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Comparative evaluation of alternative rainfed fodder silages: Additive-mediated improvement in silage quality of Maize, Cumbu Napier, and Fodder Sorghum

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Abstract

This study evaluated the nutritional composition and fermentation characteristics of silage prepared from maize, Cumbu Napier and fodder sorghum harvested under rainfed conditions in the Theni region of Tamil Nadu with the inclusion of salt (0.5%) and jaggery (1%) as additives. A total of nine treatments comprising each fodder with control, salt and salt + jaggery were studied with four replicates. Silage samples were analyzed for proximate composition, neutral detergent fiber (NDF), acid detergent fiber (ADF), and fermentation quality through silage pH. Significant variations were observed among fodder types and additive treatments. Maize silage recorded higher DM and NFE contents with lower pH, indicating superior fermentation efficiency due to greater availability of fermentable carbohydrates. Sorghum silage exhibited intermediate nutritional and fermentation characteristics, while Cumbu Napier silage showed higher CP, fiber fractions and mineral content but comparatively higher pH in the control treatment, reflecting slower fermentation. The addition of salt and jaggery significantly improved silage quality across all fodders by reducing pH and slightly lowering fiber fractions. Among the treatments, the salt + jaggery combination produced the most desirable fermentation profile. These findings demonstrate that additive supplementation enhances the ensiling potential of alternative fodders. The use of locally available additives, such as jaggery and salt, can therefore improve silage quality and support sustainable fodder preservation in rainfed livestock production systems.

Keywords: Silage, maize, Cumbu Napier, fodder sorghum, jaggery, salt and rainfed

Introduction

Livestock production plays a crucial role in sustaining rural livelihoods and ensuring food security in many developing countries, including India. However, livestock productivity is largely constrained by the limited availability of high-quality fodder throughout the year. In India, the anticipated deficit of green fodder is estimated to be 33,562.9 million tons in 2030, which significantly affects animal performance and farm profitability (Jadhav *et al.*, 2025) [6]. Seasonal variability in forage production is particularly evident in rainfed farming systems, where fodder availability depends largely on rainfall patterns. During the monsoon season, excess green fodder is often available, whereas severe shortages occur during the dry season (Kumari *et al.*, 2017) [9]. Under such circumstances, ensiling is considered one of the most effective methods for conserving surplus fodder while maintaining its nutritional value for extended periods (Coblentz and Akins, 2018; Muck *et al.*, 2018; Kumar *et al.*, 2019) [4, 13, 8]. Silage production involves anaerobic fermentation of green fodder, during which lactic acid bacteria convert soluble carbohydrates into organic acids, primarily lactic acid, resulting in a rapid decline in pH and stabilization of the forage biomass (Kung *et al.*, 2018) [10]. Successful silage fermentation therefore depends largely on the availability of fermentable carbohydrates, appropriate dry matter content and the activity of beneficial microbial populations. Among fodder crops, maize is widely recognized as one of the most suitable crops for silage production because of its high biomass yield, optimal dry matter content and relatively high concentration of water-soluble carbohydrates that support rapid fermentation (Muck *et al.*, 2018; Karnatam *et*

al., 2023) [13, 7]. Consequently, maize silage is considered an important high-energy feed resource for ruminants and has been widely adopted in many dairy production systems.

However, exclusive reliance on maize for silage production may not always be feasible in rainfed agricultural regions, where crop establishment may be affected by irregular rainfall and limited irrigation resources. Under such conditions, alternative fodder crops such as Cumbu Napier and Fodder sorghum are widely cultivated for their high biomass productivity, drought tolerance, and adaptability to semi-arid conditions (Meena *et al.*, 2026) [12]. These crops, therefore, represent important alternative fodder resources for silage production in rainfed farming systems. Despite their agronomic advantages, tropical grasses such as cumbu Napier and sorghum often contain lower concentrations of readily fermentable carbohydrates than maize, which may result in slower fermentation and a comparatively higher silage pH (Kung *et al.*, 2018) [10]. Such conditions may compromise silage preservation and increase the risk of undesirable microbial activity during storage.

To overcome these limitations, the use of additives during ensiling has been widely recommended. Silage additives can enhance fermentation efficiency, improve nutrient preservation, and suppress the growth of undesirable microorganisms (Muck *et al.*, 2018) [13]. Among various additives, carbohydrate sources such as molasses or jaggery are commonly used to supply readily fermentable sugars that stimulate the activity of lactic acid bacteria. Carbohydrate additives such as molasses or jaggery provide readily fermentable sugars that stimulate lactic acid bacteria and accelerate lactic acid production, thereby reducing silage pH and improving fermentation quality (Venkataramanan *et al.*, 2010; Luo *et al.*, 2021) [17, 11]. Similarly, mineral additives such as salt may influence microbial dynamics during ensiling and contribute to improved silage stability and preservation (Reddy *et al.*, 2025) [15].

In southern India, particularly in the Theni district, livestock farmers largely depend on locally available fodder resources cultivated under rainfed conditions. However, systematic evaluation of silage prepared from different fodder crops with additive supplementation under these agro-climatic conditions remains limited. Therefore, the present study was undertaken to compare the nutritional composition and fermentation characteristics of silage prepared from maize, cumbu napier and fodder sorghum, with and without supplementation of salt (0.5%) and jaggery (1%). The objective of the study was to evaluate the influence of these additives on proximate composition and silage pH and to identify suitable fodder-additive combinations for improving silage quality under rainfed livestock production systems.

Materials and Methods

The experiment was conducted at the Livestock Farm Complex, Veterinary College and Research Institute, in Theni district, Tamil Nadu, which is characterized by a semi-arid tropical climate with moderate rainfall and warm temperatures. The region largely depends on rainfed agriculture, and fodder availability fluctuates considerably across seasons. The fodder crops used in the study were Maize (*Zea mays*), Fodder sorghum (*Sorghum bicolor*) and Cumbu Napier hybrid (*Cenchrus purpureus* × *Pennisetum glaucum*) – CO4 variety. The fodder crops (Maize and fodder sorghum) were harvested at 75 – 80 days, while Cumbu Napier grass was harvested at 55–60 days of growth. The harvested fodders were chopped into pieces of approximately 2–3 cm using a mechanical chaff cutter. Each chopped fodder was divided into four treatment groups, viz.,

Control (without additives), Salt (0.5%), Jaggery (1%), and Salt (0.5%) + Jaggery (1%) are depicted in Table 1.

Additives were thoroughly mixed into the chopped fodder before ensiling. The treated fodder was packed tightly into airtight polythene bags to create anaerobic conditions. The silos were sealed and allowed to ferment for 42 days at ambient temperature. After the fermentation period, silage samples were collected and analyzed for its proximate analysis (Dry matter (DM), Crude protein (CP), Crude fiber (CF), Ether extract (EE), Total Ash and Nitrogen free extract (NFE)), Fiber fractions, including neutral detergent fiber (NDF) and acid detergent fiber (ADF) and pH as per AFIA laboratory manual procedures (AFIA, 2011) [2]. The titratable acidity (% lactic acid) was estimated as per the calorimetric titration method of Barnett (1951) [3].

The data obtained from the experiment were analysed using one-way analysis of variance (ANOVA) in IBM SPSS Statistics (Version 20.0; IBM Corp., Armonk, NY, USA) to assess the effects of the treatments. All treatment means were compared using Duncan's multiple range tests at a significance level of $p < 0.05$.

Results

The proximate composition and fermentation characteristics of silage prepared from maize, Cumbu Napier and sorghum under different additive treatments are presented in Table 2. Significant differences were observed among fodder types and additive treatments for most of the nutritional and fermentation parameters evaluated. Dry matter content differed significantly among the fodder types and treatments, ranging from 27.83 to 35.18%. Among the three fodders, maize silage recorded the highest dry matter values across all treatments, followed by sorghum and Cumbu Napier silage. The highest DM value was observed in maize silage treated with salt and jaggery (35.18%), which was significantly higher than all other treatments. The higher dry matter content in maize silage can be attributed to its relatively lower moisture content and higher accumulation of soluble carbohydrates at harvest. Cumbu Napier silage exhibited comparatively lower DM values, with the control treatment recording 27.83%, which was significantly lower than maize and sorghum silages. However, the addition of salt and jaggery increased the DM content of Cumbu Napier silage to 28.85%, indicating improved preservation and reduced nutrient loss during the fermentation process. Sorghum silage showed intermediate DM values, ranging from 30.83% in control to 31.68% in the salt + jaggery treatment. These results suggest that the addition of jaggery improved fermentation efficiency, thereby reducing dry matter losses during ensiling.

The crude protein (CP) content varied significantly among the three fodders. Cumbu Napier silage recorded the highest CP values across treatments, ranging from 10.05% to 10.28%, reflecting the naturally higher protein content of this perennial grass. In contrast, maize silage showed comparatively lower CP levels (8.28–8.58%), while sorghum silage exhibited moderate CP values (8.90–9.08%). The addition of salt and jaggery had minimal effect on CP concentration within each fodder type. However, a slight reduction in CP was observed in treatments containing jaggery, which may be due to dilution effects associated with increased carbohydrate fermentation during the ensiling process. Despite these minor variations, the protein content remained relatively stable across treatments, indicating that the additives primarily influenced fermentation characteristics rather than protein preservation.

Cumbu Napier silage recorded the highest crude fiber (CF)

values, with the control treatment showing 32.73%, which gradually decreased to 31.68% in the salt + jaggery treatment. This reduction suggests partial breakdown of structural carbohydrates during fermentation when readily fermentable sugars were available. Sorghum silage exhibited moderate fiber levels (29.00–29.88%), while maize silage had the lowest CF values among the three fodders (26.40–26.90%). The reduction in fiber fractions observed in additive treatments indicates enhanced microbial fermentation and possible solubilization of structural carbohydrates.

Neutral detergent fiber (NDF), representing the total structural carbohydrate fraction, was significantly higher in Cumbu Napier silage compared to maize and sorghum silage. NDF values in Cumbu Napier ranged from 63.90% to 65.88%, reflecting its fibrous nature. Sorghum silage recorded intermediate NDF values (55.35–56.65%), whereas maize silage exhibited significantly lower NDF values (47.03–48.15%). The addition of jaggery resulted in a slight reduction in NDF across all fodders, particularly in Cumbu Napier silage. This reduction may be associated with improved microbial fermentation facilitated by the availability of fermentable sugars. Acid Detergent Fiber (ADF) values followed a trend similar to NDF, with Cumbu Napier silage recording the highest values (37.15–38.45%). Sorghum silage showed intermediate ADF values (32.65–33.58%), while maize silage had the lowest values (29.00–29.80%). The addition of jaggery slightly reduced ADF values in all fodders, suggesting improved degradation of cellulose and lignin-associated components during fermentation.

Ether extract content varied within a narrow range among treatments, ranging from 2.45% to 3.35%. Maize silage recorded slightly higher EE values compared to Cumbu Napier and sorghum silages. However, the inclusion of additives did not significantly influence ether extract levels within each fodder type, indicating that lipid fractions remained relatively stable during the ensiling process. Total ash content differed significantly among fodders, reflecting inherent mineral composition. Cumbu Napier silage recorded the highest ash content across treatments (9.40–10.20%), followed by sorghum (8.18–8.75%) and maize silage (6.80–7.35%). The salt-treated silages showed slightly higher ash values due to the mineral contribution from the added salt. Nitrogen free extract values, which represent soluble carbohydrate fractions, were highest in maize silage treatments (54.35–54.78%). Sorghum silage recorded intermediate NFE values (50.08–50.43%), while Cumbu Napier silage showed the lowest NFE levels (45.03–45.88%). The relatively higher NFE content in maize silage contributes to its superior fermentation characteristics, as soluble carbohydrates are essential substrates for lactic acid bacteria during ensiling.

Silage pH is a key indicator of fermentation quality. In the present study, pH values ranged from 3.81 to 4.69. Maize silage recorded the lowest pH values among the three fodders, with the salt + jaggery treatment achieving the lowest pH of 3.81, indicating efficient lactic acid fermentation. Sorghum silage recorded moderate pH values, ranging from 4.04 to 4.44, while Cumbu Napier silage exhibited the highest pH values, particularly in the control treatment (4.69). The addition of jaggery significantly reduced pH across all fodders, indicating enhanced fermentation due to increased availability of fermentable sugars. Salt supplementation also contributed to improved fermentation stability by limiting undesirable microbial activity during ensiling.

Among the three fodders evaluated, maize silage exhibited superior fermentation characteristics, reflected by higher dry

matter content, higher soluble carbohydrate fractions and lower pH values. Sorghum silage showed intermediate nutritional characteristics and responded positively to additive supplementation. Cumbu Napier silage, although rich in protein and minerals, exhibited higher fiber content and comparatively higher pH values in the control treatment, indicating slower fermentation in the absence of additives. The combination of salt (0.5%) and jaggery (1%) consistently improved fermentation characteristics across all fodder types, as evidenced by reduced pH values and slight reductions in fiber fractions. These findings highlight the importance of carbohydrate additives in improving the fermentation efficiency of tropical forage silage, particularly for high-fiber fodders such as Cumbu Napier.

Discussion

The present study evaluated the nutritional composition and fermentation characteristics of silage prepared from maize, Cumbu Napier and fodder sorghum harvested under rainfed conditions in the Theni region of Tamil Nadu with the inclusion of salt (0.5%) and jaggery (1%) as additives. The results clearly demonstrate that both the type of fodder and additive supplementation significantly influence silage quality, particularly fiber fractions and fermentation characteristics. Among the three fodders evaluated, maize silage exhibited superior fermentation characteristics, as reflected by higher dry matter and nitrogen free extract (NFE) values along with lower pH. This is primarily attributed to the higher concentration of water-soluble carbohydrates in maize compared with most tropical grasses. Adequate WSC availability facilitates rapid growth of lactic acid bacteria, resulting in efficient lactic acid production and rapid decline in silage pH (Arriola *et al.*, 2021; Oliveira *et al.*, 2021) ^[1, 14]. The higher NFE observed in maize silage in the present study further supports this mechanism, as soluble carbohydrates serve as the primary substrate for fermentation.

In contrast, Cumbu Napier silage recorded higher crude protein, crude fiber, NDF and ADF values compared with maize and sorghum silage. Napier grass is known for its high biomass production and structural carbohydrate content, which contributes to higher fiber fractions. However, the relatively lower soluble carbohydrate content in tropical grasses often results in slower fermentation and higher pH values when ensiled without additives. This observation is consistent with the present study, where the control Cumbu Napier silage recorded the highest pH among all treatments. Sorghum silage showed intermediate nutritional characteristics between maize and Cumbu Napier. Sorghum contains moderate levels of fermentable carbohydrates and generally produces acceptable silage quality, although fermentation may not be as rapid as in maize silage (Rodrigues *et al.*, 2020) ^[16]. The intermediate values of DM, fiber fractions and pH observed in sorghum silage in the present study align with earlier reports on sorghum silage quality.

The inclusion of salt and jaggery significantly improved fermentation characteristics across all fodders, particularly by reducing silage pH. Among the treatments, the salt + jaggery combination consistently produced the lowest pH values, indicating enhanced lactic acid fermentation. Jaggery serves as a readily fermentable carbohydrate source that stimulates lactic acid bacteria, leading to rapid lactic acid production and a faster decline in silage pH (Venkataramanan *et al.*, 2010) ^[17]. This process is critical for inhibiting undesirable microorganisms and preserving silage nutrients. The improvement in fermentation quality was especially evident in Cumbu Napier silage, where

the addition of jaggery substantially reduced pH compared to the control treatment. This suggests that carbohydrate supplementation is particularly beneficial for high-fiber tropical grasses that naturally contain limited fermentable sugars. Similar findings have been reported in several studies indicating that carbohydrate additives significantly improve fermentation quality in tropical forage silages (Oliveira *et al.*, 2021) [14]. Salt supplementation also contributed to improved silage stability. Although salt does not directly participate in fermentation, it can inhibit undesirable microbial activity and reduce proteolysis during the ensiling process. Previous studies have suggested that moderate levels of salt may enhance aerobic stability and reduce nutrient losses during storage (Kung *et al.*, 2018; Arriola *et al.*, 2021) [10, 1].

The slight reductions in crude fiber, NDF, and ADF observed in the salt + jaggery treatments across all fodders suggest improved fermentation and partial breakdown of structural carbohydrates. Enhanced microbial activity during fermentation can limit the solubilization of cell wall components, thereby slightly reducing fiber fractions in the final silage (Kung *et al.*, 2018) [10]. This effect was more pronounced in Cumbu Napier silage, likely due to its higher initial fiber content.

When all treatments were compared, maize silage with salt and jaggery exhibited the best fermentation characteristics, indicated by the highest dry matter and lowest pH values. Sorghum silage also responded positively to additive supplementation, showing improved fermentation quality compared to the control treatment. However, Cumbu Napier silage showed the greatest

relative improvement with additives, suggesting that carbohydrate supplementation is particularly important for tropical grasses with lower soluble carbohydrate levels. These findings indicate that alternative fodders such as Cumbu Napier and sorghum can be effectively utilized for silage production when appropriate additives are used, which is particularly relevant for rainfed regions where maize availability may be limited. The use of locally available carbohydrate sources such as jaggery can therefore serve as a practical strategy for improving silage quality in smallholder livestock production systems. Overall, the results of the present study highlight the importance of fodder selection and additive supplementation in optimizing silage fermentation and nutritional quality, particularly under rainfed conditions typical of southern India.

Table 1: Experimental design and treatment combinations for evaluating additive effects on silage quality

Treatment	Particulars (green fodder)
T ₁	Maize (Control)
T ₂	Maize (Control) + Salt (0.5%)
T ₃	Maize (Control) + Salt (0.5%) + Jaggery (1%)
T ₄	Cumbu Napier (Control)
T ₅	Cumbu Napier (Control) + Salt (0.5%)
T ₆	Cumbu Napier (Control) + Salt (0.5%) + Jaggery (1%)
T ₇	Sorghum (Control)
T ₈	Sorghum (Control) + Salt (0.5%)
T ₉	Sorghum (Control) + Salt (0.5%) + Jaggery (1%)

Table 2: Proximate composition and fermentation characteristics of silage prepared from maize, Cumbu Napier, and sorghum with salt (0.5%) and jaggery (1%)

Treatment	DM (%)	CP (%)	CF (%)	NDF (%)	ADF (%)	EE (%)	TA (%)	NFE (%)	pH	LA (%)
T ₁ -Maize Control	34.00 ^c	8.77 ^{ab}	28.06 ^b	49.60 ^a	30.99 ^b	3.15 ^c	6.84 ^a	53.19 ^c	3.94 ^b	7.85 ^f
T ₂ -Maize Salt	34.25 ^c	8.60 ^a	27.29 ^{ab}	49.06 ^a	30.63 ^{ab}	3.20 ^c	7.13 ^{ab}	53.79 ^c	3.90 ^b	8.10 ^f
T ₃ -Maize Salt + Jaggery	35.12 ^c	8.47 ^a	26.75 ^a	48.44 ^a	30.06 ^a	3.24 ^c	7.39 ^b	54.16 ^c	3.81 ^a	9.05 ^g
T ₄ -Cumbu Napier Control	27.71 ^a	10.52 ^d	33.38 ^f	67.84 ^d	39.99 ^f	2.38 ^a	9.46 ^e	44.28 ^a	4.46 ^g	5.10 ^a
T ₅ -Cumbu Napier Salt	28.19 ^a	10.34 ^d	33.16 ^{ef}	67.29 ^d	39.65 ^{ef}	2.49 ^a	9.87 ^f	44.15 ^a	4.26 ^e	5.85 ^b
T ₆ -Cumbu Napier Salt + Jaggery	28.80 ^a	10.25 ^d	32.32 ^e	65.82 ^c	38.64 ^e	2.53 ^a	10.27 ^g	44.63 ^a	4.12 ^d	6.65 ^c
T ₇ -Sorghum Control	30.70 ^b	9.28 ^c	30.99 ^d	58.30 ^b	34.92 ^d	2.78 ^b	8.29 ^c	48.67 ^b	4.36 ^f	6.20 ^c
T ₈ -Sorghum Salt	31.00 ^b	9.18 ^c	30.15 ^{cd}	57.86 ^b	34.40 ^{cd}	2.87 ^b	8.67 ^d	49.13 ^b	4.15 ^d	6.85 ^d
T ₉ -Sorghum Salt + Jaggery	31.62 ^b	9.05 ^{bc}	29.79 ^c	57.01 ^b	33.83 ^c	2.89 ^b	8.77 ^d	49.51 ^b	4.04 ^c	7.45 ^e
SEM	0.454	0.131	0.405	1.252	0.624	0.056	0.198	0.667	0.035	0.182
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Values are mean ± SD (n = 4). Means with different superscripts within a column differ significantly (p < 0.05).

Conclusion

Maize silage showed superior fermentation quality with higher dry matter, higher soluble carbohydrates and lower pH, while sorghum silage exhibited intermediate characteristics. Cumbu Napier silage contained higher crude protein and fiber but showed relatively higher pH, indicating slower fermentation. The addition of salt (0.5%) and jaggery (1%) significantly improved fermentation quality in all fodders by lowering pH and slightly reducing fiber fractions. These results suggest that additive supplementation can enhance the ensiling potential of alternative fodders under rainfed conditions. Future studies should emphasize optimizing additive formulations and assessing their effects on animal productivity to develop sustainable silage preservation strategies for livestock production in water-limited regions.

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Conflict of Interest

No conflicts of interest have been declared.

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