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(Review Article)

A review of maize forage systems for enhancing livestock feed sustainability in Sri Lanka

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Abstract

The livestock sector in Sri Lanka faces critical feed shortages due to seasonal forage variability, low nutritive value of native grasses, and increasing climate stress. Maize (*Zea mays* L.), a high-yielding and nutrient-rich C4 cereal crop, has emerged as a strategic forage option, particularly in the form of silage, to address these challenges. This review synthesizes current knowledge on maize cultivation, nutritional value, and silage applications within the Sri Lankan context. It discusses varietal performance, agronomic traits, silage quality determinants, seasonal and climate influences, and gaps in silage-specific hybrid development and feed integration. Finally, the review proposes research directions for developing climate-resilient, sustainable forage systems to support livestock productivity in Sri Lanka.

Keywords: Forage; Silage; Livestock; *Zea mays*

1. Introduction

Livestock production around the world encompasses a wide range of systems, differing in the species kept, the roles they fulfil, the scale and intensity of production, the agroecological environments they occupy, and the inputs they require [1]. In Sri Lanka, the cultivation of forage has not been a common practice; consequently, ruminants are predominantly dependent on naturally occurring grasses found in various landscapes such as natural grasslands, roadsides, marginal lands, paddy bunds, home gardens, fallow paddy fields, and coconut plantations. However, both the quantity and quality of forage from these sources are generally inadequate to meet the nutritional requirements of livestock [2]. While this informal forage system has supported smallholder livestock production for decades, the importance of high-quality forage in enhancing livestock productivity needs to be more widely recognized. Strengthening forage quality is critical not only for improving milk and meat yields but also for delivering significant economic and environmental benefits, including better feed efficiency, lower greenhouse gas emissions, and more sustainable land use [3]. Under the extensive production systems in Sri Lanka's dry zone, cattle primarily graze on commonly available forages such as *Cynodon dactylon, Cyperus rotundus, Imperato cylindrica, Oryza sativa* (rice) straw, and *Eleusine indica*, all of which are generally low in nutritional quality. Additionally, small quantities of forage legumes such as *Gliricidia sepium* and *Leucaena leucocephala* are occasionally available within these grazing areas [4]. The seasonal nature of forage availability driven by Sri Lanka's bimodal rainfall pattern creates critical feed gaps during dry periods, resulting in reduced milk yields, lower weight gains, and economic losses for farmers [5]. In recent decades, climate change has manifested through increased temperatures and erratic rainfall patterns, contributing to more frequent and prolonged droughts. These climatic stresses have had a direct impact on fodder availability, posing serious challenges to livestock productivity and feed security [6]. In light of these challenges, the advancement of resilient, high-yielding, and nutritionally balanced forage systems has become a strategic national priority to enhance livestock feed security and support sustainable animal production. Maize (*zea mays L.*), sorghum (*Sorghum bicolor L.*), and hybrid Napier grass (*Pennisetum purpureum* × *P. glaucum*) have been recognized as key forage species with considerable

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potential to enhance livestock feed security in Sri Lanka, owing to their high productivity, adaptability to diverse ago-climatic conditions, and favorable nutritional profiles [7],[8]. These forage crops offer several advantages, including high biomass productivity, adaptability to a wide range of agro-climatic conditions, and the potential to enhance nutritional quality. Over the past decade, the introduction of improved varieties and hybrids, along with the promotion of enhanced agronomic practices, has aimed to optimize their productivity and overall performance. Despite these advancements, substantial gaps persist in the development of forage systems in Sri Lanka. Existing research has predominantly concentrated on the performance of individual forage crops, with limited emphasis on their integration within whole-farm systems. Comprehensive evaluations comparing key forage species, particularly concerning biomass productivity, nutritional quality, resilience to abiotic stresses, and environmental impact, remain scarce. Furthermore, there is a notable deficiency in data related to optimal management practices, forage-livestock integration strategies, and the application of decision support models to inform sustainable forage development and utilization. This review aims to synthesize current knowledge on maize-based forage systems in Sri Lanka. It critically examines their potential to address the country's forage shortages, highlights the challenges and research gaps limiting their wider adoption, and proposes future directions for developing sustainable, climate-resilient forage systems tailored to Sri Lankan conditions.

1.1. Maize (*Zea mays* L.)

Maize (*Zea mays* L.) is recognized as the most significant upland cereal crop in Sri Lanka, owing to its wide adaptability, high productivity, and diverse uses in human consumption, animal feed, and industrial applications [9]. Maize is the second most widely cultivated cereal crop in Sri Lanka, grown on over 70,000 hectares; however, local production remains insufficient to meet national demand, resulting in import dependence. Over the past decade, production has fluctuated significantly, and given its vital role in both human and livestock diets, enhancing the maize sector is essential for sustainable agricultural development [10]. Maize serves as a critical component of Sri Lanka’s agricultural sector, with approximately 80–85% of its production allocated to the poultry and cattle feed industries. Given its significance, it has been designated a priority crop under the Department of Agriculture’s research and development programs, resulting in substantial advancements over the past four decades, particularly in the development of open-pollinated varieties (OPVs) and hybrid cultivars through collaboration with CIMMYT. Currently, hybrid maize cultivation accounts for 95% of the total maize-growing area, with a majority of hybrid seed requirements being met through imports. This widespread adoption of high-yielding hybrids has contributed to an increase in the national average yield, reaching up to 3.6 t/ha. However, sustaining these productivity gains remains a pressing concern due to the adverse effects of land degradation and various abiotic and biotic stresses [11]. It is a vital C_4 cereal crop and exhibits comparatively high drought tolerance, showing distinct physiological and developmental responses to water stress across all growth stages, including seedling establishment, vegetative growth, and reproductive development, from germination to physiological maturity [12]. C_4 crops are generally known for their broad adaptability to a wide range of climatic conditions; however, recent climate trends and associated variability appear to be pushing the threshold limits of even resilient C_4 species such as maize [13]. According to Weerakoon and Kumari (2014), maize cultivation in Sri Lanka experienced a substantial expansion between 2007 and 2012, with the cultivated area increasing from approximately 34,000 hectares to over 59,000 hectares, predominantly in the dry and intermediate zones. This growth was largely driven by the adoption of hybrid maize varieties such as 'Sampath' and 'MI Maize 1H', which enhanced national average yields from about 1 ton per hectare to 3.4 tons per hectare. Currently, more than 95% of maize cultivation relies on hybrid varieties, the majority of which are imported. The increasing demand for poultry products has significantly elevated the need for maize as a key component in animal feed. However, the limited availability of arable land necessitates productivity improvements to meet future demand. National research efforts are now directed toward developing high-yielding, pest- and disease-resistant maize varieties, although emerging diseases such as sheath blight and southern rust present growing challenges. Karunaratne and Wheeler (2015) emphasized that climate variability has a significant impact on maize yields across different districts in Sri Lanka. Their study identified rainfall as a critical factor positively influencing yields in districts such as Anuradhapura, Hambantota, and Monaragala. In contrast, elevated seasonal mean temperatures were found to adversely affect yields, particularly in Monaragala, which is categorized as a 'hot-dry' zone. Interestingly, in Badulla, classified as a 'cold-dry' region, a positive correlation was observed between mean seasonal temperature and maize yield, suggesting that the crop's response to temperature fluctuations varies according to regional ago-climatic conditions. High-yielding maize accessions such as SEU2, SEU16, SEU15, SEU9, and SEU10 have demonstrated superior performance in Sri Lanka, surpassing commercial varieties in terms of photosynthetic efficiency, biomass, and grain yield. These accessions hold strong potential for future crop improvement and breeding programs aimed at enhancing maize productivity under local conditions [16].

Table 1 Characteristics of Open-Pollinated (OP) and Hybrid (H) Maize Varieties in Sri Lanka

Variety	Type	Seed Colour	Cob Shape	Plant Height	Days to Maturity	Yield (t/ha)	Special Features
Bhadra	OP	Orange	Conical	Tall	105–110	4.0	—
Ruwan	OP	Yellow	Conical	Tall	105–110	4.0	Requires proper spacing for light reception
M.I.M.S. Hybrid 01	H	Orange	Conical, long (19–21 cm)	Tall	—	5.5–6.5 (Potential: 8.0)	High protein; double lysine and tryptophan
M.I.M.S. Hybrid 02	H	Yellowish-orange	Cylindrical	Medium	105–110	5.0–6.5 (Potential: 8.0)	Seeds fill well to cob tip
M.I.M.S. Hybrid 03	H	Deep orange	Cylindrical	Medium	100–105	5.5–6.5 (Potential: 8.0)	Seeds well-filled to cob tip
M.I.M.S. Hybrid 04	H	Orange	Conical	Medium	105–110	5.5–6.5 (Potential: 8.0)	Seeds well-filled to cob tip
M.I.M.S. Hybrid 05	H	Deep orange	Conical	Medium	100–105	5.5–6.5 (Potential: 8.0)	Seeds well-filled to cob tip

1.2. Nutritional importance

Maize is a highly efficient energy source in animal feed, particularly for poultry, due to its high starch and fat content, low fiber levels, and excellent digestibility. It can contribute up to 60% of the total energy in poultry diets and supports effective nutrient utilization with minimal anti-nutritional effects. Maize varieties rich in starch and fat offer higher metabolizable energy, while excess fiber reduces efficiency [17]. Maize is a crucial high-energy feed ingredient in poultry diets, particularly for laying hens. Zuber and Rodehutscord (2017) reported that the apparent metabolizable energy corrected for nitrogen (AME_n) in corn ranges between 15.7 and 17.1 MJ/kg of dry matter, confirming its value as an energy source. However, their study revealed notable variations in the digestibility of key amino acids, such as lysine (64–85%), methionine (86–94%), threonine (72–89%), and tryptophan (21–88%), across different maize batches. This variability indicates that not all maize offers consistent nutritional quality, and physical traits like test weight or grain appearance alone cannot reliably predict its feeding value. Consequently, evaluating each maize batch for amino acid digestibility and energy content is essential for accurate feed formulation. This approach leads to better protein and energy utilization, improved bird performance, and supports more sustainable poultry production [18]. According to Liu *et al*. (2020), corn retains significant metabolizable energy even after being stored for three years, which confirms its reliability as a feed ingredient. This sustained energy supply supports consistent egg production and overall bird health.

1.3. Maize silage: Importance, Quality Factors, and Varietal Performance

Maize silage serves as a vital component in dairy cow diets, primarily due to its high metabolizable energy content. According to Szymanska *et al*. (2014), maize silage is a valuable high-energy roughage commonly used in feeding dairy and beef cattle due to its high yield, energy content, and ease of inclusion in total mixed rations. However, maximizing its nutritional benefits depends on the production of high-quality silage through proper ensiling practices. As reported by Khan *et al*., (2015), the nutritional value of maize silage is highly dependent on the stage of crop maturity at harvest, which significantly influences dairy cow performance and milk composition. Harvesting maize at the optimal dry matter (DM) content of 300–350 g/kg has been shown to improve dry matter intake, milk yield, and milk protein concentration, while also altering the fatty acid profile of milk. Consequently, the strategic utilization and timely harvesting of maize silage are critical for enhancing dairy productivity and overall feed efficiency. According to Zafar *et al*. (2020), the preservation of fodder through silage, haylage, or hay is essential for minimizing feed wastage and ensuring year-round availability of nutritious feed for livestock. Maize silage is highlighted as a preferred option due to its superior biomass yield, favorable nutritional composition, and high concentration of water-soluble carbohydrates, which facilitate effective lactic acid fermentation. It serves as a cost-effective and energy-rich source of fiber and starch, making it a valuable supplement to grazing systems throughout much of the year. However, the authors emphasize that when maize silage is heavily incorporated into the diet, it is crucial to address potential deficiencies in protein, minerals, and sometimes fiber to achieve optimal milk solids output. While some nutrient losses during fermentation and storage are unavoidable, improved management practices can significantly reduce these losses. According to Sanyal *et al.* (2024), significant variation exists among maize varieties in both agronomic and nutritional traits relevant to silage production. MX-77 and Pioneer outperformed other cultivars, offering the highest herbage yield, crude protein content, and overall forage quality. Key traits such as leaf area, stem diameter, and plant height showed positive correlations with yield and crude protein, making them useful indicators for selecting superior silage maize varieties. As highlighted by Karnatak *et al.* (2023), the adoption of improved mechanization in silage maize production significantly reduces labor requirements and avoids the moisture-related marketing challenges commonly encountered with grain maize. Additionally, maize silage allows for early field clearance, enabling timely planting of subsequent crops, and serves as a cost-effective and practical feed source that supports the viability of smallholder dairy systems. These factors collectively contribute to the growing economic attractiveness of maize silage. However, the long-term profitability of this enterprise hinges on breeding hybrids specifically tailored for silage purposes. Despite its importance, limited efforts have been made to develop ideal plant types focused on silage-specific traits. These include optimizing dry matter and nutrient yields, enhancing digestible energy content, improving cell wall composition and digestibility, ensuring stalk standability, selecting appropriate maturity durations, and minimizing losses during the ensiling process. Serva (2024) highlighted that seasonal variation significantly affects the quality of maize silage. Using an open-source database, the study analyzed how different pre-ensiling conditions, particularly the chemical composition of freshly harvested maize, influence the final silage quality. The results showed that seasonality plays a critical role, and while predictive models based on initial crop composition can be useful, their effectiveness is limited to screening-level applications, especially when relying on in-field sensor technologies.

Table 2 Silage Quality of Selected Maize Cultivars

Cultivar	**Dry Matter (%)**	**Crude Protein (%)**	**NDF (% DM)**	**ADF (% DM)**	**Digestibility (% DM)**	**Remarks**
Bhadra	30–32	7.5–8.5	50–55	30–34	65–68	Moderate energy content
Ruwan	28–30	8.0–9.0	52–56	32–36	63–67	Higher protein than Bhadra
M.I.M.S. Hybrid 01	32–35	9.0–10.5	45–50	28–32	68–72	High lysine and tryptophan; good silage
M.I.M.S. Hybrid 02	30–33	8.5–9.5	48–52	30–34	66–70	Good balance of yield and nutrition
M.I.M.S. Hybrid 03	31–34	8.5–9.5	47–51	29–33	67–71	Well-filled grains; good starch content
M.I.M.S. Hybrid 04	30–32	8.0–9.0	48–53	31–35	65–69	Uniform cobs; reliable silage quality
M.I.M.S. Hybrid 05	31–34	9.0–10.0	46–50	28–32	68–72	Deep orange grain; better digestibility

2. Conclusion and Future Directions

Maize plays a critical role in advancing sustainable forage systems in Sri Lanka. Its nutritional richness, high yield potential, and silage suitability make it a valuable feed source for dairy and meat production. However, maximizing its benefits requires a shift toward integrated forage planning, silage-specific breeding, and better management of climate-related risks.

To strengthen maize-based forage systems, future efforts should focus on

- Breeding and promoting silage-specific hybrids.
- Expanding research on regional performance under varying climate and soil conditions.

- Developing decision-support models for forage-livestock integration.
- Promoting mechanization and silage-making technologies.
- Enhancing farmer awareness and extension services.

A holistic, systems-oriented approach combining genetics, agronomy, and climate adaptation is essential to secure feed sustainability and improve livestock productivity in Sri Lanka's dry zones.

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