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2. Millets: Nurturing Sustainable Agriculture and Food Security

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2.1 Introduction:

Millets are emerging as a sustainable superfood that addresses the pressing concerns of both environmental sustainability and human health. Their low resource requirements, resilience, and nutritional benefits make them an attractive option for a planet grappling with climate change and food security issues.

The chapter summarizes that how millets play role in sustainable agricultural practices, which would add to world's food and nutritional security and helping in achieving sustainable development goals (SDGs).

By incorporating millets into our diets and supporting their cultivation, we can contribute to a healthier planet and a more sustainable future. Millets are essential for sustainable agriculture due to their adaptability and environmentally friendly characteristics.

They are known for their resilience to challenging conditions, such as drought and poor soils, making them ideal for regions facing climate change impacts. Millets require less water, have short growing seasons, and support crop rotation, reducing soil degradation and pest issues.

Their lower carbon footprint, nutritional value, and preservation of local traditions make them a sustainable choice. Millets contribute to economic stability, support biodiversity, and help mitigate climate change by sequestering carbon. They play a vital role in food security, particularly in regions prone to food shortages (Saxena et. al. 2018). Promoting millet cultivation is crucial for addressing climate challenges, resource scarcity, and food security in sustainable farming systems.

Millets are a group of small-seeded, hardy, and resilient cereal grains that have been cultivated by humans for thousands of years. They belong to the Poaceae family and are characterized by their ability to adapt to a wide range of environmental conditions, making them particularly valuable in regions with challenging climates and limited resources.

Millets have been a staple food source for millions of people across the world, especially in arid and semi-arid regions where they serve as a reliable source of nutrition and nourishment (Amadou et al. 2013).

They constitute an important source of food and fodder for millions of resource-poor farmers and play a vital role in ecological and economic security of India. These millets are also known as "coarse cereals" or "cereals of the poor".

Indian Millets are nutritionally superior to wheat and rice as they are rich in protein, vitamins and minerals. They are also gluten-free ((Kumar and Singh 2015).) and have a low glycemic index, making them ideal for people with celiac disease or diabetes (Shinde et. al. 2023.).

Millets are an excellent source of fiber and contain a number of important nutrients. They score 52.7 on the glycemic index (GI), which is a medium value and lower than the value for maize, refined wheat flour, and rice.

Millets come in various species and varieties, for example finger millet/Ragi (*Eleusine coracana*), jowar (*Sorghum bicolor*) kodo millet (*Paspalum scrobiculatum*), foxtail millet Kakum (*Setaria italica*), proso millet (*Panicum miliaceum*), barnyard millet (*Echinochloa esculenta*), little millet (*Panicum sumatrense*), teff (*Eragrostis tef*), guinea millet (*Brachiaria deflexa*), fonio (*Digitaria exilis*), browntop millet (*Urochloa ramosa*) and Job's tears (*Coix lacryma-jobi*) Rajgira or ramdana (*Amaranthus cruentus*). pearl millet (major millet) (Cenchrus americanus), finger millet (Eleusine coracana), kodo millet (Paspalum scrobiculatum), foxtail millet (Setaria italica), proso millet (Panicum miliaceum), barnyard millet (Echinochloa esculenta), little millet (Panicum sumatrense), teff (Eragrostis tef), guinea millet (Brachiaria deflexa), fonio (Digitaria exilis), browntop millet (Urochloa ramosa) and Job's tears (Coix lacryma-jobi) pearl millet (major millet) (Cenchrus

americanus), finger millet (Eleusine coracana), kodo millet (Paspalum scrobiculatum), foxtail millet (Setaria italica), proso millet (Panicum miliaceum), barnyard millet (Echinochloa esculenta), little millet (Panicum sumatrense), teff (Eragrostis tef), guinea millet (Brachiaria deflexa), fonio (Digitaria exilis), browntop millet (Urochloa ramosa) and Job's tears (Coix lacryma-jobi)

Each variety has its unique characteristics and nutritional properties, but they all share some common advantages that make them a critical component of sustainable agriculture. These advantages include drought tolerance, water efficiency, short growing seasons, low input requirements, and a diverse array of ecosystem benefits.

With the aim to create awareness and increase production & consumption of millets, United Nations, at the behest of the Government of India, declared 2023 the International Year Millets.

Botany of millets: All millets belong to the order of *Poales*, and there to the family of *Poaceae* (also *Gramineae* or true grasses). They belong to either of the two subfamilies of *Panicoideae* or *Chloridoideae*.

***Eragrostideae* tribe (*Chloridoideae* subfamily):**

- *Eleusine coracana*: finger millet, mawere (ragi, nachani or mandwa in India) (Joshi et al. 2021)
- *Eragrostis tef*: teff

***Paniceae* tribe (*Panicoideae* subfamily):**

- ***Panicum miliaceum:*** proso millet, common millet, broom corn millet, hog millet, yellow hog, white millet (Sharma and Niranjan 2017)
- ***Pennisetum glaucum*:** pearl millet (kambu or bajra in India)
- ***Setaria italica:*** foxtail millet, German millet (thinai, kang or rala in India) (Kalsi and Bhasin 2023).
- ***Digitaria* spp.:** white fonio, black fonio, raishan, Polish millet

- ***Echinochloa* spp.:** Japanese barnyard millet, Indian barnyard millet, sawa millet, burgu millet (kuthirai vaali, bhagar or varai in India)
- ***Panicum sumatrense*:** little millet (samai in India)
- ***Paspalum scrobiculatum*:** kodo millet (varagu in India)
- ***Urochloa* spp.** (also known as *Brachiaria*): browntop millet (*U. ramosa*, dixie signalgrass), Guinea millet.

These are some of the millet species commonly cultivated in India. They are known for their resilience in diverse environmental conditions, making them important crops for food security in various regions of the country. The taxonomy of millets may involve additional subspecies or varieties within these species, depending on the specific cultivars and local adaptations.

2.2 Important Botanical Features of Millets:

Each type of millet has its own set of botanical characteristics, but there are some common features that are shared among many millet species. Here are some general botanical characteristics of millets:

A. Growth Habit:

Millets are annual grasses that can range in height from 1 to 4 feet, depending on the species. They typically have slender, upright stems.

B. Leaves:

The leaves of millet plants are usually long and narrow, with a blade-like shape. They can vary in color from green to grayish green, depending on the species.

C. Inflorescence:

Millets produce inflorescences, which are clusters of flowers. These inflorescences can be in the form of panicles, spikes, or racemes**,** depending on the species. The flowers are often small and may be wind pollinated.

D. Seeds:

Millet seeds are small, round or oval in shape, and vary in color depending on the species. They can be white, yellow, brown, or even red. The seeds are the primary edible part of millet plants.

E. Roots:

Millet plants typically have fibrous root systems that help anchor the plant and absorb nutrients and water from the soil.

F. Adaptability:

Millets are known for their ability to grow in a wide range of environmental conditions. They are often grown in regions with low rainfall and poor soil quality, making them important crops for food security in arid and semi-arid areas.

G. C4 Photosynthesis:

Many millet species employ C4 photosynthesis, which is an efficient method of carbon fixation that helps them thrive in hot and dry conditions.

H. Short Growing Season:

Millets have relatively short growing seasons and can be harvested in as little as 60 to 90 days, depending on the species and growing conditions.

I. Gluten-Free:

Millet is a gluten-free grain, making it a suitable dietary choice for people with celiac disease or gluten sensitivity**.**

J. Nutrient Content:

Millet seeds are rich in nutrients such as carbohydrates, fiber, vitamins (especially B vitamins), and minerals like magnesium, phosphorus, and iron.

These botanical characteristics may vary somewhat among different millet species, but they share the common trait of being hardy, drought-tolerant, and nutritious grains that have been cultivated for thousands of years as staple foods in various parts of the world.

2.3 Health Benefits of Millets:

A. Rich in Nutrients:

Millets are rich in essential nutrients, including protein, dietary fiber, vitamins (B-complex), and minerals (iron, calcium, magnesium) (Devi et al. 2014).

B. Low Glycemic Index:

They have a low glycemic index, which helps in regulating blood sugar levels, making them suitable for individuals with diabetes (Geetha et al. 2020).

C. Gluten-Free:

Millets are naturally gluten-free, making them an excellent choice for those with gluten sensitivities or celiac disease.

D. Heart-Healthy:

They contain heart-healthy fats and can help reduce the risk of heart disease.

E. Weight Management:

The high fiber content in millets promotes a feeling of fullness and aids in weight management (Anitha et al. 2021b).

F. Digestive Health:

Millets support digestive health due to their dietary fiber, aiding in preventing constipation.

G. Antioxidants:

Some millet varieties are rich in antioxidants, which help protect the body from oxidative stress and chronic diseases.

H. Bone Health:

Millets are a good source of calcium and magnesium, essential for strong bones (Devdas et al. 1984).

I. Improved Iron Absorption:

The presence of vitamin C in some millets can enhance the absorption of dietary iron (Anitha et al. 2021a).

J. Lower Cholesterol:

Consumption of millets has been linked to lower cholesterol levels, reducing the risk of cardiovascular diseases (Prasad et. al. 2015, Singh et al. 2020).Various millets, including finger millet (ragi), pearl millet (bajra), foxtail millet, proso millet, and little millet, are associated with potential benefits for lowering blood cholesterol levels. These millets are rich in soluble fiber, antioxidants and other nutrients that contribute to heart health.

2.4 Millets as a Part of Sustainable Agriculture:

In recent years, millets have gained renewed attention as part of efforts to promote sustainable agriculture and food security. objective of SDG 2 is ‘to end hunger, achieve food security and improve the nutrition and promote sustain-able agriculture’ (UN General Assembly, 2015).

Their resilience to climate change, minimal environmental impact, and high nutritional value makes them a valuable crop for addressing global challenges related to food production, environmental sustainability, and nutrition. As a result, millets have become a subject of research and development for enhancing agricultural systems and ensuring the well-being of communities worldwide (Ceasar and Maharajan 2022).

Millets play a crucial role in sustainable agriculture for several reasons:

A. Resilience to Climate Change:

Millets are hardy crops that can grow in a wide range of environmental conditions, including regions with poor soil quality and limited water resources (Awika, 2011).

They are drought-resistant and can adapt to both high and low-temperature conditions. This resilience makes them a dependable food source, even in the face of climate change.

B. Low Water Requirements:

Millets are known for their low water requirements compared to major cereal crops like rice and wheat. They are well-suited to rain-fed agriculture and can thrive with minimal irrigation. This reduces the pressure on water resources, making them a sustainable option in water-scarce regions.

C. Soil Health:

Millets have a low nutrient demand, which can reduce the need for synthetic fertilizers. They also improve soil health by enhancing its organic matter content which results in improved soil structure, nutrient retention, and reduced soil erosion (Prabhakar et al. 2023).

D. Biodiversity:

Millets contribute to crop diversity, which is vital for sustainable agriculture. Growing a variety of crops, including millets, helps prevent pest and disease outbreaks and reduces the reliance on a single crop.

E. Reduced Pesticide Use:

Millets generally require fewer pesticides than some other crops, partly due to their natural resistance to certain pests and diseases (Shobana et al. 2013). This reduction in pesticide use has environmental benefits and lowers production costs for farmers.

F. Nutritional Benefits:

Millets are highly nutritious, rich in essential vitamins and minerals. Including them in diets can improve food security and nutrition, especially in regions with limited access to diverse food sources (Verma and Patel 2017).

G. Sustainable Farming Practices:

Millets can be integrated into sustainable farming systems like organic and conservation agriculture. These practices promote biodiversity, reduce the use of synthetic chemicals (Thilakarathna and Raizada 2015) and enhance overall farm sustainability.

H. Local Food Security:

Growing millets can enhance food security at the local level, as they are often well-suited to the specific environmental conditions of a region. This reduces the vulnerability of communities to external food supply disruptions.

I. Economic Benefits:

Millet cultivation can be economically viable for smallholder farmers. They have lower production costs and can be sold in local and niche markets, providing income diversification opportunities.

J. Cultural Significance:

In many regions, millets have cultural and historical significance. Promoting their cultivation helps preserve traditional farming practices and maintains the genetic diversity of crops.

In conclusion, millets are an essential component of sustainable agriculture due to their adaptability to challenging environmental conditions, minimal resource requirements, and contributions to soil health, biodiversity, and food security. As a result, they are increasingly being recognized as an important part of sustainable farming systems and strategies for climate-resilient agriculture (Devkota et al. 2016).

2.5 Botanical Advantages of Millets for Sustainable Agriculture:

Millets possess several botanical characteristics that make them beneficial for sustainable agriculture:

A. Short Growth Duration:

Millets typically have a shorter growth duration compared to many major cereals like rice and wheat. This means they require fewer resources and are often less susceptible to extreme weather events or diseases that can occur later in the growing season. Many millet varieties have exceptionally short growing seasons, typically ranging from 60 to 90 days. Some can even mature in as little as 45 days. Short growing seasons allow for multiple cropping cycles in a year, providing a practical solution for food security and income generation in areas prone to unpredictable weather conditions.

B. C4 Photosynthesis:

Most of the millets utilize C4 photosynthesis, which is more efficient in hot and arid conditions. This adaptation allows them to maintain higher rates of photosynthesis and water use efficiency in environments with high temperatures and water stress (Bandyopadhyay et al. 2017). Millets have the potential to enhance carbon sequestration in the soil due to their deep root systems and efficient water use. This can contribute to mitigating climate change and improving soil quality.

C. Drought Tolerance:

Millets, especially pearl millet and sorghum are known for their exceptional drought tolerance. They can withstand prolonged periods of water scarcity by efficiently utilizing available water resources and closing their stomata to reduce water loss through transpiration. Millets have evolved to thrive in arid and semi-arid regions (Tadele 2016). Their deep root systems enable them to access water stored in deeper soil layers during dry spells (Ajithkumar and Panneerselvam 2014). This drought tolerance is a critical advantage in regions with erratic rainfall patterns or limited access to irrigation. Farmers can rely on millets even during extended periods of water scarcity.

D. Low Water Requirements:

Millets are relatively low-input crops, requiring significantly less water compared to major cereal crops like rice and wheat.

They can thrive in regions with limited irrigation infrastructure and are less susceptible to water stress (Ullah et. al. 2017).

This adaptability reduces the need for extensive soil amendments and makes millets a versatile option for farmers in areas with diverse soil conditions.

E. Wide Adaptability:

Millets are versatile and can thrive in diverse agroecological zones, from arid and semi-arid regions to tropical and subtropical climates. Their adaptability reduces the risk of crop failure due to changing environmental conditions.

F. Low Nutrient Requirements:

Millets are generally less demanding when it comes to soil nutrients. They can grow well in soils with lower fertility and are less reliant on synthetic fertilizers. This helps maintain soil health and reduces the environmental impact of agriculture.

G. Tillage and Weed Suppression:

The growth habits of certain millet varieties can help suppress weed growth due to their canopy structure and shading effect. This can reduce the need for herbicides and minimize soil disturbance through reduced tillage (Sneha and Sheeja 2022).

H. Minimal Water logging Sensitivity:

Millets are less sensitive to water logging compared to crops like rice (Matsuura et. Al. 2022). This trait ensures they can be grown in areas with poor drainage or during periods of excessive rainfall (Kheya et. al. 2023).

I. Crop Rotation and Diversification:

Millets can be integrated into crop rotation systems, reducing soil degradation and promoting soil health (Pan et. al. 2020).

Crop diversification involving millets also helps manage the risk of pest and disease outbreaks and it also manage the risk of crop failures and ensure a more stable food supply.

J. Adaptation to Low-Input Farming:

Millets are well-suited for low-input and subsistence farming systems. They can thrive with minimal synthetic inputs, making them accessible and cost-effective for smallholder farmers.

The low-input nature of millet cultivation, including reduced water, fertilizer, and pesticide requirements, can lead to cost savings for farmers, making them a more economically sustainable choice (Kumar et al. 2018).

K. Local Adaptation:

Millets have a long history of cultivation in various regions, and numerous landraces and varieties have evolved to suit specific local conditions.

This adaptation can reduce the need for extensive genetic modifications or specialized crop management practices promoting the preservation of indigenous agricultural knowledge and practices.

L. Biodiversity and Ecosystem Benefits:

Growing millets can contribute to increased agricultural biodiversity. Millet fields provide habitat and food sources for various beneficial insects and wildlife, promoting ecosystem health.

Millets exhibit significant genetic diversity, which provides opportunities for breeding and selection of varieties that are better adapted to specific local conditions (Patil 2020).

M. Biomass Utilization:

Some millet varieties have potential for dual use, providing both grain and biomass. The biomass can be used for fodder, biofuel, or as a source of organic matter to enhance soil fertility (Tagade and Sawarkar, 2023).

N. Low Carbon Footprint:

Millets generally have a lower carbon footprint compared to some other crops due to their reduced need for energy-intensive inputs and shorter growing seasons (Tiwari et. al. 2022)

Millets are an excellent choice for sustainable agriculture due to their remarkable botanical advantages such as their drought tolerance, low nutrient requirements, adaptability to diverse environments, and resistance to pests and diseases.

These qualities reduce the environmental footprint of agriculture, enhance resilience to climate change, and make millets an attractive option for sustainable and climate-resilient farming systems.

2.6 Role of Millets in Achieving Food Security:

Millets play a crucial role in gaining food security for both individuals and communities. Here's an explanation of their role in achieving food security:

A. Diverse Food Source:

Millets provide a diverse source of food. They can be used to make various food products, including porridge, bread, roti, and even fermented foods. This diversity enhances dietary options, reducing dependence on a limited set of staple foods.

B. Nutrient-Rich Grains:

Millets are highly nutritious, containing essential vitamins, minerals, dietary fiber, and antioxidants. They contribute to a balanced and nutrient-rich diet, helping combat malnutrition and ensuring that people receive the necessary nutrients for good health (15).

C. Gluten-Free and Allergen-Friendly:

Millets are naturally gluten-free, making them suitable for individuals with celiac disease or gluten sensitivity.

This expands food options for those with dietary restrictions, contributing to their food security.

D. Climate-Resilient Crops:

Millets are known for their adaptability to diverse agro-climatic conditions. They can thrive in areas with erratic rainfall and extreme temperatures, helping communities maintain a stable food supply even in the face of climate change and adverse weather events.

E. Drought Tolerance:

Millets are drought-tolerant crops that require less water compared to traditional staples like rice and wheat.

This feature is particularly important in regions with water scarcity, as it ensures a more reliable source of food.

F. Crop Diversity:

The cultivation of a variety of millet species can enhance food security by reducing the risk of crop failure due to pests, diseases, or changing environmental conditions. Crop diversity provides a safety net for communities reliant on agriculture.

G. Sustainable Farming Practices:

Millets are often cultivated using sustainable and eco-friendly farming practices. They promote soil health, reduce the need for chemical inputs, and support biodiversity.

These practices contribute to long-term food security by ensuring the resilience of agricultural systems.

H. Local Food Systems:

The cultivation and consumption of millets are often embedded in local food systems and cultural traditions. Supporting these systems helps communities maintain their food security by preserving local knowledge and resources.

I. Economic Viability:

The cultivation of millets can provide income opportunities for smallholder farmers. By diversifying their crop portfolio, farmers can reduce economic vulnerability and enhance their ability to meet their own food needs.

J. Global Significance:

Millets are not limited to a single region but are cultivated in various parts of the world, from Africa and Asia to the Americas and beyond. This global significance ensures that lessons learned from millet cultivation can be applied to enhance food security in multiple regions.

Thus, we can conclude millets are an integral part of strategies to achieve food security and thus SDG 2 (zero hunger). Their nutritional value, climate resilience, and role in promoting sustainable agriculture make them a valuable asset for ensuring a stable and diverse food supply, particularly in regions facing challenges related to environmental changes and limited resources.

Millets contribute significantly to the achievement of Sustainable Development Goals (SDGs) through their nutritional, environmental, and economic benefits. Serving as a staple food, millets address malnutrition and enhance food security (SDG 2). With their resilience to diverse climates, millets support climate action (SDG 13) and sustainable land use (SDG 15).

The cultivation of millets fosters economic growth (SDG 8) and partnerships for sustainable agriculture (SDG 17), while their low environmental impact aligns with responsible consumption and production (SDG 12).

Millets empower women (SDG 5) and reduce inequality by providing affordable and accessible nutrition (SDG 10). Overall, the incorporation of millets into agricultural practices and diets contributes to a holistic approach to sustainable development.

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