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CULTIVATING SUSTAINABILITY: THE ENVIRONMENTAL BENEFITS OF FOXTAIL MILLET (*Setaria italica* L.) FARMING

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Abstract: The ancient grain known as foxtail millet (*Setaria italica*) has attracted new interest due to its potential as a crop that may be grown sustainably in contemporary agriculture. The advantages of foxtail millet farming practices for the environment are reviewed in this article. Many factors such as its water use efficiency, advantages to soil health, potential for sequestering carbon, and effect on biodiversity in foxtail millet production. The incorporation of foxtail millet into agricultural systems has major environmental benefits, especially in areas where problems like degraded soil and water scarcity are prevalent. In this article, we have also discussed about how foxtail millet farming affects resilient agroecosystems, climate change mitigation, and sustainable food production.
Keywords: Foxtail millet, sustainable agriculture, environmental benefits, water use efficiency, soil health, carbon sequestration, biodiversity, climate change mitigation.

Introduction

Millets have been utilized as food, feed, and forage since the Neolithic era. Among the many millets, sorghum (*Sorghum bicolor* L.) and pearl millet (*Pennisetum glaucum* L.) are considered as major and the remaining are categorized as minor millets. With an acreage of over 7.0 lakh ha and a productivity of 633 kg ha^{-1}, India is the world leader in the production of tiny millets. (Maitra and Shankar, 2019). In uplands of dry and semi-arid climates, little millets are mostly grown through rainfed techniques with suboptimal levels of management (Maitra *et al*. 1997; 1998). After the green revolution, the production of high-quality cereals—rice, wheat, and millets—became the primary focus in India, while other grains were neglected. Additionally, millets became the food of the poor due to urbanization, income growth, and dietary habits. However, the reassessment of millets nutritional value has given them their lost glory in recent years (Maitra, 2020). Small millets have nutraceutical qualities and are high in protein, energy, and dietary fiber. (Banerjee and Maitra, 2020). Moreover, due to their numerous applications, tiny millets are referred to as "miracle crops." These days, global warming and climate change are causing enormous problems for the agricultural sector. The

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primary consequences of climate change are rising temperatures, unpredictable rainfall patterns, and increased emissions of greenhouse gases, primarily carbon dioxide. Millets are C4 plants that can take more CO_2 from the atmosphere to produce biomass. (Brahmachari *et al*. 2018). Millets are known as climate-smart crops because they are environmentally sound crops that can survive in hot, dry circumstances while leaving a little carbon imprint.

The foxtail millet (*Setaria italica* L.), one of the various small millets, is native to Asia and was domesticated in central China centuries ago (Miller *et al*. 2016). It is a member of the Panicoideae subfamily of the Poaceae family, similar to other millets. Each 100 g of edible portion of foxtail millet is rich in nutrients, containing 2.4 g of fiber, 12.3 g of protein, 60.9 g of carbohydrates, 4.3 g of fat, 31 mg of calcium, 2.8 mg of iron, 290 mg of phosphorus, 3.3 g of minerals, and 331 K Cal of food energy (Vanithasri *et al*. 2012; Banerjee and Maitra, 2020). Since foxtail millet is highly drought-tolerant, it is mostly grown as a rainfed crop in arid regions of India. Foxtail millet is only grown in a few southern Indian states *viz.*, Andhra Pradesh, Karnataka, Tamil Nadu, and Telangana. It is also planted in Bihar, Uttar Pradesh, and Uttarakhand in restricted areas. Although the average productivity of small millets, such as foxtail millets, is low and the better varieties with sufficient potential have recently been created. To increase foxtail millet yield, better variety selection and effective agronomic management are essential, and agronomic management research should be expanded. Hence, an attempt has been made to review agronomic management practices in this article is currently available for boosting yield of foxtail millet.

Improved varieties and uniform stand establishment

It is possible to grow foxtail millet in both temperate and tropical climates. But because of its ability to withstand moisture stress, it is grown in India's marginal, arid tropical drylands, mostly with rain. Local foxtail millet variants are typically grown by small and marginal farmers with poor plant stand and poor management. In order to get a decent yield, stand establishment is crucial and depends on uniform germination and the sowing of high-quality seeds with ideal spacing. In India, there are improved state-specific varieties that can be grown for increased yield (Table 1). The results of the field tests carried out at various sites made it abundantly evident that better foxtail millet varieties produced higher yields than small millets on average. Navya Jyothi *et al*. (2016) observed that in the kharif season at Tirupati, Andhra Pradesh, the foxtail varieties SiA 3088, SiA 3085, SiA 3156, and Srilaxmi generated grain yields of 1001 to 1141 kg ha-1 under rainfed circumstances. An additional trial conducted at Naira, Andhra Pradesh, Ramyasri *et al*. (2018) observed that during the Rabi season, SiA 3156 produced larger yield (1290 kg ha-1) than the other two types, SiA 3085 and SiA 3088. During the kharif season in Karnataka, the SiA 2644 variety of foxtail millet surpassed the HMT-1 and local cultivars on the red sandy clay soil of the southern transition zone (Nandini and Sridhara, 2019a). But at Prayag, Uttar Pradesh, the variety SiA 326 (Prasad) gave more yields in *kharif* season than SiA 3156 in sandy loam soil (SelectstarMarwein *et al*. 2019).

Foxtail millet is often grown as a kharif crop, and tillage is done in preparation for the monsoon season. The land is ploughed or harrowed and seeds are sowed once the monsoon season begins. Farmers with limited resources typically disperse their seeds (15 kg ha-1). However, line sowing is always the best option because it requires fewer seeds (810 kg ha-1) and yields the best stand establishment. While line sowing, a spacing of 8–10 cm is maintained between plants inside a row and between rows of 25–30 cm (Chapke *et al*. 2018). But Nandini and Sridhara (2019a) in a study conducted in Karnataka found that foxtail millet plants spaced 20 cm by 10 cm produced a higher grain yield, likely as a result of larger plant stands. The grain production was higher (by 55%) when farmers used a tractor-drawn seed drill for line sowing than their usual method. (AICRPSM, 2017). Foxtail millet is sown in Andhra Pradesh and Maharashtra during the first and third week of July. However, in Bihar and Uttar Pradesh, seeding begins in the middle of June but in Karnataka, the foxtail millet is said to be sown in the months of June to August. Two crops are farmed in Tamil Nadu, a summer irrigated crop is sown in January, and a kharif crop is sown in June or July. In general, foxtail millet is sown in September through October during the rabi season. The findings of the experiment showed that the foxtail millet's productivity is greatly influenced by the timing of sowing. Mubeena *et al.* (2019) found that in black soils in Raichur, Karnataka, foxtail millet sown in the second and first weeks of June and July produced a larger yield than the crop sown in the second and first weeks of July or August. Similarly, Nandini and Sridhara (2019b) in an experiment conducted at Shivamogga, Karnataka, it was also shown that the crop sowed in June produced significantly larger grain yield (2049.25 kg ha-1) and straw yield (4261.56 kg ha-1) than foxtail millet sown in July and August.

Table 1: Foxtail millet varieties cultivated in different states of India

State	**Varieties of foxtail millet**
Andhra Pradesh	SiA-3223 (Renadu), SiA 3156, Prasad, SiA 2644, SiA 3085, SiA 3088, SiA 3085, Lepakshi, SiA 326, Narasimharaya, Krishnadevaraya, PS-4, Srilaxmi
Karnataka	SiA 326, HMT 100-1, PS 4,Narasimharaya, SiA 3088, SiA 3156, SiA 3085, DHFt-109-3

Tamil Nadu	TNAU 43, TNAU-186, TNAU 196, CO 1, CO 2, CO 4, CO 5, K2, K3, SiA 3088, SiA 3156, SiA 3085, PS-4
Rajasthan	PrathapKangani (SR 1) and SR 51, SR 11, SR 16, SiA 3085, SiA3088, SiA-3156, PS 4
Uttar Pradesh	PRK 1 and PS 4, SiA 326 (PRASAD), SiA 3156, SiA 3088, SiA 3085, Sreelaxmi, Narasimharaya, S-114, PS-4
Uttarakhand	PS 4 and PRK 1, Sreelaxmi, SiA 326, SiA 3088, SiA 3156, SiA 3085, PS 4
Bihar	RAU-1, SiA 3088, SiA 3156, SiA 3085, PS 4

There are various attributes of foxtail millet that make it a good fit for environmentally friendly farming methods. First, it uses a lot less irrigation water to produce a unit of grain than other cereal crops, which has an impressive water use efficiency. This makes foxtail millet a desirable alternative in areas where traditional crops might not be able to survive due to drought and water constraint. Furthermore, foxtail millet's deep root system has been demonstrated to benefit soil health by promoting nitrogen cycling, improving soil structure, and breaking up compacted soils. The capacity of foxtail millet, a C4 photosynthetic plant, to absorb carbon from the atmosphere and store it in the soil helps to reduce greenhouse gas emissions and support attempts to adapt to climate change.

1. **Water Use Efficiency**: In drylands, foxtail millet is grown as a rainfed kharif crop. However, there may be sporadic intervals between rainy spells, and if water is accessible, irrigation that could save lives can be provided. However, the crop needs irrigation where it is cultivated during the Rabi season. Chapke *et al*. (2018) proposed that two irrigation schedules i.e., 25–30 and 45–50 DAS significantly increased productivity of foxtail millet (AICRPSM, 2017).

2. **Soil Health Benefits**: Foxtail millet particularly in India's semi-arid and arid regions, where soil fertility is a key concern, millet farming is important for managing soil nutrients. Because of their adaptability and resilience, millets are frequently grown in marginal soils with poor nutrient contents. This is a perfect crop for sustainable farming methods because of their amazing capacity to flourish in these circumstances with little assistance. The ability of millet plant roots to efficiently absorb nutrients is well-known. This ability is especially useful for removing phosphorus from less fertile soils, which is essential for farming in nutrient-poor areas. Since millets are more in biomass, they also help to improve soil fertility. Reviving the organic matter from millet plants into the soil improves soil organic carbon, which is essential to the health of the soil. By strengthening the soil's structure and increasing its ability to hold

onto water and nutrients, this technique makes the soil more productive for crops that come after it.

3. **Carbon Sequestration**: Foxtail millet cultivating has a lot to offer the environment, especially when it comes to lowering greenhouse gas (GHG) emissions and carbon footprint. When compared to agricultural systems with heavy input, like rice and wheat, millets require less chemical pesticides and fertilizers. Lowering the usage of these inputs is essential for reducing greenhouse gas emissions, especially nitrous oxide, a strong greenhouse gas linked to fertilizer use. Additionally, compared to crops like rice that require a lot of water, millets are frequently cultivated in rainfed environments, which reduces irrigation energy and water consumption and helps to minimize carbon emissions. The cultivation techniques related to millets, such as crop rotation and intercropping, can improve soil carbon sequestration in addition to their low input requirements. Millets deep roots allow them to store carbon in the soil, which reduces atmospheric carbon dioxide and helps to mitigate climate change.

4. **Biodiversity Conservation**: Growing foxtail millet can aid in the preservation of biodiversity by giving a range of insects, birds, and other animal species a place to live and eat. The genetic diversity of agricultural landscapes is crucial for developing resistance against pests, diseases, and environmental challenges. The different genetic features of foxtail millet varieties contribute to this genetic diversity. Farmers can preserve agricultural productivity while enhancing biodiversity and ecosystem services by implementing foxtail millet into diverse cropping systems and promoting agroecological principles.

5. **Nutrient management**: In India, foxtail millet is grown on soils devoid of resources and without the finest agronomic practices. However, better cultivars of foxtail millet react favorably to fertilizers. Adoption of Integrated Nutrient Management (INM) is recommended in order to achieve optimum productivity and to maintain soil health. Applying 5 to 10 t FYM, 40 kg N, 20 kg P_2O_5, and 20 kg K_2O is generally advised (Chapke *et al*., 2018). During primary tillage, FYM is applied, and basal fertilizer applications consist of half of N, the whole amount of 20 kg P_2O_5, and 20 kg K_2O. The remaining 50% of N is added three to four weeks after seeding. Agronomic research showed that applying a larger quantity of nitrogen than is advised increased the production of foxtail millet. 50 kg N applied at Tirupati, Andhra Pradesh, increased productivity (Nandini *et al*., 2018), however, at Naira maximum yield was obtained with 80 kg N (Ramyasri *et al*., 2018). Furthermore, in south Odisha, combine applications of N and P_2O_5 @ 60 kg and 40 kg ha^{-1} increased foxtail millet productivity (Reddy et al., 2019). Upendranaik *et al.* (2018) found that foxtail millet grew more quickly and produced more when

mulched with a mix of different organic manures. Rafi *et al*. (2012) and Rafi and Charyulu (2016) found that foxtail millet yield was increased by both the individual and combined inoculation of Azospirillum sp. and phosphate solubilizing bacteria (PSB). INM produced higher yields in foxtail millet, according to experimental results. In sandy loam soils at Madurai, Tamil Nadu, application of 50% RDF + 25% N as neem cake + Azophos produced greater grain yield than 100% RDF (44:22:0 kg $N:P_2O_5:K_2O$ ha^{-1}) and absolute control. (Monisha *et al*. 2019). However, in Tiruvannamalai, Tamil Nadu, Kumaran and Parasuraman (2019) found that INM increased the grain yield of foxtail millet. The maximum grain yield (1652.5 kg ha^{-1}) was achieved by combining the application of farmyard manure, the recommended dose of fertilizer, and 3% panchagavya foliarly applied 20 days after sowing. At Prayagraj, Uttar Pradesh, INM with 75% RD N through Urea + 25% N through PM + Azospirillum seed inoculation had the highest grain production (2.31 t ha^{-1}). (SelectstarMarwein *et al*. 2019).

6. **Yield attributes:** In the Kurnool area of Andhra Pradesh, on-farm tests were carried out to examine the performance of the foxtail millet variety SiA -3223 (Renadu) during the Kharif season in 2020 and 2021. Three foxtail millet varieties—SiA-3223 (TO1), SIA-3156 (TO2), and Prasad (TO3)—were used in ten presentations every year. After two years of evaluation, the combined data showed that the SiA-3223 variety had the longest panicle length (26.8 cm), followed by the SiA-3156 (23.8 cm) and Prasad (21.5 cm) kinds. SiA-3223 variety also recorded the highest test weight (3.6 gram) and seed yield (2369 kg/ha) when compared to SiA-3156 and Prasad variants. In comparison to the SiA-3156 and Prasad cultivars, the SiA-3223 variety showed a 15.5% and 45.3% percent increase in yield, respectively (Table 2).

Table 2: Salient features of foxtail millet varieties.

Sr. No.	**Variety**	**Duration (Days)**	**Year of notification**	**Potential Yield kg ha^{-1}**	**Specific features**
1.	SiA-3223	85-90	2020	2700-3200	High seed and fodder yield, cream white seeds, tolerant to blast and downy mildew
2.	SiA-3156	85-90	2012	2000-2500	High yielding, tolerant to blast and downy mildew
3.	Prasad	80-85	1982	2000-2500	Locally adopted high yielding, variety.

In 2020, SiA-3223 had the greatest average panicle length (26.4 cm) and test weight (3.7 gm), followed by SiA-3156 (23.1 cm and 2.8 gm). The local variety recorded the lowest average panicle length (21.3 cm) and test weight (2.2 gram). In 2021, a similar pattern was observed for test weight and panicle length. In 2020, SiA-3223 had an average yield of 2367 kg ha-1, 16.4% higher than SiA-3156 (2032 kg ha-1) and 41.3 % greater than the Prasad variety (1675 kg ha-1), respectively. SiA-3223 produced an average yield of 2371 kg ha-1 in 2021, which was 14.5%, 43.6%, and higher than SiA-3156 (2070 kg ha-1) and the Prasad variety (1650 kg ha-1) in that order (Table 3).

Table 3: Performance of foxtail millet varieties in 2020, 2021 and pooled

Particulars	**Panicle length (cm)**			**Test weight (gm)**			**Seed Yield kg ha^{-1}**		
	2020	**2021**	**pooled**	**2019**	**2020**	**pooled**	**2020**	**2021**	**pooled**
SIA-3223 (TO1)	26.4	27.2	26.8	3.7	3.5	3.6	2367	2371	2369
SIA-3156 (TO2)	23.1	24.4	23.75	2.8	2.5	2.65	2032	2070	2051
Prasad (TO3)	21.3	21.8	21.55	2.2	2.1	2.15	1675	1650	1630

7. **Climate Resilience**: Foxtail millet can withstand climate extremes, such as heat, drought, and low soil fertility. Because of its ability to endure climate fluctuation, it is a beneficial crop for developing agricultural systems that are climate resilient—that is, able to withstand extreme weather events and shifting climate conditions. In order to mitigate the risks associated with climate change and guarantee food security for future generations, farmers need diversify their cropping systems and include resilient crops such as foxtail millet.

8. **Cultural and Social Importance**: Since it has been grown for thousands of years in Asia and Africa, foxtail millet holds great cultural and social value in numerous societies worldwide. In addition to protecting cultural legacy, resurrecting traditional foxtail millet farming methods fosters local food sovereignty and increases community resilience to outside shocks. Policymakers and stakeholders may improve livelihoods, strengthen local communities, and advance social fairness and inclusion by integrating foxtail millet into sustainable food systems. They provide economic resilience in addition to food security since they can be cultivated in environments where other crops would not thrive, giving a reliable source of revenue. Millets are frequently grown and processed in communities, which promotes social cohesiveness and community resilience. In addition, women's empowerment is

facilitated by millet farming since they are heavily involved in the planting, harvesting, and processing of this crop.

9. **Integration of Millets in Global Sustainable Farming Strategies:** Increasing acceptance of millets importance in tackling issues related to food security, nutrition, and the environment has led to their incorporation into worldwide sustainable farming practices. International agencies like the FAO and IFAD are pushing for millets to be included in agricultural policies and programs, particularly in nations that are vulnerable to the effects of climate change. Several Sustainable Development Goals (SDGs), such as eradicating hunger, promoting health and wellbeing, and addressing climate change, are in line with the development of millets. Moreover, efforts worldwide are concentrated on improving the millets' value chain, from cultivation to consumption. This entails enhancing processing technology, producing new products based on millet, and establishing connections with markets to guarantee that farmers are fairly compensated for their supply. Additionally, efforts are being undertaken to increase consumer acceptance and consumption of millets worldwide by educating consumers about their advantages and incorporating them into public health and nutrition initiatives.

Conclusion

Growing foxtail millet is an important part of sustainable agricultural techniques since it has a lot of positive environmental effects. With its ability to use water and nutrients efficiently, as well as its benefits for soil health, sequestering carbon dioxide, and promoting biodiversity, foxtail millet has promise for building robust and ecologically sustainable farming systems. However, in order to fully fulfill foxtail millet's potential as a sustainable crop and to remove current obstacles to its acceptance, further study and funding are required. In order to effectively address the urgent issues of food security, climate change, and environmental sustainability, policymakers, farmers, and stakeholders can collaborate on the development of foxtail millet and incorporate it into varied cropping systems.

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