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Millets for next-generation climate-smart agriculture

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Abstract
Millets have regained importance in climate-smart agriculture because they combine stress tolerance, modest input requirements, and high nutritional quality. Compared with water-intensive cereals, these small-grained crops perform more reliably under drought, heat, and low-fertility conditions, especially in rainfed and marginal environments. This review synthesizes recent literature published during 2022–2026 to assess the contribution of millets to resource-use efficiency, soil health, diversified farming systems, ecosystem services, and nutritional security. Current evidence shows that millet-based systems can reduce production risk, support crop diversification, and strengthen resilience in semi-arid regions while also contributing useful amounts of dietary fibre, minerals, and other nutrients. At the same time, limited seed systems, weak value chains, inadequate processing infrastructure, and lower market visibility continue to constrain wider adoption. The review concludes that millets can serve as central crops in next-generation climate-smart agriculture when agronomic improvement, breeding, policy support, and market development are addressed together.

Keywords: Climate-smart agriculture, millets, dryland farming, nutritional security, sustainable agriculture

Introduction

Climate change is reshaping agricultural production through erratic rainfall, rising temperatures, more frequent droughts, and growing pressure on land and water resources. Production systems that depend heavily on a small number of high-input cereals face increasing instability, particularly in rainfed areas and on marginal lands.

Climate-smart agriculture seeks to improve productivity, strengthen resilience and adaptation, and reduce environmental pressure. Within this framework, millets have re-emerged as strategically important crops because they can withstand harsh growing conditions while contributing to household nutrition and farming-system diversity.

Millets include pearl millet, finger millet, foxtail millet, little millet, barnyard millet, kodo millet, and proso millet. These crops are adapted to semi-arid and sub-humid ecologies and are commonly grown under low-input conditions. Their ability to tolerate moisture stress, heat, and relatively poor soils makes them attractive alternatives where rice or wheat are less dependable.

Recent literature also highlights the broader relevance of millets to sustainable food systems. They are associated with lower external input demand, useful nutritional density, and better fit within mixed or diversified farming. This review therefore examines recent evidence from 2022–2026 on the role of millets in climate-smart agriculture, with emphasis on resilience, resource-use efficiency, soil health, diversified systems, and mainstreaming constraints.

Materials and Methods

This article is based on a structured narrative review of literature published between 2022 and 2026. Relevant studies were identified from peer-reviewed journals and institutional sources using databases such as Google Scholar, Web of Science, Scopus, and AGRICOLA. Search combinations included terms related to millets, climate-smart agriculture, drought resilience, sustainable intensification, soil health, agroforestry, food security, and nutritional security.

Peer-reviewed articles, institutional technical reports, and well-documented review papers were retained when they directly addressed agronomic, ecological, nutritional, or value-chain dimensions of millets. Sources with limited relevance, unclear bibliographic detail, or weak methodological grounding were not used in the final synthesis. Evidence was organized under thematic headings covering climate resilience, water and input efficiency, soil and ecosystem functions, nutrition, and adoption constraints.

Results and Discussion

Millets as resilient cereals for climate adaptation

Recent studies consistently identify millets as climate-resilient cereals because of rapid establishment, deeper or efficient rooting, tolerance to intermittent moisture stress, and capacity to perform under high temperatures. FAO materials released during and after the International Year of Millets emphasize that millets can be grown with relatively little water and can still produce grain where other major cereals fail under severe weather stress.

This resilience is especially important in dryland agriculture, where production variability directly affects household food security. However, resilience should not be interpreted as immunity to all constraints; varietal choice, sowing time, and local management remain important determinants of field performance.

Water saving, short duration and lower external-input demand

One of the clearest climate-smart advantages of millets is their comparatively low water requirement. Indicative agronomic ranges suggest that millets often perform within roughly 250–500 mm of water, compared with about 450–

650 mm for wheat and 1200–1500 mm for rice. Their crop duration is also generally shorter, often around 70–100 days, which reduces exposure to terminal drought and other late-season climatic risks.

Millet cultivation is also commonly associated with lower fertilizer and pesticide requirements than highly intensified cereal systems. This combination can reduce production costs, improve suitability for smallholders, and lessen environmental burdens linked with input-intensive farming.

Soil health, biodiversity and diversified farming systems

Millets support climate-smart agriculture not only as individual crops but also as components of diversified systems. Literature on millet-based intercropping, mixed farming, and agroforestry indicates potential benefits for land-use efficiency, ground cover, and farm-level resilience. Studies further suggest improvements in soil organic carbon, moisture conservation, and nutrient cycling where millets are integrated into broader resource-conserving systems.

Because millets fit well in dryland and marginal environments, they can also help sustain agro-biodiversity and reduce overdependence on a narrow cereal base. This diversification function is an important ecological service under increasingly unstable climatic conditions.

Nutrition, livelihoods and future food systems

Millets are relevant to climate-smart agriculture because resilience at field level must also translate into resilience in diets and livelihoods. Several millet species provide more dietary fibre and, in some cases, much higher calcium or iron contents than polished rice. Finger millet is particularly noted for its calcium content, whereas pearl millet contributes useful levels of iron and protein.

Their nutritional value strengthens the case for linking millet promotion with food and nutrition security programmes, especially in regions where climate shocks and micronutrient deficiencies overlap.

Constraints and priorities for mainstreaming millets

Despite strong ecological and nutritional advantages, millets remain underutilized in many regions. Weak seed systems, insufficient processing facilities, poor branding, lower consumer familiarity in urban markets, and policy bias toward major cereals continue to restrict their expansion.

A central challenge is the perceived trade-off between resilience and yield potential under favorable, high-input conditions. Future efforts therefore need to combine breeding for yield and stress tolerance with better processing, public procurement support, extension, and market development so that climate resilience is matched by economic attractiveness.

A comparative overview of the nutritional composition of selected millets and major cereals is presented in Table 1.

Table 1: Comparative nutritional composition of selected millets and major cereals.

Crop	Protein (%)	Calcium (mg/100 g)	Iron (mg/100 g)	Dietary fibre (%)
Finger millet	7.3	344	3.9	11.5
Pearl millet	10.6	42	8.0	8.5
Foxtail millet	12.3	31	2.8	8.0
Rice	6.8	10	0.7	0.2
Wheat	11.8	30	3.5	1.2

Figure 1 illustrates the strong contrast in water requirement among millets, wheat and rice. The shorter duration of millets, shown in the x-axis labels, further highlights their suitability for climate-risk-prone environments.

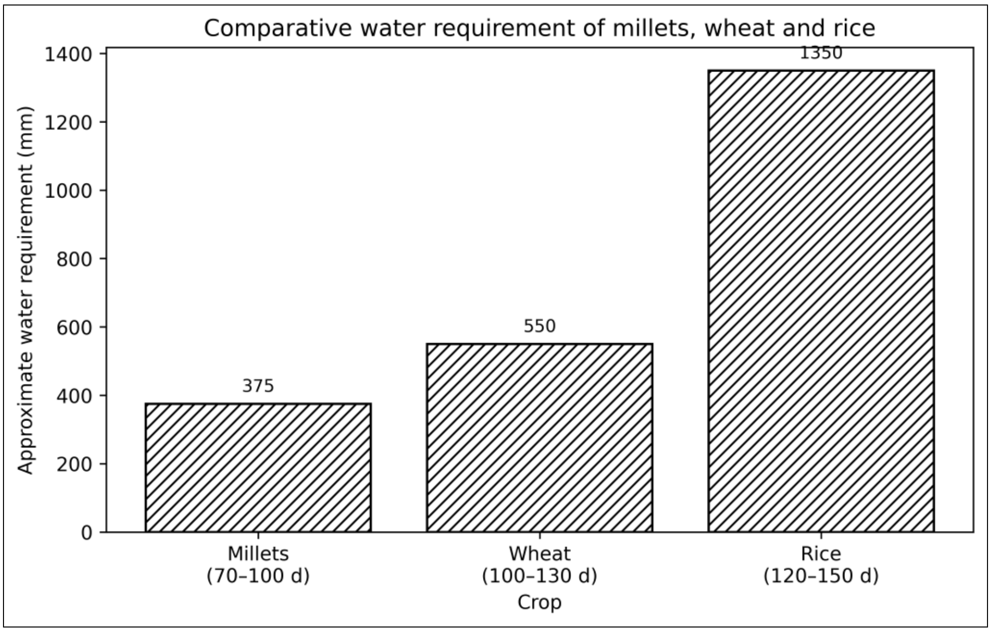

Fig 1: Black-and-white comparison of approximate water requirement of millets, wheat and rice; crop duration is indicated in the category labels.

Key agronomic differences among millets, wheat and rice under contrasting production conditions are summarized in Table 2.

Table 2: Indicative comparison of key agronomic traits of millets, wheat and rice.

Trait	Millets	Wheat	Rice
Approximate water requirement (mm)	250–500	450–650	1200–1500
Approximate crop duration (days)	70–100	100–130	120–150
Performance under moisture stress	High	Moderate	Low to moderate
Fertilizer and pesticide demand	Low	Moderate	High
Suitability for marginal/rainfed lands	High	Moderate	Low

Conclusion

Millets are well suited to next-generation climate-smart agriculture because they combine stress tolerance, modest input demand, and substantial nutritional value. Their inclusion in diversified farming systems can improve resource-use efficiency, strengthen resilience in rainfed areas, and support food and nutritional security. At the same time, broader adoption depends on better seed delivery, improved processing and value chains, stronger policy support, and continued breeding for both productivity and resilience. With coordinated agronomic, institutional, and market interventions, millets can move from being underused crops to becoming core components of climate-resilient food systems.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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