Dry matter (%)</i>				
Ash	9.1	3.3	11.6	10.9
Organic matter	79.8	78.6	87.2	78.5
Crude protein	10.9	8.5	30.1	21.7
Ether extract	7.3	1.2	5.3	6.1
Crude fibre	12.7	4.6	12.9	9.5

Cows fed on the control diet consumed an average of 7.87 kg DM of Guatemala grass compared to 6.84 kg and 7.37 kg DM consumed by cows supplemented with Leucaena and cassava, respectively (Table 2). Cows consumed similar amounts of dried Leucaena and cassava leaves. Cows consumed all the 1.25kg DM of the brewers' spent grain offering. The average daily CP supplement intake was 0.98 kg for Leucaena compared to 0.78 kg for cassava. The average total DM intake per cow for the control diet was

9.12 kg. Total DM intake significantly increased with Leucaena and cassava supplementation by 20% and 26%, respectively.

Table 2
Average daily intake (kg) for Holstein Friesian x Ankole crossbred cows fed Guatemala grass and supplemented with dried Leucaena and cassava leaves

	Treatments			SEM	Prob > F
	Control	Leucaena	Cassava		
Dry Matter intake					
Tree and shrub supplements	0.00 ^b	2.83 ^a	2.83 ^a	0.20	0.001
Guatemala grass	7.87 ^a	6.84 ^c	7.37 ^b	0.18	0.001
Brewers' spent grain	1.25	1.25	1.25	0.00	-
Total	9.12 ^c	10.92 ^b	11.45 ^a	0.24	0.001
Organic matter intake					
Tree and shrub supplements	0.00 ^c	2.73 ^a	2.49 ^b	0.18	0.001
Guatemala grass	7.07 ^a	6.14 ^c	6.62 ^b	0.16	0.001
Brewers' spent grain	1.09	1.09	1.09	0.00	-
Total	8.16 ^b	9.97 ^a	10.20 ^a	0.22	0.001
Crude protein intake					
Tree and shrub supplements	0.00 ^c	0.98 ^a	0.78 ^b	0.06	0.001
Guatemala grass	1.07 ^a	0.93 ^c	1.01 ^b	0.02	0.001
Brewers' spent grain	0.12	0.12	0.12	0.00	-
Total	1.19 ^c	2.03 ^a	1.91 ^b	0.06	0.001
Means within rows with different superscripts differ (p < 0.05)					
SEM, standard error of means					
Prob > F probability value					

Feeding the cows on the control diet resulted in an average daily milk production per cow of 5.96 kg. Supplementing the cows with dried cassava and Leucaena leaves increased this amount by 3% and 15% of daily milk production. However, the increase in milk production in cows supplemented with dried cassava leaves did not significantly differ from those fed on the control diet, as presented in Table 3. The

milk fat content from cows supplemented with dried *Leucaena* leaves was higher than those supplemented with dried *Cassava* leaves. The milk protein, lactose, and non-fat solids contents from cows supplemented with dried cassava leaves were higher than those of *Leucaena*.

Table 3
Average daily milk production (kg) and milk composition (g) of Holstein Friesian x Ankole crossbred cows fed Guatemala grass supplemented with dried *Leucaena* and cassava leaves

	Treatments			SEM	<i>Prob > F</i>
	Control	<i>Leucaena</i>	Cassava		
Milk production	5.96 ^b	6.83 ^a	6.13 ^b	0.44	0.001
Milk composition					
Fat	29.89 ^b	38.44 ^a	28.17 ^b	1.40	0.002
Protein	38.43 ^a	33.28 ^b	38.53 ^a	0.68	0.001
Lactose	56.11 ^a	48.26 ^b	56.79 ^a	1.00	0.001
Solids-not-fat	101.27 ^a	89.23 ^b	102.41 ^a	1.61	0.001
Means within rows with different superscripts differ ($p < 0.05$)					
SEM, standard error of means					
<i>Prob > F</i> probability value					

Discussions

In this study, the CP content of Guatemala grass was higher than the 6.9% reported by Nivyobizi et al. (2010) and 8.9% reported by Mtengeti et al. (2006). This content was, however, comparable to the 11.8% reported by Maleko et al. (2022). The plant and environmental factors can explain the fluctuation in the nutritional composition of Guatemala grass because its nutritional quality tends to degrade with maturity, which is also associated with a decrease in the proportion of leaves relative to stems, reducing forage intake (Perera and Perera, 1994). The CP content of dried *Leucaena* leaves was 30.1% higher than cassava. This content was within the range of 24 to 34% reported by Verdecia et al. (2019) and low compared to the 40.1% DM reported by Barwani et al. (2022). This trend was similar for ash, organic matter, and crude fibre. Conversely, cassava had a higher ether extract content (6.1%) than *Leucaena* (5.3%). The dried cassava leaves ether extract was comparable to the 5.9 to 6.2% range reported by Wanapat (2003).

Leucaena and cassava supplements significantly ($p < 0.001$) decreased the DM intake of Guatemala grass. This can be explained by the bulkiness of the forages, leading to the substitution effect. In this

study, supplementing Guatemala grass with dried cassava and *Leucaena* leaves increased total DM intake by 20% and 26%, respectively. Cassava results match that of Wanapat et al. (2018), who reported that total DM intake in lactating crossbred cows was higher due to the good palatability of cassava silage which would be comparable to the dried leaves used in this study. The results for dried *Leucaena* leaves supplementation also agree with those of Stifkens et al. (2022), who reported the increment in dry matter intake of beef steers on the Rhodes grass basal diet coupled with supplementation of an increased proportion of *Leucaena* hay.

This study showed that *Leucaena* supplements significantly ($p < 0.001$) increased daily milk production more than cassava. Despite their high CP content and total DM intake, there were no significant differences in milk production between cows fed the control diet, and cows supplemented with dried cassava leaves. Contrary, Wanapat et al. (2018) reported an increase in milk production when crossbred cows were supplemented with different levels of cassava top silage. This difference in milk production can be attributed to the crossing of the experimental animals, climate, diseases, and diet. With regard to the diet, the anti-nutritional content of cassava leaves (condensed tannins and hydrocyanic acid), their stage of maturity, means of supplementation, and the amount added would affect this milk production. For instance, the means of supplementation in this study were different from those of Wanapat et al. (2018). This study used dried cassava leaves, while Wanapat et al. (2018) supplemented cows with top silage. It has been reported that silage plays a critical role in reducing anti-nutritional contents and improving the feed quality of tree and shrub legumes (Balehegn et al., 2022), which could increase milk production in this study.

The concentration of 5–9% of condensed tannins has been reported to form complexes with protein, reducing nutrient digestibility and feed intake and thus affecting livestock performances (Ebrahim and Negussie, 2020). The current study recorded the highest milk production when Guatemala grass was supplemented with dried *Leucaena* leaves. This result confirms the high forage value of this species (Maasdorp et al., 1999, Barwani et al., 2022). Protein has been reported to be an important factor in maintaining the rumen environment of animals, thus stimulating DM intake and digestibility (Nguyen et al., 2017). Therefore, supplementing *Leucaena* with a higher CP content (30.1%) in this study resulted in an improved intake of Guatemala grass, leading to high milk production.

The milk composition of cows fed on the control diet was similar to those supplemented with dried cassava leaves but significantly different ($p < 0.05$) from cows supplemented with dried *Leucaena* leaves (Table 3). The milk fat content was higher from cows fed basal diet plus dried *Leucaena* leaves supplement than for the control diet and those on dried cassava leaves. Therefore, the average value of milk fat in this study is considered to be lower than that obtained by Nugroho et al. (2019). This higher milk fat content from cows supplemented with dried *Leucaena* leaves could be attributed to its high crude fibre content (Table 1), which increases the molar proportion of acetate and butyrate in the rumen. Acetic and butyric acids are known as precursors of milk synthesis (Flores-Cocas et al., 2021). Additionally, supplementing cows with dried *Leucaena* leaves in this study is also beneficial in maintaining crude fibre levels in the rumen.

The milk protein, lactose, and solids not-fat contents of cows fed on the control diet and cows supplemented with dried cassava leaves were higher than those from cows supplemented with dried *Leucaena* leaves. Since cows supplemented with dried cassava and *Leucaena* leaves consumed an additional CP of 0.78 kg and 0.98 kg, respectively, it was expected that the lesser increase in milk protein and lactose contents would be realised from cows supplemented with dried *Leucaena* leaves. Unexpectedly, higher milk protein contents were recorded from cows supplemented with cassava leaves as well as from the control diet. In this study, dried *Leucaena* leaves had higher CP content which would help in the supply of amino acids and indirectly supported milk protein synthesis, thus increasing milk protein content. Kakengi et al. (2001) reported similar results, whose supplementation of *Leucaena* to grazing crossbred cows increased milk production, weight gain, and enhanced milk composition but had no significant effect on milk protein.

In this study, the milk lactose content from cows fed a basal diet and supplemented with dried *Leucaena* leaves was similar to that of Osorio et al. (2016). This study showed that supplementing Guatemala grass with dried *Leucaena* leaves on lactose content followed the same trend as milk production. It has been reported that lactose content in the milk is nearly stable and is, therefore, crucial for the volume of produced milk in the udder (Osorio et al., 2016). Lactose acts as a water binder; more lactose synthesised leads to more amount of milk production. Milk production depends on the mammary synthesis of lactose because its osmoregulation of milk induces mammary absorption of water. Thus, the rate of lactose synthesis in the epithelial cells of the mammary gland serves as a major factor influencing milk volume production (Osorio et al., 2016).

Conclusion

The results indicate that supplementing Guatemala grass with dried *Leucaena* or cassava leaves increased total DM intake and milk production and improved milk quality. *Leucaena* and cassava, which establish easily and are found abundant in eastern DRC, can be used as sources of proteins and play a significant role in efficiently utilising Guatemala grass. Hence, according to our study, we recommend incorporating 20% of dried *Leucaena* or cassava leaves into the diet of Holstein Friesian x Ankole crossbred cows raised in the middle and highlands of eastern DRC.

Declarations

Ethics approval

The study was ethically cleared (license No: 55.00/99/IPPEL/SK/2021).

Consent to participate

Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

Data are available from the corresponding author upon reasonable request.

Acknowledgements

The authors thank the International Institute of Tropical Agriculture (IITA) for the fieldwork and laboratory analyses grant. We also wish to acknowledge the Catholic University of Bukavu farm workers for their cooperation and assistance during data collection.

Funding

This study was supported by the Integrated Project for Agricultural Growth in the Great Lake regions (PICAGL), funded by the World Bank Group through the Government of the Democratic Republic of the Congo (DRC) and implemented by the International Institute of Tropical Agriculture (IITA) in South-Kivu and Tanganyika provinces.

Author contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Didier Kichochi Barwani, Mathew Gitau Gicheha, Dieudonne Musala Katunga, Rodriguez Basengere Balthazar Ayagirwe, Samy Bashizi Bacigale, and Isaac Maina Osuga. Didier Kichochi Barwani wrote the first draft of the manuscript, and all authors commented on previous versions. All authors read and approved the final manuscript.

References

1. Abdulrazak, S. A., and Fujihara, T., 1999. Animal nutrition. A Laboratory Manual, (K
2. Balehegn, M., Ayantunde, A., Amole, T., Njarui, D., Nkosi, B. D., Müller, F. L., Meeske, R., Tjelele, T. J., Malebana, I. M., Madibela, O. R., Boitumelo, W. S., Lukuyu, B., Weseh, A., Minani, E., and Adesogan, A. T., 2022. Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. *Agronomy Journal*, 114(1), 75–99.
3. Bayissa, T., Dugumaa, B., and Desalegn, K., 2022. Chemical composition of major livestock feed resources in the medium and low agroecological zones in the mixed farming system of Haru District, Ethiopia. *Heliyon*, 8(2).
4. Barwani, D. K., Bacigale, S. B., Kibitok, N. K., Webala, A. W., Gicheha, M. G., Katunga, D. M., & Osuga, I. M. (2022). Nutritional characterization of eight trees and shrub used livestock feeds in the Eastern Democratic Republic of the Congo. *Livestock Research for Rural Development*, 34(86).
5. De Angelis, A., Gasco, L., Parisi, G., and Danieli, P. P., 2021. A multipurpose leguminous plant for the mediterranean countries: *Leucaena leucocephala* as an alternative protein source: a review. *Animals*,

11(8), 1–16.

6. Derero, A., and Kitaw, G., 2018. Nutritive values of seven high priority indigenous fodder tree species in pastoral and agro-pastoral areas in Eastern Ethiopia. *Agriculture and Food Security*, 7(1), 1–9.
7. Ebrahim, H., and Negussie, F., 2020. Effect of secondary compounds on nutrients utilization and productivity of ruminant animals: A review. *Journal of Agricultural Science and Practice*, 5(1), 60–73.
8. Flores-Cocas, J. M., Aguilar-Pérez, C. F., Ramírez-Avilés, L., Solorio-Sánchez, F. J., Ayala-Burgos, A. J., and Ku-Vera, J. C., 2021. Use of rice polishing and sugar cane molasses as supplements in dual-purpose cows fed *Leucaena leucocephala* and *Pennisetum purpureum*. *Agroforestry Systems*, 95(1), 43–53.
9. Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., and Wambugu, C., 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, 6(1), 98–103.
10. Gebreyowhans, S., and Zegeye T., 2018. Effect of dried *Sesbania sesban* leaves supplementation on milk yield, feed intake, and digestibility of Holstein Friesian x Zebu (Arado) crossbred dairy cows. *Tropical Animal Health and Production*.
11. Henry, B. K., Eckard, R. J., and Beauchemin, K. A., 2018. Review: adaptation of ruminant livestock production systems to climate changes. *Animal*, 12(2), 445–456.
12. Kakengi, A. M., Shem, M. N., Mtengeti, E. P., and Otsyina, R., 2001. *Leucaena leucocephala* leaf meal as supplement to diet of grazing dairy cattle in semiarid Western Tanzania. *Agroforestry Systems*, 52(1), 73–82.
13. Katunga, M.M.D., Muhigwa, B.J.B., Kashala, K.J.C., Kambuyi, M., Nyongombe, N., Maass, B. L., and Peters, M., 2014. Agro-ecological adaptation and participatory evaluation of multipurpose tree and shrub legumes in mid altitudes of Sud-Kivu, DR. Congo. *American Journal of Plant Sciences*, 5, 2031–2039.
14. Katunga, M.M.D., 2013. Evaluation des légumineuses fourragères dans un système d'élevage, (Unpublished PhD thesis, University of Lubumbashi).
15. Maasdorp, B. V., Muchenje, V., and Titterton, M., 1999. Palatability and effect on dairy cow milk yield of dried fodder from the forage trees *Acacia boliviana*, *Calliandra calothyrsus*, and *Leucaena leucocephala*. *Animal Feed Science and Technology*, 77, 49–59.
16. Maass, B. L., Katunga, M.M.D., Chiuri, W. L., Gassner, A., and Peters, M., 2012. Challenges and opportunities for smallholder livestock production in post-conflict South Kivu, eastern DR Congo. *Tropical Animal Health and Production*, 44(6), 1221–1232.
17. Maleko, D., Msalya, G., and Mtei, K., 2022. Effects of dry season supplementation of *Calliandra calothyrsus* leaf-meal mixed with maize-bran on dairy cattle milk productivity in the west Usambara Highlands, Tanzania. *Livestock Research for Rural Development*, 34(8).
18. Mtengeti, E., Kavana, N., Urio, P., and Shem, M., 2006. Chemical composition and fermentative quality of fodder grasses ensiled with derided fresh sugarcane crush. *Tropical and Subtropical Agroecosystems*, 6, 157–165.

19. Mugumaarhahama, Y., Ayagirwe, R. B. B., Mutwedu, V. B., Cirezi, N. C., Wasso, D. S., Azine, P. C., and Karume, K., 2021. Characterization of smallholder cattle production systems in South-Kivu province, eastern Democratic Republic of Congo. *Pastoralism: Research, Policy and Practice*, 11(4).
20. Munyahali, W., Pypers, P., Swennen, R., Walangululu, J., Vanlauwe, B., and Merckx, R., 2017. Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. *Field Crops Research*, 214, 194–201.
21. Mutwedu, V. B., Bacigale, S. B., Mugumaarhahama, Y., Muhimuzi, F. L., Munganga, B., Ayagirwe, R. B. B., Nguetzet, P. M. D., and Manyawu, G., 2022. Smallholder farmers' perception and challenges toward the use of crop residues and agro-industrial byproducts in livestock feeding systems in Eastern DR Congo. *Scientific African*, 16.
22. Nguyen, T. T. G., Wanapat, M., Phesatcha, K., and Kang, S., 2017. Effect of inclusion of different levels of *Leucaena* silage on rumen microbial population and microbial protein synthesis in dairy steers fed on rice straw. *Asian-Australasian Journal of Animal Sciences*, 30(2), 181–186.
23. Nivyobizi, A., Deswysen, A., Dehareng, D., Peeters, A., and Larondelle, Y., 2010. Nutritive value of some tropical grasses used by traditional small farms in the highlands of Burundi. *Tropical Animal Health and Production*, 42(4), 561–567.
24. Nugroho, D. F., Suranindyah, Y. Y., and Astuti, A., 2019. The effect of supplementation of *Leucaena leucocephala* leaf in Friesian Holstein cows ration on milk production and composition. *IOP Conference Series: Earth and Environmental Science*, Volume 387, the 8th international seminar on tropical animal production, 23–25 september 2019, Yogyakarta, Indonesia.
25. Osorio, J. S., Lohakare, J., and Bionaz, M., 2016. Biosynthesis of milk fat, protein, and lactose: Roles of transcriptional and posttranscriptional regulation. *Physiological Genomics*, 48(4), 231–256.
26. Osuga, I.M., Abdulrazak, S. A., Muleke, C. I., and Fujihara, T., 2011. Effect of supplementing Rhodes grass hay (*Chloris gayana*) with *Berchemia discolor* or *Zizyphus mucronata* on the performance of growing goats in Kenya. *Journal of Animal Physiology and Animal Nutrition*, 96(4), 634–639.
27. Osuga, I.M., Wambui, C. C., Abdulrazak, S. A., Ichinohe, T., and Fujihara, T., 2008. Evaluation of nutritive value and palatability by goats and sheep of selected browse foliages from semiarid area of Kenya. *Animal Science Journal*, 79, 582–589.
28. Pello, K., Okinda, C., Liu, A., and Njagi, T., 2021. Adaptation to climate change through Agroforestry in Kenya. *Land*, 10(4), 1–16.
29. Perera, A. N., and Perera, E. R., 1994. Nutritive value and ensiling characteristics of Guatemala grass harvested at different stages of maturity. *Journal of the National Science Council of Sri Lanka*, 3(22), 245–251.
30. R Core Team, 2022. R: A language and environment for statistical computing. <http://www.r-project.org>
31. Steinfeld, H., Wassenaar, T., and Jutzi, S., 2006. Livestock production systems in developing countries: Status, drivers, trends. *Revue Scientifique et Technique International Office of Epizootics*, 25(2), 505–516.

32. Stifkens, A., Matthews, E. M., McSweeney, C. S., and Charmley, E., 2022. Increasing the proportion of *Leucaena leucocephala* in hay-fed beef steers reduces methane yield. *Animal Production Science*, 62(7), 622–632.
33. Verdecia, D. M., Herrera, R. S., Ramírez, J. L., Leonard, I., Bodas, R., Andrés, S., Giráldez, F. J., Valdés, C., Arceo, Y., Paumier, M., Santana, A., Álvarez, Y., Mendez, Y., and López, S., 2019. Effect of age of regrowth, chemical composition and secondary metabolites on the digestibility of *Leucaena leucocephala* in the Cauto Valley, Cuba. *Agroforestry Systems*, 94(4), 1247–1253.
34. Wanapat, Metha, Phesatcha, K., Viennasay, B., Phesatcha, B., Ampapon, T., & Kang, S., 2018. Strategic supplementation of cassava top silage to enhance rumen fermentation and milk production in lactating dairy cows in the tropics. *Tropical Animal Health and Production*, 50(7), 1539–1546.
35. Wanapat, M., Boonnop, K., Promkot, C., and Cherdthong, A., 2011. Effects of alternative protein sources on rumen microbes and productivity of dairy cows. *Maejo International Journal of Science and Technology*, 5(1), 13–23.
36. Wanapat, M., 2003. Manipulation of cassava cultivation and utilization to improve protein to energy biomass for livestock feeding in the tropics. *Asian-Australasian Journal of Animal Sciences*, 16(3), 463–472.