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Millet crop residue: sustainable livestock feed in a changing social and climatic context

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Abstract

Climate change, increasing temperatures, erratic rainfall patterns, and declining availability of conventional feed resources have intensified the search for climate-resilient crops and alternative livestock feed resources. Various climate models indicate that rising global temperatures are likely to reduce the productivity of staple cereals such as rice and wheat, thereby encouraging the cultivation of climate-resilient crops like millets. Millets are drought tolerant, require less water and fertilizer, possess short crop cycles, and are less susceptible to environmental stress. The increasing cultivation and consumption of millets have resulted in greater availability of crop residues, including straw and stover, which can be utilized as livestock feed. India, possessing the world's largest livestock population and facing substantial deficits in dry fodder, green fodder, and concentrate feed, requires efficient utilization of crop residues to sustain livestock productivity. Millet crop residues, although characterized by low crude protein and mineral contents, offer significant potential as roughage sources. Several physical, chemical, biological, and nutritional treatments have been investigated to enhance their feeding value. Experimental studies have demonstrated the positive effects of millet residues on nutrient utilization, milk production, growth performance, and feed economics. This review summarizes the nutritional characteristics, limitations, improvement strategies, and experimental evidence supporting the utilization of millet crop residues as sustainable livestock feed resources.

Keywords: Millet crop residue, straw, stover, climate resilience, fodder scarcity, nutrient utilization.

Introduction

Climate change has emerged as one of the most significant challenges affecting agricultural productivity worldwide. Various climate models suggest that increasing global temperatures and changing weather patterns are likely to diminish the yields of staple cereal crops such as rice and wheat, prompting the search for more climate-resilient alternatives **(Wang *et al.*, 2018).** In wheat cultivation, an increase of 1°C in temperature has been reported to reduce production yields by 3–10% **(You *et al.*, 2009).**

Among the available alternatives, millets have gained increasing attention because of their ability to thrive under drought conditions and extreme heat stress **(Das and Rakshit, 2016).** Millets possess several agronomic advantages, including short cultivation periods, diverse crop cycles, low dependence on synthetic fertilizers, reduced water requirements, and lower susceptibility to environmental stresses **(Tagade and Sawarkar, 2023).** Recognizing their importance for nutritional security and climate resilience, the United Nations declared 2023 as the International Year of Millets.

The increasing emphasis on millet cultivation has contributed to enhanced production. In India, millet production increased from 173.21 lakh tonnes in 2022–23 to 175.72 lakh tonnes in 2023–24 **(MOA& FW, 2025).** India is currently the world's largest millet producer, accounting for approximately 38.4% of global millet production **(FAO, 2023).** Consequently, the availability of millet by-products, particularly straw and stover, has also increased, creating opportunities for their utilization in livestock feeding systems.

India possesses the world's largest livestock population, estimated at 536 million animals, including approximately 526.45 million ruminants **(BAHS, 2019).** Simultaneously, the country faces substantial shortages of feed resources, including 23% dry fodder, 32% green fodder, and 36% concentrate feed **(ICAR-NIANP, 2019–20).** This imbalance between feed demand and supply has been identified as a major factor limiting livestock productivity **(Prajapati *et al.*, 2019).**

Crop residues constitute a major component of livestock feeding systems in India. Approximately 54% of the total fodder supply originates from crop residues, whereas cultivated fodders and grazing lands contribute 28% and 18%, respectively **(Hegde, 2010).** Furthermore, the area under cultivated fodders has remained relatively static over the past several decades, while grazing lands continue to decline due to overgrazing and land-use changes **(Dagar *et al.*, 2017; Halli *et al.*, 2018).** Under these circumstances, efficient utilization of crop residues becomes essential for sustainable livestock production.

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Millets And Their Crop Residues

Millets are small-seeded cereal crops belonging primarily to the Poaceae family and are predominantly cultivated in arid and semi-arid regions. They are commonly referred to as “Nutri-Cereals,” “coarse cereals,” “cereals of the poor,” and more recently as the “future crop for the tropics” **(FSSAI, 2019).**

The expansion of millet cultivation has resulted in increased production of crop residues. In India, sorghum and pearl millet generate approximately 22.52 million tonnes and 14.76 million tonnes of crop residues annually, respectively **(Harinarayana *et al.,* 2005).** In several regions of southern and western India, millet straws, particularly finger millet and sorghum straw, are traditionally used as livestock feed. Barnyard millet stover also serves as an important winter fodder resource in states such as Uttarakhand, Madhya Pradesh, Maharashtra, and Tamil Nadu **(Bhat *et al.,* 2023).**

Although millet crop residues alone may not be sufficient to maximize livestock productivity, they can effectively maintain animals when supplemented with additional nutrients **(Gowda and Chethan, 2023).** Their widespread availability and adaptability make them important feed resources, especially under conditions of fodder scarcity.

Nutritional Characteristics of Millet Crop Residues

Millet straws are generally characterized by high fiber content, low crude protein concentrations, low mineral content, and varying lignin levels. The total digestible nutrient (TDN) content of millet straws ranges from 37% to 50%, which is lower than that of high-quality forages but generally superior to many conventional cereal straws **(Ramana and Venkateswarlu, 2023).**

Finger millet straw has been reported to contain greater concentrations of crude protein, calcium, phosphorus, magnesium, copper, zinc, and cobalt than rice straw and exhibits superior digestibility characteristics **(Gowda and Prasad, 2005).**

The nutrient composition of millet crop residues varies among species. Crude protein concentrations range from approximately 3.7% in sorghum and proso millet straw to 5.2% in pearl millet straw. Neutral detergent fiber concentrations range from 73.0% in foxtail millet straw to over 80% in finger millet, pearl millet, and proso millet straws. Finger millet straw contains notably higher calcium levels (1.0%) compared with most other millet residues **(Gowda and Chethan, 2023).**

Digestibility studies indicate that sorghum and finger millet residues exhibit relatively favorable feeding characteristics. In vitro dry matter digestibility (IVDMD) values of 57.5%

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and 52.5% have been reported for sorghum and finger millet straw, respectively, in cattle, compared with 47.5% for rice straw (**Bhat *et al.,* 2023).**

Similarly, barnyard millet, finger millet, little millet, foxtail millet, kodo millet, and proso millet residues demonstrate moderate nutritional value, with metabolizable energy values ranging from 1314.53 to 1577.44 kcal/kg and in vitro organic matter digestibility values ranging from 41.4% to 47.9% (**ICAR-IIMR, 2016).**

Anti-Nutritional Factors in Millet Crop Residues

Despite their nutritional potential, millet crop residues contain several anti-nutritional compounds that may influence feed utilization. Dhurrin, a cyanogenic glycoside, occurs predominantly in the aerial portions of sorghum plants, particularly in young or drought-stressed plants. Tannins are present in relatively high concentrations in sorghum and finger millet straw. Phytates are more abundant in finger millet straw compared with pearl millet, sorghum, foxtail millet, and barnyard millet residues. Oxalates occur in moderate to high concentrations in finger millet and barnyard millet straw, while silica concentrations may be high in mature barnyard and pearl millet stover. These compounds can reduce nutrient availability and digestibility, highlighting the need for processing and treatment methods to improve feeding value.

Strategies For Improving Millet Crop Residues

Millet crop residues are rich in structural carbohydrates but deficient in nitrogen, soluble sugars, minerals, and vitamins **(Venkateswarlu *et al.,* 2013).** Consequently, several strategies have been explored to improve their nutritional value.

Physical Methods

Physical processing methods include chopping, grinding, pelleting, heat treatment, soaking, and ensiling. These techniques primarily enhance feed handling, intake, and digestibility.

Chemical Methods

Chemical treatments involve the use of alkalis such as sodium hydroxide and lime, as well as ammoniation through urea treatment. These methods improve fiber digestibility by disrupting lignocellulosic bonds and increasing nitrogen content.

Biological Methods

Biological approaches include fungal treatments, particularly with white-rot fungi, and supplementation with exogenous enzymes. These treatments target lignin degradation and improved fiber utilization.

Nutritional Enrichment

Nutritional enhancement strategies involve supplementation with molasses, vitamins, minerals, and other nutrient sources to overcome deficiencies in crop residues.

EXPERIMENTAL EVIDENCE

Finger Millet Straw versus Rice Straw in Lactating Dairy Cows

Gowda and Prasad (2005) evaluated the utilization of macro- and micronutrients in eleven Holstein Friesian crossbred dairy cows during late lactation. Animals received diets containing concentrate mixture, green fodder, and either finger millet straw or rice straw. Cows fed finger millet straw consumed more dry matter (10.1 kg/day) than those receiving rice straws (9.0 kg/day). Digestibility of dry matter, crude protein, neutral detergent fiber, and acid detergent fiber was significantly higher in the finger millet straw group. Crude protein digestibility reached 72.8% compared with 67.5% in the rice straw group. Furthermore superior calcium, magnesium, copper, and manganese utilization in cows receiving finger millet straw. Enhanced nutrient utilization was reflected in milk production, with cows fed finger millet straw producing 7.0 L milk/day compared with 6.3 L/day in cows fed rice straw. The study concluded that finger millet straw represents a superior roughage source compared with rice straw due to its enhanced nutrient content and utilization efficiency.

Sorghum Straw-Based Complete Rations for Nellore Ram Lambs

Venkateswarlu *et al.* (2014) investigated the effects of sorghum straw-based complete rations containing different roughage-to-concentrate ratios in growing Nellore ram lambs. Increasing concentrate proportions resulted in significant improvements in growth performance. Final body weights increased from 21.33 kg in the 70:30 roughage-to-concentrate ration to 29.85 kg in the 40:60 ration. Similarly average daily gain improved from 61.67 g/day to 104.44 g/day, while feed conversion ratio improved from 11.71 to 9.07. Carcass characteristics remained largely unaffected across treatments. Based on growth performance and economics, the study concluded that sorghum straw could be included at levels of 50–60% in complete rations without compromising growth rate or carcass quality while maintaining favorable economic returns.

Substitution of Millet Straw for Corn Silage and Alfalfa Hay in Dairy Cows

Wang *et al.* (2023) evaluated the effects of replacing corn silage and alfalfa hay with finger millet straw in late-lactation Holstein dairy cows. Four dietary treatments included 0%, 10%, 20%, and 30% millet straw in the forage component. Dry matter intake, milk yield, and nutrient digestibility were maintained in cows receiving up to 20% millet straw inclusion. However, inclusion at 30% significantly reduced dry matter intake, milk yield, feed efficiency, nitrogen conversion efficiency, and nutrient digestibility. Milk yield decreased from 29.2 kg/day in the control group to 26.3 kg/day in the high millet straw group. Similarly, dry matter digestibility declined from 76.2% to 70.9%. The study concluded that millet straw can effectively replace a portion of corn silage and alfalfa hay in late-lactation dairy cow diets, provided that the substitution level does not exceed 20% .

Urea Treatment of Sorghum and Millet Straw

Mattoni *et al.* (2007) examined the effects of urea treatment on the nutritional value of sorghum and pearl millet straw and the growth performance of Djallonké rams. Crop residues were treated using a 5% urea solution and stored in sealed silos for three weeks. Urea treatment substantially increased crude protein content. In sorghum straw, crude protein increased from 2.6% to 11.7%, while in millet straw it increased from 3.7% to 6.7%. Dry matter digestibility improved from 31.7% to 34.5% in sorghum straw and from 32.5% to 40.0% in millet straw. Treated straw also increased dry matter intake. Growth performance of rams improved significantly following urea treatment. Mean net weight gain increased from 5.8 kg to 7.5 kg in sorghum-fed animals and from 5.7 kg to 7.2 kg in millet-fed animals. The study concluded that urea treatment is an effective and economically feasible method for improving the nutritional value of sorghum and millet crop residues **(Mattoni *et al.,* 2007).**

Ammonia Fiber Expansion (AFEX) Technology

Blummel *et al.* (2018) evaluated the Ammonia Fiber Expansion (AFEX) technique as a means of upgrading cereal crop residues for livestock feeding. AFEX treatment involved exposing chopped biomass to high-pressure anhydrous ammonia followed by rapid pressure release. The process substantially increased crude protein content and improved digestibility characteristics across several cereal straws and stovers. Average crude protein concentration increased from 62 g/kg to 161 g/kg dry matter following AFEX treatment. Neutral detergent fiber content decreased from 656 g/kg to 609 g/kg. Metabolizable energy increased from 6.9 to 8.6 MJ/kg dry matter. Similarly, apparent in vitro organic matter digestibility (IVOMD) increased from 493 g/kg to 630 g/kg, while true in vitro organic matter digestibility increased from 602 g/kg to 770 g/kg. The study suggested that AFEX technology has the potential to upgrade cereal crop residues to feed resources comparable with high-quality roughages. However, further animal studies are required to confirm effects on voluntary feed intake and product safety.

CONCLUSION

The increasing cultivation of millets in response to climate change and food security concerns is expected to enhance the availability of millet crop residues for livestock feeding.

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India's substantial livestock population and persistent fodder deficits necessitate efficient utilization of alternative feed resources, making millet crop residues particularly important. Finger millet straw demonstrates superior nutrient composition and digestibility compared with rice straw, while sorghum straw can be successfully incorporated into complete rations for growing lambs. Millet residues possess moderate nutritional value and can serve as effective roughage sources for livestock. Various treatment methods, including urea treatment and AFEX technology, significantly enhance the nutritional quality of millet crop residues by improving crude protein content, digestibility, and energy value. These approaches provide opportunities to convert low-quality agricultural by-products into valuable livestock feed resources.

Therefore, millet crop residues represent an important component of sustainable livestock production systems and offer a practical solution to fodder shortages in India.

FUTURE RECOMMONDATION:

Further research and development efforts are required to optimize their quality, quantity and feeding value for improved livestock productivity.

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