



Millets for Saline *Vertisols*: An Opportunity for Crop Diversification and Productive Use of Saline Water

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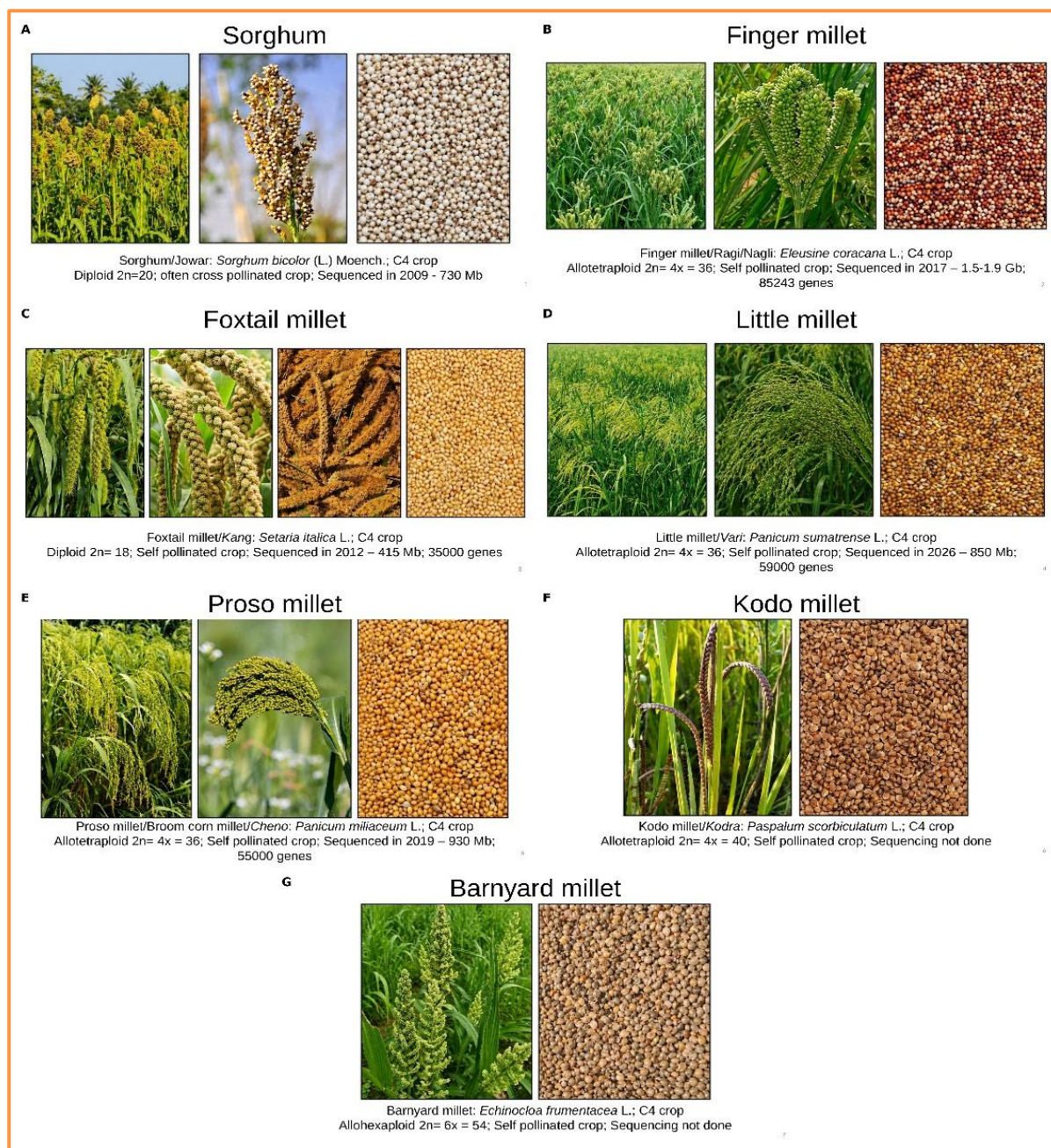
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Soil salinity is one of the major challenges threatening agricultural productivity and the sustainability of farming systems. India has about 6.73 million hectares of salt-affected soils, including approximately 2.96 million hectares of saline soils. The problem is further aggravated by the increasing use of poor-quality groundwater for irrigation. In the Bara tract of Gujarat, subsurface salinity affects nearly 75% of cultivated land, while groundwater used for irrigation is often saline to highly saline. Gujarat is particularly vulnerable to salinity because of its extensive coastal and canal-command areas and the increasing dependence on groundwater for irrigation. Salt-affected *Vertisols* of the state present additional challenges because of their high clay content, low hydraulic conductivity, restricted drainage and narrow workable moisture range. These characteristics make the management of salinity particularly difficult and can adversely affect crop establishment, growth and yield (Chinchmalatpure *et al.*, 2008). The scarcity of good-quality irrigation water during the rabi season further restricts farmers to a limited number of crops, thereby reducing cropping diversity and the productive use of available land and water resources. Exploring crops capable of producing economic yields with saline irrigation water could therefore provide an important pathway for diversification of agriculture in salt-affected regions.

Why millets?

In recent years, there has been growing interest in underutilized, nutrient-rich and stress-resilient crops for sustainable agriculture and dietary diversification. Millets are particularly attractive in this context because of their nutritional value, climate resilience, low water requirement and adaptability to marginal environments (Talabi *et al.*, 2026). Historically, millets have been important food crops in arid and semi-arid regions and are capable of performing under rainfed conditions, low soil fertility and limited moisture availability (Nagaraja *et al.*, 2024). They are also good sources of dietary fibre, minerals and micronutrients. Millets include major cereals such as sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*), as well as small or minor millets such as finger millet, foxtail millet, little millet, proso millet, kodo millet and barnyard millet. This diversity provides an opportunity to identify species and genotypes capable of adapting to different levels of salinity and soil conditions (Fig. 1). Globally, millets are cultivated over 75 million hectares, producing approximately 93.42 million tonnes. India is the leading producer, contributing around 18.3 million tonnes from 12.5 million hectares during 2024–25, accounting for more than 15% of global production. Gujarat has about 5.53 lakh hectares under millet cultivation, predominantly under pearl millet, while sorghum and several small millets occupy smaller areas. Importantly, about 9,770 hectares of small millets are cultivated during the rabi season in Gujarat. This existing rabi cultivation demonstrates the potential for expanding millet-based diversification beyond conventional cropping systems.



Can millets tolerate salinity?

Millets are generally considered glycophytic crops and are traditionally regarded as relatively sensitive to salinity. However, emerging research indicates considerable variation among species and genotypes, suggesting that this generalisation needs to be revisited. Some millet species possess physiological and biochemical mechanisms that may enable them to withstand saline environments. Sorghum is considered moderately salt tolerant and has been reported to perform better than several conventional cereals under saline conditions. Its tolerance is associated with osmotic adjustment, maintenance of photosynthetic activity, ionic homeostasis and antioxidant defence (Dehnavi *et al.*, 2020; Punia *et al.*, 2021). Salt-tolerant sorghum genotypes can therefore potentially provide both grain and fodder under salt-affected conditions. Finger millet is a C4 crop with efficient water and nitrogen utilisation and is widely recognised for its adaptation to harsh environments. Screening studies have identified variation in salinity response, although quantitative information on its performance under saline irrigation and field conditions remains limited.

Foxtail millet is another stress-resilient C4 crop with considerable potential for marginal environments. Its genome contains several genes associated with ion transport and ionic regulation, suggesting that mechanisms related to maintenance of ion balance may

contribute to its stress tolerance (Zhao *et al.*, 2019; Wu *et al.*, 2023). However, detailed information on its response to saline irrigation under field conditions is still limited. Among the other small millets, proso millet has attracted attention because of its ability to withstand several abiotic stresses, including salinity. Mechanisms involving osmotic adjustment, regulation of stomatal behaviour and coordinated functioning of ion transporters have been associated with its salinity tolerance (Yuan *et al.*, 2021). In contrast, little millet remains poorly studied, with most available information restricted to laboratory-level germination and seedling studies. Kodo millet has been reported to be relatively sensitive to salinity, while comprehensive information on barnyard millet is still very limited.

These differences indicate that salinity tolerance cannot be assumed to be similar across all millet species. Even within a species, considerable genetic variation may exist. Several potentially tolerant genotypes have already been identified in finger millet, proso millet, kodo millet, barnyard millet and other millets, providing valuable material for further evaluation and breeding (Table 1).

Table 1. Salt tolerant genotypes of various minor millets reported so far

Crop	Tolerant genotypes	Reference
Indian Barnyard millet	ACM161, ACM295, ACM335, GECH10, IEc167	Williams <i>et al.</i> , 2019
	MDU 1 and BAR 119	Subramanian <i>et al.</i> , 2020
	BAR 242, BAR 264, BAR 351 and BAR 353	Dhanalakshmi <i>et al.</i> , 2019
	ACM21022, ACM21016, ACM21017, ACM21024, and ACM21014	Vigneshwari <i>et al.</i> , 2023
Proso millet	K-1437, Shortandinskoye-7, Shortandinskoye-10, Kokchetavskoye-66, Barnaulskoye kormovoye, K-3742, and K-10278	Rysbekova <i>et al.</i> , 2019
	008211 and 008215	Sabir and Ashraf, 2008
	008211, 008214, 008226	Sabir <i>et al.</i> , 2011
	10 strongly tolerant genotypes	Yuan <i>et al.</i> , 2021
Kodo millet	IC 426676	Kumari and Vishnuvardhan, 2015
Finger millet	GBK043094 and GBK043137	Mukami <i>et al.</i> , 2020
	GPU28, CO12 and VI 149 (Best general combiners)	Shailaja <i>et al.</i> , 2010
	GPU 28, GPU 67, ML 365, Udurumallige, PYR1, GPU 48 and ML 368	Divya <i>et al.</i> , 2022
	CO 12, GPU 48 and Indaf 5	Shailaja and Thirumeni, 2007
Foxtail millet	ICERI-5 and ICERI-6	Ardie <i>et al.</i> , 2015

The major knowledge gap: laboratory tolerance versus field performance

One of the major limitations of existing research is that much of the available information on millet salinity tolerance comes from laboratory, hydroponic or pot experiments, particularly at the germination and seedling stages. Such experiments are useful for identifying initial responses to salinity, but tolerance at the seedling stage does not necessarily translate into superior grain or fodder yield under field conditions. Field conditions are considerably more complex. Soil texture, groundwater quality, salt accumulation, soil moisture dynamics, weather conditions, root-zone salinity and crop duration interact to determine actual crop performance. This is particularly important in the heavy-textured saline Vertisols of Gujarat, where low hydraulic conductivity and subsurface salinity can influence the distribution and movement of salts in the soil profile. Therefore, field-based evaluation under realistic saline

irrigation conditions is essential to determine which millet species can establish, grow and produce economically useful yields in salt-affected Vertisols. Such studies can also help establish the threshold level of irrigation-water salinity that different millet species can withstand.

From tolerance screening to suitable crops

A systematic approach is needed to identify millet species and genotypes suited to saline Vertisols. Initially, different millet species can be compared under graded levels of irrigation-water salinity to identify those with superior establishment, growth, biomass and grain/fodder productivity. The most promising species can subsequently be evaluated using diverse germplasm to identify genotypic variation in salinity tolerance. Importantly, evaluation should extend beyond visible growth. Root and shoot growth, biomass production, chlorophyll and photosynthetic performance, ion accumulation, particularly Na^+ and K^+ , osmotic adjustment, antioxidant responses and yield components can provide insights into the mechanisms underlying tolerance. Understanding the relationship between these traits and final yield can help identify reliable indicators for screening and breeding. The ultimate objective should therefore not simply be to identify a millet that survives saline conditions, but to identify species and genotypes that maintain economically acceptable productivity under saline irrigation. Such information will be particularly valuable for farmers who have access to saline groundwater but lack sufficient good-quality water during the rabi season.

An opportunity for Gujarat's saline lands

The saline Vertisols of Gujarat should not necessarily be viewed only as degraded resources. With appropriate crop selection and management, these soils and associated poor-quality water resources can potentially be brought into more productive use. Millets offer an attractive option because of their relatively short duration, nutritional value, adaptability to marginal environments and diversity of species and genotypes.

Introducing suitable millets into saline areas could provide several benefits:

- Diversification of rabi cropping systems
- Productive utilisation of saline groundwater
- Additional grain and fodder production
- Improved resilience under water scarcity
- Potential expansion of nutritious food crops
- Better utilisation of otherwise underproductive salt-affected lands
- Identification of new genetic resources for salinity-tolerance breeding

Way forward

A comprehensive field-based evaluation of sorghum and small millets under salt-affected Vertisols of Gujarat can bridge an important knowledge gap between controlled-environment screening and real-world agricultural production. The evaluation should determine the threshold salinity of irrigation water, species-wise adaptation, yield response, genetic variability and physiological, ionic, biochemical and molecular mechanisms associated with tolerance. Such information will help identify suitable millet species and genotypes for saline environments and provide a scientific basis for developing millet-based production systems using poor-quality irrigation water. It can also contribute to breeding programmes by identifying physiological and molecular traits associated with salinity tolerance.

Conclusion

The increasing extent of salt-affected soils and poor-quality groundwater calls for a shift from viewing salinity solely as a constraint towards identifying crops capable of utilising these challenging resources productively. Millets, with their nutritional richness, stress resilience and diversity, offer considerable promise in this regard. Systematic evaluation under field conditions in saline Vertisols can identify suitable species and genotypes, establish their salinity limits and reveal the mechanisms that enable them to maintain productivity. Integrating such salt-tolerant millet options into diversified cropping systems could provide a

practical pathway for productive utilisation of saline water, improving farm resilience, food and nutritional security, and the long-term sustainability of salt-affected lands in Gujarat and similar agro-ecosystems.

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