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Recent advances in millet research and development: A comprehensive review for sustainable agricultural systems in India

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ABSTRACT

Millet, a diverse group of small-seeded cereals that includes pearl millet, finger millet, foxtail millet, proso millet and several minor millets, are regaining global attention as climate-resilient and nutrient-dense crops. This review summarises recent advances in millet research and development, using India, the world's largest producer, as the central case and drawing comparisons from Africa, East Asia and other regions. Although the area under millets in India has declined by about 60% over seven decades, productivity has roughly tripled through improved cultivars and management. Millets supply more calcium, iron, zinc and dietary fibre than polished rice, and biofortified pearl millet cultivars with high grain iron and zinc are already in farmers' fields. Deep roots, C₄ photosynthesis and short crop duration allow millets to yield under low rainfall and high temperature, and replacing part of the rice area with millets could substantially reduce irrigation demand. Reference genomes, genomic selection and genome editing are accelerating breeding, while integrated and site-specific nutrient management, nano-fertilisers, intercropping and moisture conservation are raising yields sustainably. Policy support, notably India's designation of millets as nutri-cereals (2018) and the United Nations International Year of Millets (2023), has strengthened demand, but procurement, processing and market linkages remain weak. We identify research, policy and value-chain priorities for making millets mainstream components of climate-smart and nutrition-sensitive food systems.

Keywords: Biofortification, Climate resilience, Millets, Nutri-cereals, Sustainable intensification, Value chain

1. Introduction

Global agriculture must feed a growing population under a changing climate while also tackling widespread malnutrition. Micronutrient deficiencies affect more than two billion people worldwide (Tulchinsky, 2010) [1], and anaemia remains common among women of reproductive age in South and Southeast Asia (Sunuwar *et al.*, 2020) [2]. Millets are small-seeded cereals that have been cultivated for over 10,000 years, mainly in the arid and semi-arid regions of Asia and Africa (Muskan *et al.*, 2025) [3]. They combine tolerance of drought and heat with grain that is rich in minerals, fibre and bioactive compounds (Anal *et al.*, 2024; Kheya *et al.*, 2023) [4, 5]. These attributes make them relevant well beyond their traditional homelands; proso millet, for example, is being evaluated as a low-input rotation crop in the Pacific Northwest of the United States (Habiyaemye *et al.*, 2017) [6].

India, Niger and China together account for about 60% of global millet production (Muskan *et al.*, 2025) [3], and India is the largest single producer (Mohan *et al.*, 2025) [7]. Yet the area under millets in India fell by roughly 60% over the last seven decades, as procurement at guaranteed prices and subsidised public distribution favoured rice and wheat (Yadav *et al.*, 2024) [8]. Interest revived after the Government of India designated millets as "nutri-cereals" in 2018 and the United Nations declared 2023 the International Year of Millets (Muskan *et al.*, 2025; Sahoo *et al.*, 2023) [3, 9]. This review synthesises recent advances in millet production, nutrition, climate resilience, breeding, agronomy, policy and markets, using India as the central case while drawing on evidence from other millet-growing regions, and outlines priorities for future research and development.

2. Current status of millet production

2.1 Global trends

Millets are grown mainly by smallholder farmers in Asia and sub-Saharan Africa (Harish *et al.*, 2024) [10]. Pearl millet, the sixth most important cereal after rice, wheat, maize, barley and sorghum, is grown on about 30 million ha in the arid and semi-arid tropics of Asia and Africa and accounts for almost half of global millet production (Satyavathi *et al.*, 2021) [11]. Finger millet is a staple in eastern and southern Africa and South

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Asia (Maharajan *et al.*, 2021) [12], whereas foxtail and proso millets are important in East Asia (Kheya *et al.*, 2023) [5]. In most traditional growing regions, millet area has contracted because of shifts toward higher-value crops, urbanisation and changing diets; at the same time, interest is rising in drier and non-traditional zones where millets are being tested as climate-resilient alternatives (Harish *et al.*, 2024; Mukherjee *et al.*, 2025) [10, 13].

2.2 The Indian scenario

India cultivates all major millet species across diverse agroclimatic zones, with pearl millet concentrated in the north-western arid states, finger millet in the southern and hill states, and sorghum in the central and southern Deccan (Yadav *et al.*, 2024) [8]. Over seven decades, millet area declined by about 60% while productivity rose by about 200%, leaving total production broadly unchanged (Yadav *et al.*, 2024) [8]. In pearl millet, hybrid breeding and periodic replacement of cultivars have delivered annual yield gains of about 4% over the last three decades (Yadav *et al.*, 2021) [14]. The decline in area reflects policy incentives that favoured rice and wheat, changing consumer preferences, and weak processing and marketing infrastructure (Shah *et al.*, 2023; Yadav *et al.*, 2024) [15, 8]. In the North Eastern Himalayan region, millets remain embedded in tribal food systems, but dietary change, cash crops and subsidised rice have reduced their cultivation (Majumdar *et al.*, 2026) [16]. A three-year evaluation under organic management in this region found that finger, little and foxtail millets were the most productive (1.16–1.43 t ha⁻¹), and that local finger millet landraces performed close to improved cultivars (Layek *et al.*, 2023) [17]. Persistent constraints include erratic rainfall, soil degradation, labour shortages, pest pressure, and limited procurement, storage and producer–consumer linkages (Harish *et al.*, 2024; Kheya *et al.*, 2023) [10, 5].

3. Nutritional significance and health benefits

3.1 Nutritional composition

Millets are good sources of protein, dietary fibre, minerals, B vitamins and phytochemicals (Hassan *et al.*, 2021) [18]. Finger millet is exceptional for calcium, containing about 364 ± 58 mg per 100 g across varieties, roughly three times the level in milk (Anitha *et al.*, 2021) [19] and far more than rice, wheat or maize (Maharajan *et al.*, 2021) [12]. A global systematic review reported mean protein contents of about 12 g per 100 g in proso and barnyard millets and high but highly variable iron and zinc concentrations across species and genotypes, underlining the need to select nutrient-dense varieties for nutrition programmes (Anitha *et al.*, 2024) [20]. Millet starch and protein are digested more slowly than those of other cereals, which contributes to a lower glycaemic response (Annor *et al.*, 2017) [21], and phenolic acids, flavonoids and other antioxidants add further health-promoting properties (Jacob *et al.*, 2024) [22].

3.2 Health benefits

Regular millet consumption is associated with better glycaemic control, weight management and a lower risk of non-communicable diseases such as type 2 diabetes and cardiovascular disease (Bhattacharya, 2023; Jacob *et al.*, 2024) [23, 22]. A meta-analysis showed significant retention (about 23%) of calcium from finger millet-based diets in children, and reduced bone resorption in peri- and post-menopausal women (Anitha *et al.*, 2021) [19]. Phytic acid, polyphenols and tannins can lower mineral bioavailability, although phytate also has antioxidant activity (Zhou *et al.*, 1995) [24]. Soaking, germination, fermentation and other processing methods reduce these anti-nutrients and improve nutrient availability (Faizal *et al.*, 2023) [25].

3.3 Biofortification

Biofortification through breeding, agronomy and transgenic approaches offers a sustainable route to higher micronutrient intake (Kudapa *et al.*, 2023; Vinoth *et al.*, 2017) [26, 27]. HarvestPlus and Indian public breeding programmes have released iron-dense pearl

millet cultivars such as the variety Dhanashakti and hybrids such as HHB 299 and AHB 1200Fe, which combine high yield with grain iron above 70 ppm and zinc of about 35–40 ppm (Kudapa *et al.*, 2023; Satyavathi *et al.*, 2021) [26, 11]. Agronomic biofortification complements breeding: in finger millet, foliar application of 0.5% ZnSO₄·7H₂O at flowering and 20 days after flowering raised grain zinc from 25–30 to about 40 µg g⁻¹, whereas soil application of 12.5 kg ha⁻¹ ZnSO₄·7H₂O mainly increased grain yield (Nanja Reddy *et al.*, 2025) [28]. Transgenic expression of zinc transporters and the identification of calcium transporter and sensor genes in finger millet open further options for nutritional enhancement (Maharajan *et al.*, 2021; Vinoth *et al.*, 2017) [12, 27].

4. Climate resilience and sustainability

4.1 Drought and heat tolerance

Millets tolerate water deficit through deep and extensive root systems, C₄ photosynthesis with high water-use efficiency, osmotic adjustment and antioxidant defences (Bandyopadhyay *et al.*, 2017; Satyavathi *et al.*, 2021) [29, 11]. In pearl millet, a glutaredoxin gene (*PgGRXC9*) that regulates primary root growth has been linked to early drought tolerance (de la Fuente *et al.*, 2024) [30]. Short crop duration and flexible sowing dates also allow millets to escape end-of-season drought (Babele *et al.*, 2022) [31]. In India, sorghum yields are less sensitive than wheat yields to high maximum temperatures, and the seasonal water requirement of wheat is about 1.4 times that of sorghum (DeFries *et al.*, 2023) [32].

4.2 Resource efficiency and climate risk

Replacing rice in each Indian district with the alternative cereal (maize, finger millet, pearl millet or sorghum) that has the lowest irrigation water footprint could cut irrigation demand by 33% while increasing iron production by 27% and zinc production by 13% (Davis *et al.*, 2018) [33]. Because millets are grown without flooding and with few external inputs, they also avoid the methane emissions associated with paddy rice and have a smaller environmental footprint (Babele *et al.*, 2022; Mukherjee *et al.*, 2025) [31, 13]. Millets are not immune to climate change, however: genomic analysis shows that some West African pearl millet populations are poorly adapted to projected climates, which calls for regional germplasm exchange and breeding for local adaptation (Hausmann *et al.*, 2012; Rhoné *et al.*, 2020) [34, 35].

4.3 Integration into sustainable farming systems

Millets fit well into organic and low-input systems, crop–livestock integration and diversified rotations (Babele *et al.*, 2022; Kheya *et al.*, 2023) [31, 5]. In China, intercropping proso millet with legumes altered soil microbial communities and improved nitrogen assimilation and grain yield (Dang *et al.*, 2020) [36]. In southern India, finger millet–pigeon pea intercropping combined with arbuscular mycorrhizal fungi and plant growth-promoting rhizobacteria increased yield while reducing fertiliser input (Mathimaran *et al.*, 2020) [37].

5. Advances in breeding and genomics

Improved varieties with higher yield, disease resistance and better nutritional quality have been released for pearl millet and the small millets (Nagaraja *et al.*, 2024; Vetriventhan *et al.*, 2020) [38, 39]. Pearl millet benefits from a stable cytoplasmic male sterility system and a strong hybrid breeding pipeline (Yadav *et al.*, 2021) [14]. Reference genomes are now available for the major millets, and three near gap-free pearl millet genomes representing the global heterotic pool have recently been assembled, providing a framework for marker-assisted and genomic breeding (Ramu *et al.*, 2023) [40]. Transcriptomic resources have identified genes and pathways underlying drought and heat tolerance and nutrient accumulation (Maharajan *et al.*, 2024) [41]. Genome-wide association studies, genomic selection and speed breeding can shorten breeding cycles, and CRISPR/Cas genome editing allows precise trait improvement without lengthy backcrossing (Chen *et al.*, 2019; Mukherjee *et al.*, 2025) [42, 13]. Nevertheless, the

small millets still lack adequate genomic tools, efficient transformation systems and large breeding programmes (Nagaraja *et al.*, 2024; Vetriventhan *et al.*, 2020) [39].

6. Agronomic innovations

6.1 Nutrient management

Integrated nutrient management, which combines organic manures, crop residues, biofertilisers and mineral fertilisers, increased crop yields by 1.3–66.5% across major cropping systems while improving soil health and reducing greenhouse gas emissions (Paramesh *et al.*, 2023) [43]. In finger millet grown on calcareous soils in Bihar, India, GreenSeeker-guided site-specific nutrient management gave the highest grain yield (2,873 kg ha⁻¹) and an agronomic nitrogen efficiency of 30.6 kg grain per kg N, outperforming even 125% of the recommended fertiliser dose (Pramanick *et al.*, 2024) [44]. In pearl millet–mustard and maize–wheat systems, supplying 75% of the recommended nitrogen together with a nano-urea spray reduced energy requirement by about 8–11% and increased energy-use efficiency by 6–9% compared with 100% nitrogen from prilled urea (Upadhyay *et al.*, 2023) [45].

6.2 Water and crop management

In-situ moisture conservation, mulching, conservation tillage and supplementary irrigation at critical growth stages improve water-use efficiency and yield stability in rainfed millets (El-Beltagi *et al.*, 2022; Mukherjee *et al.*, 2025) [46, 13]. Intercropping spreads risk and raises land productivity; in Tamil Nadu, foxtail millet intercropped with vegetable cowpea gave foxtail millet grain-equivalent yields of up to 3,873 kg ha⁻¹ (Aravind *et al.*, 2023) [47]. Timely sowing, optimum plant population, integrated weed management and seed treatment remain low-cost practices with large effects on farm yields (Kheya *et al.*, 2023) [5].

7. Policy support and institutional initiatives

India's policy framework for millets includes the nutri-cereals component of the National Food Security Mission, the Rashtriya Krishi Vikas Yojana, minimum support prices (MSP) for pearl millet, finger millet and sorghum, and the inclusion of millets in the public distribution system and nutrition schemes (Gireesh *et al.*, 2025) [48]. The ICAR–Indian Institute of Millets Research, Hyderabad, coordinates national research through the All India Coordinated Research Projects on pearl millet, sorghum and small millets (Nagaraja *et al.*, 2024) [38]. The International Year of Millets 2023 raised global awareness, strengthened collaboration with international organisations such as ICRISAT and FAO, and promoted trade in millet products (Muskan *et al.*, 2025; Sahoo *et al.*, 2023) [3, 9]. Nevertheless, public procurement of millets remains small compared with rice and wheat, which limits price assurance for farmers (Yadav *et al.*, 2024) [8].

8. Value chains and markets

Processing remains a key bottleneck. Small millets must be dehulled, traditional methods are laborious, and modern decorticators, mills and packaging are needed to improve quality and shelf life (Kheya *et al.*, 2023; Mohanan *et al.*, 2025) [5, 7]. Ready-to-eat, bakery, snack and fermented products are expanding urban and export demand, including gluten-free markets (Mohanan *et al.*, 2025; Muskan *et al.*, 2025) [7, 3]. Millet entrepreneurs, however, report difficulties with raw-material supply, processing technology, consumer awareness and price competitiveness (Shah *et al.*, 2023) [15]. Farmer producer organisations can aggregate produce, add value and improve price realisation for smallholders (Sangappa *et al.*, 2023) [49]. Experience from Africa likewise shows that better seed systems, processing and market linkages are needed to expand finger millet production and use (Opole, 2019) [50].

9. Future prospects and recommendations

Research should prioritise (i) climate-resilient, biofortified cultivars developed by combining genomic selection, speed breeding and genome editing with conventional and participatory breeding (Chen *et al.*, 2019; Haussmann *et al.*, 2012) [42, 34]; (ii) location-specific nutrient, water and pest management for sustainable intensification (Paramesh *et al.*, 2023; Pramanick *et al.*, 2024) [43, 44]; (iii) low-cost processing technologies that retain nutrients and reduce *anti*-nutrients (Faizal *et al.*, 2023) [25]; and (iv) consumer and market research to guide product development (Muskan *et al.*, 2025) [3]. Policy should provide assured procurement at remunerative prices, wider MSP coverage, the inclusion of millets in public distribution and school and child feeding programmes, and investment in storage, processing and market linkages led by farmer producer organisations (Gireesh *et al.*, 2025; Yadav *et al.*, 2024) [48, 8]. Because climate risks to millets cross national borders, international cooperation on germplasm, breeding and trade will be essential (Rhoné *et al.*, 2020) [35].

10. Conclusion

Millets combine climate resilience, low input requirements and high nutritional value, which makes them strategic crops for sustainable and nutrition-sensitive food systems in India and worldwide. Advances in genomics, biofortification and agronomy have raised productivity, but the area under millets continues to lag because of weak procurement, processing and market support. Sustained investment in research, supportive policies and value-chain development can move millets from marginal to mainstream crops while conserving traditional knowledge and agrobiodiversity.

References

1. Tulchinsky TH. Micronutrient deficiency conditions: Global health issues. *Public Health Reviews*. 2010;32(1):243–255.
2. Sunuwar DR, Singh DR, Chaudhary NK, Pradhan PMS, Rai P, Tiwari K. Prevalence and factors associated with anemia among women of reproductive age in seven South and Southeast Asian countries: Evidence from nationally representative surveys. *PLOS ONE*. 2020;15(8):e0236449.
3. Muskan F, Redhu M, Redhu S, Rahimi M. Millets in the global market: A critical review of challenges and opportunities. *Food Production, Processing and Nutrition*. 2025;7(1):37.
4. Anal AK, Singh R, Rice D, Pongtong K, Hazarika U, Trivedi D, Karki S. Millets as supergrains: A holistic approach for sustainable and healthy food product development. *Sustainable Food Technology*. 2024;2(4):908–925.
5. Kheya SA, Talukder SK, Datta P, Yeasmin S, Rashid MH, Hasan AK, Anwar MP, Islam AKMA, Islam AKMM. Millets: The future crops for the tropics—Status, challenges and future prospects. *Heliyon*. 2023;9(11):e22123.
6. Habiyaemye C, Matanguihan JB, D'Alpoim Guedes J, Ganjyal GM, Whiteman MR, Kidwell KK, Murphy KM. Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, U.S.: A review. *Frontiers in Plant Science*. 2017;7:1961.
7. Mohanan MM, Vijayakumar A, Bang-Berthelsen CH, Mudnakudu-Nagaraju KK, Shetty R. Millets: Journey from an ancient crop to sustainable and healthy food. *Foods*. 2025;14(10):1733.
8. Yadav OP, Singh DV, Kumari V, Prasad M, Seni S, Singh RK, Sood S, Kant L, Rao BD, Madhusudhana R, Bhat BV, Gupta SK, Yadava DK, Mohapatra T. Production and cultivation dynamics of millets in India. *Crop Science*. 2024;64(5):2459–2484.
9. Sahoo JP, Mahapatra M. International Year of Millets—2023: Revitalisation of millets towards a sustainable nutritional security. *Technology in Agronomy*. 2023;3(1).

10. Harish MS, Bhuker A, Chauhan BS. Millet production, challenges, and opportunities in the Asia-Pacific region: A comprehensive review. *Frontiers in Sustainable Food Systems*. 2024;8:1386469.
11. Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK. Pearl millet: A climate-resilient nutriceal for mitigating hidden hunger and provide nutritional security. *Frontiers in Plant Science*. 2021;12:659938.
12. Maharajan T, Ceasar SA, Ajeesh Krishna TP, Ignacimuthu S. Finger millet [*Eleusine coracana* (L.) Gaertn]: An orphan crop with a potential to alleviate the calcium deficiency in the semi-arid tropics of Asia and Africa. *Frontiers in Sustainable Food Systems*. 2021;5:684447.
13. Mukherjee B, Jha RK, Sattar A, Dutta S, Bhattacharya U, Samanta S, Huirem B, Singh SK, Das S, Bal SK. Harnessing the potential of millets for climate-resilient and sustainable agriculture. *Frontiers in Plant Science*. 2025;16:1574699.
14. Yadav OP, Gupta SK, Govindaraj M, Sharma R, Varshney RK, Srivastava RK, Rathore A, Mahala RS. Genetic gains in pearl millet in India: Insights into historic breeding strategies and future perspective. *Frontiers in Plant Science*. 2021;12:645038.
15. Shah P, Dhir A, Joshi R, Tripathy N. Opportunities and challenges in food entrepreneurship: In-depth qualitative investigation of millet entrepreneurs. *Journal of Business Research*. 2023;155:113372.
16. Majumdar S, Sangappa S, Kencharaddi H, Priya GB, Muruganantham L, Madhusudhana R, Vastrad JV, Rafi D, Prakash NB, Satyavathi CT. Unlocking the ethnobotanical wisdom of millets: Reviving ancient grains cultivation in the North Eastern Himalayan region of India for food, feed, fodder, and nutritional security. *Frontiers in Sustainable Food Systems*. 2026;10:1725027.
17. Layek J, Rangappa K, Das A, Ansari MA, Choudhary S, Rajbonshi N, Patra S, Kumar A, Mishra VK, Ravisankar N, Kumar S, Hazarika S, Dutta SK, Babu S, Tahasildar M, Shettigar N. Evaluation of millets for physio-chemical and root morphological traits suitable for resilient farming and nutritional security in Eastern Himalayas. *Frontiers in Nutrition*. 2023;10:1198023.
18. Hassan ZM, Sebola NA, Mabelebele M. The nutritional use of millet grain for food and feed: A review. *Agriculture & Food Security*. 2021;10(1):16.
19. Anitha S, Givens DI, Botha R, Kane-Potaka J, Sulaiman N, Tsusaka T, Subramaniam K, Rajendran A, Parasannanavar D, Bhandari R. Calcium from finger millet—A systematic review and meta-analysis on calcium retention, bone resorption, and in vitro bioavailability. *Sustainability*. 2021;13(16):8677.
20. Anitha S, Rajendran A, Botha R, Baruah C, Mer P, Sebastian J, Upadhyay S, Kane-Potaka J. Variation in the nutrient content of different genotypes and varieties of millets, studied globally: A systematic review. *Frontiers in Sustainable Food Systems*. 2024;8:1324046.
21. Annor GA, Tyl C, Marcone M, Ragaee S, Marti A. Why do millets have slower starch and protein digestibility than other cereals? *Trends in Food Science & Technology*. 2017;66:73–83.
22. Jacob J, Krishnan V, Antony C, Bhavyasri M, Aruna C, Mishra K, Nepolean T, Satyavathi CT, Visarada KBR. The nutrition and therapeutic potential of millets: An updated narrative review. *Frontiers in Nutrition*. 2024;11:1346869.
23. Bhattacharya S. Cultivating health: Millets' potential in combating non-communicable diseases and future research avenues in India. *Frontiers in Nutrition*. 2023;10:1190111.
24. Zhou JR, Erdman JW. Phytic acid in health and disease. *Critical Reviews in Food Science and Nutrition*. 1995;35(6):495–508.
25. Faizal FA, Ahmad NH, Yaacob JS, Abdul Halim Lim S, Abd Rahim MH. Food processing to reduce antinutrients in plant-based foods. *International Food Research Journal*. 2023;30(1):25–45.
26. Kudapa H, Barmukh R, Vemuri H, Gorthy S, Pinnamaneni R, Vetriventhan M, Srivastava RK, Joshi P, Habyarimana E, Gupta SK, Govindaraj M. Genetic and genomic interventions in crop biofortification: Examples in millets. *Frontiers in Plant Science*. 2023;14:1123655.
27. Vinoth A, Ravindhran R. Biofortification in millets: A sustainable approach for nutritional security. *Frontiers in Plant Science*. 2017;8:29.
28. Nanja Reddy YA, Jayalakshmi P, Narayana Reddy AB, Udaya Kumar M, Ashok EG, Gowda MVC. Agronomic biofortification of finger millet for zinc, and its influence on yield and partitioning of zinc, iron, and calcium in the plant. *Journal of Plant Nutrition*. 2025;48(1):23–38.
29. Bandyopadhyay T, Muthamilarasan M, Prasad M. Millets for next generation climate-smart agriculture. *Frontiers in Plant Science*. 2017;8:1266.
30. de la Fuente C, Grondin A, Sine B, Debieu M, Belin C, Hajjarpoor A, Atkinson JA, Passot S, Salson M, Orjuela J, Tranchant-Dubreuil C, Brossier JR, Steffen M, Morgado C, Dinh HN, Pandey BK, Darmau J, Champion A, Petitot AS, Laplaze L. Glutaredoxin regulation of primary root growth is associated with early drought stress tolerance in pearl millet. *eLife*. 2024;12:RP86169.
31. Babele PK, Kudapa H, Singh Y, Varshney RK, Kumar A. Mainstreaming orphan millets for advancing climate smart agriculture to secure nutrition and health. *Frontiers in Plant Science*. 2022;13:902536.
32. DeFries R, Liang S, Chhatre A, Davis KF, Ghosh S, Rao ND, Singh D. Climate resilience of dry season cereals in India. *Scientific Reports*. 2023;13(1):9960.
33. Davis KF, Chiarelli DD, Rulli MC, Chhatre A, Richter B, Singh D, DeFries R. Alternative cereals can improve water use and nutrient supply in India. *Science Advances*. 2018;4(7):eaao1108.
34. Haussmann BIG, Rattunde HFW, Weltzien-Rattunde E, Traoré PSC, vom Brocke K, Parzies HK. Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa. *Journal of Agronomy and Crop Science*. 2012;198(5):327–339.
35. Rhoné B, Defrance D, Berthouly-Salazar C, Mariac C, Cubry P, Couderc M, Dequincey A, Assoumanne A, Kane NA, Sultan B, Barnaud A, Vigouroux Y. Pearl millet genomic vulnerability to climate change in West Africa highlights the need for regional collaboration. *Nature Communications*. 2020;11(1):5274.
36. Dang K, Gong X, Zhao G, Wang H, Ivanistau A, Feng B. Intercropping alters the soil microbial diversity and community to facilitate nitrogen assimilation: A potential mechanism for increasing proso millet grain yield. *Frontiers in Microbiology*. 2020;11:601054.
37. Mathimaran N, Jegan S, Thimmegowda MN, Prabavathy VR, Yuvaraj P, Kathiravan R, Sivakumar MN, Manjunatha BN, Bhavitha NC, Sathish A, Shashidhar GC, Bagyaraj DJ, Ashok EG, Singh D, Kahmen A, Boller T, Mäder P. Intercropping transplanted pigeon pea with finger millet: Arbuscular mycorrhizal fungi and plant growth promoting rhizobacteria boost yield while reducing fertilizer input. *Frontiers in Sustainable Food Systems*. 2020;4:88.
38. Nagaraja TE, Parveen SG, Aruna C, Hariprasanna K, Singh SP, Singh AK, Joshi DC, Joshi P, Tomar SMS, Talukdar A, Kumar S. Millets and pseudocereals: A treasure for climate resilient agriculture ensuring food and nutrition security. *Indian Journal of Genetics and Plant Breeding*. 2024;84(1):1–37.

39. Vetriventhan M, Azevedo VCR, Upadhyaya HD, Nirmalakumari A, Kane-Potaka J, Anitha S, Ceasar SA, Muthamilarasan M, Bhat BV, Hariprasanna K, Bellundagi A, Cheruku D, Backiyalakshmi C, Santra D, Vanniarajan C, Tonapi VA. Genetic and genomic resources, and breeding for accelerating improvement of small millets: Current status and future interventions. *The Nucleus*. 2020;63(3):217–239.
40. Ramu P, Srivastava RK, Sanyal A, Fengler K, Cao J, Zhang Y, Nimkar M, Gerke J, Shreedharan S, Llaca V, May G, Peterson-Burch B, Lin H, King M, Das S, Bhupesh V, Mandaokar A, Maruthachalam K, Krishnamurthy P, Babu R. Improved pearl millet genomes representing the global heterotic pool offer a framework for molecular breeding applications. *Communications Biology*. 2023;6(1):902.
41. Maharajan T, Ceasar SA, Ajeesh Krishna TP. Harnessing the transcriptomic resources of millets to decipher climate resilience and nutrient enrichment traits. *Critical Reviews in Plant Sciences*. 2024;43(5):348–375.
42. Chen K, Wang Y, Zhang R, Zhang H, Gao C. CRISPR/Cas genome editing and precision plant breeding in agriculture. *Annual Review of Plant Biology*. 2019;70(1):667–697.
43. Paramesh V, Mohan Kumar R, Rajanna GA, Gowda S, Nath AJ, Madival Y, Jinger D, Bhat S, Toraskar S. Integrated nutrient management for improving crop yields, soil properties, and reducing greenhouse gas emissions. *Frontiers in Sustainable Food Systems*. 2023;7:1173258.
44. Pramanick B, Choudhary S, Kumar M, Singh SK, Jha RK, Singh SK, Salmen SH, Ansari MJ, Hossain A. Can site-specific nutrient management improve the productivity and resource use efficiency of climate-resilient finger millet in calcareous soils in India? *Heliyon*. 2024;10(12):e32774.
45. Upadhyay PK, Dey A, Singh VK, Dwivedi BS, Singh T, Rajanna GA, Babu S, Rathore SS, Singh RK, Shekhawat K, Rangot M, Kumar P, Yadav D, Singh DP, Dasgupta D, Shukla G. Conjoint application of nano-urea with conventional fertilizers: An energy efficient and environmentally robust approach for sustainable crop production. *PLOS ONE*. 2023;18(7):e0284009.
46. El-Beltagi HS, Basit A, Mohamed HI, Ali I, Ullah S, Kamel EAR, Shalaby TA, Ramadan KMA, Alkhateeb AA, Ghazzawy HS. Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy*. 2022;12(8):1881.
47. Aravind K, Vadivel N, Kumar GS, Ravichandran V, Bharathi C. Performance of foxtail millet based intercropping system for improving the productivity, sustainability and economics in Western Zone of Tamil Nadu under irrigated conditions. *International Journal of Plant & Soil Science*. 2023;35(19):1824–1829.
48. Gireesh S, Dinesh GK, Adityan S, Abinaya S, Aravindharajan STM, Anokhe A, Venkatramanan V, Manu SM, Shahidha PA, Geetha IR, Surendhar P. Assessing India's millet promotion policies: Schemes and initiatives of the Government of India to promote millets for food and nutritional security through a systematic approach. *Agrivita Journal of Agricultural Science*. 2025;47(3).
49. Sangappa S, Rafi D, Laxmi B, Charishma E, Babu KS. Strengthening millet value chain through farmer producer organizations. *Indian Journal of Extension Education*. 2023;59(3):26–31.
50. Opole R. Opportunities for enhancing production, utilization and marketing of finger millet in Africa. *African Journal of Food, Agriculture, Nutrition and Development*. 2019;19(1):13863–13882.

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