Journal of Agriculture Science & Technology JAGST 25 (2) 2026, 90 - 104

ORIGINAL RESEARCH ARTICLE

Economic assessment of feeding forage-based diets to dairy goats under smallholder production systems in Gash-Barka region, Eritrea

Tekleab Kidanemariam Ghebregziabiher[1,2], Vincent Mwashi[1], Getachew Gebru Tegegn[3], Mengistu Russom Araya[2], Mathew Gitau Gicheha[1], Isaac Maina Osuga[1]

[1]*Department of Animal Sciences, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*
[2]*Department of Animal Sciences, Hamelmalo Agricultural College, Keren, Eritrea*
[3]*Fellow Ethiopian Academy of Sciences (EAS), Addis Ababa, Ethiopia*

Corresponding author email: gicheham@jkuat.ac.ke

Abstract

High feed costs and the widespread use of low-quality pastures are major constraints to the expansion of livestock sector in Eritrea. This is despite the fact that the country has livestock breeds with high genetic potential to support high production. The Hassani goat breed has good dairy characteristics capable of producing sufficient milk for household use and sale. However, its performance remains suboptimal due to inadequate nutrition and management. This study evaluated the economic performance of using forage-based diets to feed goats from the Hassani dairy breed in Gash-Barka region, Eritrea. An on-farm feeding experiment was conducted using 24 Hassani dairy goat breed which were randomly assigned to 4 dietary treatments with 6 goats for each treatment. The treatments diets comprised 80% sorghum stover with 20% *Acacia tortilis* pod meal (T1), 50% sorghum stover (*Sorghum bicolor* (L.) Moench), 20% alfalfa (*Medicago sativa*), and 30% elephant grass (*Pennisetum purpureum*) (T2), 50% sorghum stover, 30% alfalfa, and 20% elephant grass (T3), and 50% sorghum stover, 25% alfalfa, and 25% elephant grass (T4). Data corresponding to each treatment diet on dry matter intake (kg), milk yield (mL), feed costs (USD), and farm income (USD) were recorded. Milk yield and feed intake were subjected to analysis of variance using R software. The Least Significant Difference (LSD) method was used in means separation with differences considered at 0.05 level of significance while economic outcomes were evaluated using partial budget analysis. Results indicated that gross revenue ranged from 158.8 USD (T1) to 256.9 USD (T4). Total variable costs were highest in T1 (214.1 USD) and substantially lower in T2–T4 (93.2–110.5 USD). Consequently, T1 resulted in a negative gross margin (-55.3 USD), whereas T2, T3, and T4 generated positive gross margins of 160.8, 150.3, and 146.5 USD, respectively. Marginal rate of return analysis indicated economic superiority of the forage-based diets, with T2 emerging as the most economically advantageous option. An analysis of the study findings showed that supplementing sorghum stover with alfalfa and elephant grass significantly improves milk production and economic returns in smallholder dairy goat production in Gash-Barka, Eritrea.

Keywords: Forage-based diets, dairy goats, partial budget analysis

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

1.0 Introduction

In Sub-Saharan Africa, small ruminants play a pivotal role in smallholder livestock systems, sustaining both food supply and nutritional well-being (Daskiran et al., 2018). According to Wodajo et al. (2020), most smallholder family households rely on goats for provision of easily accessible animal protein and household incomes (Amayi et al. 2021). Additionally, millions of people in many developing nations depend on goats farming for their livelihoods (Nyariki and Amwata, 2019). According to Miller and Lu (2019), dairy goats provide benefits to farmers in terms of milk, meat, skins, and manure which is used as fertilizer.

The feed expenses is approximated at 70% of the total costs in livestock production systems (Alqaisi et al., 2017). This can be extrapolated to correspond to the highest cost in milk production implying the existence of a relationship between the daily milk production and the daily dry matter intake (Oliveira et al., 2014) which offers an opportunity for economic benefits analysis. In developing nations, the use of grains for supplementation in animal feeding is not economically sustainable due to high costs (Katongole et al., 2012) and inaccessibility (Haile 2017b). Thus, feeding of ruminant with higher amounts of concentrates could lead to high cost thus compromising the profitability of smallholder dairy farms.

Most tropical grazed livestock systems are characterised by inadequate and low-quality feed resources (Rocha Filho et al., 2021). More specifically, the quality and quantity of pastures become insufficient during dry seasons (Abraham et al., 2018) leading to reduced feed intake and overall herd yield (Paula et al., 2020). This can be alleviated by reduced reliance on costly feed resources through adoption of cheaper high-quality forage-based diets. For efficient and profitable dairying, provision of additional feed resources is necessary for higher milk production (Ramsbottom et al., 2015). The use of crop residues is an alternative for addressing pasture shortage during dry season. In most extensive systems, crop residues have been utilized to supplement available forage to meet animal nutritional requirements (Haile et al. 2017a; Mutimura et al., 2015). Various studies (Haile et al. 2017b; Malisetty et al., 2014; Sarnklong et al., 2010) suggest that supplementation during period of pasture unavailability is an effective way of enhancing the utilization of crop residues to sustain livestock performance. However, crop residues cannot provide the nutrients required for optimised milk production from dairy goat due to their inferior nutritional quality.

Dairy farms economic sustainability anchors on a feeding program that maximises income over feed costs (Linn et al., 2009; Maria et al., 2022). Santana et al. (2014) highlighted that the profitability of production systems depends on feed conversion efficiency in animal products. Therefore, it is necessary to evaluate the feed intake and feed efficiency of forages to ensure maximum utilization of nutrients for more milk production and attractive cost benefit ratio (Branco et al., 2011). Feed costs are among the highest expenses in milk production in many farms, making it essential for farmers to explore ways to lower the cost of feeding animals. Supplementation raises production costs, and effective farm management depends on its use for cost and efficiency (Vaintrub et al., 2021). According to Gwiriri et al. (2016), diets based on

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

forages, such as velvet beans and lablab, have a substantially greater dietary net income and lower production expenses per litre of milk produced than a commercial diet.
In small-scale dairy systems, using good quality and easy to produce forages can be an economical intervention to maximize revenue by lowering the cost of producing one litre of milk (Gwiriri et al., 2016). Utilizing inexpensive on-farm produced forages as a feed source in resources constrained production systems improve their economic sustainability. The alternative of using commercial feeds to boost production and income in smallholder dairy systems is economically not viable (Muteng'e, 2021). In Eritrea, sorghum, alfalfa and elephant grass forages have been cultivated on the arable land and riverbanks respectively (Haile et al., 2017a). Venkateswarlu et al. (2014) found that sorghum forage could be utilised in small ruminant feeding without compromising feed intake and nutrient digestibility. Alfalfa, a highly palatable protein-rich legume has been used in ruminant feeding due to its high quality fibre with high digestibility and its rumen buffering properties (Yu et al., 2021; Rukiya, 2019). Moreover, elephant grass is also valued for its high dry matter yield and ease of management (Rusdy, 2018). Sorghum and elephant grass forages have potential to provide dairy goats with nutrients necessary to boost milk production with corresponding economic benefits to the smallholder dairy goat production systems of Eritrea. The nutritional characteristics tests of different combinations of the sorghum, alfalfa, and elephant grass recorded better composition (Ghebregziabiher et al., 2025) than what is traditionally used in the study area. This implies that the feed resources have potential to increase to improve milk production. However, diets only would have limited positive impact on the production and it is imperative that a suitable dairy goat breed be identified and selected to optimize on the breed/nutrition combination.

The Hassani dairy goat breed has high prolificacy and is kept for milk production in Eritrea (Hienok, 2006). The breed belongs to the Nubian family and is found in northern Sudan and western Eritrea, as well as in North Africa, the Near East, and parts of the Middle East (Alemayehu, 1994). In Eritrea, the breed is found in the western lowlands along the Sudan–Eritrea border, particularly in the sub-regions of Tesseney and Haykota, with some populations recorded in parts of the south-western lowlands, including the Goluj and Omhajer sub-regions (Hienok, 2006). Several studies (Weldeselasie and Nsahlai, 2003; Onakuse et al., 2025; FARM-Africa and ILRI, 1996) have examined dairy production systems in Eritrea where different livestock species are collectively or individually reared. However, the amount of available literature is limited which sub-optimize design and implementation of animal improvement programmes (Haile et al. 2017a).

The limited existing literature highlights constraints such as feed shortages, poor genetics, weak extension services, and market inefficiencies. This study addresses the gaps by scientifically testing the economic benefits of forage-based diets for dairy goats in smallholder production systems in Gash-Barka region, Eritrea. The absence of such information has contributed to unsustainable dairy goat improvement programmes. To fill this gap, the study intended to evaluate the productivity and economic feasibility of different forage-based diets in Hassani dairy goat production systems in Gash-Barka region.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

2.0 Materials and methods

2.1 Study area

The study was carried out in Akurdet, one of the administrative regions of Gash-Barka in Eritrea shown in Figure 1. Akurdet sub-region lies between 15°33'00.0"N and 37°52'60.0"E at an altitude of 600 meter above sea level. The area is known for its banana plantations and Doum Palms common along the Barka River. It is the largest region in Eritrea, accounting for approximately 40% of the country and with a total of 16 sub-regions, 218 administrative district (*kebabis*) and 988 villages. The region covers 49,225 km^2 and hosts a population of 842,635 inhabitants. About 23% of its population are nomadic pastoralists, 67% agro-pastoralists while the remaining 10% are engaged in trading (MoLG/ZGB, 2023). The high number of households involved in livestock keeping and the presence of the Hassani dairy goat breed are the reasons why the area was selected for this study. It is one of the hotter places in Eritrea with temperatures ranging from 19°C – 40°C and an annual average rainfall of 320.85 mm (MoA/ZGB, 2023).

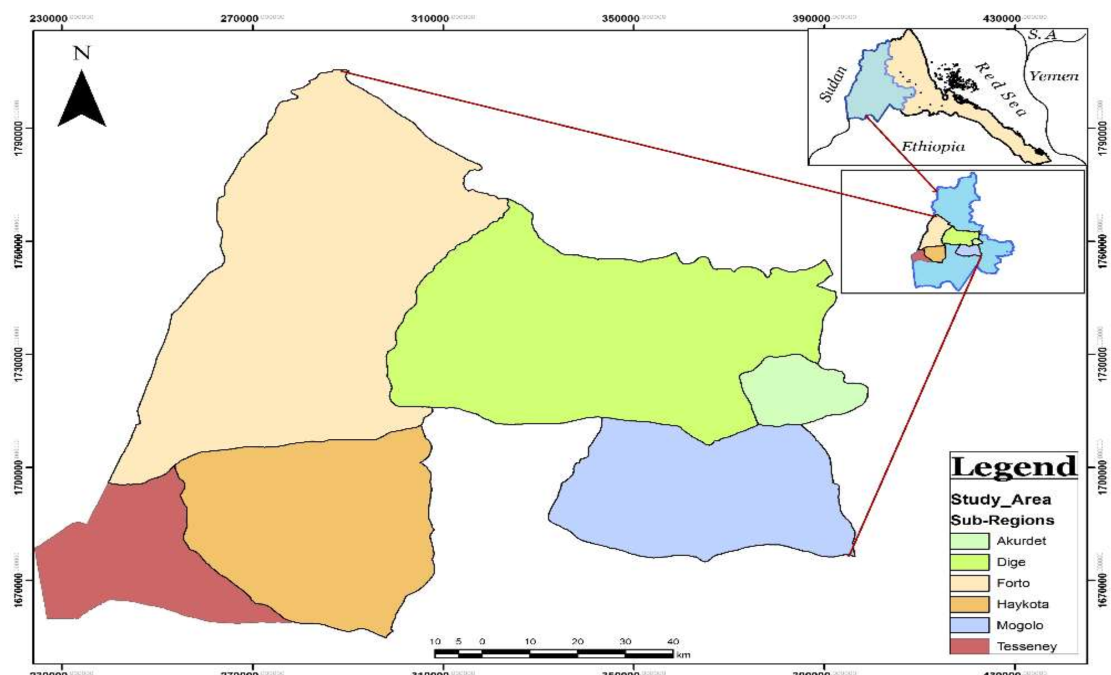

Figure 1. Map of Gash-Barka region, Eritrea

2.2 Experimental diets

Table 1 presents the experimental diets. The T1 diet was considered standard (control) based on the livestock keepers practice in the study area of using sorghum stover supplemented by the *Acacia tortilis* pods to feed lactating dairy animals.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Table 1: Experimental Diets used in the Study

	Inclusion (%)			
Treatment	Sorghum stover	*Acacia tortilis* pods	Alfalfa	Elephant grass
T1	80	20	-	-
T2	50	-	20	30
T3	50	-	30	20
T4	50	-	25	25

T- Treatment

All feed ingredients used in diets formulation were obtained from the study area. The sorghum stover and *Acacia tortilis* pods were obtained from the farmers while alfalfa and elephant grass were specifically cultivated along Barka riverbank for this research purposes. The mature alfalfa was harvested and air-dried under shade before being offered to the experimental animals. All the forages used in the feeding trials were uniformly chopped into small pieces (3–5cm) before being mixed. Four experimental treatment diets were formulated and labelled as T1, T2, T3 and T4 (see Table 1). The experimental diets were formulated to meet the nutritional requirements of lactating dairy goats according to the NRC (2007) recommendations.

2.3 Experimental design and animal management

The experiment was laid out at the Ministry of Agriculture (MoA) forage demonstration farm in Akurdet. A total of 24 third parity early stage lactating Hassani dairy goats were used in the feeding trials. The goats were bought from the farmers located in the study area. The goats were randomly assigned to 4 dietary treatment diets namely T1, T2, T3 and T4 with 6 dairy goats per treatment in a completely randomized design (CRD). They were housed in individual pens that had feed and water troughs. They were left for 14 days to adapt to the new production conditions and experimental diets before start of data collection. Thereafter, data on feed intake, feed leftovers, and milk yield data were collected for 63 days. The dietary rations were offered *ad libitum* and feed refusals collected and measured daily using a weighing scale (Model-MNCS-M (OCS-03-L), GB/T11883-2002 Class III, China). In addition to the experimental diets, each goat had free access to mineral licks (DEXID-400, Interchemie Werken De Adelaar B.V., Holland), 5 grams of sea salt, and clean drinking water. The goats were dewormed using Ivermectin (1mL/doe) against external and internal parasites one week before the start of feeding trial. Throughout the study period, all feeding and management practices were maintained consistently among the treatment diet groups.

2.4 Feed intake and milk yield

Following the lapse of the acclimatization phase, individual feed intake, and milk yield of each doe were recorded throughout the feeding trial period. The goats were offered the treatment diets in the morning of each day immediately after milking. They were hand milked twice a day at 8 AM in the morning and 5 PM in the evening with the milk yield being recorded. A 1000 mL graduated plastic jug was used for measurement of milk produced by each goat. Hygiene was maintained using sterilized equipment to prevent contamination of the collected milk. The feed leftovers samples were collected daily into marked plastic buckets for use in estimation

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

of the feed intake. Daily feed intake was determined by calculating the difference between the amount of feed offered and the feed refusals.

2.5 Comparative economic analysis

A partial budget analysis (PBA) was used to evaluate the economic benefits associated with different levels of feed supplementation. The partial budgeting is a widely used farm management tool that aid in assessing the financial consequences of changes in production practices by comparing the added costs and the resultant economic benefits, while assuming that all other components of the farming system remain unchanged (Ehui and Rey, 1992; Kay et al., 2019). This approach is particularly appropriate for assessing alternative technologies or management interventions that affect only a limited number of cost and revenue components as is the case with this study. Similar analytical approaches have been applied in livestock feeding and supplementation studies to assess the economic feasibility of dietary interventions under smallholder conditions (Tesfaye, 2009; Holmann and Lascano, 2004; Anwar et al., 2012). In the present study, the analysis focused exclusively on costs and returns directly associated with milk production, and feed supplementation which was deemed to be the primary variable cost. Fixed costs were assumed to be identical across treatments, and no additional labour, housing, or marketing costs were incurred; thus, these costs were excluded from the analysis. Feed costs were calculated on a dry matter (DM) basis for each experimental diet, following the approach recommended by Holmann and Lascano (2004). The cost of both purchased and cultivated feeds was estimated by multiplying the daily quantity of feed offered (kg) by the total number of feeding days during the experimental period, using prevailing market prices to determine the unit cost per kilogram of each diet. Gross benefits were derived from milk sales, and net economic returns were computed using standard partial budget procedures as outlined by Ehui and Rey (1992) and Kay et al. (2019). The method entails calculating gross margin (GM) which is the amount of money left when total variable costs (TVC) are subtracted from the gross revenue (GR):

$$\mathrm{GM} = \mathrm{GR} - \mathrm{TVC} \tag{1}$$

Where GR is gross revenue, and TVC is the total variable cost

$$\mathrm{GR} = \text{Total milk yield (mL) x the price of milk (USD/litre)} \tag{2}$$

$$\mathrm{TVC} = \text{Total feed intake (kg DM) x price of the feed(USD/kg)} \tag{3}$$

One United States Dollar (USD) exchanged at 15 Eritrean Nakfa at the time of data collection and was the value adopted throughout the study period.

Total variable costs include the costs of all inputs that change due to the change in production technology. The most important criterion in deciding whether or not to adopt a new

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

technology is the change in gross margin (ΔGM). This amount is the difference between the changes in gross revenue (ΔGR) and the change in total variable costs (ΔTVC).

$$\Delta GM = \Delta GR - \Delta TVC \quad (4)$$

The marginal rate of return (MRR) measures the increase in net income (ΔGM) associated with each additional unit of expenditure (ΔTVC) and was derived as:

$$\text{MRR (\%)} = \left(\frac{\Delta \text{GM}}{\Delta \text{TVC}}\right) x100 \quad (5)$$

The GM the total revenue realized from the sale of milk for each treatment minus the total costs of the feed intake.

2.6 Statistical analysis

Data on milk yield and feed intake was entered into Microsoft Excel (Microsoft Corporation, 2013) and exported to R-studio for Windows, Version 4.2.1 (R Core Team, 2023) for analysis. Normality and variance homogeneity were tested using the Shapiro-Wilk test and Bartlett's test, respectively. The Least Significant Difference (LSD) method was used in means separation with differences considered at 0.05 level of significance. The model used is presented below:

$$Yij = \mu + \beta \cdot FIij + Ti + \varepsilon ij \quad (6)$$

Where Yij is the milk yield (mL/day) for j^{th} dairy goat on treatment i^{th} diet, μ is the overall mean, β is the change in milk yield per kg DM intake, FIij is feed intake (kg DM/day), Ti is the treatment i effect (i=1, 2, 3, 4) and εij is the random error.

3.0 Results and discussion

3.1 Feed intake and milk yield

This study findings indicate that supplementing sorghum stover with *Acacia tortilis* pods, alfalfa and elephant grass had significant ($p<0.05$) impact on feed intake as seen from results presented in Table 2.

Table 2. Average daily feed intake and milk yield recorded for 63 days in the Hassani dairy goats

Parameters	Treatment				SEM	P-Value
	T1	T2	T3	T4		
Initial feed intake (kg DM)	0.40^{b}	0.91^{a}	1.02^{a}	1.06^{a}	0.043	< 0.001
Initial milk yield (ml/doe/day)	401.67	498.33	478.33	461.67	22.376	0.47
Feed intake (kg DM)	0.83^{d}	1.00^{c}	1.04^{b}	1.18^{a}	0.215	< 0.001
Milk yield (mL/goat/day)	315.20^{d}	504.43^{c}	507.86^{b}	510.52^{a}	0.088	< 0.001

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

T1 (80% sorghum stover with 20% *Acacia tortilis* pods meal); T2 (50% sorghum stover, 20% alfalfa and 30% elephant grass); T3 (50% sorghum stover, 30% alfalfa, and 20% elephant grass); T4 (50% sorghum stover, 25% alfalfa, and 25% elephant grass); DM, Dry matter

*Means within rows with different letter superscripts differ ($p<0.05$); SEM, standard error of means

Dry matter feed intake significantly varied amongst treatments with T4 having the highest value of 1.18 kg DM and T1 the lowest at 0.83 kg DM. In addition, supplementing sorghum stover with *Acacia tortilis* pods, alfalfa and elephant grass had significant ($p<0.05$) effects on milk yield between and amongst treatment diets.

According to Hidosa et al. (2020), goats are browsers and thus select about 50%-80% of what they consume. This implies that given a free access to a forage of varying characteristics, they select parts that are highly nutritious and degradable which are often characterised by high protein and little fibre content. The dairy goats in this study were stall fed using feed materials that were uniformly chopped and fed as mixed ration thus reducing the selection ability. The results showed that goats fed on diet T1 had the lowest feed intake. This could be explained by the high inclusion of sorghum stover (80%) which contain tannins (Ondiek, 2024) and constrain dry matter nutrient intake and utilization.

Goats fed on T4 yielded more milk at 510.52 mL/day when compared to the other experimental diets. Those fed on T1 recorded the lowest milk yield at 315.20 mL/day. It's plausible that the higher milk yield resulted to the higher DM feed intake realized from goats on T4. This findings are consistent with the study of Silva et al. (2022) who elucidated that reduced dry matter intake directly influences milk production. It has been reported that high feed intake, high digestibility, and enhanced rumen fermentation directly result to increased milk production (Kholif et al., 2016). The diet offered to an animal and its nutrient profile impacts milk production and its constituents (Dias et al., 2017). The nutritional characteristics of the test diets utilised in this study are presented in (Ghebregziabiher et al., 2025).

3.2 Economic analysis of feed intake and milk yield

The economic analysis results presented in Table 3 showed that the gross revenue (GR) varied across the treatments groups. The T1 realized the lowest gross revenue of USD 158.8, while T2, T3, and T4 recorded values of USD 254.1, USD 255.5, and USD 256.9, respectively.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Table 3. Partial budget analysis of Hassani dairy goats fed different diets

Parameters*	Treatment			
	T1	T2	T3	T4
Total milk yield (L)	119.5	191.05	192.10	193.16
Price of milk per litre (USD)	1.33	1.33	1.33	1.33
Gross revenue (USD)	158.8	254.1	255.5	256.9
ΔGR (USD)	-	95.3	96.8	98.2
Total feed intake (kg DM)	516.04	453.18	508.06	535.15
Price of the feed (USD/kg DM)*	0.41	0.21	0.21	0.21
Total variable cost (USD)	214.1	93.2	105.2	110.5
ΔTVC (USD)	-	-120.9	-108.9	-103.6
Gross Margin (Net change in Profit) (USD)	-55.3	160.8	150.3	146.5
ΔGM (USD)	-	216.2	205.7	201.8
MRR (%)	-	-178.9	-188.9	-194.7

T1 (80% sorghum stover with 20% *Acacia tortilis* pods meal); T2 (50% sorghum stover, 20% alfalfa and 30% elephant grass); T3 (50% sorghum stover, 30% alfalfa, and 20% elephant grass); T4 (50% sorghum stover, 25% alfalfa, and 25% elephant grass); USD, United States Dollar (1 USD = 15 ERN); ERN, Eritrean Nakfa; *The price of the individual feeds with different inclusion levels per kg DM was calculated and summed for every doe's ration consumed per day (Sorghum stover was bought at 0.33 USD/kg DM; Acacia tortilis pods at 0.75 USD/kg DM; Alfalfa at 0.09 USD/kg DM and elephant grass at 0.08 USD/kg DM)

T2, T3, and T4 resulted to respective GR changes of USD 95.3, USD 96.8, and USD 98.2 when compared to the control group (T1). This increase can be attributed to improved milk production due to availability of sufficiently high-quality nutrients availed in treatment diets T2, T3 and T4 as a result of using alfalfa and elephant grass whose nutritional characteristics were previously investigated by Ghebregziabiher et al. (2025). These results are consistent with those of Marques et al. (2022), who observed that diets incorporating alfalfa result in the lower production costs per litre of milk.

T1 recorded higher total variable cost of USD 214.1 when considered against T2, T3, and T4 whose respective values were USD 93.2, USD 105.2, and USD 110.5. The change in total variable costs (ΔTVC) relative to T1 resulted to economically significant cost savings across all alternative treatments, with reductions of USD 120.9, USD 108.9, and USD 103.6 for T2, T3, and T4, respectively. The reduction in the feed cost may be attributed to the better utilisation of the forages used in supplementing T2, T3 and T4 (Ghebregziabiher et al., 2025) and the lower costs in cultivation of alfalfa and elephant grass. Feed resources which are not traditionally used in a production system and which are cheaper to establish and propagate can be utilized to substitute common feed ingredients to reduce the costs (Lian et al., 2024). Cheaper nutrients sources enhance enterprise economic viability which has been identified as a driving factor that smallholder farmers consider in adopting new feed and feeding technologies (Mengistu et al., 2021).

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Based on this study, it is noteworthy that T1 had a gross margin of USD -55.3, indicating that the feed costs exceeded the milk sale income implying that the strategy resulted to a loss. It should be noted that the diet is mainly adopted during dry seasons when grazing and browsing resources are scarce and it therefore does not imply that the farmers make losses throughout the production cycle. Conversely, T2, T3, and T4 had gross margins of USD 160.8, USD 150.3, and USD 146.5, respectively and would be economically attractive to the smallholder dairy goat farmers. This would subsequently support faster adoption of alfalfa and elephant grass supplementation.

The realization of positive gross margin and the corresponding increase was substantial and nearly uniform across the three alternative treatments, decreasing marginally from USD 216.2 for T2, USD 205.7 for T3, and USD 201.8 for T4. The findings show that, within the context of low input smallholder farming systems where limited capital investment often constrains productivity, the three alternative feeding strategies have potential to enhance economic efficiency when considered against what is currently being practiced by the dairy goat farmers. The marginal rate of return (MRR) provides insight into the economic efficiency of the additional investment required for each treatment relative to T1. All the alternative treatment diets (T2, T3 and T4) had values of -178.9%, -188.9%, and -194.7%, respectively. The negative sign preceding each of the value imply a reduction in costs whose result is better economic outcomes.

4.0 Conclusion

Results obtained from this study indicate that Hassani dairy goats fed on diets consisting varying amounts of sorghum stover, alfalfa and elephant grass performed better in terms of milk yield. In the study area, supplementing the standard diet with 20% alfalfa and 30% elephant grass resulted to the highest milk yield recorded implying its superior cost-effectiveness when compared to the other experimental diets. The T1 resulted in a negative gross margin (-55.3 USD), whereas T2, T3, and T4 generated positive gross margins of USD 160.8, 150.3, and 146.5 respectively. Therefore, supplementation of sorghum stover basal diet with alfalfa and elephant grass has potential to realize higher milk yield and corresponding higher returns to investment in smallholder dairy goat production system in areas constrained by availability of sufficiently good quality feeds in Gash-Barka region. Eritrea. Based on this study findings, it can be recommended that policy measures that support access to diverse fodder resources, capacity building in feed management, and risk mitigation strategies could facilitate the adoption of such economically efficient feeding strategies, thereby strengthening the resilience and livelihoods of dairy farmers in the Gash-Barka region.

5.0 Acknowledgments

The authors would like to express their appreciation to the EU DeSIRA- CSARIDE Project for funding the research.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

5.1 Ethics Statement

This study was approved by the joint members of ethical committee of National Higher Education and Research Institute (NHERI), Eritrea. The approval number was 0.1/247/A.32/25

5.2 Conflicts of Interest

None.

5.3 Funding

The authors acknowledge the 'Climate Smart Agriculture Research and Innovation Support for Dairy Value Chains in Eritrea (CSARIDE)' project, which is funded by the EU under the Initiative-Development Smart Innovation through Research in Agriculture (DeSIRA) for funding this research work.

8.0 References

Abraham, H., Gizaw, S., & Urge, M. (2018). Identification of breeding objectives for Begait goat in western Tigray, North Ethiopia. *Tropical Animal Health and Production*, 50(8), 1887-1892. https://doi.org/10.1007/s11250-018-1640-5

Alemayehu, N. (1994). Characterization of Indigenous Goat Types of Eritrea. *Northern and Western Ethiopia*. M.Sc. Thesis. Alemaya University of Agriculture. Addis Ababa, Ethiopia.

Alqaisi, O., Ndambi, O. A., & Williams, R. B. (2017). Time series livestock diet optimization: cost-effective broiler feed substitution using the commodity price spread approach. *Agricultural and Food Economics*, 5(1), 25. https://doi.org/10.1186/s40100-017-0094-9

Amayi, A.A, Okeno, T. O., Gicheha, M. G., & Kahi, A. K. (2021) Breeding dairy goats for disease resistance is profitable in smallholder production systems. Small Ruminant Research, 197. https://doi.org/10.1016/j.smallrumres.2021.106337

Anwar, M. Z., Ali, A., & Khan, M. A. (2012). Assessment of feed supplementation to dairy goat: Results of research and technology dissemination trials. *Asian journal of agriculture and rural development*, 2(4), 609-620. https://archive.aessweb.com/index.php/5005/article/view/631

Branco, R. H., Rodrigues, M. T., Silva, M. M. C. D., Rodrigues, C. A. F., Queiroz, A. C. D., & Araújo, F. L. D. (2011). Performance of lactating goats fed diets containing different fiber levels from forage with advanced maturity. *Revista Brasileira de Zootecnia*, 40, 1061-1071. https://doi.org/10.1590/S1516-35982014001000003

Daskiran, I., Savas, T., Koyuncu, M., Koluman, N., Keskin, M., Esenbuga, N., & Bingöl, M. (2018). Goat production systems of Turkey: Nomadic to industrial. *Small Ruminant Research*, 163, 15-20. https://doi.org/10.1016/j.smallrumres.2017.10.001

Dias, M. B. D. C., Leão, K. M., Carmo, R. M. D., Silva, M. A. P. D., Nicolau, E. S., & Marques, T. C. (2017). Milk composition and blood metabolic profile from holstein cows at different calving orders and lactation stages. *Acta Scientiarum. Animal Sciences*, 39, 315-321. https://doi.org/10.4025/actascianimsci.v39i3.34807

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Ehui, S., & Rey, B. (1992). *Partial budget analysis for on-station and on-farm small ruminant production systems research: Method and data requirements-L'analyse par budgets partiels dans la recherche en station et en exploitation sur les systèmes de production ovins et caprins: Méthode et données*. https://www.fao.org/4/x5520b/x5520b0a.htm

FARM-Africa. (1996). Goat Types of Ethiopia and Eritrea. Physical description and management systems. Published jointly by FARM-Africa, London, UK, and ILRI (International Livestock Research Institute), Nairobi, Kenya. 76 pp.

Ghebregziabiher, T. K., Mwashi, V., Tegegn, G. G., Araya, M. R., Gicheha, M. G., & Osuga, I. M. (2025). Improvement of feed intake, digestibility and lactation performance of hassani dairy goats by supplementing sorghum stover-based diets with alfalfa and elephant grass. *Journal of Agricultural Science*, *17*(11), 113-130.

Gwiriri, L. C., Manyawu, G., Mashanda, P. B., Chakoma, I., Moyo, S., Chakoma, C., & Maasdorp, B. V. (2016). The potential of replacing conventional dairy supplements with forage legume-based diets in Zimbabwe's smallholder dairy sector. *African Journal of Range & Forage Science*, 33(3), 155-163. https://doi.org/10.2989/10220119.2016.1170727

Haile, E., Gicheha, M., Njonge, F. & Asgedom, G. (2017b). Determining Nutritive Value of Cereal Crop Residues and Lentil (*Lens esculanta*) Straw for Ruminants. *Open Journal of Animal Sciences*, 7, 19-29. https://doi.org/10.4236/ojas.2017.71003

Haile, E., Njonge, F., Asgedom, G. & Gicheha, M. (2017a). Chemical Composition and Nutritive Value of Agro-Industrial By-Products in Ruminant Nutrition. *Open Journal of Animal Sciences*, 7, 8-18. https://doi.org/10.4236/ojas.2017.71002

Hidosa, D., Belachew, B., & Kibiret, S. (2020). Evaluation of Desho (Pennisetum pedicellatum) grass varieties for dry matter yield and chemical composition in South Omo Zone, South Western Ethiopia. *Agricultural Research and Technology*, 25(2), 001-008. https://doi.org/10.20372/eajs.v15i1.1396

Hienok, G. (2006). Characterization and carcass studies on Nubian family goats in the western lowlands of Eritrea. M.Sc. Thesis. Asmara, Eritrea.

Holmann, F. J., & Lascano, C. E. (Eds.). (2004). Feeding systems with forage legumes to intensify dairy production in Latin America and the Caribbean: A project executed by the Tropileche Consortium. Centro Internacional de Agricultura Tropical (CIAT); Tropileche Consortium, Cali, Colombia; SLP (System-, Nairobi, Kenya. 172p. https://cgspace.cgiar.org/items/043691d8-a008-4d5c-a57d-6afbdcfd5270

Katongole, C. B., Nambi-Kasozi, J., Lumu, R., Bareeba, F., Presto, M., Ivarsson, E., & Lindberg, J. E. (2012). Strategies for coping with feed scarcity among urban and peri-urban livestock farmers in Kampala, Uganda. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, 113(2), 165-174. http://nbn-resolving.de/urn:nbn:de:hebis:34-2012092441842

Kay, R., Edwards, W., & Duffy, P. (2019). *Farm management* (8th ed.). 2 Penn Plaza, New York, NY 10121: McGraw-Hill.

Kholif, A. E., Morsy, T. A., Gouda, G. A., Anele, U. Y., & Galyean, M. L. (2016). Effect of feeding diets with processed Moringa oleifera meal as protein source in lactating Anglo-Nubian goats. *Animal Feed Science and Technology*, 217, 45-55. https://doi.org/10.1016/j.anifeedsci.2016.04.012

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Lian, X., Shi, M., Liang, Y., Lin, Q., & Zhang, L. (2024). The effects of unconventional feed fermentation on intestinal oxidative stress in animals. *Antioxidants*, 13(3), 305. https://doi.org/10.3390/antiox13030305

Linn, J., Raeth-Knight, M., & Litherland, N. (2009). Role of feed (dairy) efficiency in dairy management. In *Proceedings of the 44th Pacific Northwest Animal Nutrition Conference, Boise, Idaho* (pp. 167-176). https://www.pnwanc.org/Portals/0/SiteContent/Documents/Proceedings/2009_13_role_of_feed_dairy_efficiency.pdf

Malisetty, V., Yerradoddi, R. R., Devanaboina, N., Mallam, M., & Mitta, P. (2014). Effect of feeding sorghum straw based complete rations with different roughage to concentrate ratio on dry matter intake, nutrient utilization, and nitrogen balance in Nellore ram lambs. *Tropical Animal Health and Production*, 46(5), 759-764. https//doi.org/10.1007/s11250-014-0560-2

Maria, T., Dimitrios, G., Christos, K., & Stamatis, A. (2022). Techno-economic and financial index analysis for the improvement of entrepreneurship and competitiveness strategies of Greek goat enterprises. *Frontiers in Sustainable Food Systems*, 6, 982307. https://doi.org/10.3389/fsufs.2022.982307

Marques, R. O., Gonçalves, H. C., Meirelles, P. R. D. L., Ferreira, R. D. P., Gomes, H. F. B., Lourençon, R. V., & Cañizares, G. I. L. (2022). Production, intake, and feeding behavior of dairy goats fed alfalfa via grazing and cassava. *Revista Brasileira de Zootecnia*, *51*, e20210102. https://doi.org/10.37496/rbz5120210102

Mengistu, S., Nurfeta, A., Tolera, A., Adie, A., Mekonnen, K., Wolde-meskel, E., & Bezabih, M. (2021). Forage yield and replacing concentrate supplements with oat and vetch mixed forage on the performance of sheep fed Desho grass (*Pennisetum pedicellatum*) based diets. *Ethiopian Journal of Applied Science and Technology*, 12(1), 10-21. https://hdl.handle.net/10568/114291

Microsoft Corporation. (2013). Microsoft Excel (Version 2013) [Computer software]. Microsoft.

Miller, B. A., & Lu, C. D. (2019). Current status of global dairy goat production: An overview. *Asian-Australasian journal of animal sciences*, 32(8), 1219. https://pmc.ncbi.nlm.nih.gov/articles/PMC6668863/

Ministry of Agriculture (MoA)/GBZ, Gash Barka Zone. (2023). (Unpublished document). Gash Barka Region. Eritrea.

Ministry of Local Government, Zoba Gash Barka (MoLG/ZGB). (2023). Statistical records of Gash Barka Region, Barentu, Eritrea.

Muteng'e, M. S. (2021). Evaluation of cactus (opuntia ficus-indica) and prosopis juliflora as potential supplementary feed resources for livestock in drought-prone areas of Kenya. *Egerton University*. http://172.16.31.117:4000/handle/123456789/957

Mutimura, M., Ebong, C., Rao, I. M., & Nsahlai, I. V. (2015). Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. *Tropical animal health and production*, 47(6), 1131-1137.. https://doi.org/10.1007/s11250-015-0839-y

National Research Council (NRC). (2007). *Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelids* (7th ed.). Washington, DC: *National Academy Press*. https://doi.org/10.17226/11654.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Nyariki, D. M., & Amwata, D. A. (2019). *The value of pastoralism in Kenya: Application of total economic value approach. Pastoralism* 9 (1)*: 1–13*. https://doi.org/10.1186/s13570-019-0144-x

Oliveira, T. S. D., Leonel, F. D. P., Silva, C. J. D., Baffa, D. F., Pereira, J. C., & Zervoudakis, J. T. (2014). Factors affecting feed efficiency in dairy goats. *Revista Brasileira de Zootecnia*, 43(10), 524-529. 10.1590/S1516-35982014001000003

Onakuse, S., Treasure, L., Msghina, O. B., & Negash, K. (2025). Efficiency estimation and determinant in Small-scale Dairy Production in Eritrea. *African Journal of Rural Development*, 10(1), 17-30.

Ondiek, J. O. (2024). Assessment and utilization of tree and shrub forages as livestock feed in Kenya: A review. *International Journal of Veterinary Sciences and Animal Husbandry*, 9(2), 31-39. https://doi.org/10.1023/A:1006066128640

Paula, E. M., Broderick, G. A., & Faciola, A. P. (2020). Effects of replacing soybean meal with canola meal for lactating dairy cows fed 3 different ratios of alfalfa to corn silage. *Journal of dairy science*, 103(2), 1463-1471. https://doi.org/10.3168/jds.2019-16947

R Core Team. (2023). *A language and environment for statistical computing (4.2.1)*. R Foundation for Statistical Computing.

Ramsbottom, G., Horan, B., Berry, D. P., & Roche, J. R. (2015). Factors associated with the financial performance of spring-calving, pasture-based dairy farms. *Journal of Dairy Science*, 98(5), 3526-3540. https://doi.org/10.3168/jds.2014-8516

Rocha Filho, R. R., Santos, D. C., Véras, A. S. C., Siqueira, M. C. B., Novaes, L. P., Mora-Luna, R., ... & Ferreira, M. A. (2021). Can spineless forage cactus be the queen of forage crops in dryland areas?. *Journal of Arid Environments*, 186, 104426. https://doi.org/10.1016/j.jaridenv.2020.104426

Rukiya, y. M. (2019). Forage productivity and growth performance of Afar sheep grazing on *Panicum antidotale*, *Chloris gayana* and *Cenchrus ciliaris* each cultivated with *Medicago sativa* (Master's thesis), Hawassa University.

Rusdy, M. (2018). A review of the effects of quality forage supplementation on growth performance of cattle and goats fed elephant grass basal diet. *Livestock Research for Rural Development*, 30, Article #203. Retrieved May 7, 2023, from http://www.lrrd.org/lrrd30/12/muhru30203.html.

Santana, M. H. A., Rossi Jr, P., Almeida, R., & Cucco, D. C. (2014). Feed efficiency and its correlations with carcass traits measured by ultrasound in Nellore bulls. *Livestock Science*, 145(1-3), 252-257. https://doi.org/10.1016/j.livsci.2012.02.012

Sarnklong, C., Cone, J. W., Pellikaan, W., & Hendriks, W. H. (2010). Utilization of rice straw and different treatments to improve its feed value for ruminants: a review. *Asian-Australasian Journal of Animal Sciences*, 23(5), 680-692. https://doi.org/10.5713/ajas.2010.80619

Silva, W. P., Santos, S. A., Cirne, L. G. A., dos Santos Pina, D., Alba, H. D. R., de Carvalho Rodrigues, T. C. G., & de Carvalho, G. G. P. (2022). Nutrient intake, digestibility, feeding behavior, nitrogen balance, and performance of feedlot goat kids fed high-concentrate diets containing licury cake (Syagrus coronata). *Tropical Animal Health and Production*, 54(2), 131. https://doi.org/10.1007/s11250-022-03131-9

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5

Tesfaye, T. (2009). Characterization of Goat Production Systems and On- Farm Evaluation of the Growth Performance of Grazing Goats Supplemented with Different Protein Sources in Metema Woreda, Amhara Region. (MSc Thesis. Haramaya University), Ethiopia. https://hdl.handle.net/10568/707

Vaintrub, M. O., Levit, H., Chincarini, M., Fusaro, I., Giammarco, M., & Vignola, G. (2021). Precision livestock farming, automats and new technologies: Possible applications in extensive dairy sheep farming. *Animal*, 15(3), 100143. https://doi.org/10.1016/j.animal.2020.100143

Venkateswarlu, M., Reddy, Y. R., Nagalakshmi, D. and Mahender, M. (2014). Effect of feeding sorghum straw based complete rations with different roughage to concentrate ratio on growth and carcass characteristics in Nellore ram lambs. Animal Nutrition and Feed Technology, 14(3), 563-572.

Weldeselasie, A. M., & Nsahlai, I. V. (2003). Dairy constraint analysis in Eritrea, with special emphasis on Asmara and surrounding dairy farms. *FAO AGRIS - International System for Agricultural Science and Technology. Thesis (M.Sc.Agric.)-University of Natal, Pietermaritzburg.*

Wodajo, H. D., Gemeda, B. A., Kinati, W., Mulem, A. A., van Eerdewijk, A., & Wieland, B. (2020). Contribution of small ruminants to food security for Ethiopian smallholder farmers. *Small Ruminant Research*, 184, 106064. https://doi.org/10.1016/j.smallrumres.2020.106064

Yu, L.-X., & Kole, C. (2021). Compendium of Plant Genomes. The Alfalfa Genome. Springer International Publishing. https://doi.org/10.1007/978-3-030-74466-3

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v25i2.5