

REVIEW PAPER

Cultivation of Nutrient-Dense and Climate-Resilient Small Millets for Achieving Sustainable Development Goals

Sagar Maitra¹, Masina Sairam¹, Shaik Rishitha¹, Harun I. Gitari², Dinkar J. Gaikwad², Santosh D.T.³, Satya Prasad Nanda¹, N. Swathi¹ and Sumit Ray^{1*}

¹M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha, India

²Department of Agricultural Science and Technology, Kenyatta University, Nairobi, Kenya

³Research Centre of Excellence for Smart Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha, India

*Corresponding author: sumit.ray@cutm.ac.in (ORCID ID: 0000-0003-3405-1087)

Received: 20-03-2026

Revised: 27-05-2026

Accepted: 07-06-2026

ABSTRACT

Present agriculture suffers from several constraints, including declining and polluting natural resources, increasing input demands, climatic vagaries, and abiotic and biotic stresses. In this situation, raising a healthy crop is difficult, particularly for major cereals. Cereals are major sources of caloric energy for human beings, who suffer because of these problems. These consequences call for ecologically and nutritionally sound crops. Small millets have the qualities to confront this situation. They earlier remained the principal cereals for small and marginal farmers. Their cultural heritage made them an inevitable part of rural livelihood in several African and Asian countries. Small millets are nutrient-rich minor cereals that can be grown on resource-constrained marginal lands with low inputs under diversified cropping and farming systems. Moreover, their alignment with some Sustainable Development Goals highlights their importance for food and nutritional security. This article investigated the potential of some important small millets as nutrient-rich, agroecologically sound crops suitable for several cropping systems.

HIGHLIGHTS

- ① Small millets can be successfully grown in resource-constrained, diversified cropping and farming systems.
- ① Small millets are nutritionally rich and can help alleviate hidden hunger;
- ① Their agroecological significance has made small millets climate-resilient crops under the current climate change scenario.
- ① Small millet cultivation is potentially aligned with achieving the Sustainable Development Goals.

Keywords: Small millets, nutritional quality, functional food, cropping system, intercropping, SDG

Contemporary agriculture faces significant challenges due to population growth, land degradation, persistent nutritional deficits, and evolving dietary patterns, all of which strain current food systems (Santosh *et al.* 2024; Zaman *et al.* 2017; Nungula *et al.* 2023). Recent projections indicate that the global population will surpass 9 billion by 2050, necessitating a substantial increase in food production to satisfy future demand

(Habib *et al.* 2025). Existing food systems struggle to provide adequate, healthy, and sustainable food and nutritional security (Ray *et al.* 2025a, b). Additionally, the impacts of climate change (CC)

How to cite this article: Maitra, S., Sairam, M., Rishitha, S., Gitari, H.I., Gaikwad, D.J., Santosh, D.T., Nanda, S.P., Swathi, N. and Ray, S. (2026). Cultivation of Nutrient-Dense and Climate-Resilient Small Millets for Achieving Sustainable Development Goals. *Int. J. Bioresource Sci.*, 13(01): 115-127.

Source of Support: None; **Conflict of Interest:** None



further complicate efforts to achieve universal food and nutritional security. The Green Revolution era was marked by a heavy dependence on a limited genetic base, primarily wheat, rice, and maize. While the Green Revolution achieved notable productivity gains, it also reduced agrobiodiversity, depleted groundwater reserves, and increased the vulnerability of farming systems to environmental shocks (Das *et al.* 2021; Hossain *et al.* 2022). High-input, intensive cultivation practices have contributed to soil degradation, water resource depletion, and declining factor productivity (Maitra and Ray, 2019). Micronutrient deficiency, often referred to as “hidden hunger,” represents a significant public health challenge, disproportionately affecting populations in low- and middle-income countries (Ray *et al.* 2024; Maitra *et al.* 2023). A considerable portion of the global population continues to experience malnutrition, micronutrient deficiencies, and hidden hunger, especially in developing countries where cereal-based diets predominate (Hossain *et al.* 2021; Rishitha *et al.* 2025).

Crop diversification and encouraging the use of nutrient-rich millets are important steps toward sustainable food and nutrition security (Mohanty *et al.* 2020; Maitra *et al.* 2026a, b). In 2023, the International Year of Millets brought more attention

to how millets support sustainable farming and healthy diets (Sahoo and Mahapatra, 2023; Mukherjee *et al.* 2025). Sorghum and pearl millet, known as major millets, are grown widely and have been studied the most (Lalichetti *et al.* 2021; Das *et al.* 2025). On the other hand, small millets have not received as much focus from farmers or researchers. Still, small millets like finger millet, foxtail millet, kodo millet, little millet, proso millet, barnyard millet, and browntop millet are mainly grown in Africa and Asia to meet local needs (Maitra *et al.* 2001, 2025b; Reddy *et al.* 2026). These small millets offer important farming and nutritional benefits that can help solve current food security and sustainability challenges (Fig. 1).

Nutritionally small millets surpass major cereals in dietary fiber, calcium, iron, zinc, polyphenolic antioxidants, and flavonoids. Their low glycemic index (GI) designates them as functional foods relevant for managing the increasing global prevalence of metabolic disorders (Nanda *et al.* 2010; Banerjee and Maitra, 2020). Cultivated for centuries in dryland and semi-arid regions, these crops exhibit adaptive traits including drought tolerance, efficient water-use physiology, and the ability to yield consistently in low-fertility soils with minimal external inputs (Maitra *et al.* 2026c). Agronomically, their short growing cycles,

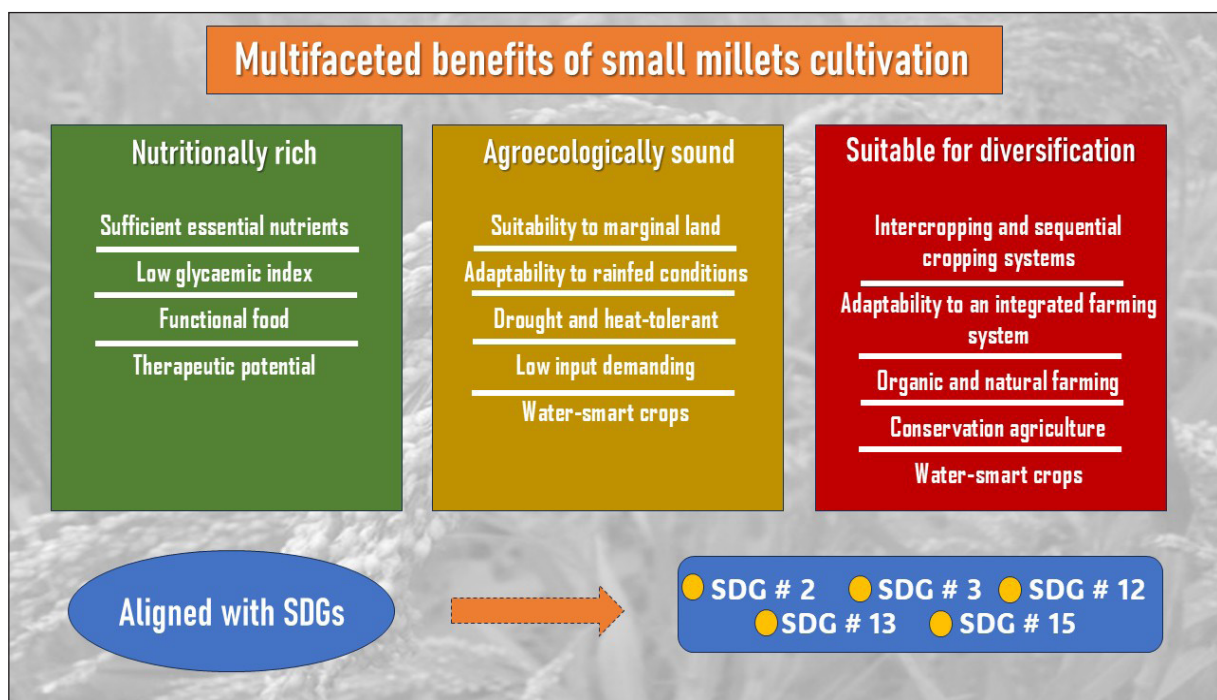


Fig. 1: Versatile significance of small millets cultivation



compatibility with intercropping systems, and low carbon footprint render them strategically important for climate-smart agriculture (Sairam *et al.* 2025a, b). Small millets are particularly suitable for rainfed and resource-constrained farming systems. Their efficient water use, drought tolerance, and capacity to perform under poor soil conditions enhance their value under CC scenarios (Mohanty *et al.* 2016; Maheswari *et al.* 2025; Nori *et al.* 2025). Furthermore, small millets contribute to the livelihoods of tribal and smallholder farmers by providing food, fodder and income security.

This review comprehensively examines the role of small millets in sustainable agriculture and future food systems. Synthesizing current scientific evidence, it provides insights into the potential of small millets as future crops capable of addressing the interconnected challenges of food and nutritional security in the context of CC.

Important Small Millets

Small millets have a heritage of cultivation in African and Asian countries from the prehistoric period (Maitra *et al.* 1998; Mukesh *et al.* 2024). Small millets were domesticated independently across multiple regions around the world such as finger millets in Ethiopian highlands before spreading to Indian subcontinents, foxtail and proso millet in northern China before moving into Asia and Europe, and little, *kodo* and barnyard millet within Indian subcontinent. The adaptability, to various environment has made the way to Europe and America. India is one of the world's largest producer and consumer of millets, cultivated especially in semi-arid, hilly and tribal area where major cereals struggle to thrive (Brahmachari *et al.* 2019; Maitra *et al.* 2020). Among various millets, finger millet (ragi) is one of the economical and widely grown millet around Asia and valued for its calcium, dietary fiber, protein and mineral content. Further the drought tolerance and performance in low-fertile, rainfed system adds up to the adaptation of ragi by the farmers (Maitra, 2020a). Foxtail millet is also among of the oldest domesticated, early-maturing, water-efficient and drought-resistant species with high protein and micronutrient content. Other than foxtail millet, barnyard millet also have low glycemic index, high iron and fiber content which made it popular among diabetic and health-

conscious consumers (Maitra, 2020b). Another such millet is little millet which can not only grow under poor farming conditions, marginal lands, and minimal inputs but also is rich in fibre, iron and antioxidant while supporting food security in drought-prone areas. The tolerance to drought and poor soil while offering a high dietary fibre and antioxidant polyphenols in its grain makes *kodo* millet unique (Maitra *et al.* 2022a, b). Similarly, proso millet is also among the primitive cultivated cereals across Asia, Europe and North America. The short life-cycle, high water use efficiency, low input tolerance along with enhanced protein, carbohydrate and mineral content makes it widely adaptable by farmers and consumers. Further, a nutrient rich small millet such as brown top millet, is also gaining popularity due to its tolerance to poor-soil and drought (Maitra, 2020a; Maitra *et al.* 2023a).

Nutritional Composition and Health Benefits of Small Millets

The exceptional nutritional quality of small millets, surpasses major cereal in dietary fiber, minerals, vitamins and bioactive compounds which gives small millets a second name as “nutri-cereals” in the modern food system. Small millets generally have high resistance starch and non-starch polysaccharides which slows the digestion and promotes gradual glucose release, supporting less insulin spike and constant energy (Maitra *et al.* 2022 a,b). The protein content ranges between 7 to 14%, with a wide amino acid profile such as methionine, cysteine and lysine. Further, the dietary fiber present in small millets exceeds the content in polished rice and wheat while supporting the gastrointestinal health, satiety and digestion (Banerjee and Maitra, 2020). Further, it also aids in glucose and cholesterol regulations, cardiovascular diseases and gut disorders. Additionally, millets carry moderate lipid content of 2-5% which includes unsaturated fatty acids such as linoleic and oleic acid. Millets such as finger millet are rich in calcium content which is vital for bone and dental health, muscle and nerve function, whereas barnyard and little millets are rich in iron, thiamine, riboflavin, niacin. Folic acid, phenolics, flavonoids and tannins (Maitra *et al.* 2022a, b; Maitra *et al.* 2023a). Other than nutrition, small millets have anti-inflammatory, anti-microbial

and anti-cancer properties. Therefore, small millets are valued not only for nutritional properties but also for therapeutic benefits which improves immune response and metabolic regulations in human being.

Table 1: Nutritional quality of millets per 100 g of edible portion

Crops	Crude fibre (g)	Protein (g)	Fat (g)	Minerals (g)	Carbo-hydrates (g)
Barnyard millet	14.7	11.6	5.8	4.7	74.3
Browntop millet	4.92	9.0	1.9	3.9	71.3
Finger millet	3.6	7.3	1.3	2.7	72.0
Foxtail millet	8.0	12.3	4.3	3.3	60.0
Kodo millet	9.0	8.3	1.4	2.6	65.9
Little millet	8.6	8.7	5.3	1.7	75.7
Proso millet	2.2	12.5	1.1	1.9	70.4

Source: Maitra *et al.* 2023b; Ponnappalli *et al.* 2023.

Combating Malnutrition and Therapeutic Potential

Malnutrition and hidden hunger remain as a pressing concern across developing and underdeveloped countries. The richness of carbohydrates, proteins, dietary fiber, vitamins and minerals along with calcium, iron, zinc content makes small millets valuable for tackling micronutrient deficiencies when incorporated to school feeding programmes, maternal nutrition initiative and community health intervention (Jacob *et al.* 2024). For combating malnutrition, food should cater more than filling the stomach and nutrients which is possible through small millets. Other than nutrition, small millet supports gut health, weigh management and satiety (Banerjee and Maitra, 2020). Further, the low glycaemic index and complex carbohydrate aids diabetes management and metabolic regulation while the antioxidants and bioactive compounds help to reduce the oxidative stress and inflammation. Additionally, along with supporting the immunity and cognitive development, it helps in gut microbiome modulation and prevention of life-style related diseases (Banerjee and Maitra, 2020). With increasing consciousness towards good food, small millets demand is going to increase due to its exceptional nutritional composition and help

promoting properties which strengthens global food and nutritional security.

Agroecological Importance of Small Millets

Small millets have the potential to contribute to sustainable agriculture production in various agroecological conditions. Small millets are inherently more drought and high temperature-stresses tolerant than many high-input cereals and are more likely to be able to achieve stable yields during periods of unfavourable weather conditions (Maitra *et al.* 2022 a). They are valued for their short growth period, use of natural resources, and ability to grow in diversified cropping systems which make an important contribution to more climate-resilient agriculture. They enrich biodiversity and promote sustainable use of resources (Maitra *et al.* 2025a). Their incorporation into cropping systems can help to improve agricultural productivity and decrease environmental impacts, contributing to a more resilient and sustainable food production system (Hossain *et al.* 2022; Mangaraj *et al.* 2025; Priya *et al.* 2025).

Suitable to marginal and rainfed conditions

Small millets are well suited for marginal and rainfed situations where major cereals such as rice, wheat and maize may not grow (Maitra *et al.* 2026a). They can withstand erratic rainfall, poor soil fertility, limited irrigation and degraded soils thanks to their efficient root system, nutrient uptake and resistance to stress. These are well adapted to dry and semi-dry areas and are capable of growth on acidic, shallow and poor soils. Accordingly, small millets are a reliable food source for rural and tribal communities, contribute to food security and foster the productive use of marginalized agricultural lands (Kumar *et al.* 2021).

Drought and heat stress tolerant crops

Drought and heat stress are key climate-induced challenges for global agriculture. Small millets have natural stress resistance because of their extensive root systems, efficient water use, stomatal regulation and osmotic adjustment mechanisms. These characteristics help them to grow and produce well in dry environments (Choudhary *et al.* 2023). They also withstand heat at critical growth phases and minimise yield losses and stable production.



Hence, small millets are important crops for climate-resilient agriculture and sustainable farming in vulnerable situations.

Low input demanding

Small millets are low input crops that yield good crop whenever fertilizers, pesticides and water are not much used. They can be cultivated in less fertile soil types, and are tolerant to many pests and diseases, which lowers costs and reliance on agrochemicals. This makes them an ideal choice for small-scale farmers in developing countries and contributes to a more sustainable and profitable agriculture.

Water-smart crops

Water scarcity is a growing challenge to agriculture due to increasing population, CC and competing water demands. Small millets are a sustainable option as they are efficient in water use, and require less water than major cereals. They establish quickly, have a short growth period and use water effectively to yield reasonable crops in short of rain. Small millets reduce groundwater usage and strain on freshwater resources due to their lesser irrigation needs. They are drought tolerant and resilient to rainfall fluctuations, making them valuable crops for water smart and climate-resistant agriculture, especially in water limited areas. Further, the integration of drip irrigation or micro-irrigation can enhance the water-use efficiency (Santosh *et al.* 2021).

Small Millets in Diversified Cropping Systems

Small millets can be integrated in a variety of cropping and farming systems to improve system productivity, resource-use efficiency and ecological sustainability. They are versatile and can be grown with a range of crops and farming enterprises, enabling farmers to maximize the use of their land and reduce the risk of crop losses.

Intercropping system

Intercropping is commonly adopted in small-millet based cropping systems particularly by the smallholders (Panda *et al.* 2022; Priya *et al.* 2025). The small millets are sometimes cultivated with pulses, oilseeds and other cereals for better resource

utilization and productivity. Legume intercrops lend biological nitrogen fixation to boost soil fertility and intercropping contributes to biodiversity and risk reduction due to pests, diseases and climatic risks (Maitra, 2020b; Sudharani *et al.* 2018).

Sequential cropping system

Crop diversification is being viewed as a major way to increase the sustainability and resilience of agriculture (Gouda *et al.* 2024). The ability of small millets to accommodate with a variety of agroecological situations and low input requirement coupled with their relatively short duration in the soil makes them to play an important role in sequential cropping system (Palai *et al.* 2026). They mature early and make it possible to plant subsequent crops at an early stage, which helps to ensure that cropping intensity and land use efficiency are maximized. Small millets can be intercropped with pulses, oilseeds and vegetables, thereby providing alternative crop rotations that are sustainable. Cultivation of these crops helps to use up the residual soil moisture efficiently and also minimises the chances of crop failure in rain-fed areas. Sequential cropping of small millets contributes to a healthy farm, better farm productivity and increased income stability and resilience of farming systems.

Integrated farming systems

Integrated farming systems are designed to maximize the synergies between the various enterprises of the farm, including crops, livestock, fisheries and other enterprises, with the objective of increasing productivity and sustainability. The multifunctional nature of small millets makes them compatible to these systems. They are a source of nutritious grain for human consumption, and of fodder for livestock and crop residues for composting and mulching. Small millets are also integrated in farming systems which help in nutrient recycling, increasing farm profits and resilience to climatic and economic shocks (Kumar *et al.* 2024). They are short term and flexible, which helps plan crops and can integrate into a range of agricultural enterprises.

Organic and natural farming

With the rise in demand for food products which

are made without the use of chemicals, an interest in organic and natural farming systems has risen. Small millets are especially well adapted for these kinds of systems, as they have low nutrient needs and are naturally tolerant of environmental stresses. They can be cultivated in a sustainable manner with farmyard manure, compost, green manures and biofertilizers without any substantial reduction in yields. For millets, low-impact, organic production systems may also have a lower environmental footprint, but yield acceptable amounts. Organically grown millet grains often fetch high market prices which enhances farm income. Small millets are also known to be suitable for eco-agriculture and regenerative farming methods, offering potential benefits for sustainable agriculture efforts.

Conservation agriculture

The core principles of conservation agriculture are minimum soil disturbance, permanent soil cover and diversified crop rotations to enhance long-term agricultural sustainability. The principles are well suited to small millets, which have proven to be an adaptable and resource-efficient crop in the field. Conservation agriculture systems based on millets help to save soil moisture and decrease soil erosion thus increasing soil organic matter sequestration. The residues can also be left on the soil surface to act as protection, improving soil health and water holding capacity (Krishna *et al.* 2024). There is also a benefit of using small millets as part of crop rotations to work on the reduction of

pest and disease cycles as well as system diversity. Small millets are a good option for sustainable intensification, especially in fragile and resource-poor agroecosystems, and their integration into conservation agriculture practices is a promising approach. With the increasing concerns over soil degradation, climate variability, and resource scarcity, the use of small millet-based conservation systems is expected to be an important component in agricultural development in the future.

Contribution to Sustainable Development Goals

In 2015, the United Nations adopted 17 Sustainable Development Goals (SDGs) which are a collective call to action to eradicate poverty, safeguard the planet and secure prosperity for everyone by 2030 (Fig.2). Agricultural systems are perfectly situated in the centre of this agenda that can help address the hunger and poor nutrition challenge, environmental issues and CC. (Maity *et al.* 2025; Sairam *et al.* 2026). Small millets with their high nutritional value, great agroecological adaptability, low environmental impact and strong cultural linkages in traditional food chains in Asia and Africa are associated with several SDGs in a specific, measurable, actionable manner. The analysis of the specific contributions of these small millets to the SDGs of relevance presented here are: SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 15 (Life on Land) (Fig. 2).

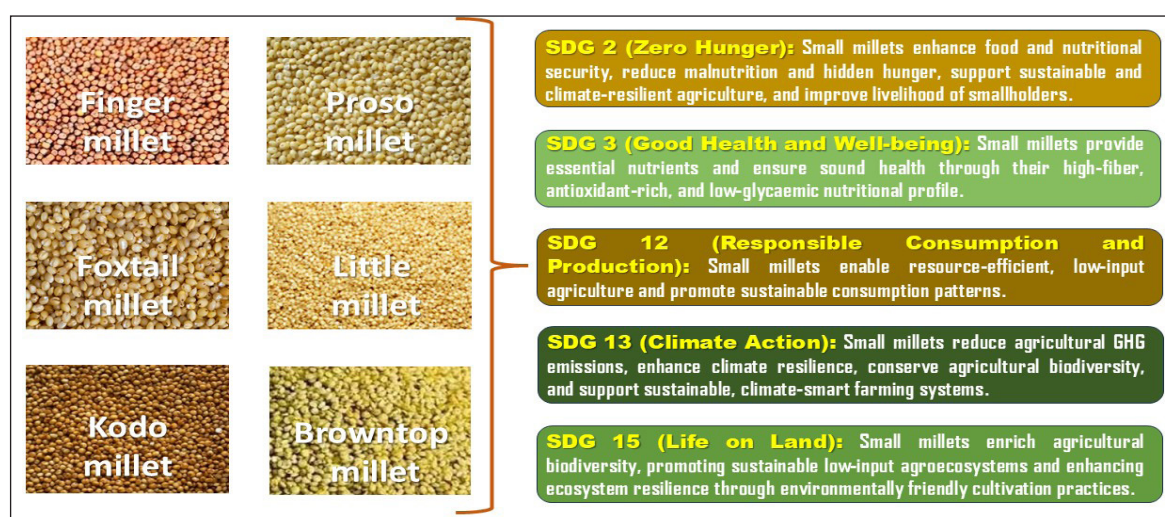


Fig. 2: Alignment of small millets with Sustainable Development Goals



SDG 2: Zero hunger

Food insecurity and hunger are one of the most pressing development issues of today's world. According to UN in 2024, nearly 8.2% of the world's population were experiencing hunger, while approximately 2.33 billion individuals in 2023 suffered from moderate to severe food insecurity (Wiemers *et al.* 2024). Two billion people still don't have regular access to safe, nutritious, and adequate food. 23.23% of children in the country were undernourished and 6.6 per cent were wasted among children under five. Development and promotion of small millets are important for attaining SDG 2 – promoting sustainable agriculture, improving food security and nutrition, and ending hunger. They help to meet key targets including food security on an all-year round basis, malnutrition reduction, improved productivity and incomes of smallholders and sustainable food production systems. The small millets can withstand irregular rainfall, poor soils and limited irrigation and are therefore considered to be reliable food security crops for vulnerable farming communities. Small millets not only promote food self-sufficiency; they also increase food accessibility by being part of public food programmes like India's Public Distribution System and Mid-Day Meal Scheme.

Their outstanding nutritional value contributes to the solution of micronutrient deficiencies and hidden hunger. It has been observed that finger millet contains 300-380 mg Ca/100 g which is far better than polished rice (10 mg) and wheat (34 mg). Likewise, barnyard millet and little millet contain 15-18 mg iron per 100 g in comparison to 0.5-2.0 mg in polished rice, which makes them a good source for combating iron-deficiency anaemia. Small millets are also a good source of zinc, niacin, riboflavin and folic acid that are essential for immunity, growth, energy metabolism and neural development. From an agricultural perspective, they represent crops that need less external inputs, are drought tolerant, heat stress resistant and are compatible with traditional seed saving practices, making them more profitable and cost-effective for the farmers (Reddy *et al.* 2026). Their adoption into intercropping, crop rotation and livestock systems improves the productivity of these systems per unit area, contributing to the overall livelihood and resilience of smallholder and family farmers globally.

SDG 3: Good health and well-being

Small millets can contribute significantly to SDG 3 (Good Health and Well-being) as a source of nutrition and as a means to prevent and mitigate chronic diseases. Although there have been improvements in global health, access to nutritious foods is still disproportionately low, especially in low-income areas in South Asia and sub-Saharan Africa. The nutritional value of small millets complements the public health and nutrition initiatives, particularly for the vulnerable sections of the population. Calcium, iron, zinc, folic acid and protein requirements are greater in pregnant and lactating women, infants, and young children. Cereal-based diets are often deficient in these nutrients while small millets are a good source of these nutrients. Finger millet contains a higher amount of calcium, which is vital for fetal skeletal development, maternal bone health and healthy child growth. Calcium is important for building bones and will help maintain bone health in mothers and prevent rickets in children, particularly in low dairy consumption regions. Barnyard millet and little millet are good sources of iron and will help prevent iron-deficiency anaemia, one of the common causes of maternal health problems, low birth weight and poor child development. They are also a good source of folic acid, a B vitamin that plays a vital role in the development of a baby's neural tube during early pregnancy. Thus, millet foods are suitable for maternal and child nutrition programmes.

Small millets are also helping to reduce and control non-communicable diseases (NCDs) such as diabetes, cardiovascular diseases, hypertension, obesity and some cancers. They have low to moderate glycaemic index, which helps maintain blood sugar levels, enhance insulin sensitivity and decrease diabetes risk. Millet consumers have been found to have improved level of blood glucose, fasting and post-prandial blood glucose, and HbA1c. In addition, they are rich in dietary fiber (8-12%), have beneficial unsaturated fatty acids, polyphenols with antioxidant activities that help keep the heart healthy, reduce cholesterol levels, improve digestive function, maintain the balance of the gut microbiota and decrease the risk of metabolic disorders. The small millets are a

good dietary option to enhance global health and nutrition due to the above attributes.

SDG 12: Responsible consumption and production

Small millets play a vital role in SDG 12 by encouraging sustainable consumption practices, minimizing waste, and fostering efficient resource utilization. The world's population continues to expand and food demand is also on the rise, putting pressure on natural resources. From this point of view, small millets are an extremely sustainable crop alternative to conventional cereals. They are one of the biggest advantages because of their efficiency in using resources. Small millets have significantly lower requirements for water, fertilizer and pesticides. Irrigated rice and wheat require about 1200–2000 litres of water per kg of grain whereas small millets require 300–500 litres of water and are mostly rainfed. Their low use of synthetic fertilizers also cuts down on the energy use and greenhouse gas emissions in the manufacturing of synthetic fertilizers. When grown in association with legumes, small millets can be cultivated with low input requirements, thus maximizing existing soil fertility, organic manures and biological nitrogen fixation. Moreover, small millets are naturally resistant to several pests and diseases, thereby also reducing the need for chemical pesticides and reducing contamination and health risks to the environment. They have hard husks around their grains that make them less vulnerable to post harvest pests, leading to less loss and better storability, especially in smallholder farming systems without modern grain storage.

By-products like bran, husk and broken grains can be processed to yield high fibre flours and dietary fibre concentrates, promoting circular economy and minimizing waste. Small millets have a better nutrient profile from the consumption point of view as they are rich in minerals, vitamins, dietary fibre and bioactive compounds when compared to many refined cereals. Millet foods like breakfast cereals, health bars, drinks and multi-grain flours are becoming popular, as are healthy and sustainable diets. In this regard, small millets can contribute to resilient food systems and SDG 12 by promoting resource efficient agriculture, waste reduction and sustainable consumption.

SDG 13: Climate action

Climate change is one of the great challenges of our time and a central concern of SDG 13 (Climate Action). Global warming, higher levels of greenhouse gas (GHG) emissions and more often extreme weather events are a risk to food security, livelihoods and ecosystems around the world. Climate resilience building needs to involve not only adaptation strategies to help adapt to shifting climatic conditions, but also mitigation strategies to help lower emissions. In this context, small millets provide a sustainable means to achieve both of these goals. Agriculture makes a significant contribution to global GHG emissions from flooded rice fields, soils fertilized with N_2O and livestock related emissions (Pradhan *et al.* 2026). Carbon footprint of small millets is comparatively low since generally they are grown under rain fed and aerobic conditions with negligible methane production. Where suitable, and in some areas, it is possible to partially or fully replace irrigated rice with small millets, thereby reducing agricultural methane emissions. Small millets use less of synthetic fertilizers, which helps to reduce nitrous oxide emission and the energy consumption needed for their manufacturing and application. They also have a high C:N ratio and are suitable for the application of organic manures, crop residues and legumes intercropping which further improves environmental sustainability.

In addition to mitigation, small millets have tremendous potential to be utilized for adaptation to climate change. Their deep root system, short growth period and adaptations for drought and heat and poor soils make them excellent candidates for semi-arid and dryland areas. They are able to withstand climatic stresses and produce food, thereby stabilizing food production and minimizing the likelihood of crop failure. The farming systems with small millets are less vulnerable to shocks than monoculture systems, thus enhancing food security and rural livelihoods. Small millets also contribute to the conservation of agricultural biodiversity by maintaining the diversity of landraces which are valuable sources of genetic diversity for future crop improvement. Small millets play a significant role in the achievement of SDG 13 through reduction in emissions, increased resilience, conservation of biodiversity, and sustainable livelihoods.



SDG 15: Life on land

SDG 15 seeks to protect terrestrial ecosystems, combat land degradation, and conserve biodiversity. Small millets contribute to these objectives through biodiversity-friendly cultivation practices, adaptation to marginal environments, and support for sustainable agroecosystems. One of the primary contributions of small millets is the conservation of agricultural biodiversity. Farmers in Asia and Africa have preserved numerous millet landraces over centuries, resulting in substantial genetic diversity. For example, finger millet includes thousands of locally adapted varieties that differ in maturity, stress tolerance, yield potential, and nutritional quality. The ongoing cultivation of these traditional varieties through community seed systems, participatory breeding, and on-farm conservation preserves valuable genetic resources and enables crops to adapt to local environmental conditions. This dynamic conservation approach enhances agricultural resilience and supports broader biodiversity conservation efforts.

Small millets also contribute to addressing land degradation, which poses a significant threat to global ecosystems. These crops perform well on marginal and degraded lands where many other species are unsuccessful, providing stable yields even under poor soil and moisture conditions. Their extensive root systems and rapid canopy development improve soil structure, increase organic matter, reduce runoff, and protect against erosion. These attributes are especially beneficial in upland and hilly regions that are susceptible to soil loss. Continuous cultivation of small millets enhances soil biological activity and supports long-term land restoration, thereby advancing the objectives of Land Degradation Neutrality and ecosystem rehabilitation. Small millet-based cropping and farming systems further promote biodiversity by employing low-input cultivation, intercropping, mixed cropping, and maintaining diverse vegetation. These systems create habitats for beneficial soil organisms, pollinators, birds, and natural pest enemies, thereby enhancing ecological balance. Since small millets require fewer external inputs and can be grown on existing farmlands, they reduce the pressure to convert forests, grasslands, and other natural habitats into agricultural land. Through biodiversity conservation, soil restoration,

sustainable land use, and increased ecosystem resilience, small millets play a significant role in achieving SDG 15.

Future Scope of Research

- ♦ The substantial progress has been made in understanding the nutritional, agronomic, ecological, and socioeconomic importance of small millets, however, several research gaps remain that need to be addressed to unlock their full potential in sustainable agriculture and global food systems. Future research should adopt interdisciplinary approaches integrating crop science, nutrition, climate science, biotechnology, economics, and policy analysis with the integration of the Artificial Intelligence and Machine Learning (AI-ML applications) for the development of suitable models for the improved agronomical management targeting Agriculture 4.0 (Ray *et al.* 2025c).
- ♦ One of the foremost priorities is the genetic improvement of small millets through conventional breeding, molecular breeding, genomic selection, and genome-editing approaches. Greater emphasis should be placed on developing high-yielding, climate-resilient, biofortified, and pest- and disease-resistant cultivars while simultaneously conserving the rich genetic diversity of traditional landraces. Comprehensive characterization of millet germplasm using genomic and phenomic tools will facilitate the identification of valuable traits for future crop improvement. So far, among minor millets, finger millet is a more researched crop; however, considering the potential of other millets in terms of nutritional benefits and agroecological soundness, they are to be explored for food and agricultural sustainability.
- ♦ Investigations are required to optimize agronomic management practices across diverse agroecological regions. Long-term experiments should evaluate conservation agriculture, regenerative agriculture, precision nutrient management, integrated nutrient and pest management, water-saving technologies, and climate-smart production systems involving small millets. Research should also quantify their effects on soil health, carbon sequestration,

greenhouse gas emissions, biodiversity conservation, and ecosystem services under varying climatic conditions.

- ♦ Although the nutritional superiority of small millets is well established, additional clinical and epidemiological studies are needed to validate their long-term health benefits. Research should explore the bioavailability of nutrients, gut microbiome interactions, functional food properties, nutraceutical applications, and the role of millet-based diets in preventing non-communicable diseases. Product development studies focusing on ready-to-eat, value-added, gluten-free, and fortified millet foods will further enhance consumer acceptance and market demand.
- ♦ Future studies should also focus on strengthening millet-based cropping systems through diversified intercropping, sequential cropping, integrated farming systems, and organic production models (Das *et al.* 2026). System-level analyses assessing productivity, profitability, resource-use efficiency, resilience, and livelihood impact across different farming environments will provide valuable guidance for sustainable agricultural planning.
- ♦ Socioeconomic and policy-oriented research deserves greater attention. Studies evaluating market development, value-chain efficiency, consumer preferences, post-harvest processing, mechanization, and institutional support mechanisms are essential for expanding millet cultivation and commercialization. Policy analyses examining incentives, public procurement, seed systems, and integration of small millets into food and nutrition security programmes will facilitate evidence-based decision-making.
- ♦ Robust assessment frameworks should be developed to quantify the direct contribution of small millets toward achieving the Sustainable Development Goals, particularly those related to food security, nutrition, stress and climate resilience, responsible production, and biodiversity conservation (Maitra *et al.* 2026c). Such multidisciplinary research will strengthen scientific evidence, guide policy formulation, and accelerate the transition toward resilient,

sustainable, and nutrition-sensitive agricultural systems where small millets play a central role.

CONCLUSION

The preceding sections of this review have assembled a comprehensive, evidence-grounded portrait of small millets as crops of exceptional, multidimensional significance: agronomically resilient, nutritionally superior, ecologically compatible, and socioeconomically relevant across a wide range of farming systems and food security contexts. As global agriculture confronts climate change, population growth, land degradation, persistent malnutrition, and the escalating burden of diet-related non-communicable diseases, the evidence reviewed here makes a compelling and increasingly urgent case for systematically mainstreaming small millets within national and international agricultural, food, nutrition, and environmental policy frameworks. This conclusion synthesizes the principal findings of the review, articulates the strategic importance of small millets for the future of agriculture and food systems, presents specific and actionable recommendations for research, policy, and farmer adoption, and offers closing reflections on their role within the broader transition toward sustainable, equitable, and nutritionally adequate global food systems.

REFERENCES

- Banerjee, P. and Maitra, S. 2020. The role of small millets as functional food to combat malnutrition in developing countries. *Indian J. Nat. Sci.*, **10**: 20412-20417.
- Brahmachari, K., Sarkar, S., Santra, D.K. and Maitra, S. 2019. Millet for food and nutritional security in drought prone and red laterite region of Eastern India. *Int. J. Plant Soil Sci.*, **26**: 1-7.
- Choudhary, P., Shukla, P. and Muthamilarasan, M. 2023. Genetic enhancement of climate-resilient traits in small millets: a review. *Heliyon.*, **9**: e14502.
- Das, S., Maitra, S., Lalichetti, S., Guchhait, D., Masina, S., Ray, S. and Bochalya, R.S. 2026. Optimizing nitrogen application strategies using nano urea for improving growth, yield and nitrogen use efficiency of pearl millet (*Pennisetum glaucum*). *J. Appl. Biol. Biotech.*, **14**(5): 109-114
- Das, S., Maitra, S., Sagar, L., Balaji, M., Pavan, A., Sairam, M. and Bochalya, R.S. 2025. Effect of split nitrogen application on yield attributes and grain yield of pearl millet (*Pennisetum glaucum* L.). *Crop Res.*, **60**: 12-17.
- Das, S., Mitra, B., Saha, A., Mandal, S., Paul, P.K., El-Sharnouby, M., Hassan, M.M., Maitra, S. and Hossain, A.



2021. Evaluation of quality parameters of seven processing type potato (*Solanum tuberosum* L.) cultivars in the Eastern Sub-Himalayan plains. *Foods*, **10**: 1138.
- Gouda, H.S., Singh, Y.V., Shivay, Y.S., Biswas, D.R., Bana, R.S., Poornima, S., Manu, S.M., Maitra, S., Sairam, M., Salmen, S.H. and Alharbi, S.A. 2024. Root parameters and water productivity of rice and wheat in a rice-wheat cropping system as influenced by enriched compost and crop establishment methods. *J. Agric. Food Res.*, **18**: 101317.
- Habib, M., Singh, S., Jan, S., Jan, K. and Bashir, K. 2025. The future of the future foods: understandings from the past towards SDG-2. *NPJ Sci. Food*, **9**: 138.
- Hossain, A., Maitra, S., Garai, S., Mondal, M., Ahmed, A., Islam, M.T. and Nayak, J. 2022. Next-generation climate-resilient agricultural technology in traditional farming for food and nutritional safety in the modern era of climate change. In: *Plant Abiotic Stress Physiology*. Apple Academic Press, pp. 225-291. <https://doi.org/10.1201/9781003180562-8>
- Hossain, A., Pramanick, B., Bhutia, K.L., Ahmad, Z., Moulick, D., Maitra, S., Ahmad, A. and Aftab, T. 2021. Emerging roles of osmoprotectant glycine betaine against salt-induced oxidative stress in plants: a major outlook of maize (*Zea mays* L.). In: Aftab, T. and Hakeem, K.R. (Eds.), *Frontiers in Plant-Soil Interaction*. Academic Press, pp. 567-587. <https://doi.org/10.1016/B978-0-323-90943-3.00015-8>
- Jacob, J., Krishnan, V., Antony, C., Bhavyasri, M., Aruna, C., Mishra, K., Nepolean, T., Satyavathi, C.T. and Visarada, K.B. 2024. The nutrition and therapeutic potential of millets: an updated narrative review. *Front. Nutr.*, **11**: 1346869.
- Krishna, T.G., Maitra, S., Sairam, M., Maheswari, N., Hemasree, K.R. and Ray, S. 2024. Precision nutrient management and plant stand influence the growth and productivity of maize under North Eastern Ghat Region of Odisha, India. *Int. J. Bioresour. Sci.*, **11**: 191-204.
- Kumar, P.S.M., Sairam, M., Praharaj, S. and Maitra, S. 2021. Soil moisture conservation techniques for dry land and rainfed agriculture. *Indian J. Nat. Sci.*, **12**: 37386-37391.
- Kumar, S., Kumar, A., Sen, H., Janeja, H.S., Maity, S., Banerjee, S., Singh, P. and Arun, M.C. 2024. Small millets: A multifunctional crop for achieving sustainable food security under climate change. *World*, **718**: 863.
- Lalichetti, S., Lalichetti, S., Singh, S., Maitra, S. and Keerthipriya, O. 2021. Potential role of weed management on growth and productivity of pearl millet: A review. *Int. J. Agric. Environ. Biotechnol.*, **14**: 169-173. <https://doi.org/10.30954/0974-1712.02.2021.7>
- Maheswari, N., Maitra, S., Sairam, M., Ray, S., Sagar, L., Santosh, D.T. and Gaikwad, D.J. 2025. Impact of real time nitrogen management on the performance of maize cowpea intercropping system. *Crop Res.*, **60**: 139-146.
- Maitra, S. 2020a. Intercropping of small millets for agricultural sustainability in drylands: A review. *Crop Res.*, **55**: 162-171.
- Maitra, S. 2020b. Potential horizon of brown-top millet cultivation in drylands: A review. *Crop Res.*, **55**: 57-63.
- Maitra, S. and Ray, D.P. 2019. Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems: A review. *Int. J. Bioresour. Sci.*, **6**: 11-19.
- Maitra, S., Ghosh, D.C., Sounda, G. and Jana, P.K. 2001. Performance of intercropping legumes in finger millet (*Eleusine coracana*) at varying fertility levels. *Indian J. Agron.*, **46**: 38-44.
- Maitra, S., Ghosh, D.C., Sounda, G., Jana, P.K. and Roy, D.K. 1998. Effect of seed treatment on growth and productivity of finger millet under rainfed lateritic belt of West Bengal. *Indian Agriculturist*, **48**(1): 37-48.
- Maitra, S., Hossain, A., Patro, T.S.S.K., Shankar, T., Brestic, M., Sairam, M., Sarker, U., Adeel, M., Skalicky, M., Ondrisik, P., Vachova, P. and Gitari, H. 2022a. Small millets: The next-generation smart crops in the modern era of climate change. In: Pudake, R.N., Solanke, A.U., Sevanthi, A.M. and Rajendrakumar, P. (Eds.), *Omics of Climate Resilient Small Millets*. Springer, Singapore, pp. 1-31. https://doi.org/10.1007/978-981-19-3907-5_1
- Maitra, S., Patro, T.S.S.K., Reddy, A., Hossain, A., Pramanick, B., Brahmachari, K., Prasad, K., Santosh, D.T., Mandal, M., Shankar, T., Sagar, L., Banerjee, M., Palai, J.B., Praharaj, S. and Sairam, M. 2023a. Brown top millet (*Brachiaria ramosa* L. Stapf; *Panicum ramosum* L.): A neglected and smart crop in fighting against hunger and malnutrition. In: Farooq, M. and Siddique, K.H.M. (Eds.), *Neglected and Underutilized Crops*. Academic Press, pp. 221-246. <https://doi.org/10.1016/B978-0-323-90537-4.00012-0>
- Maitra, S., Pine, S., Banerjee, P., Pramanick, B. and Shankar, T. 2022b. Millets: robust entrants to functional food sector. In: Pirzadah, T.B., Malik, B., Bhat, R.A. and Hakeem, K.R. (Ed.), *Bioresource Technology: Concept, Tools and Experience*. Wiley, pp. 3-27.
- Maitra, S., Ray, S., Pradhan, P., Pattanayak, S., Nanda, S.P., Battaglia, M.L., Sagar, L., Sairam, M., Gitari, H.I., Maity, B. and Santosh, D.T. 2026c. Repercussions of salinity on field crops and achieving Sustainable Development Goals. In: Moulick, D., Sarkar, S. and Brahmachari, K. (Eds.), *Salinity Stress and Remediation in Agro-Ecosystems*. Springer, Cham, pp. 367-414. https://doi.org/10.1007/978-3-032-24001-9_13
- Maitra, S., Ray, S., Sagar, L., Sairam, M., Pramanick, B., Gitari, H. and Chappa, L.R. 2025a. Cropping system approach in climate-resilient food crop production. In: Pramanick, B., Singh, S.V., Maitra, S., Celletti, S. and Hossain, A. (Ed.), *Climate-Smart Agricultural Technologies. Sustainability Sciences in Asia and Africa*. Springer, Singapore, pp. 327-356. https://doi.org/10.1007/978-981-96-7699-6_15
- Maitra, S., Ray, S., Suman, S., Pushpa, K., Divya, B.S., Sairam, M., Sagar, L., Gitari, H.I., Santosh, D.T. and Hossain, A. 2026a. Evaluating the intercropping systems in the context of agroecological resilience in the current era of the changing climate: A scenario of scientific analysis of last decade data. *Clim. Resil. Sustain.*, **5**: e70050.
- Maitra, S., Reddy, M.D. and Nanda, S.P. 2020a. Nutrient management in finger millet (*Eleusine coracana* L. Gaertn) in India. *Int. J. Agric. Environ. Biotechnol.*, **13**: 13-21.

- Maitra, S., Sahoo, U., Sairam, M., Gitari, H.I., Rezaei-Chiyaneh, E., Battaglia, M.L. and Hossain, A. 2023. Cultivating sustainability: A comprehensive review on intercropping in a changing climate. *Res. Crop.*, **24**: 702-715.
- Maitra, S., Sairam, M., Sagar, L., Ray, S., Santosh, D.T., Gaikwad, D.J., Atapattu, A.J. and Gitari, H.I. 2025b. Alley cropping: A sustainable agroforestry system for enhancing productivity, soil health and biodiversity. *In: Plant Biotechnology and Sustainable Agriculture: Bridging the Gap for Global Food Security*. CABI, GB, pp. 235-248. <https://doi.org/10.1079/9781800627659.0016>
- Maitra, S., Santosh, D.T., Jena, J., Behera, S.D., Ray, S., Sairam, M., Palai, J.B., Gaikwad, D.J., Rishitha, S., Gitari, H.I. and Atapattu, A.J. 2026b. Understanding plant responses to abiotic stress through systems biology. *In: Aftab, T. (Ed.), Systems Biology for Crop Improvement: Emerging Tools and Technologies*. Academic Press, pp. 59-100. <https://doi.org/10.1016/B978-0-443-36457-0.00011-0>
- Maitra, S., Shankar, T., Hossain, A., Sairam, M., Sagar, L., Sahoo, U., Gaikwad, D.J., Pramanick, B., Mandal, T.K., Sarkar, S., Gitari, H.I. and Rezaei-Chiyaneh, E. 2023b. Climate-smart millets production in future for food and nutritional security. *In: Mahdi, S.S., Bhat, M.A., Mir, A.A. and Wani, M.A. (Eds.), Adapting to Climate Change in Agriculture: Theories and Practices*. Springer, Cham, Switzerland, pp. 11-41. https://doi.org/10.1007/978-3-031-28142-6_2
- Maity, B., Sairam, M., Ray, S., Maitra, S., Dash, B. and Guchhait, D. 2025. Evaluation of polyhalite as a potassium and sulphur source for improving the growth and productivity of summer groundnut (*Arachis hypogaea* L.). *Crop Res.*, **60**: 357-362.
- Mangaraj, S., Pradhan, S.R., Pattnayak, B.R., Mishra, P., Sethi, D. and Maitra, S. 2025. Climate-smart millet cultivation: A promising option for next-generation agriculture. *In: Pramanick, B., Singh, S.V., Maitra, S., Celletti, S. and Hossain, A. (Eds.), Climate-Smart Agricultural Technologies: Approaches for Field Crops Production Systems*. Springer Nature Singapore, Singapore, pp. 233-245. https://doi.org/10.1007/978-981-96-7699-6_11
- Mohanty, L.K., Roja, M., Maitra, S. and Reddy, M.D. 2020. Chemical weed management in finger millet (*Eleusine coracana* L. Gaertn.). *Agro Economist*, **7**: 47-52.
- Mohanty, S.S., Dash, N., Nanda, S.P. and Dey, R.K. 2016. Synthesis, characterization and removal of heavy metal ions from water bodies using novel hybrid materials based on silica. *IOSR J. Appl. Chem.*, **9**: 2278-5736.
- Mukesh, G., Sairam, M., Maitra, S., Gaikwad, D.J., Sagar, L. and Ray, S. 2024. Agrometeorological indices, physiological growth parameters and performance of finger millet as influenced by different cultivars under hot and sub humid region of Odisha. *Int. J. Exp. Res. Rev.*, **42**: 148-161.
- Mukherjee, B., Jha, R.K., Sattar, A., Dutta, S., Bhattacharya, U., Samanta, S., Huirem, B., Singh, S.K., Das, S. and Bal, S.K. 2025. Harnessing the potential of millets for climate-resilient and sustainable agriculture. *Front. Plant Sci.*, **16**: 1574699.
- Nanda, S.P., Padhy, A.K. and Dey, R.K. 2010. Synthesis of some benzothiazolyl and imidazole derivatives and evaluation of antibacterial activities. *J. Chem. Pharm. Res.*, **2**: 785-792.
- Nori, M., Masina, S., Sagar, M., Sumit, R., Hemasree, K.R., Roman Kumar, M., Dinkar, J.G. and Rajesh Shriram, K. 2025. Influence of precision nitrogen management in Rabi maize and cow pea intercropping system under varied planting proportions in south Odisha. *Crop Res.*, **60**: 139-146.
- Nungula, E.Z., Mugwe, J., Nasar, J., Massawe, B.H., Karuma, A.N., Maitra, S., Seleiman, M.F., Dindaroglu, T., Khan, N. and Gitari, H.I. 2023. Land degradation unmasked as the key constraint in sunflower (*Helianthus annuus*) production: Role of GIS in revitalizing this vital sector. *Cogent Food Agric.*, **9**: 2267863.
- Palai, J.B., Malik, G.C., Maitra, S., Sairam, M., Banerjee, M., Dey, J.K., Ray, S., Alkeridis, L.A., Al Shuraym, L.A., Sayed, S. and Gaber, A. 2026. Seed inoculation with Rhizobium and integrated nutrient management influences the productivity of groundnut and their residual impact on finger millet. *Sci. Rep.* <https://doi.org/10.1038/s41598-026-38775-2>
- Panda, S.K., Sairam, M., Sahoo, U., Shankar, T. and Maitra, S. 2022. Growth, productivity and economics of maize as influenced by maize-legume intercropping system. *Farm. Manage.*, **7**: 61-66.
- Ponnappalli, H., Karkannavar, S.J. and Hemalatha, S. 2023. The nutritional composition of browntop millet. *Pharma Innov. J.*, **12**: 1861-1864.
- Pradhan P, Sairam M, Ray S, Sagar L, Maitra S. 2026. Influence of real time nitrogen management and optimisation of phosphorus and potassium on productivity of grain sorghum in South Odisha. *Plant Sci. Today*. **13**(sp2): 1-7.
- Priya, G.S., Maitra, S., Sairam, M. and Ray, S. 2025. Spatial arrangement in pearl millet-groundnut intercropping system influences productivity, competition and economics. *Int. J. Exp. Res. Rev.*, **47**: 108-119.
- Ray, S., Hemasree, K.R., Maheswari, N., Maity, B., Sairam, M., Santosh, D.T., Sagar, L., Gitari, H.I. and Maitra, S. 2025c. Optical sensing and site-specific nutrient management for sustainable precision agriculture. *Int. J. Bioresour. Sci.*, **12**: 135-146.
- Ray, S., Maitra, S., Sairam, M. and Maity, B. 2025a. Effect of precision nitrogen management and plant stimulants on the growth and yield in a Rabi maize-summer groundnut cropping system. *Crop Res.*, **60**: 299-307.
- Ray, S., Maitra, S., Sairam, M. and Sagar, L. 2025b. Impact of maize-groundnut intercropping system on growth and yield as influenced by phosphorus, potassium and sulphur fertilisation. *Crop Res.*, **60**: 308-316.
- Ray, S., Maitra, S., Sairam, M., Sravya, M., Priyadarshini, A., Shubhadarshi, S. and Padhi, D.P. 2024. An unravelled potential of foliar application of micro and beneficial nutrients in cereals for ensuring food and nutritional security. *Int. J. Exp. Res. Rev.*, **41**: 19-42.



- Reddy, Y.N., Gaikwad, D.J., Sairam, M., Maitra, S., Anuradha, N. and Patro, T.S.S.K. 2026. The role of PEG in inducing osmotic stress by restricting water uptake in foxtail millet [*Setaria italica* (L.) Beauv.]. *Trop. Agric.*, **103**: 32-47.
- Rishitha, S., Santosh, D.T., Ray, S., Gitari, H.I., Sairam, M., Lalichetti, S., Gaikwad, D.J., Nanda, S.P. and Maitra, S. 2025. Resilient fields, profitable yields: The promise of intercropping systems in a changing climate for economic gains. *Int. J. Agric. Sci.*, **12**: 55-67.
- Sahoo, J.P. and Mahapatra, M. 2023. International year of millets - 2023: Revitalisation of millets towards a sustainable nutritional security. *Technol. Agron.*, **3**: 10.
- Sairam, M., Maitra, S., Ray, S., Pradhan, P. and Maity, B. 2025a. Evaluating nutrient uptake and efficiency in maize through precision nutrient management strategies. *Int. J. Exp. Res. Rev.*, **48**: 92-102.
- Sairam, M., Maitra, S., Sagar, L., Biswas, T., Bárek, V., Brestic, M. and Hossain, A. 2025b. Application of precision nutrient tools for the optimization of fertilizer requirements and assessment of the growth and productivity of maize (*Zea mays* L.) in the northeastern Ghat of India. *J. Agric. Food Res.*, **21**: 101958.
- Sairam, M., Rishitha, S., Padhi, D.P., Ray, S., Nanda, S.P., Santosh, D.T. and Maitra, S. 2026. Impact of growing media on the growth, productivity and quality of gerbera (*Gerbera jamesonii* L.) cultivars. *Res. Crop.*, **27**: 294-300.
- Santosh, D.T., Debnath, S., Maitra, S., Sairam, M., Sagar, L., Hossain, A. and Moulick, D. 2024a. Alleviation of climate catastrophe in agriculture through adoption of climate smart technologies. In: Chatterjee, U., Shaw, R., Kumar, S., Raj, A.D. and Das, S. (Ed.), *Climate Crisis: Adaptive Approaches and Sustainability*. Springer Nature, Switzerland, pp. 307-332. https://doi.org/10.1007/978-3-031-44397-8_17
- Santosh, D.T., Tiwari, K.N. and Maitra, S. 2021. Influence of drip irrigation and plastic mulch on young cashew (*Anacardium occidentale* L.). *Int. J. Bioresour. Sci.*, **8**: 87-92.
- Sudharani, Y., Mohapatra, P.P., Pramanik, K. and Maitra, S. 2018. Effect of different phosphorus levels on growth and yield of cowpea (*Vigna unguiculata* L.) genotypes. *Int. J. Manage. Technol. Eng.*, **8**: 2876-2881.
- Wiemers, M., Bachmeier, M., Hanano, A., Chéilleachair, N.C., Vaughan, A., Foley, C., Mann, H., Weller, D., Radtke, K. and Fritschel, H. 2024. 2024 Global Hunger Index: How Gender Justice Can Advance Climate Resilience and Zero Hunger. Welthungerhilfe/Concern Worldwide/Institute for International Law of Peace and Armed Conflict, Bonn/Berlin/Dublin/Bochum, pp. 60.
- Zaman, A., Zaman, P. and Maitra, S. 2017. Water resource development and management for agricultural sustainability. *J. Appl. Adv. Res.*, **2**: 73-77.

