Forage Res., **51**(4) : pp. 466-477 (2026) **http://forageresearch.in**

FODDER TO FEED: SORGHUM SILAGE FOR ENHANCED LIVESTOCK NUTRITION

PUMMY KUMARI[1]*, DIBYENDU SETH[2], SATPAL[1], SACHIN YADAV[2], NEERAJ KHAROR[1], G. S. DAHIYA[1], D. S. PHOGAT[2] AND DALWINDER PAL SINGH[3]

[1]ICAR-AICRP on Sorghum & Small Millets, Forage Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[2]Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[3]Forage Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
**(e-mail: pummy.hau@gmail.com)*

(Received: 7 March 2026; Accepted: 21 March 2026)

SUMMARY

The current article focuses on investigating the feasibility of producing silage from forage sorghum, emphasizing its potential as an affordable and superior substitute for conventional choices like corn. Sorghum's adaptability to diverse agro-climatic conditions, especially its exceptional drought tolerance and low water requirement, makes it an ideal candidate crop for regions with water scarcity. Additionally, its cost effectiveness and ability to produce high biomass on marginal lands further strengthen its role as a sustainable option for silage production. This article provides an overview of the techniques involved in producing quality sorghum silage including advantages of sorghum silage over other sources. It reviews key cultivation practices and the importance of harvesting sorghum at the right stage of crop growth to maximize digestibility and nutritional quality. A step-by-step guide for the ensiling process has been discussed, elaborating best practices for chopping, compacting and fermenting the crop to ensure quality silage with minimal nutrient loss. This review highlights and compares sorghum silage to that obtained from alternatives, demonstrating its ability to support healthy livestock growth. Through the focused discussion, the article aims to equip agricultural professionals and farmers with practical insights and strategies to improve livestock nutrition, reducing production costs, promoting sustainable farming practices and enhancing farm profitability through efficient use of sorghum as silage.

Key words: *Sorghum, Silage, Ensiling, Nutrients and Livestock health*

Silage is an indispensable component of livestock nutrition, valued for its ability to provide a balanced supply of carbohydrates, proteins and essential nutrients that support growth, reproduction and milk production. Its digestibility and palatability make it a preferred feed choice for both dairy and beef cattle, ensuring consistent weight gain and improved milk yields during periods of fodder scarcity (Atim *et al.*, 2024). Incorporating silage into their feeding programs, farmers can offer year-round nutritional support to livestock, thereby enhance productivity and minimize reliance on expensive external feed inputs (Seth *et al.*, 2023). Among various silage crops, sorghum stands out as a versatile, drought tolerant and cost-effective option, particularly suited to regions facing water scarcity and extreme climatic conditions and it also contributes to sustainable farming by reducing feed costs, utilizing surplus crops efficiently and minimizing post-harvest losses.

Sorghum (*Sorghum bicolor* L. Moench) is an exceptional crop for silage due to its wide adaptability, high biomass yield and resilience to drought (Kumari *et al.*, 2023). It can grow in rainfall as low as 400 mm annual, is nutrient-rich, offers high levels of carbohydrates and moderate protein content, which is crucial for improving productivity of arid and semi-arid regions and therefore maintaining livestock health (Laxmi *et al.*, 2019). Various workers reported that sorghum silage contains about 60-65% total digestible nutrients and 8-12% crude protein, depending on the variety and harvesting stage (McCuistion *et al.*, 2019). The inclusion of sorghum silage in livestock diets has been linked to improved feed efficiency and stable milk yields, even during seasonal fodder shortages. Additionally, sorghum's rapid growth rate and capacity to flourish in difficult environment make it a cost-efficient option for farmers, further reducing the economic burden of livestock feeding.

1. Potential Silage Crops

A variety of crops can be exploited used for silage, including cereals such as maize (*Zea mays L.*), sorghum (*Sorghum bicolor L.*), oat (*Avena sativa* L.) and barley (*Hordeum vulgare L.*), which are widely used due to their high biomass yield, energy content and ensiling characteristics (Addah *et al*., 2011; da Silva Carvalho *et al*., 2017). Corn is the most widely used due to its high energy content, digestibility, and consistency. Barley provides high protein content and early harvest, while oat silage is nutrient-rich and palatable for livestock (Reddy *et al*., 2023). Additionally, legumes like alfalfa (*Medicago sativa*) and clovers (*Trifolium spp.*) have been explored for their higher protein content and nitrogen fixation capability which improves soil fertility (Martin *et al*., 2004). Kosolapov *et al*. (2021) reported that combining cereals and legumes creates more nutritionally balanced silage for enhancing livestock productivity and reducing reliance on supplemental feeds. The current status of production and consumption of silage is depicted in Table 1 and Table 2 whereas Figure 2 depicts the current status of crop-wise silage production and consumption in the world. Jukanti *et al*. (2016) reported that the potential of non-traditional crops such as pearl millet (*Pennisetum glaucum L.*), cowpea (*Vigna unguiculata L.*) and cassava (*Manihot esculenta*) in silage making, particularly in arid and semi-arid regions where these crops thrive under water-limited conditions. Rye thrives in cooler climates and offers early-season feed, while millet is highly resilient to heat and drought and grows quickly in challenging environmental conditions. Root crops like sugar beet and fodder beet have demonstrated high water-soluble carbohydrate levels, improving silage fermentation quality (Habeeb *et al*., 2017). Furthermore, agro-industrial by-products such as sweet potato vines and corn stover are increasingly being utilized as livestock feed, promoting resource efficiency. Each of these crops brings unique benefits, making them valuable options for silage production in different agro-climatic conditions.

2. Silos and Silage quality:

A silo is an agricultural building used to store and produce animal feed in optimal conditions.

Trench silos: are used mostly in areas with little rainfall for the production and storage of silage. They are frequently excavated into an elevated area, bank, or slope and are occasionally lined with concrete.

Bunker Silo: Concrete, dirt, or wood are used to build above-ground walls for bunker silos. Sufficient drainage is necessary for bunker silos. Concrete flooring are typically required to reduce feed waste and facilitate loading.

Tower Silo: The tower silo is an above-ground

TABLE 1
Country-wise Silage Production/Consumption (Source: FAO, 2023)

Country	Silage Production (Million Tons)	Consumption (Million Tons)	Major Fodder Sources
United States	140	135	Corn, Sorghum, Alfalfa
Brazil	75	70	Sugarcane, Corn, Grass
India	25	25	Maize, Sorghum, Napier Bajra hybrid
China	100	98	Corn, Millet, Grass
European Union (Total)	120	118	Corn, Rye, Alfalfa

TABLE 2
State-wise Silage Production/Consumption in India (Source: FAO, 2023)

State	Silage Production (Million Tons)	Consumption (Million Tons)	Major Crops
Punjab	8.0	7.5	Maize, Sorghum
Haryana	6.0	6.0	Maize, Bajra, Napier
Gujarat	5.0	4.8	Bajra, Napier Bajra Hybrid, Sorghum
Maharashtra	4.5	4.2	Maize, Sugarcane Tops
Karnataka	4.0	4.0	Maize, Sorghum, Grass

cylinder that is 15–20 meters high and has a diameter of 6–9 meters. Tower silo loading is challenging. To raise the cut fodder, it uses a big capacity blower or a mechanical loader.

Bag Silo: Small or marginal farmers may also make silage using a bag or tube. The polythene used should be low-density polypropylene grade and 0.1 mm thick.

The number of animals, duration of the scarcity period, type of soil and drainage, water table depth, rainfall, and other meteorological factors all influence the choice of silos for silage production. Five to six quintals can be stored in a single cubic meter silo pit.

Silage Quality

Silage is a critical component of livestock feeding systems, offering a balanced source of energy, protein and essential nutrients that promote animal health and productivity. The nutritional quality of silage is determined by factors such as crop selection, harvest timing, and ensiling conditions. High quality silage should have optimal levels of carbohydrates for fermentation, as water-soluble carbohydrates act as substrate for lactic acid bacteria, ensuring rapid pH reduction and preservation (Kung, 2010). Protein content is another essential factor, with legumes like alfalfa and clover enhancing crude protein levels in silage. Additionally, nutrient rich cereals such as corn and sorghum provide digestible energy, critical for meeting the metabolic demands of dairy and beef cattle (Addah *et al.*, 2011). The inclusion of additives such as microbial inoculants and enzymes further improves silage fermentation quality, reduces spoilage and enhances nutrient availability (Liu *et al.*, 2020). The characteristics of high-quality silage include-

1. Colour should be light green, yellow or light brown without any dark or mouldy spots.
2. It should smell nice like sweet pickles or vinegar type.
3. Firm texture with palatable material.
4. Moisture content should be 65-70%.
5. Lactic acid should be between 3-16%, Butyric acid less than 0.2%, acetic acid 1-3% and content of ammoniacal nitrogen should be less than 10% of total nitrogen.
6. pH should vary from 4-4.5.

The digestibility and nutrient content of silage are pivotal to its efficacy in livestock diets. For example, silage with a neutral detergent fiber (NDF) level of 40-50% and an acid detergent fiber (ADF) level below 35% ensures optimal intake and digestibility (Kuz'mina & Kartashova, 2020). High-energy silage, particularly from corn, has been shown to enhance milk yield and growth rates in cattle. Meanwhile, legume-cereal mixtures improve the protein-energy balance and reduce the need for supplementary feed. Minerals like calcium, phosphorus and potassium, often present in silage, support bone health and metabolic functions in livestock (Mokolopi, 2020). However, poor fermentation or harvesting crops at an inappropriate stage can result in silage with low nutrient profile and high fiber content, leading to reduced palatability and digestibility. Thus, proper management practices, from crop selection to storage, are critical to ensure the nutritional quality of silage and its role in sustainable livestock production systems.

3. Advantages of Sorghum as a source of Silage

Sorghum, in particular, is gaining attention as a reliable silage crop due to its rusticity, wide adaption, high biomass production and drought tolerance. Silage yield potential of various crops is depicted in Table 3. Compared to other silage crops like maize, sorghum offers a cost-effective and sustainable solution for maintaining livestock nutrition, especially in limited water regions due to its high water use efficiency, nearly 30% higher than that of maize, making it a sustainable alternative under water-limited regions (Getachew *et al.*, 2016). Sorghum's rich nutritional profile (Table 4), high regeneration potential, higher numbers of tillers per plant, ability to thrive in marginal soils, etc. make it a perfect choice for ensuring consistent feed availability (Kumari *et al.*, 2024), consequently improving overall farm profitability and a potential substitute for corn in near future. Moreover, sorghum varieties such as forage sorghum and sudangrass are specifically bred for silage, offering higher digestibility and improved fermentation quality (Li *et al.*, 2024). Integrating sorghum with leguminous crops like cowpea or alfalfa can further enhance nutritional profiles of silage by boosting protein content and balancing energy-protein ratios. This diversification not only enriches livestock diets but also promotes sustainable agricultural practices by enhancing soil fertility through nitrogen fixation.

The versatility of sorghum silage extends beyond its nutritional benefits. It contributes to sustainable livestock farming by minimizing food wastage and enabling the use of marginal lands

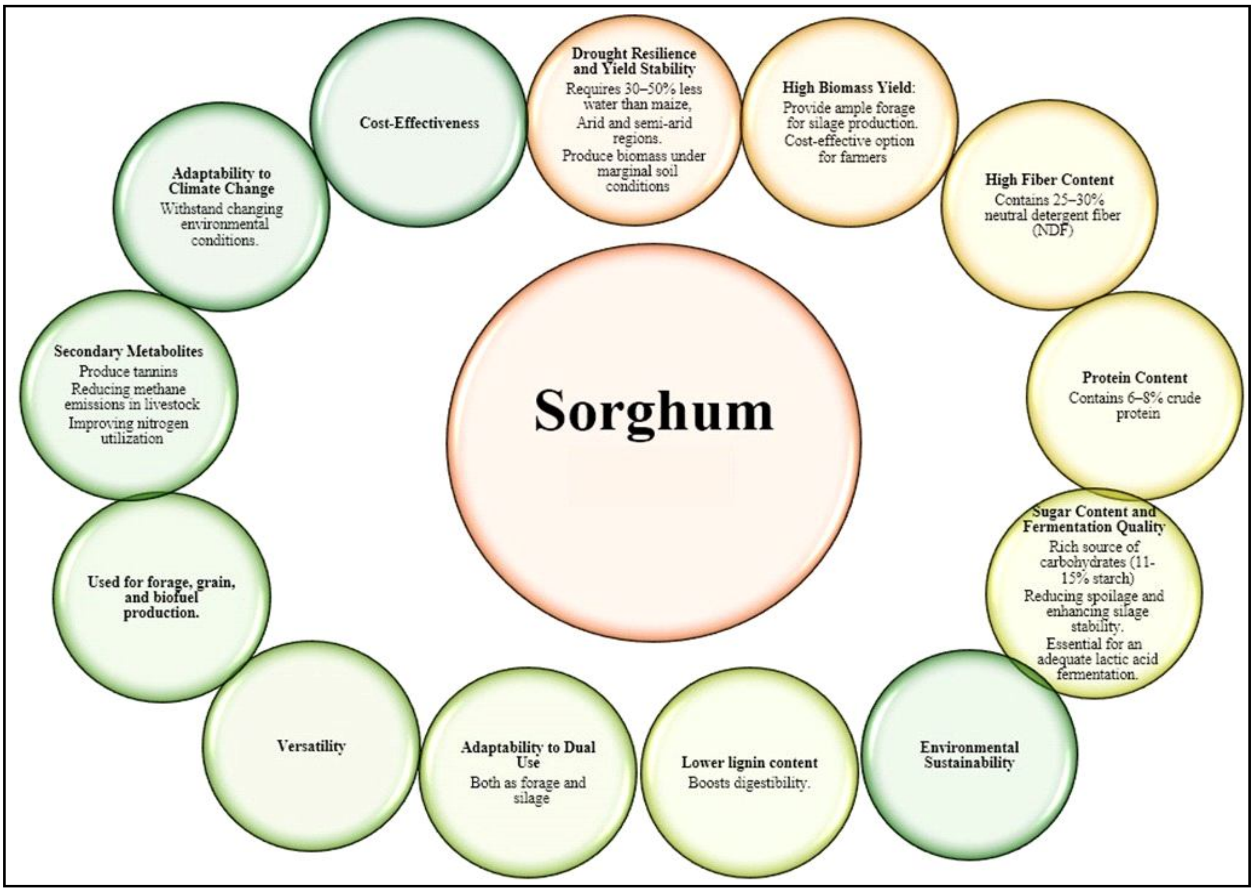


Fig. 1. Advantages of sorghum.

TABLE 3
Silage yield potential of various crops

Crop	Average Dry Matter Yield (q/ha)*	Silage Characteristics
Maize (Corn)	160-250	High energy, suitable for ensiling, excellent digestibility.
Sorghum	120-200	Drought-tolerant, good fiber content, suitable for arid regions
Oats	100-140	Lower energy, often used in mixtures for grazing or silage.
Triticale	100-150	Adaptable to various soils, higher protein content as compared to maize.
Wheat	80-120	Good for dual-purpose, moderate digestibility.
Soybean	50-70	High protein content often mixed with maize for balance.

*The values are approximate and depend on factors like crop, variety, climate, and management practices.

unsuitable for other crops (Singh *et al.*, 2022). Its compatibility with modern ensiling techniques ensures better preservation and reduced spoilage, making it a reliable feed option year-round. As farmers seek solutions to rising feed costs and erratic climatic conditions, sorghum silage emerges as a sustainable, nutrient rich and cost-effective strategy to ensure livestock health and productivity. The various advantages associated with use of sorghum as a source of silage have been depicted in Fig. 1.

4. Preparation of sorghum silage

4.1. Selection of Sorghum Variety

Choosing the appropriate sorghum variety is crucial for producing high-quality silage with optimal nutritional and fermentation characteristics. Varietal selection depends on several factors, including climatic conditions, water availability, livestock nutritional requirements and dry matter yield. Selecting the right sorghum varieties for silage involves considering

TABLE 4
Nutritional Profile of Sorghum Silage

Nutrient	Concentration	Per 1000g	Reference
Digestible Energy	2.17 Mcal / kg	0.65 Mcal	Admin and Admin, 2021
Lysine	0.25 % DM	0.74 g	Pontieri & Del Giudice, 2016
Calcium	0.49 % DM	1.47 g	Mitaru, 1978
Phosphorus	0.22 % DM	0.66 g	Gowda et al., 2015
Potassium	1.72 % DM	5.16 g	Admin and Admin, 2021
Sulphur	0.12 % DM	0.36 g	Pontieri & Del Giudice, 2016
Sodium	0.02 % DM	0.06 g	Mitaru, 1978
Zinc	32 ppm	9.58 mg	Gowda et al., 2015
Copper	9 ppm	2.7 mg	Admin and Admin, 2021
Manganese	73 ppm	21.92 mg	Mitaru, 1978
Selenium	0.03 ppm	0.01 mg	Pontieri & Del Giudice, 2016

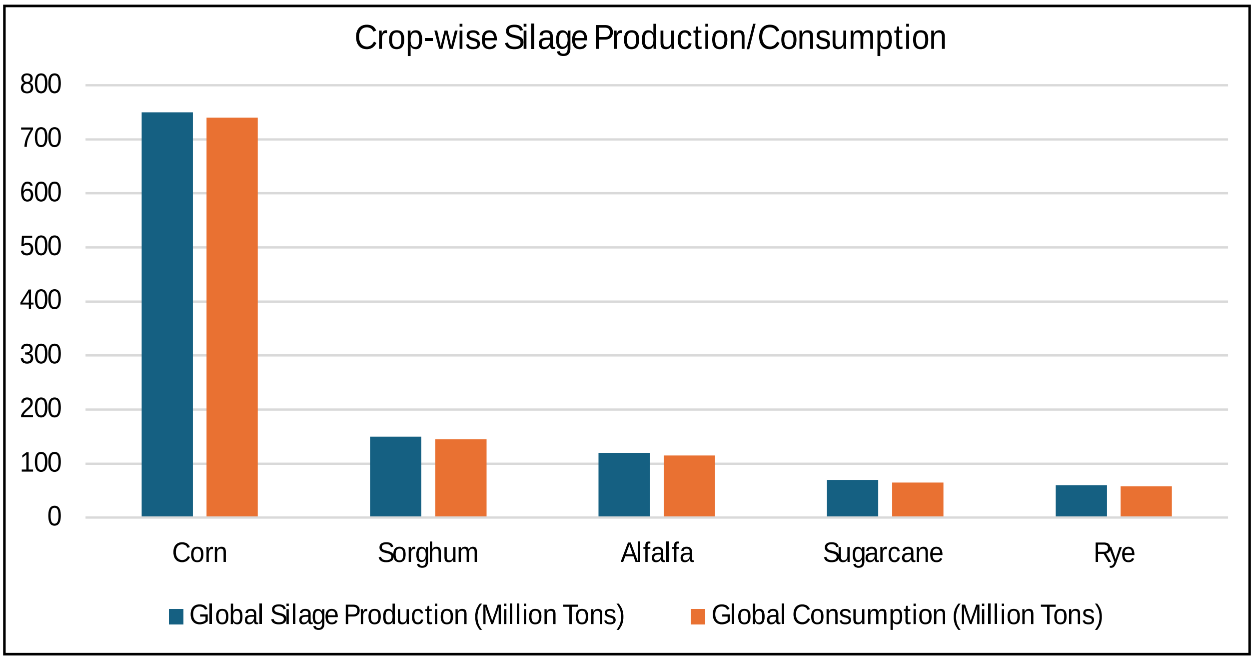


Fig. 2. Worldwide Crop-wise Silage Production and Consumption (Source: OECD & FAO, 2023).

TABLE 5
Sweet sorghum and Forage Sorghum as Silage Source

Parameter	Sweet Sorghum	Forage Sorghum
Sugar Content	High (10–20% in juice)	Low (1–3% in juice)
Biomass Yield (t/ha)	40–50	30–40
Water Use Efficiency	High	High
Digestibility	Higher due to soluble sugars	Moderate, depends on fiber content
Crude Protein (%)	5–7	6–8
Fiber Content (NDF, %)	Lower due to higher sugar levels	Higher, suitable for rumen health
Fermentability	Excellent; sugars enhance lactic acid production	Moderate; requires additives
Stage of Harvesting	Boot to dough	Boot to soft dough
Cost of Production	Moderate (requires more nutrient management)	Low to moderate
Primary Use	Dual-purpose (silage and ethanol production)	Forage and silage only

TABLE 6
Comparative performance of Sorghum types for Silage production

Variety type	Biomass yield (t/ha)	Crude protein (%)	Digestibility (% TDN)	Water requirement	Varieties	Characteristics
Sweet Sorghum	40–50	6–8	68–70	Low	CSH 22SS, Madhura, CSV49SS	High sugar content (10–20%), excellent for fermentability and high-energy silage.
Forage Sorghum	30–40	5–7	60–65	Moderate	HJ 541, CSV53F, CSV44F, Sudan Grass, Pusa Chari Hybrid	High biomass yield, drought-tolerant and good fiber digestibility.
Brown Midrib Sorghum	35–45	6–9	70–75	Moderate	CSV43BMR	High Biomass, brown midrib fodder purpose variety, less lignin,high brix, juicy and good for silage

several key criteria. First, yield potential is crucial, with high biomass yield ensuring sufficient silage quantity. Hybrids generally produce higher fodder yields than traditional open-pollinated varieties (Kumari et al., 2024). Nutritional quality is another important yard stick, as the crude protein (CP%) and digestibility (IVDMD%) must meet livestock requirements. Opting for varieties with lower lignin content can improve fiber digestibility (Jung, 1989). Water soluble carbohydrate concentration of 125.4 g/kg dry matter in fresh harvested sorghum is ideal for silage fermentation Rodrigues et al., 2019. It's also essential to prefer varieties adaptable to local conditions, such as drought-tolerant varieties for arid and semi-arid regions and flood tolerant varieties for areas with heavy rainfall. Additionally, selecting high-sugar varieties like sweet sorghum can enhance fermentation and improve palatability (Rao *et al.*, 2009; Zhang *et al.*, 2016). The comparative nutritional values of silage obtained from forage sorghum and sweet sorghum is shown in Table 5. Recommended sorghum types for silage include sweet sorghum for high-energy silage due to its high sugar content (examples: Rio, SSV84, CSV19SS, CSV49SS, CSH24SS etc), forage sorghum for high biomass production and moderate nutritional quality (Sudangrass, FS5, HJ 541, CSV53F, CSV64F, CSV44F, CSV33MF, SSG 59-3, etc), brown midrib (BMR) sorghum for enhanced digestibility due to lower lignin content (NutriHoney BMR, BMR 106, CSV43BMR), hybrid sorghums for high-yield silage with improved resistance to pests and diseases (examples: CSH 25, CSH 30, CSH 35, CSV31), and dual-purpose varieties for both grain and silage (SPV 462, CSV 15, K 12) (Table 6). The relevance of choosing a sorghum variety/hybrid stems from a study conducted by Ward & Smith 1968 that discussed the necessity of taking dry matter content into account and how it affects animals' ingestion of silage dry matter.

4.2. Agronomic practices

Sowing time is very crucial for optimal forage yields and quality of any fodder crop. As a warm-season crop, sorghum thrives well upto temperatures ranging from 77°F to 95°F *i.e*., 25°C-35°C. For spring planting, ideal for regions with a warm climate, the window spans from early spring to early summer, ensuring soil temperatures consistently reaching around 65°F (18°C) for rapid germination and early growth of sorghum for high biomass production. Planting for summers should be done in last week of March to first fortnight of April for maximum biomass accumulation before stress conditions set in (Saini *et al*., 2018). Summer planting suits regions with a long growing season or multiple cropping systems, extending upto late spring or early summer to ensure maturity before the first frost. In drought-prone areas, late planting can avoid early growth stress, though it requires careful management to ensure adequate biomass yield before harvest.

Field preparation is vital for optimal sorghum silage production, starting weeks before planting to condition the soil for rapid seedling establishment. Soil testing is necessary to determine the nutrient status and pH, because sorghum thrives well in soils with a pH of 6.0-7.5, essential nutrients (phosphorus, potassium, nitrogen) should be applied based on soil test results to support healthy plant growth (Sebnie and Mengesha, 2016). Land tillage involves deep ploughing for primary tillage to break soil compaction and improve root penetration, followed by lighter harrowing for secondary tillage to create a smooth and firm seedbed for optimal germination. Weed and pest management is crucial during early growth stages, with pre-emergence herbicides applied after planting and regular scouting for pests like shoot fly and stem borer that can damage seedlings (Buntin, 2009). Assured irrigation is essential, especially in areas with inconsistent rainfall, to ensure proper moisture management during the early vegetative stages. The recommended seeding rate for high biomass production is 25-30 kg/ha in case of small seeded multicut varieties and 50-62.5 kg/ha in case of bold seeded single cut varieties/hybrids. Optimal row to row spacing is 25 cm, although narrower spacing may increase biomass yield but also pose competition for nutrients (Porfirio *et al.*, 2021).

4.3. Harvesting

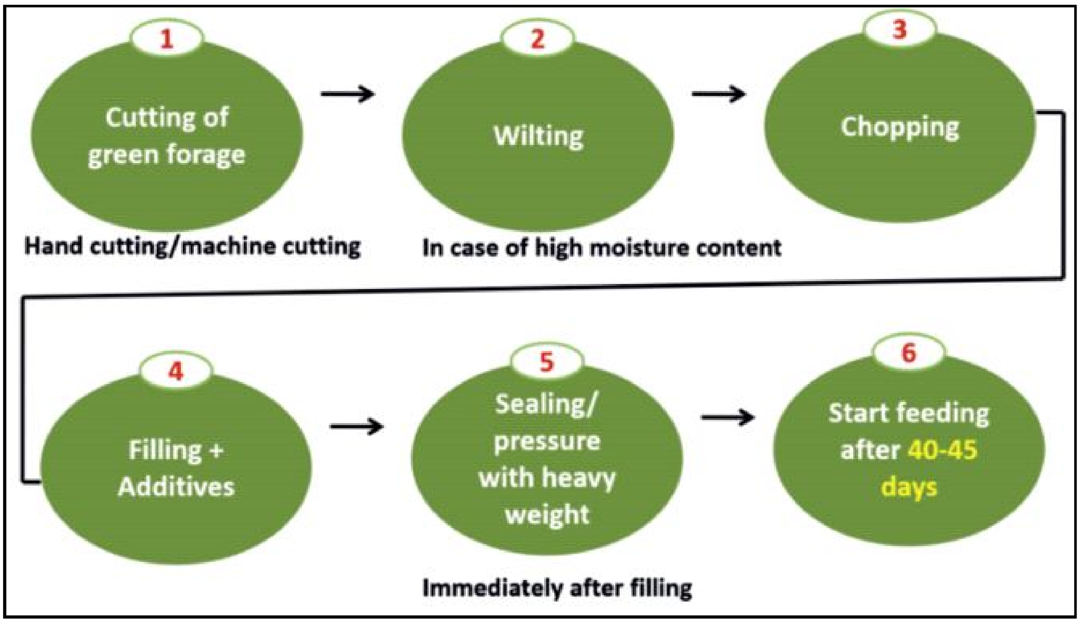
The best time to harvest sorghum for silage is at boot to early dough stage, which corresponds to approximately 50-75% grain development. At this stage, the plant achieves a balance of high biomass yield and optimal nutritional content, with sufficient energy (sugars) in the stems and leaves, but without excessive lignifications (Wallau *et al.*, 2022). Adjusting the cutting height to 15-30 cm above the soil surface ensures the most nutritious parts are harvested and prevents soil contamination. Harvesting during the boot stage is considered ideal because the plant retains high sugar content, which aids in fermentation and enhances the palatability of the silage. This stage typically occurs about 60-70 days after planting in case of multicut sorghum and 80-90 days in case of single cut types. Some farmers may choose to harvest at the dough stage for higher fiber content, but the sugar content begins to decline with maturity, potentially reducing the overall quality of silage compared to the boot stage. Harvesting considerations also include moisture content, where the ideal range is around 65-70%. Harvesting too early, when the moisture content is higher, can lead to poor fermentation, while harvesting too late, when the moisture content below 60%, would result in dry, low-quality silage formation (Dickerson, 1986). Additionally, visual indicators such as the colour of the leaves (green to yellowish) and the firmness of the stems helps to determine the optimal time of harvest. Harvesting sorghum for silage requires specialized equipment to ensure efficient processing. Key equipment includes forage harvesters, which are used for cutting and chopping sorghum stems and leaves into smaller pieces. These harvesters can be self-propelled or tractor-mounted and are preferred for their capacity and speed. Moreover, conditioners are used to cut and condition the stems, improving drying and fermentation. Choppers further break down the material into uniform pieces (about 0.25 to 0.50 inch), essential to enhance the fermentation process. Tractors and trailers transport the chopped sorghum to silage storage pits, equipped with high-capacity trailers for large volumes. Proper storage in silage bags or bunkers is crucial for quick packing and sealing to prevent air exposure, which can lead to poor fermentation. Chopping lengths should be 1-2 cm for optimal fermentation, ensuring proper packing and air escape.

4.4. Ensiling

The ensiling process is crucial for effectively preserving sorghum for silage production, involving key steps such as layering, compacting and sealing. The first step is layering, where the chopped sorghum is evenly spread in 6–8 inches' thick layers. Proper layering ensures consistent packing and fermentation by preventing air pockets, which could lead to spoilage or uneven fermentation. Next step is compacting, which involves pressing the layered sorghum to remove air, promoting anaerobic fermentation necessary for high-quality silage. Tightly packing the fodder layers with tractors equipped with large tires or specialized silage compactors lowers the possibility of spoiling via mold growth (Muller *et al.*, 2019). For optimal fermentation, a well-compacted silo can reach a density of 700–800 kg/m^3 (Woolford, 2004).

Pit Silo

To stop seepage or rainwater from entering the silo pit, it must be higher up. The silo's location makes it simple to feed the animals silage. To avoid its flavor seeping into the milk, it should be kept out of the milking and gathering rooms. The silo's bottom needs to be dry and often sits above the water table. The silo's walls must be sturdy enough to support gas pressure and prevent fresh air from entering (Hundal and others, 2024).



Ensiling Process

4.5. Fermentation

Proper fermentation is crucial for preserving sorghum silage and maintaining its nutritional value. Allow the sorghum to ferment for minimum 45 days. During fermentation, anaerobic bacteria, especially lactic acid bacteria, convert the sugars into lactic acid, which lower the pH and create an acidic environment that inhibits spoilage organisms and preserves vital nutrients, improves digestibility and prevents spoilage (Muller *et al.*, 2019; Sahoo *et al.*, 2020). During fermentation first respiration takes place after that fermentation occurs initially in presence of aerobic bacteria which can live in the presence or absence of oxygen later on anaerobic fermentation and final stage of stabilization for pH stabilization from 3.8-4.2.

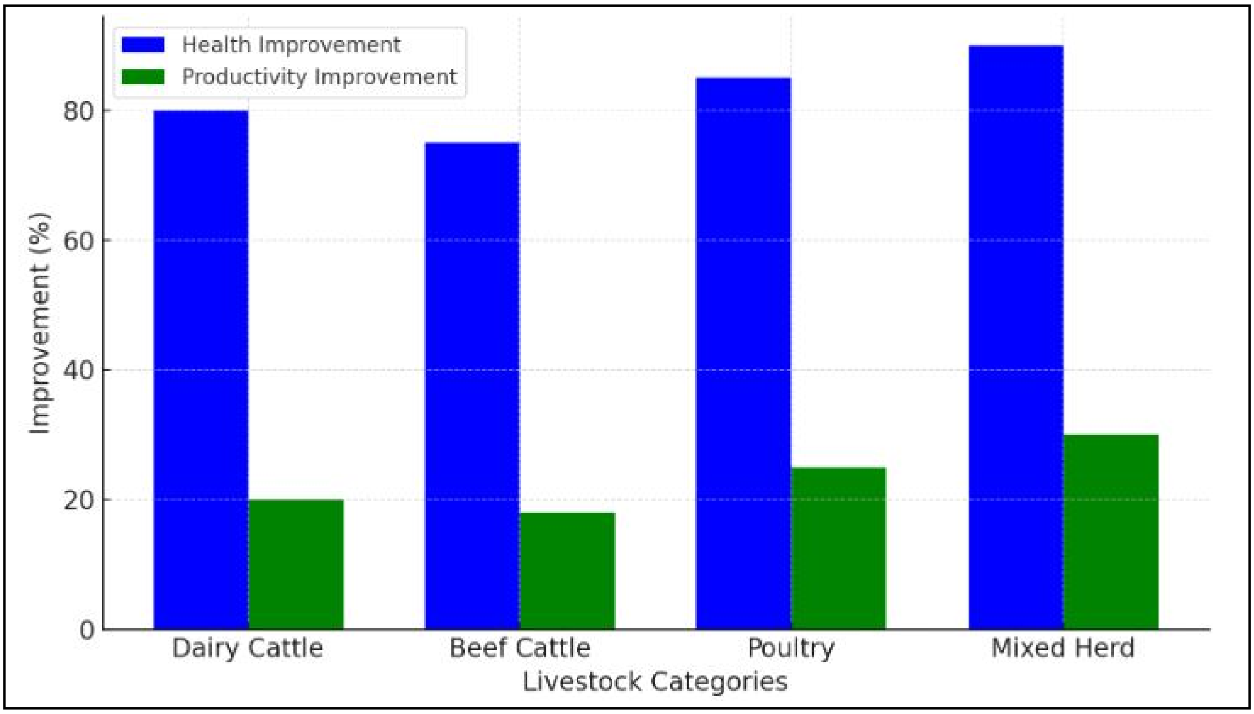


Fig. 3. Comparative potential impact of sorghum silage on livestock health and productivity.

But one should take care of several issues during ensiling which affect the fermentation quality. Excessive moisture content above 70% can lead to nutrient loss and undesirable bacterial growth. To prevent this, ensure sorghum is harvested at 60-70% moisture, possibly using absorbent materials to manage moisture. Inadequate compaction can lead to air pockets and mould growth, so use heavy machinery to compact chopped sorghum to a density of 700–800 kg/m³. Proper sealing is vital to prevent air penetration, using plastic covers or tarps with weights to maintain an air-tight seal (Woolford, 2004). Uneven fermentation can be avoided by uniformly spreading and compacting layers of chopped material. Finally, clostridia bacteria thrive in poorly sealed silage and produce butyric acid, so it's crucial to ensure proper sealing and ideal harvesting stage (Kung & Muck, 2017). Once fermentation is complete, ensure the silage remains sealed till it is needed and sealed again after use. Properly stored silage can last for several months. Testing of silage quality at different stages is must before feeding as given below:

Silage Testing

1. Time-Based Testing: Prior to feeding a test is imperative when the silage pit is opened. For routine monitoring conduct tests every 1 to 2 months, regardless of the precautions taken during use of silage.

2. Condition Based Testing: If moisture level is high in silage at the time of pulling from the pit, send a sample to the laboratory immediately. Along with this any signs of fungal infestation are there, testing is required.

4.6. Storage and Feeding

Incorporating sorghum silage into livestock diets can be highly beneficial due to its high energy content, digestibility and palatability. However, it is important to do so correctly to ensure balanced nutrition and optimal productivity. When ready to feed, open the silo from one side and use as required and maintain the integrity of the remaining silage by resealing the exposed areas. Initially silage should be fed @ 5kg /animal to adjust them on silage feeding. Gradually introduce sorghum silage into the diet to avoid digestive disturbances like bloating or acidosis. Start by mixing small amounts with other feeds and slowly increase the proportion over several days or weeks (Mertens, 2002). Balancing with other feed ingredients is also crucial. Sorghum silage is rich in carbohydrates but may lack sufficient protein levels, so supplementing the diet with protein sources like soybean meal or alfalfa hay is essential. Adding grain and concentrates can ensure a well-rounded, nutritious diet (Sahoo, 2018). Fig. 3 shows the comparative superiority of sorghum silage on livestock health and productivity.

The optimal silage intake depends on the livestock species, stage of growth and production goal. For dairy cows, the typical silage inclusion rate might range from 40% to 60% of the total dry matter intake, while for beef cattle, it could be around 50% (Miller *et al.*, 2021). Consider the nutritional value and moisture content of the silage to avoid over-feeding. Ensuring consistency in silage quality is essential for predictable animal performance. Regularly monitor the quality of silage for signs of spoilage or mould, as they can adversely impact animal health and productivity (Woolford, 2004). Regular monitoring of animal health and productivity is crucial after incorporating sorghum silage in cattle feed. Check animals for gastrointestinal issues like diarrhoea or bloating, which can occur if the silage is introduced too quickly or if the silage quality is poor (Mertens, 2009). Monitor changes in behaviour or appetite, as they may indicate digestive or metabolic issues. For dairy cattle, monitor milk yield and quality regularly, as silage quality directly affects milk production. High-quality silage leads to higher milk yields and better fat content (Koh *et al.*, 2019). For beef cattle, monitor weight gain and feed conversion efficiency to assess the effectiveness of sorghum silage as a feed source. Regular blood tests can check for deficiencies in key minerals and nutrients like calcium, phosphorus and magnesium, which can affect productivity. Additionally, faecal analysis of cattle helps to determine the digestibility and quality of the silage. Close monitoring of health and productivity of livestock, farmers can adjust the silage feeding accordingly as needed, ensuring optimal performance and minimizing the risk of metabolic disorders or nutritional imbalances.

5. Future Prospects

Sorghum is a crucial dual-purpose crop which possesses traits like high drought tolerance, high water use efficiency and less production cost among the world's top five carbohydrate-rich crops. There are high economic and social pressures on farm lands for efficient crop production due to rising world livestock population, reduced water availability and urban land encroachment. Due to global warming, cultivation of resilient fodder crops like sorghum can be expected because of its high dry matter yield potential while maintaining nutritive value, even under stress conditions. Forage sorghum being a "*Resource Conserving Crop*" helps to addresses environmental, economic, and social challenges which significantly advance global sustainability goals.

For silage production, generally single cut forage sorghum types with more stem girth are preferred. The location and agro-ecological factors may influence the selection of a specific cultivar for silage production. Brown midrib (BMR) and non BMR type sorghum can produce quality silage, but BMR cultivars had better quality compared to conventional sorghum varieties. However, whole plant forage sorghum silage provides fiber and grain fractions. Mechanization helps to alleviate the common challenges like increased NDF (neutral detergent fiber), reduced digestibility and high starch concentration and starch digestibility. But in conclusion sorghum silage shows potential as a fodder option, especially in areas where conventional forage sources are limited due to harsh climatic conditions. Sorghum's nutritional quality and capacity to withstand a variety of environmental stresses make it a perfect choice for silage production. But for popularization of sorghum silage we have to aware farmers about the feeding value of sorghum silages in dairy cattle's diets. This article emphasizes how addition of sorghum silage to livestock diets can enhance productivity, animal health, and farm sustainability especially in semiarid tropics. Future studies should concentrate on improving methods for producing silage and investigating the financial advantages of growing forage sorghum. Farmers may access a robust and nutrient-dense feed supply by adopting sorghum silage for their cattle consequently opening the door for more productive and sustainable livestock sector.

REFERENCES

Addah, W., J. Baah, P. Groenewegen, E. K. Okine, & T. A. McAllister, 2011: Comparison of the fermentation characteristics, aerobic stability and nutritive value of barley and corn silages ensiled with or without a mixed bacterial inoculant. *Canadian Journal of Animal Science*, **91(1**): 133-146.

Admin, & Admin, 2021 : *Factors affecting the nutritional composition of sorghum silage - Animal Nutrition and Health*. Animal Nutrition and Health. *https://dellait.com/nutritional-composition-of-sorghum-silage/*

Arun, P. V., 2019: *Studies of Silo Types on Qualities of Sorghum Silage* (Doctoral dissertation, Dr. Panjabrao Deshmukh Krishi Vidyapeeth).

Atim, J., T. Kaweesi, R. B. Hutmacher, D. H. Putnam, J. Pedraza, C. M. de Ben, ... and J. A. Dahlberg, 2024 : Optimizing Sorghum for California: A Multi-Location Evaluation of Biomass Yield, Feed Quality, and Biofuel Feedstock Potential. *Agronomy*, **14(12**), 2866.

Buntin, G.D., Cunfer, B.M., Ball, D.M., Barnett, R.D., Bland Jr, D.E., Bridges, D., Dyre, C.E., Elsner, E., Flanders, K.L., Gazaway, W.S. and Givan, W., 2009: Southern small grains resource management handbook.

Bhattarai, B, 2019 : *Silage production potential of forage sorghum, pearl millet, and corn under limited irrigation* (Doctoral dissertation).

Borreani, G., E. Tabacco, R. J. Schmidt, B. J. Holmes, and R. A. Muck, 2018 : Silage review: Factors affecting dry matter and quality losses in silages. *Journal of Dairy Science*, **101(5):** 3952-3979.

Colombini, S., G. Galassi, G. M. Crovetto, and L. Rapetti, 2012 : Milk production, nitrogen balance, and fiber digestibility prediction of corn, whole plant grain sorghum, and forage sorghum silages in the dairy cow. *Journal of Dairy Science*, **95(8)**: 4457-4467

da Silva Carvalho, A. P., Neto, A. B., dos Reis, R. H. P., da Silva Cabral, L., de Abreu, J. G., de Paula Sousa, D., ... & de Carvalho, P. 2017: Fermentation characteristics of different purposes sorghum silage. *Semina: Ciências Agrárias*, **38**(4), 2607-2617.

Dickerson, J. T., 1986 : Yield, composition, and nutritive value of forage sorghum silages: hybrid and stage of maturity effects.

Elferink, S., F. Driehuis, J. C. Gottschal and S. F. Spoelstra, 2000 : Silage fermentation processes and their manipulation. *FAO Plant Production and Protection Papers*, 17-30.

Filya, I., 2003 : The effect of Lactobacillus buchneri, with or without homofermentative lactic acid bacteria, on the fermentation, aerobic stability and ruminal degradability of wheat, sorghum and maize silages. *Journal of Applied Microbiology*, **95(5),** 1080-1086.

Food and Agriculture Organization of the United Nations, 2023: *World Food and Agriculture – Statistical Yearbook 2023*. https://openknowledge.fao.org/server/api/core/bitstreams/6e04f2b4-82fc-4740-8cd5-9b66f5335239/content

Getachew, G., D. H. Putnam, C. M. De Ben and E. J. De Peters, 2016: Potential of sorghum as an alternative to corn forage. *American Journal of Plant Sciences*, **7**(7), 1106-1121.

Gowda, P. H., P. V. Prasad, S. V. Angadi, U. M., Rangappa and P. Wagle, 2015: Finger millet: An alternative crop for the southern high plains. *American Journal of Plant Sciences*, **6(16),** 2686.

Habeeb, A. A. M., A. E. Gad, A. A. El-Tarabany, M. M. Mustafa and M. A. A. Atta, 2017: Using of sugar beet pulp by-product in farm animals feeding. *Int. J. Sci. Res. Sci. Technol*, **3**, 107-120.

Hundal, J. S., P. N. Prakash, J. Kaur, and J. S. Sidhu, Scientific Technique for Making Silage and its Quality Indicators. *A et umnus V*, 99.

Jukanti, A. K., C. L. Gowda, K. N. Rai, V. K. Manga and R. K. Bhatt, 2016: Crops that feed the world 11. Pearl Millet (*Pennisetum glaucum* L.): an important source of food security, nutrition and health in the arid and semi-arid tropics. *Food Security*, **8**: 307-329.

Jung, H. G., 1989 : Forage lignins and their effects on fiber digestibility. *Agronomy Journal*, **81**(1): 33-38.

Kumari, P., N. Kharor, S. K. Pahuja and D. S. Phogat, 2024 : Morphological and biochemical traits attribution for fodder yield and quality in forage sorghum using principal component analysis. *Vegetos*, **37**(5): 2059-2068.

Kumari, P., V. K. Malik, V. Kumar, Satpal and S.K. Pahuja, 2023: Nutritional enhancement of cultivated fodders using potential plant breeding strategies - A Review. *Forage Res*. **49**(1): 29-38.

Kosolapov, V.M., S.I. Kostenko, Y.S. Tyurin, E.Z. Shamsutdinova, Y.M. Piskovskii, 2021 : Perennial forage grasses-the basis for greening agricultural production. IOP Conf Ser **663**(1): 012022

Kung Jr, L., E. Stough, E. McDonell, R. Schmidt, M. Hofherr, L. Reich and C. Klingerman, 2010: The effect of wide swathing on wilting times and nutritive value of alfalfa haylage. *Journal of Dairy Science*, **93**(4): 1770-1773.

Kung Jr, L. and R.E. Muck, 2017: Silage harvesting and storage. *Large Dairy Herd Management; Beede, DK, Ed.; American Dairy Science Association: Champaign, IL, USA*, pp.723-738.

Kuz'mina, L. N., & Kartashova, A. P, 2020: The quality of fiber and the effectiveness of use in rations of Holstein-Kholmogor cows. *Ural Agrarian Bulletin*.

Laxmi, V., S. K. Pahuja, and P. Kumari, 2019 : Identification of New Sources for Good Quality High Biomass Yield and other Promising Traits in Mini Core Collection of Forage Sorghum. *Indian Journal of Plant Genetic Resources*, **32**(02): 150-157.

Li, L., C. Ji, Y. Liu, M. Fu, Z. Li, J. Tong and T. Peng, 2024: Effects of Mixed Ensiling of Rice with Sorghum Sudangrass Hybrid on Forage Nutritional Quality and Microbial Community. *Journal of Henan Agricultural Sciences*, **53**(9): 132.

Liu, B., Yang, Z., Huan, H., Gu, H., Xu, N., & Ding, C, 2020: Impact of molasses and microbial inoculants on fermentation quality, aerobic stability, and bacterial and fungal microbiomes of barley silage. *Scientific reports*, **10**(1): 5342.

Martin, N. P., D. R. Mertens, and P. J. Weimer, 2004 : Alfalfa: hay, haylage, bailage, and other novel products. In *Alfalfa and Forage Conference* (pp. 23-24).

McCuistion, K. C., Selle, P. H., Liu, S. Y., & Goodband, R. D, 2019: Sorghum as a feed grain for animal production. *Sorghum and Millets*, 355-391.

Mertens, D.R., 2002: April. Measuring fiber and its effectiveness in ruminant diets. In *Proc. Plains Nutr. Cncl. Spring Conf. San Antonio, TX* (pp. 40-66).

Mhere, O., B. Maasdorp and M. Titterton, 2002: Forage production and conservation manual. Growing and ensiling annual and perennial forage crops suited to marginal and semi-arid areas of Southern Africa. DFID, London, UK.

Miller, M. D., Kokko, C., Ballard, C. S., Dann, H. M., Fustini, M., Palmonari, A. and Grant, R. J, 2021: Influence of fiber degradability of corn silage in diets with lower and higher fiber content on lactational performance, nutrient digestibility, and ruminal characteristics in lactating Holstein cows. *Journal of dairy science*, **104**(2): 1728-1743.

Mitaru, B. N., 1978 : *Evaluation of maize and forage sorghum silage using Boran steers* (Doctoral dissertation, University of Nairobi).

Mokolopi, B. G, 2020 : The role of bone phosphorus, calcium and magnesium on bone reserves of indigenous mixed breed cattle grazing natural pasture during times of mineral stress induced by drought in Mogosane Village of North West Province, South Africa. *Indian Journal of Animal Research*, **54**(12): 1558-1564.

Porfirio, M.D., M.A. Neres, C.A. Fuhr, T.H. da Silva, and I.C.D.S.B. Guimarães, 2021: Effects of row spacing and planting density of forage sorghum on dry matter yield, morphologic parameters, nutritive value, and predicted milk yield of dairy cows. *Research, Society and Development*, **10**(11), pp.e36101119374-e36101119374.

Pontieri, P. and L. Del Giudice, 2016 : Sorghum: a novel and healthy food. In *Encyclopedia of food and health* (pp. 33-42). Academic Press.

Rao, S. P., Rao, S. S., Seetharama, N., Umakath, A. V., Reddy, P. S., Reddy, B. V. S., & Gowda, C. L. L, 2009: *Sweet sorghum for biofuel and strategies for its improvement*. International Crops Research Institute for the Semi-Arid Tropics.

Reddy, P. M., Kumar, S., Sharma, N., Hemasri, K., Nandana, S. K., & Hirwe, O. R, 2023: Exploring the Effects of Nutrient Management on Growth Attributes, Fodder Qualities and Soil Properties of Fodder Oats (*Avena sativa*): An Overview. *International*

Journal of Plant & Soil Science, **35**(11): 147-159.

Rodrigues, P.H.M., Pinedo, L.A., Meyer, P.M., da Silva, T.H. and Guimarães, I.C.D.S.B., 2020. Sorghum silage quality as determined by chemical-nutritional factors. *Grass and Forage Science*, **75**(4): 462-473.

Saini, L. H., S. J. Trivedi, B. K. Davda and A. K Saini, 2018 : Effect of sowing dates on growth, yield and economics of sorghum (*Sorghum bicolor* L. Moench) genotypes. *Journal of Pharmacognosy and Phytochemistry*, **7**(5): 535-538.

Sebnie, W., and M. Mengesha, 2016: Nitrogen and Phosphorus Rate Determination for Sorghum Production in Wag-Lasta, North Eastern Ethiopia. In the Proceedings of the 9th and 10th Annual Regional Conferences on Completed Research Activities on Soil and Water Management Research March, 10-20, 2015 and Feb., 16-23, 2016, Bahir Dar, Ethiopia.

Seth, D., P. Ghosh and L. Roy, 2023: Integrated farming systems a way for long-term farming viability: a review. *Plant Archives (09725210)*, **23**(1).

Singh, B., N. Kumar and H. Kumar, 2017: Seasonal incidence and management of sorghum shoot fly, *Atherigona soccata* Rondani - A review. *Forage Research*, **42**: 218-224.

Singh, D. N., J. S. Bohra, V. Tyagi, T. Singh, T. R. Banjara and G. Gupta, 2022: A review of India's fodder production status and opportunities. *Grass and Forage Science*, **77**(1): 1-10. *Sorghum grain | Feedipedia*. (n.d.). https://www.feedipedia.org/node/224

Sahoo, A., 2018 : Silage for climate resilient small ruminant production. *Ruminants: The Husbandry, Economic and Health Aspects*, **11**. pp. 11-39.

Thevakumaran, S, 2020 : *Evaluating the Establishment of Perennial Forages with Sudangrass or Sorghum-Sudangrass as Annual Companion Crops on Forage Yield, Forage and Silage Quality, and Predicted Milk Yields*. McGill University (Canada).

Wallau, M., J. Vendramini, A. Adesogan, D. Vyas, and K. Korus, 2022 : Silage Crops for Dairy and Beef Cattle II: Sorghum and Other Forage Crops: SS-AGR-461/AA269, 02/2022. *EDIS*, *2022*(1).

Ward, G. and E.F. Smith, 1968: Nutritive value of sorghum silage as influenced by grain content. *Journal of Dairy Science*, **51**(9): 1471-1473.

Wilkinson, J. M., and R. E. Muck, 2019 : Ensiling in 2050: Some challenges and opportunities. *Grass and Forage Science*, **74**(2): 178-187.

Xu, H., N. Wu, N. Na, L. Sun, Y. Zhao, H. Ding and J. Zhong, 2022: Fermentation weight loss, fermentation quality, and bacterial community of ensiling of sweet sorghum with lactic acid bacteria at different silo densities. *Frontiers in Microbiology*, **13**: 1013913.

Zhang, S. J., A. S. Chaudhry, D. Ramdani, A. Osman, X. F. Guo, G. R. Edwards and L. Cheng, 2016 : Chemical composition and in vitro fermentation characteristics of high sugar forage sorghum as an alternative to forage maize for silage making in Tarim Basin, China. *Journal of Integrative Agriculture*, **15**(1): 175-182.