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Little millet - A tiny grain with big potential for nutrition and climate-resilient agriculture

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Intricacies of the subject

In the search for crops that can simultaneously support human nutrition, sustainable farming and climate resilience, an ancient grain is receiving renewed scientific attention little millet (*Panicum sumatrense* Roth ex Roem. and Schult.). Known as samai in Tamil, kutki in Hindi, sama, suan, vari and by several other regional names, little millet has been cultivated and consumed in India for generations. Evidence indicates that the Indian peninsula is an important centre of origin of the cropand it is presently cultivated mainly in India and parts of Sri Lanka, Nepal, Myanmar, Malaysia and China (FAO, 2023). Little millet was traditionally considered a crop of resource-poor and rainfed regions. However, this very ability to survive under difficult conditions has now increased its importance. It can grow on marginal soils, requires comparatively modest external inputs and possesses useful adaptation to drought-prone environments. Research has also reported its ability to withstand temporary waterlogging conditions (Vetriventhan *et al.*, 2021). These characteristics make little millet an interesting crop for agriculture under increasingly uncertain rainfall and climate conditions. For many years, little millet remained scientifically neglected compared with rice, wheat and maize. Today, however, research is rapidly expanding from conventional crop improvement and nutritional evaluation to genomics, molecular breeding, stress biology, biofortification, food processing and value addition.

A nutritional treasure in a tiny grain

One of the strongest reasons for the renewed interest in little millet is its nutritional composition. According to the Food and Agriculture Organization, 100 g of little millet provides approximately 353 kcal energy, 66.2 g available carbohydrate, 9.4 g protein, 3.9 g fat and 7.7 g dietary fibre. It is also reported to be high in copper, magnesium and selenium and to provide thiamin, phosphorus and zinc (FAO, 2023). The nutritional value of little millet should not be viewed simply as a fixed number because considerable differences occur among varieties and landraces. This variability is highly valuable to plant breeders. In a detailed evaluation of 200 diverse little millet landraces, Vetriventhan *et al.*, (2021) observed substantial variation for protein, iron, zinc, calcium and several agronomic characters.

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Iron concentration among the materials evaluated ranged approximately from 17.6 to 58.0 mg kg^{-1}, depending on the season, while zinc ranged roughly from 19.4 to 39.5 mg kg^{-1}. Protein content also showed wide variability, ranging from about 6 to more than 15 per cent among germplasm lines. Such diversity indicates that naturally occurring genetic resources already contain valuable donors that could be used to develop nutritionally superior cultivars (Vetriventhan *et al.,* 2021). Little millet also contains complex carbohydrates, dietary fibre and slowly digestible starch fractions. These characteristics have encouraged research into millet-based foods suitable for diversified and balanced diets. Reviews of millet processing have noted that little millet can produce a relatively slow glycaemic response compared with many highly refined cereal foods, although the actual response depends strongly on processing, cooking method, particle size and the complete meal composition (Nanje Gowda *et al.,* 2022). Therefore, little millet should not be promoted as a medicine or a miraculous "*superfood.*" Its real value lies in being a nutrient-dense whole grain that can contribute to dietary diversity. Processing is also important. Excessive polishing and milling can remove fibre and micronutrient-rich outer layers, whereas germination and fermentation can improve digestibility and, in some circumstances, nutrient bioavailability (Nanje Gowda *et al.*, 2022; Kumari *et al.,* 2025).

Where is little millet research heading?

Little millet research now extends across several interconnected fields. Traditional research has concentrated on collection and characterization of germplasm, evaluation of yield-related characters, flowering duration, plant height, tillering ability, panicle characters, grain size and adaptation to different production environments. These studies remain important because India's traditional landraces represent a reservoir of genetic diversity. A second major research area is nutritional characterization and biofortification. Scientists are screening germplasm for higher iron, zinc, protein and other useful nutritional traits. Interestingly, Vetriventhan *et al.,* (2021) observed that accessions belonging to the nana group tended to possess higher concentrations of several nutrients, whereas robusta types tended to have better grain productivity. This creates an attractive breeding opportunity: crossing nutrient-rich donors with high-yielding material to develop varieties combining both attributes. Research is also expanding into drought tolerance, salinity responses, waterlogging tolerance, nutrient-use efficiency and climate adaptation. Small millets generally possess characteristics favourable to production in marginal environments, but researchers are now attempting to understand the genes and physiological mechanisms responsible for these responses (Choudhary *et al.,* 2023). Another growing field is food science. Little millet is being investigated for use in traditional foods as well as modern products such as flakes, noodles, bakery products, ready-to-cook mixes, fermented products, extruded snacks and composite flours. The challenge is to increase convenience without losing the nutritional advantages of the whole grain.

Crop improvement: From farmers' fields to modern breeding

For centuries, farmers themselves served as the first little millet breeders. By repeatedly retaining seed from plants that survived local conditions and produced desirable grain, farming communities developed a large number of locally adapted landraces. Modern crop improvement initially built upon this variation through selection, hybridization and multi-location evaluation. Breeders have selected lines for higher grain yield, early

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or medium maturity, improved tillering, lodging tolerance, disease and pest resistance and desirable grain quality. Improved varieties such as OLM 203, JK 8, BL 6 and DHLM 36-3, among others, have contributed to little millet cultivation in different Indian production environments. More recently, coordinated testing programmes of ICAR have continued to identify promising breeding lines with higher yield potential. However, conventional breeding of little millet has historically progressed more slowly than breeding in crops such as rice and wheat because fewer financial, genomic and breeding resources were available.

The genomic revolution in little millet

A major breakthrough came when genome-wide marker information became available for the crop. Johnson *et al.*, (2019) applied genotyping-by-sequencing to minor millet germplasm and generated thousands of single nucleotide polymorphism markers. Population genetic analysis identified eight genetic subpopulations within little millet, demonstrating that substantial genetic structure exists within available germplasm. Such information helps breeders select genetically diverse parents and avoid repeatedly crossing closely related materials (Johnson *et al.*, 2019). The most important recent development has been the construction of a high-quality chromosome-scale little millet genome. Gali *et al.,* 2026 reported an approximately 850-megabase tetraploid genome containing 18 chromosomes and 59,045 annotated genes. Eleven chromosomes were assembled from telomere to telomere. Researchers also resequenced 300 little millet accessions, revealing extensive single nucleotide and structural variation within the species (Gali *et al.*, 2026). Even more importantly for crop improvement, genome-wide association studies identified genomic regions related to grain micronutrient content, including iron concentration, as well as important agronomic characters. This is a major transition for little millet—from an orphan crop with limited genomic tools to a species where genome-assisted breeding is increasingly realistic. Genomic information allows breeders to move beyond simply observing that one plant has high iron or another produces more grain. Researchers can now begin asking which genes and genomic regions are responsible and whether favourable alleles can be brought together into a single improved variety.

Breeding the little millet of tomorrow

Future crop improvement must go beyond simply increasing yield. A successful future variety should combine several characteristics simultaneously. For example, a farmer may require high and stable grain yield, short duration, tolerance to drought, resistance to lodging and pests, good fodder production and reliable performance under low-input conditions. Consumers and food industries may simultaneously demand larger grains, attractive colour, easy dehulling, better cooking characteristics, higher protein and increased iron and zinc. Importantly, the germplasm study of Vetriventhan *et al.,* (2021) reported negative associations between grain yield and some nutritional traits, including iron, zinc and protein. This means that simply selecting the highest-yielding plant may unintentionally reduce nutritional quality. Modern approaches such as selection indices, marker-assisted selection, genome-wide association studies and eventually genomic selection can help breeders combine these traits more efficiently. The new genome also creates opportunities to investigate candidate genes controlling micronutrient accumulation, plant architecture, maturity and stress responses. Genome editing technologies such as CRISPR/Cas could eventually become useful; however, transformation and regression systems suitable for routine gene editing must first become sufficiently reliable in little millet. Thus, gene editing remains a future opportunity rather than an immediate replacement for conventional breeding (Choudhary *et al.*, 2023).

Climate change could give little millet a bigger role

Climate change is producing a difficult combination of rising temperatures, irregular rainfall, drought, sudden heavy rainfall and declining soil quality in many agricultural regions. Crop diversification is therefore becoming increasingly important. Little millet is particularly attractive because it evolved under comparatively low-input farming systems and can perform in environments where intensive cereal cultivation may be difficult. Its relatively short crop duration can also help farmers escape terminal drought in some environments. Nevertheless, the frequently used term “climate-smart crop” needs stronger scientific validation at the variety level. Future research should quantitatively compare little millet genotypes for drought tolerance, heat tolerance, salinity tolerance, waterlogging tolerance, root architecture and water-use efficiency rather than assuming that all little millet varieties possess equal resilience.

Biofortification: nutrition can become a breeding target

The existence of large natural variation for iron, zinc and protein provides a strong opportunity for little millet biofortification. Instead of adding nutrients after harvesting, biofortification aims to develop varieties that naturally accumulate higher amounts of nutritionally important minerals in their edible grain. Trait-specific accessions already identified in germplasm collections provide valuable parental material for this work (Vetriventhan *et al.*, 2021). The recently developed genomic resources could accelerate this process. If genomic regions responsible for elevated iron or zinc are validated across environments, breeders could track favourable alleles using DNA markers even before grain samples from every breeding line are chemically analysed. The eventual objective should not merely be a “high-iron little millet.” The goal should be a high-yielding, farmer-preferred and nutritionally enhanced little millet that retains its nutrient advantage across different growing environments and processing systems.

The forgotten challenge: processing and consumer convenience

One reason for declining consumption of several small millets has been the difficulty involved in cleaning, dehulling and processing their tiny grains. Rice and wheat have highly developed processing industries and convenient consumer products. Little millet requires similar innovation. Modern dehullers, graders and small-scale processing units suitable for farmer producer organizations and rural entrepreneurs could significantly improve the crop’s value chain. At the same time, processing research must protect nutritional quality. Heavy polishing may produce visually attractive grain but can reduce fibre and micronutrients. Research indicates that processing methods such as germination and fermentation can improve several nutritional characteristics, whereas excessive removal of outer grain layers can cause nutritional losses (Nanje Gowda *et al.*, 2022). Value-added foods must therefore combine convenience, taste, storage stability and nutrition.

Future prospects

Future breeding programmes can make extensive use of landraces and genebank collections to identify donors for nutrient density, stress tolerance, grain size, maturity and yield. The newly developed refernce genome should be converted into inexpensive breeder-friendly molecular markers. Larger multi-location populations can support genomic selection for complex traits such as yield stability and drought tolerance. Research must also focus more strongly on genotype × environment interaction. A nutritionally superior genotype is useful only when it maintains its mineral concentration under diverse soils and climates. Similarly, a high-yielding variety must be evaluated under the actual low-input environments where many smallholder farmers grow the crop. High-throughput phenotyping, remote sensing, artificial intelligence and machine learning may eventually help researchers analyse complex interactions among genotype, weather, soil and plant performance. At the nutritional level, greater attention is needed on mineral bioavailability, rather than simply total mineral content. Iron present in grain is valuable only when an adequate proportion can be absorbed by the human body. Breeding for higher minerals should therefore be connected with research on phytate, polyphenols, processing and food preparation. Strong seed systems, decentralized processing, farmer producer organizations, attractive millet-based foods, better market linkages and consumer awareness will be equally important.

Conclusion

Little millet demonstrates why an underutilized crop should not be confused with an unimportant crop. Its small grain contains valuable nutrients, while its genetic diversity offers breeders opportunities to improve yield, micronutrient density and adaptation. Farmers have conserved this diversity for generationsand modern science is only now beginning to reveal its full potential. The progression from traditional landrace selection to genome-wide SNP analysis and finally to a chromosome-scale genome represents a remarkable transformation in little millet research. The crop now stands at a point where traditional knowledge, conventional plant breeding, nutritional science and advanced genomics can be integrated. Its strength may instead lie in providing a reliable, nutritious and climate-resilient grain for environments where agricultural risk is increasing. If research translates its genetic diversity into productive varieties and food systems translate those varieties into convenient and profitable products, this tiny grain could make a surprisingly large contribution to nutrition security, climate-resilient agriculture and sustainable rural livelihoods.

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