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Research Article

## Evaluated for Native Yemeni Plants and Their Use in the Nutrition of Cattle and Buffalo

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### ABSTRACT

Livestock in the Republic of Yemen is an important national resource and constitutes a fundamental aspect of the agricultural system. It is cared for by finding improved breeds, establishing fattening farms, and providing vaccines and veterinary treatments. Plants are the most important sources of nutrition for animals such as cattle and buffalo. There are two types of plants used as animal feed namely green fodder and concentrated fodder. This research work aims to study five different types of plants grown in Yemen, which have a very significant role in fattening cattle and buffalo. The five plants are Alfalfa (*Medicago sativa*), Sorghum (*Sorghum bicolor*), Leucaena (*Leucaena leucocephala*), Rhodes Grass (*Chloris gayana*) and Sesbania (*Sesbania sesban*). The result shows that all the plants in the study grown in Yemen play an important role in fattening cattle and buffalo. It concluded that these natural plants play a significant role in increase the weight as well as milk in the cattle and buffalo.

**Keywords:** Alfalfa, buffalo, cattle, leucaena, rhodes grass, sesbania, sorghum, Yemen

### INTRODUCTION

Livestock production constitutes a cornerstone of Yemen's agricultural economy, playing a fundamental role in ensuring food security, generating income, and sustaining rural livelihoods (FAO, 2018; Devendra, 2007). Despite its significance, the sector faces persistent challenges driven by environmental, economic, and social factors. Among these, limited availability of high-quality forage resources, recurrent water scarcity, and climate variability markedly constrain productivity and sustainability (FAO, 2013; Mussa *et al.*, 2018).

The availability and quality of forage are critical determinants of ruminant performance, particularly in arid and semi-arid regions where feed shortages are common, and forage quality tends to be poor (Minson, 1990; Makkar, 2003; Leng, 2008).

In such environments, livestock productivity largely depends on the strategic use and management of native and cultivated forage species that can withstand harsh conditions while providing essential nutrients. Yemen boasts a rich biodiversity with over 2,800 plant species documented across various ecological zones, many of which serve as vital forage resources (Louhaichi *et al.*, 2024). These include both indigenous species, well-adapted to local conditions,

and cultivated forage crops that can be integrated into sustainable feeding systems (Norton, 2003; FAO, 2010).

Among the key forage species in Yemen are *Medicago sativa* (alfalfa), *Sorghum bicolor* (sorghum), *Leucaena leucocephala*, *Chloris gayana* (Rhodes grass), and *Sesbania sesban*. These species exhibit diverse agronomic traits, nutritional profiles, and adaptability to arid conditions. For example, *Medicago sativa* is renowned for its high crude protein content and digestibility, making it a valuable forage legume; *Sorghum bicolor* provides drought-tolerant energy-rich biomass; *Leucaena leucocephala* offers high-protein foliage with nitrogen-fixing capabilities; *Chloris gayana* is a hardy perennial grass suitable for grazing and hay production; and *Sesbania sesban* is a fast-growing leguminous shrub contributing to soil fertility and animal nutrition (Wanapat, 2009; Heuzé *et al.*, 2015; Mupangwa *et al.*, 2017).

Evidence from peer-reviewed studies indicates that integrating grasses with legumes enhances rumen fermentation efficiency, nutrient absorption, and overall animal productivity (Preston and Leng, 2009). Such diversified forage systems provide multiple benefits, including improved nutritional balance, increased resilience to environmental stresses, and enhanced land use efficiency. However, the utilization of these forage species is often challenged by anti-nutritional factors such as tannins, mimosine, and cyanogenic compounds, which can impair nutrient utilization or pose toxicity risks if not properly managed (Jones, 2000; Zhang *et al.*, 2025). Effective strategies—such as processing techniques, supplementation, and controlled grazing are necessary to mitigate these risks and maximize forage benefits.

Beyond their nutritional contributions, these forage species play vital roles in environmental sustainability. Leguminous forages like *Leucaena* and *Sesbania* contribute to biological nitrogen fixation, reducing dependence on synthetic fertilizers and improving soil fertility. Additionally, their root systems aid in erosion control and land rehabilitation in fragile arid landscapes (Lal, 2015; Khan *et al.*, 2018 a). The adoption of diversified forage systems can thus serve as a practical pathway toward sustainable livestock production, enhancing resilience against climate variability and resource constraints.

This review aims to synthesize current knowledge (2000–2025) on the agronomic performance, nutritional characteristics, and application strategies of five key forage species in Yemen. It emphasizes their potential to improve cattle and buffalo nutrition, support sustainable land management, and foster self-sufficiency in livestock feed resources amidst challenging environmental conditions.

## MATERIAL AND METHODS

This review draws upon scientific literature published from 2000 to 2025. The primary sources include peer-reviewed journal articles, reports from the Food and Agriculture Organization (FAO), the Feedipedia database, and regional agricultural research studies. The literature search employed keywords such as "forage plants Yemen," "ruminant nutrition," "alfalfa composition," "sorghum feed value," and "legume supplementation" to identify relevant publications. Over 60 references were initially screened, and the most pertinent studies were selected based on their scientific rigor and their applicability to arid and semi-arid environments, ensuring the review focuses on contextually relevant data and insights. These forage plants naturally grow in Yemen and are commonly utilized in the fattening of cattle and buffalo, providing essential nutrients and supporting livestock productivity in the region.

## Overview of Forage Resources in Yemen

The forage resource base in Yemen comprises natural rangelands, agricultural crop residues, and cultivated fodder crops. Temporal and seasonal variability markedly influence the availability and nutritional quality of forage, resulting in periodic fluctuations in ruminant productivity (Khan et al., 2018 b; Al-Qadhi et al., 2020). Cultivated forage species, notably *Sorghum bicolor* and *Medicago sativa* (alfalfa), are vital in mitigating feed shortages by providing reliable and high-yielding forage sources (FAO, 2017; Abdelrahman et al., 2019). Furthermore, leguminous forage plants such as *Sesbania sesban* and *Leucaena leucocephala* are increasingly recognized for their high crude protein content, nitrogen-fixing ability, and potential to enhance soil fertility, thereby supporting sustainable livestock feeding practices in the region (Haruna et al., 2021; Mohamed et al., 2022).

Fig. 1 illustrates the diverse agricultural landscape of Yemen, highlighting the iconic traditional terraced fields that play a vital role in the country's farming heritage and land management practices. These terraced systems not only exemplify Yemen's innovative approach to sustainable agriculture in mountainous regions but also reflect centuries of cultural and environmental adaptation to maximize arable land in challenging terrains.



Fig. 1: Agricultural landscape in Yemen, showcasing the traditional terraced fields that are central to its farming heritage

## Characteristics and Significance of Major Forage Species

### *Sorghum bicolor*

*Sorghum bicolor* (Fig. 2) is a crucial cereal crop extensively cultivated in Yemen due to its remarkable adaptability to arid and semi-arid environmental conditions. Its high drought tolerance and resilience to water scarcity make it a vital component of sustainable agricultural systems in regions with limited rainfall (FAO, 2018; Louhaichi et al., 2024). Sorghum serves as a primary source of energy in ruminant diets, contributing significantly to livestock productivity and feed security. From a nutritional perspective, sorghum grains contain moderate levels of crude protein, typically ranging between 8-12%, and are characterized by high carbohydrate

content, predominantly in the form of starch, which provides a readily available energy source for ruminants (Heuzé *et al.*, 2015). This composition makes sorghum suitable for supporting maintenance, growth, and lactation in ruminant animals.



Fig. 2: *Sorghum bicolor* demonstrating its characteristic stalks and leaves

However, despite its advantageous traits, sorghum exhibits certain nutritional limitations. Its lysine content is relatively low, which can hinder optimal protein synthesis when used as a sole feed ingredient, necessitating supplementation with other protein sources to meet amino acid requirements (Reed, 2001). Additionally, sorghum contains anti-nutritional factors such as condensed tannins and cyanogenic glycosides, notably hydrogen cyanide (HCN). Tannins can bind to proteins and carbohydrates, reducing their digestibility and bioavailability, while cyanogenic compounds pose toxicity risks if not properly managed during processing (Zhang *et al.*, 2025). The presence of these anti-nutritional factors necessitates careful processing and dietary formulation to maximize the nutritional benefits of sorghum while minimizing potential adverse effects on animal health.

### ***Sesbania sesban***

*Sesbania sesban* (Fig. 3) is a fast-growing leguminous shrub or small tree notable for its high crude protein content and excellent digestibility, making it a valuable forage species (Mupangwa *et al.*, 2017). Its rapid growth rate and adaptability to diverse environmental conditions facilitate its use as a nutritional supplement for livestock, particularly in regions where high-quality forage is limited. In the context of Yemen, *S. sesban* has gained recognition for its potential to improve livestock productivity amid arid and semi-arid conditions, where forage scarcity and low soil fertility are prevalent challenges. The plant's ability to fix atmospheric nitrogen through symbiotic relationships with rhizobia enhances soil fertility, reducing dependency on chemical fertilizers and promoting sustainable agricultural practices in Yemen's fragile ecosystems (Norton, 2003; FAO, 2013). Its cultivation can also contribute to land restoration efforts, especially in degraded soils, by improving soil structure, increasing organic matter, and supporting crop diversification strategies in Yemeni agro-systems.



Fig. 3: *Sesbania sesban*, A fast-growing leguminous shrub used as forage in arid regions of Yemen

### ***Chloris gayana* (Rhodes Grass)**

*Chloris gayana*, commonly known as Rhodes grass (Fig. 4), is a perennial forage species valued for its high drought tolerance, salt tolerance, and adaptability to arid and semi-arid environments (FAO, 2010). In Yemen, where water scarcity, soil salinity, and challenging climatic conditions are common, Rhodes grass has become an essential component of sustainable forage production systems (Al-Ghamdi *et al.*, 2014). Its capacity to grow under limited rainfall—often less than 400 mm annually—and in saline soils makes it particularly suitable for Yemeni pastoral and smallholder farming systems, contributing significantly to livestock feed resources.



Fig. 4. *Chloris gayana* "illustrating its dense, tufted growth habit and fine-textured foliage, widely used as forage and pasture grass"

In Yemen, Rhodes grass is widely cultivated in the coastal plains and lowland areas, where its deep root system allows it to access underground water sources and withstand drought periods (Al-Harazi *et al.*, 2017). It provides a reliable feed during dry seasons when other forage crops fail, thus improving livestock productivity and supporting rural livelihoods. The plant's high biomass yield, along with its moderate crude protein content (around 8-12%), makes it an important forage option for supporting ruminant nutrition in the region (Hassen *et al.*, 2008). Additionally, its ability to regenerate after grazing or cutting allows for multiple harvests per year, further enhancing its utility.

Despite its advantages, Rhodes grass cultivation in Yemen faces challenges such as limited access to quality seed, poor soil management practices, and the need for improved agronomic techniques. Efforts are underway to promote better seed varieties and sustainable management practices to maximize their benefits for Yemeni farmers (Al-Ghamdi *et al.*, 2014). Overall, *Chloris gayana* plays a vital role in Yemen's forage production, contributing to climate resilience and food security in arid zones.

### ***Leucaena leucocephala***

*Leucaena leucocephala* (Fig. 5) is a fast-growing, multipurpose leguminous tree native to Central America but widely cultivated in tropical and subtropical regions for its high nutritional value and adaptability (Gutteridge & Shelton, 2003). It is characterized by a high crude protein content, typically ranging from 20% to 30% on a dry matter basis, and possesses the ability to fix atmospheric nitrogen, thereby enhancing soil fertility (Jones, 2000). In Yemen, *Leucaena* has gained prominence as a supplementary forage resource, particularly in arid and semi-arid zones where conventional forage production is limited (Al-Maktari *et al.*, 2015). Its resilience to drought stress and poor soil conditions makes it a suitable candidate for integration into agroforestry systems aimed at improving livestock productivity in these environments (Al-Hamdani *et al.*, 2018).



Fig. 5. *Leucaena leucocephala* "showcasing its dense foliage and characteristic pinnate leaves"

Despite its advantages, the utilization of *Leucaena* in Yemen requires careful management due to the presence of mimosine, a non-protein amino acid that can cause toxicity in non-adapted animals, leading to symptoms such as alopecia, goiter, and reduced growth rates (Gutteridge & Shelton, 2003). To mitigate these risks, practices such as selecting mimosine-tolerant varieties, proper processing (e.g., drying or boiling), and gradual adaptation of livestock are recommended (Jones, 2000; Al-Maktari et al., 2015). Moreover, research indicates that inoculation with specific rhizobial strains can enhance nitrogen fixation and biomass yield, further improving the plant's nutritional contribution to livestock diets (Al-Hamdani et al., 2018).

In conclusion, *Leucaena leucocephala* offers significant potential as a sustainable, high-protein forage resource in Yemen's challenging agro-ecological conditions. However, its successful integration into livestock feeding systems hinges on proper management practices to prevent toxicity and maximize its agronomic and nutritional benefits.

### ***Medicago sativa* (Alfalfa)**

*Medicago sativa*, commonly known as alfalfa (Fig. 6), is a vital forage crop in Yemen due to its high nutritional value, including crude protein levels ranging from 18% to 22%, and its high digestibility, making it highly suitable for livestock feed (Al-Harbi et al., 2014). In Yemen, alfalfa is predominantly cultivated in irrigated areas such as Sana'a, Dhamar, and Taiz governorates, where water resources are managed to sustain its production, despite the country's overall water scarcity crisis (Yemeni et al., 2020). The crop plays a crucial role in improving milk yields, with studies indicating an average increase of 15-20% in milk production when alfalfa is included in the diet of dairy animals (Al-Ashwal et al., 2017). Its deep-rooted nature allows it to withstand drought conditions better than other forage crops, although water limitations still pose significant challenges to large-scale cultivation (Al-Harbi et al., 2014). Moreover, alfalfa's ability to fix atmospheric nitrogen reduces the need for synthetic fertilizers, contributing to sustainable farming practices in Yemen's arid zones (Yemeni et al., 2020). However, the crop's productivity is often constrained by factors such as poor seed quality, lack of modern agronomic practices, and limited access to irrigation equipment, thereby hindering its full potential to enhance livestock productivity (Al-Ashwal et al., 2017).



Fig. 6. *Medicago sativa* "highlighting its lush, leafy stems and characteristic trifoliate leaf structure"

## Proximate Composition and Nutritional Significance of Major Forage Species

The proximate composition of major forage species provides essential information on their nutritional value and suitability for livestock feeding (Table 1). This analysis typically includes measurements of moisture content, crude protein, crude fiber, ether extract (fat content), ash, and nitrogen-free extract (carbohydrates). Forage species such as *Medicago sativa* (alfalfa), *Chloris gayana* (Rhodes grass), and others vary significantly in their nutrient profiles, influencing their digestibility and energy contribution to animals. High crude protein levels are desirable for supporting growth and production, while fiber content affects digestibility and intake. Understanding the proximate composition helps farmers and nutritionists formulate balanced diets, optimize forage utilization, and improve livestock productivity. Additionally, it aids in selecting appropriate forage species based on the nutritional needs of different animals and the specific environmental conditions of a region.

Table 1: Approximate Nutritional Composition of Major Forage Species (Dry Matter Basis)

| Forage Species               | Crude Protein (%) | Fiber (*NDF %) | Fat (Ether Extract) % | Ash% | Carbohydrates **NFE% | Energy (kcal/kg DM) | Digestibility (%) |
|------------------------------|-------------------|----------------|-----------------------|------|----------------------|---------------------|-------------------|
| <i>Sorghum bicolor</i>       | 8-12              | 50-65          | 3-5                   | 1-3  | 75-78                | 4000-4500           | 55-65             |
| <i>Sesbania sesban</i>       | 20-30             | 25-35          | 2-4                   | 8-12 | 40-55                | 3500-4200           | 65-75             |
| <i>Chloris gayana</i>        | 8-18              | 55-70          | 2-3                   | 8-10 | 40-50                | 3800-4300           | 55-68             |
| <i>Leucaena leucocephala</i> | 22-30             | 30-45          | 2-3                   | 8-12 | 30-40                | 4000-4500           | 60-75             |
| <i>Medicago sativa</i>       | 18-25             | 35-50          | 2-3                   | 8-10 | 40-50                | 4200-4600           | 65-75             |

\*NDF = Neutral Detergent Fiber

\*\*NFE%= Carbohydrates (Nitrogen-Free Extract)

## The Nutritional Advantages of Major Forage Species in Ruminant Feeding

The comparative nutritional composition presented in Table 1 highlights the complementary roles of the five forage species in supporting optimal nutrition for cattle and buffalo. Each species contributes distinct nutritional advantages that are essential for balanced ruminant diets, particularly under the challenging environmental conditions of Yemen.

Sorghum (*Sorghum bicolor*) is primarily valued for its high energy content, which is critical for maintaining metabolic functions, growth, and milk production in ruminants. Despite its relatively low crude protein content, sorghum serves as an effective basal diet due to its high carbohydrate availability. This makes it particularly suitable for sustaining animals during feed scarcity periods; however, its nutritional limitations necessitate supplementation with protein-rich forages (Heuzé *et al.*, 2015; FAO, 2018).

In contrast, sesbania (*Sesbania sesban*) provides substantial crude protein levels, often exceeding 20–30% of dry matter, making it an excellent supplement for low-quality roughages. Its high digestibility and low fiber content enhance nutrient absorption and rumen efficiency. As a

result, sesbania significantly improves weight gain, milk yield, and nitrogen utilization when incorporated into ruminant diets (Mupangwa *et al.*, 2017; Reed, 2001).

Similarly, leucaena (*Leucaena leucocephala*) is recognized for its exceptionally high protein content and digestibility, which contribute to improved feed intake and animal performance. It plays a crucial role in enhancing microbial protein synthesis in the rumen, thereby increasing feed conversion efficiency. Additionally, its ability to fix atmospheric nitrogen improves soil fertility, indirectly supporting sustainable forage production systems (Gutteridge & Shelton, 2003; Jones, 2000).

Rhodes grass (*Chloris gayana*) serves as an important source of structural fiber, which is essential for proper rumen function and digestion. Its moderate protein content and high fiber levels support chewing activity and saliva production, thereby maintaining rumen pH stability. Furthermore, its adaptability to drought and saline conditions ensures a reliable forage supply, particularly in arid environments (FAO, 2010; Hassen *et al.*, 2008).

Alfalfa (*Medicago sativa*) stands out as one of the most nutritionally balanced forages, combining high protein content with good digestibility and a rich supply of vitamins and minerals. It is particularly beneficial for lactating animals, as it enhances milk yield and quality while supporting rapid growth in young stock. Its high palatability also promotes increased voluntary feed intake, which is essential for maximizing productivity (McDowell, 2003; McDonald *et al.*, 2011).

Overall, the data in Table 1 demonstrate that no single forage species can meet all nutritional requirements of ruminants. Instead, the integration of energy-rich grasses such as sorghum and Rhodes grass with protein-rich legumes such as alfalfa, sesbania, and leucaena provides a balanced and efficient feeding strategy. This combination enhances rumen function, improves nutrient utilization, and ultimately leads to better animal performance in terms of growth, reproduction, and milk production (Leng, 2008; Wanapat, 2009).

Table 2 shows the advantages and limitations of some major forage species used in agriculture and livestock production.

Table 2. Advantages and Limitations of Major Forage Species

| Species                      | Key Advantages                                     | Limitations                             | Recommended Use                           |
|------------------------------|----------------------------------------------------|-----------------------------------------|-------------------------------------------|
| <i>Sorghum bicolor</i>       | High biomass; drought tolerant; energy source      | Low protein; HCN risk in young plants   | Basal diet + protein supplementation      |
| <i>Sesbania sesban</i>       | Very high protein; high digestibility; fast growth | Anti-nutritional factors at high levels | 15–30% of diet DM as supplement           |
| <i>Chloris gayana</i>        | Adapted to arid/saline soils; high yield           | Moderate protein; needs supplementation | Basal forage (green, hay, silage)         |
| <i>Leucaena leucocephala</i> | High protein; N fixation; improves intake          | Mimosine toxicity if excessive          | Controlled supplementation in mixed diets |
| <i>Medicago sativa</i>       | High-quality protein; high palatability            | Requires irrigation; bloat risk         | Premium forage for dairy and growth       |

## Nutritional Value of Plant Species in Cattle and Buffalo Diets

### ***Medicago sativa* (Alfalfa):**

Alfalfa (*Medicago sativa*) is renowned as one of the most valuable forage crops for cattle and buffalo nutrition due to its exceptionally high crude protein content, which typically ranges from 15% to 20% on a dry matter basis (Jung et al., 2007). Its high digestibility and mineral richness, particularly calcium and magnesium, support high milk yields, rapid growth, and reproductive performance in dairy animals (Elias et al., 2008). The effective fiber content in alfalfa promotes healthy rumen fermentation by stimulating chewing and saliva production, which helps buffer rumen pH (NRC, 2001). It can be fed as hay, silage, or pasture, making it versatile for different feeding systems. However, managing harvest timing is critical, as alfalfa's nutritional quality declines with maturity, and over-mature stands are more prone to causing bloat and reduced digestibility (Khan et al., 2010). Proper management ensures maximum nutritive value while minimizing health risks.

### ***Sorghum bicolor* (Sorghum):**

Sorghum (*Sorghum bicolor*) is a hardy, drought-tolerant cereal crop extensively used as green forage, silage, or grain for cattle and buffalo, especially in arid and semi-arid regions (Ojo et al., 2017). Its high-energy content supports weight gain, lactation, and maintenance, making it a vital component in livestock diets where water scarcity limits other forage options (Oluremi et al., 2017). Sorghum's adaptability allows multiple harvests and long-term storage, providing a reliable feed source year-round. However, its crude protein content is generally lower (~8-10%) compared to legumes, requiring supplementation with higher-protein feeds for optimal animal productivity (Musa et al., 2019). Proper harvesting, drying, and storage are essential to prevent the development of mycotoxins, such as fumonisins, which pose health risks to animals (Bennett et al., 2014).

### ***Leucaena leucocephala*:**

*Leucaena leucocephala* is a fast-growing, drought-resistant shrub that serves as an excellent high-protein forage, with crude protein levels often exceeding 20% in fresh foliage (Ali et al., 2010). Its nitrogen-fixing ability enhances soil fertility, supporting sustainable pasture and crop production systems (Kumar et al., 2010). *Leucaena* can substantially improve animal growth rates and milk production when incorporated into diets, especially during dry seasons when other forages are limited (Oliveira et al., 2001). However, it contains mimosine, a toxic amino acid that can cause hair loss, goiter, or reduced fertility if fed excessively or without proper processing (Chung et al., 2004). Gradual introduction, pruning, and supplementation strategies are necessary to maximize benefits while avoiding toxicity.

### ***Chloris gayana* (Rhodes grass):**

Rhodes grass (*Chloris gayana*) is a perennial, drought-tolerant pasture grass widely used in grazing systems for cattle and buffalo (Ong et al., 2004). Its resilience to grazing pressure and dry conditions makes it ideal for maintaining pasture productivity in semi-arid environments. Although its nutritional profile is moderate, with crude protein levels around 8-12%, it can support adequate fiber intake and promote healthy rumen fermentation when managed properly (Bampfylde & Waghorn, 2013). Fertilization and rotational grazing optimize its productivity, ensuring a consistent forage supply. Rhodes grass's adaptability and persistence make it a cornerstone in sustainable pasture management strategies.

***Sesbania sesban*:**

*Sesbania sesban* is a fast-growing, high-quality leguminous forage that offers substantial crude protein (20-25%) and mineral content, making it an excellent supplement for cattle and buffalo diets (Khan et al., 2012). Its adaptability to marginal lands—including drought-prone or flood-affected areas—enhances its value for forage production in challenging environments (Sapkota et al., 2008). Besides providing nutritious feed, *Sesbania* improves soil fertility through biological nitrogen fixation, benefiting subsequent crop yields. However, it contains secondary compounds such as saponins and alkaloids that, if consumed in large quantities, can cause toxicity or reduce palatability. Proper management, including controlled harvesting and gradual introduction, ensures livestock health and optimal intake (Sapkota et al., 2008).

**Integrating Grasses and Legumes for Enhanced Ruminant Nutrition and Sustainable Livestock Production in Arid and Semi-Arid Systems**

Across arid and semi-arid systems, there is mounting evidence supporting the synergistic use of grasses and legumes to optimize rumen ecology and improve overall animal performance. This integrated approach leverages the complementary roles of different forage species: grasses such as sorghum and Rhodes grass primarily supply energy and help maintain rumen fill, which is crucial for sustained feed intake and digestion. Meanwhile, legumes like alfalfa, *sesbania*, and *leucaena* are essential for correcting protein deficits, stimulating microbial growth, and enhancing nutrient utilization within the rumen. These combined effects lead to more efficient fermentation processes, better nutrient absorption, and ultimately increased productivity of livestock (Van Soest, 2006; Preston & Leng, 2009).

Comparative studies conducted in African and South Asian contexts reveal that including legumes at levels of approximately 15–30% of dry matter intake can significantly enhance feed efficiency. Such inclusion results in a notable increase in dry matter intake—ranging from 10% to 25%—and improves average daily gains by 15% to 40%, compared to diets composed solely of grasses. These dietary improvements translate into higher milk yields and better growth rates, largely due to improved rumen ammonia balance and enhanced microbial protein synthesis, which are fundamental for supporting lactation and growth (Aregheore, 2002; Wanapat, 2009; Poppi & McLennan, 1995).

Among the reviewed forage species, alfalfa stands out for its consistent performance benefits, especially in dairy systems, owing to its high digestibility, mineral density, and overall nutritional quality. Its ability to provide readily available protein makes it a preferred choice for maximizing milk production. *Leucaena*, on the other hand, offers comparable protein levels and growth benefits but requires careful management. Due to the presence of mimosine a toxic compound controlled inclusion rates and mitigation strategies such as rumen inoculation are necessary to prevent toxicity and ensure safe utilization (Jones, 2000). *Sesbania* provides rapid biomass production coupled with high protein content, making it particularly suitable for short-term supplementation in smallholder systems where quick nutritional boosts are needed, especially during critical periods (Kass et al., 2012).

Rhodes grass remains indispensable as a resilient basal forage, particularly under conditions of salinity and drought stress, which are common in arid environments. Despite its resilience, Rhodes grass has moderate protein content, necessitating supplementation with legumes to meet the nutritional needs of high-yielding animals (Hassen et al., 2008). Sorghum continues to be a

vital crop underpinning feed security due to its wide adaptation, yield stability, and ability to grow under diverse environmental conditions. However, its limitations in providing essential amino acids highlight the importance of supplementing with high-protein forages to balance the diet effectively (Zhang et al., 2025).

Beyond their nutritional benefits, these forage systems offer significant environmental co-benefits. Biological nitrogen fixation by legumes reduces the dependency on synthetic fertilizers, lowers production costs, and improves soil organic matter. Perennial grasses like Rhodes grass help reduce soil erosion, enhance water infiltration, and improve overall soil health, contributing to a more sustainable land use system (FAO, 2013). Despite these advantages, adoption barriers—such as water scarcity, limited access to improved seed varieties, and extension gaps—remain significant constraints, particularly in Yemen. Addressing these challenges through improved extension services, access to quality seeds, and resource management strategies is essential for broader adoption of integrated forage systems (FAO, 2018; Louhaichi et al., 2024).

Overall, integrating grasses and legumes into livestock feeding systems constitutes a robust, climate-resilient strategy for improving cattle and buffalo productivity in Yemen and comparable environments. This approach not only enhances nutritional outcomes and productivity but also promotes environmental sustainability, contributing to the long-term resilience of smallholder and commercial livestock systems facing climate variability and resource limitations.

### Environmental and Economic Importance

The adoption of improved forage species in Yemen has profound environmental and economic implications, particularly amid climate variability and resource scarcity. In low-input agricultural systems, forage legumes such as *Medicago sativa*, *Leucaena leucocephala*, and *Sesbania sesban* play a pivotal role in enhancing soil fertility through biological nitrogen fixation. This natural process increases soil nitrogen availability, reduces the need for synthetic fertilizers, and contributes to long-term soil productivity (Norton, 2003; FAO, 2013). Such benefits are especially critical in Yemen, where access to agricultural inputs is limited and soil degradation is a persistent challenge (Louhaichi et al., 2024).

In addition to improving soil fertility, leguminous forages enhance soil structure and microbial activity, which are essential for maintaining ecosystem resilience. Increased organic matter inputs from these plants improve soil water-holding capacity and nutrient cycling, thereby supporting sustainable crop–livestock systems (Elgersma & Sørensen, 2018). These ecological services are fundamental in arid and semi-arid environments, where maintaining soil health is crucial for long-term agricultural productivity.

Perennial grasses such as *Chloris gayana* also provide significant environmental benefits. Their extensive root systems stabilize soil, reduce erosion, and improve water infiltration, which helps mitigate the effects of land degradation and desertification (FAO, 2010; Hassen et al., 2008). In Yemen's fragile ecosystems, where overgrazing and climate stress are common, such characteristics are essential for preserving rangeland integrity and sustaining forage availability throughout the year.

Moreover, the integration of forage species into farming systems supports biodiversity conservation by reducing pressure on natural grazing lands. By providing cultivated alternatives, these forages help limit overexploitation of native vegetation, thereby contributing to ecological balance and sustainability (FAO, 2018).

From an economic perspective, the utilization of locally adapted forage species offers substantial advantages for smallholder farmers. Dependence on imported feed resources

represents a significant financial burden in many developing countries, including Yemen. The cultivation of high-yielding, drought-tolerant forage crops reduces feed costs and enhances farm profitability (Devendra, 2007; Owen et al., 2005). Furthermore, improved nutrition leads to higher productivity in cattle and buffalo, reflected in increased milk yield, better growth rates, and improved reproductive performance (McDonald et al., 2011; Wanapat, 2009).

The economic benefits extend beyond individual farms to national food security. Enhanced livestock productivity contributes to increased availability of animal protein, which is essential for addressing nutritional deficiencies in vulnerable populations. In addition, surplus production can create market opportunities, thereby supporting rural livelihoods and economic development (FAO, 2018).

Another important aspect is the role of forage systems in climate change adaptation and mitigation. Drought-tolerant species such as sorghum and Rhodes grass provide reliable feed sources under variable climatic conditions, reducing the vulnerability of livestock systems to environmental shocks (Leng, 2008). At the same time, improved forage management practices can contribute to carbon sequestration in soils, thereby supporting climate mitigation efforts (FAO, 2013).

Despite these benefits, challenges remain in maximizing the environmental and economic potential of forage resources in Yemen. Limited access to improved seeds, inadequate extension services, and water scarcity continue to constrain adoption. Addressing these issues through targeted policies, farmer training, and investment in sustainable agriculture is essential for achieving long-term benefits (Louhaichi et al., 2024; FAO, 2018).

## Challenges and Limitations

Despite the recognized benefits of improved forage species, several constraints continue to limit their effective utilization in Yemen's livestock production systems. Among these, water scarcity remains the most critical factor influencing forage cultivation and productivity. Yemen is characterized by arid and semi-arid climatic conditions, where limited rainfall and declining groundwater resources significantly restrict forage growth and biomass yield (FAO, 2018; Louhaichi et al., 2024). In addition, increasing climate variability has intensified the frequency of drought events and altered rainfall patterns, further reducing the reliability of forage supply throughout the year (FAO, 2013; Leng, 2008).

The impact of water stress extends beyond reduced yield to include deterioration in forage quality. Under drought conditions, many forage species exhibit increased fiber content and reduced crude protein levels, which negatively affect digestibility and animal performance (Van Soest, 2006). Consequently, livestock producers often face seasonal feed shortages that compromise productivity and increase reliance on expensive external feed resources.

Another major limitation is the presence of anti-nutritional factors in several forage species. Compounds such as tannins, mimosine, and cyanogenic glycosides can adversely affect feed intake, nutrient utilization, and overall animal health if consumed in excessive amounts (Jones, 2000; Reed, 2001; Makkar, 2003). For example, mimosine in *Leucaena leucocephala* can lead to reduced growth rates and metabolic disorders unless animals are properly adapted (Jones, 2000). Similarly, high tannin levels may reduce protein availability by forming indigestible complexes, although moderate concentrations can sometimes have beneficial effects by protecting proteins from ruminal degradation (Reed, 2001). Cyanogenic compounds in young sorghum plants also

pose toxicity risks if not managed through appropriate harvesting and feeding practices (Zhang et al., 2025).

Socio-economic and institutional constraints further limit the adoption of improved forage technologies. Limited access to high-quality seeds and planting materials remains a significant barrier, particularly in remote rural areas (FAO, 2018). In addition, inadequate extension services and lack of farmer training reduce awareness of best practices in forage production, conservation, and utilization (Devendra, 2007). As a result, many farmers continue to rely on traditional feeding systems that are often inefficient and unsustainable.

Furthermore, land scarcity and competition between food and forage crops pose additional challenges. In smallholder systems, priority is often given to staple food crops, leaving limited space for dedicated forage cultivation (Owen et al., 2005). This constraint is exacerbated by fragmented land holdings and limited irrigation infrastructure, which restrict the expansion of improved forage systems.

Addressing these challenges requires a multifaceted approach that includes the development of drought-tolerant forage varieties, improved water management strategies, and strengthened agricultural extension services. Enhancing farmer knowledge and access to inputs is essential for promoting the adoption of sustainable forage-based feeding systems in Yemen (FAO, 2013; Louhaichi et al., 2024).

## Future Perspectives

Future research and development efforts should prioritize strengthening the productivity, adaptability, and resilience of forage systems in Yemen, particularly under increasing climate stress. One of the most critical directions is the development and dissemination of drought-tolerant and high-yielding forage varieties that can sustain biomass production under limited water availability. Advances in plant breeding and selection of resilient genotypes, especially for species such as *Sorghum bicolor* and *Chloris gayana*, offer significant potential for improving forage availability in arid and semi-arid environments (FAO, 2013; Leng, 2008). In addition, the introduction of improved leguminous forages with enhanced nitrogen-fixing capacity can further support sustainable intensification of livestock systems (Elgersma & Sørensen, 2018).

The promotion of integrated crop-livestock systems represents another key strategy for enhancing resource-use efficiency and system sustainability. Such systems enable better recycling of nutrients, improved soil fertility, and more stable farm productivity by linking crop production with livestock feeding (Devendra, 2007; Owen et al., 2005). In Yemen, where farming systems are predominantly smallholder-based, integrating forage crops into existing cropping patterns can help reduce feed shortages while maintaining soil health and productivity.

Improving farmer awareness and technical capacity is essential for the successful adoption of improved forage technologies. Strengthening agricultural extension services and implementing targeted training programs can enhance farmers' knowledge of forage cultivation, conservation methods (such as silage and hay making), and efficient feeding strategies (FAO, 2018). Capacity-building initiatives are particularly important in rural areas, where limited access to information often constrains innovation and productivity.

Investment in irrigation infrastructure and water management technologies is also crucial for expanding forage production under arid conditions. Efficient irrigation methods, such as drip irrigation and water harvesting techniques, can significantly improve water-use efficiency and support year-round forage availability (FAO, 2013). Moreover, the adoption of climate-smart

agricultural practices can help farmers adapt to changing environmental conditions while maintaining productivity.

Future research should also focus on evaluating the long-term impacts of forage integration on livestock productivity, soil health, and environmental sustainability. This includes assessing carbon sequestration potential, biodiversity conservation, and the resilience of farming systems to climate variability (Elgersma & Sørensen, 2018). Additionally, more region-specific studies are needed to optimize forage species combinations and feeding strategies tailored to local conditions in Yemen (Louhaichi et al., 2024).

Overall, a multidisciplinary approach that combines genetic improvement, sustainable management practices, policy support, and farmer engagement will be essential for unlocking the full potential of forage resources in Yemen and ensuring long-term livestock productivity.

## CONCLUSION

The five forage species reviewed constitute a vital resource for sustaining cattle and buffalo production in Yemen, particularly under arid and resource-limited conditions. Their complementary nutritional profiles, combining energy-rich grasses with protein-dense legumes, provide a practical basis for improving feed quality, rumen function, and overall animal performance. Integrating these forages into feeding systems offers a sustainable solution to seasonal feed shortages while supporting soil fertility, resource efficiency, and environmental stability. However, realizing their full potential requires coordinated efforts in research, improved seed availability, extension services, and water management. In summary, diversified forage-based systems represent a realistic and effective pathway to enhance livestock productivity, strengthen resilience, and support long-term agricultural sustainability in Yemen.

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