

## REVIEW ARTICLE

## AN OVERVIEW ON FINGER MILLET: MORPHOLOGICAL AND PHYSIOLOGICAL ASPECTS

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## ARTICLE DETAILS

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## ABSTRACT

Finger millet, *Eleusine coracana* L., is a nutrient-rich cereal that plays a vital role in food security, especially in semi-arid and tropical regions. Due to its hardiness against unfavorable environmental conditions, coupled with its high nutritional value, it offers immense health benefits, including diabetes management, improved bone health, and immune function. The crop is also recognized for its rich source of minerals such as calcium, iron, and potassium, which contribute to its health-promoting properties. Originated in East Africa, finger millet has conventionally been a staple food not only in Asia but also in Africa due to its adaptability and capability to grow on marginal soils. Furthermore, it can withstand drought, making it a suitable option for regions facing water scarcity. It is a crop with many prospects, but the problems of low productivity, awareness, and investment have obstructed its widespread dissemination. This review discusses taxonomy, morphology, nutritional composition, health benefits, and the place of finger millet in sustainable agriculture. Additionally, it explores the environmental conditions under which it thrives, emphasizing its role in crop diversification and agroecosystem resilience. It highlights the processing methods it uses, its value addition, and the potential for the same to be a climate-resilient crop. Efforts towards increasing its productivity through innovative farming practices, along with the promotion of its health benefits, are crucial in ensuring its contribution to food security. Meeting the knowledge gaps about its cultivation supported by research and policy could establish its positioning as an imperative in global food security.

## KEYWORDS

Finger millet, nutritional value, health, climate resilience.

## 1. INTRODUCTION

In the 21<sup>st</sup> century, rising population growth, global warming, climate change, water scarcity, rising food prices and urbanization are the major threats to the agriculture and food security (Harish et al., 2024). Cereals are the main staple diet for most people in the modern world. Around the world, people choose wheat, rice, and corn as staple foods among the cereals. However, millets have received little attention as a dietary supplement, particularly in the context of the post-Green Revolution era. Finger millet, *E. coracana* L. is also known as ragi and mandua (India); kodo (Nepal); fingerhirse (Germany); petit mil, koracan (France); bulo (Uganda); kambale, bule (Zambia); poo, mazhovole (Zimbabwe); finger millet, African millet, koracan (England); dagussa, tokuso, barankiya (Ethiopia); wimbi, mugimbi (Kenya). Finger millet is believed to have originated in Eastern Africa, specifically in the highlands of Ethiopia and Uganda, before spreading to Asia, particularly India and Nepal, through ancient trade routes and human migration. The crops domestication dates back over 5000 years, and its genetic adaptation to diverse agro-ecological zones has contributed to its survival and widespread cultivation. The semi-arid tropical region of Africa and Asia especially Nigeria and India are the major producers of millets contributing 97% productivity of the world (Jagati et al., 2021). Finger millet (*Eleusine coracana* (L.) Gaertn.) is an important crop used for food, forage and industrial products (Kandel et al., 2019). Finger millet (*Eleusine coracana*) is also referred as a 'Poor People's Crop' (Dhanushkodi et al., 2023). In the world, millet is cultivated in around 30 million hectares of land with the productivity of 1.03t/ha

(FAOSTAT, 2024). India is the major producer of finger millet contributing nearly 60% of the global production (Gull et al., 2014). Underscoring the importance of millet, the United Nations designated 2023 as the International Year of Millet in collaboration with FAO (Harish et al. 2024; (Sahoo and Mahapatra, 2023). Out of 15 species reported in the world, 3 species (*Eleusine coracana*, *E. indica* and *E. aegyptica*) of finger millets are found in Nepal (Kandel et al., 2019). This diversity plays a crucial role in its adaptability to different climatic conditions, making it a resilient crop in both tropical and temperate regions. It may be cultivated in drought conditions because of its resistant character. However, despite its potential, finger millet faces several production constraints, including low productivity, poor agronomic practices, inadequate research and development efforts, and limited market access. Additionally, a lack of improved seed varieties and mechanization further hinders its large-scale cultivation. Addressing these challenges through research, policy interventions, and improved agronomic practices can enhance its role in food security and nutrition. Prior research has discovered the diversity of finger millet. As compared to other cereals, finger millet has the highest concentration of iron and calcium. Cattle and birds are fed finger millet in addition to being consumed by humans. Finger millet is used to make a variety of meals, including puddings, pancakes, biscuits, roti, bread, noodles, and various snacks, both in their natural and malted forms. In addition, it's considered a healthy meal for diabetics and utilized as a nourishing food for babies when malted. Finger millet is devoid of gluten and has a high concentration of carbohydrates, dietary fibre, phytochemicals, and essential amino acids. One of its key advantages is its long storage capacity, as the grains can be stored for years without

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significant deterioration, making it an ideal food security crop. Its natural resistance to spoilage and minimal post-harvest losses make it highly suitable for subsistence farming in developing regions. It also includes vital minerals. Numerous studies have reported that finger millet promotes natural weight loss, builds bone, guards against diabetes, delays the aging process, regulates blood pressure, wards off illness, enhances children's haemoglobin status, etc (Dhanushkodi et al., 2023). Millets are important but underutilized crops in tropical and semiarid regions of the world due to their greater resistance to pests and diseases, short growing season, resistant to water logging, drought tolerant, requires little inputs during growth and with increasing world population and decreasing water supplies represents important crops for future human use (Chandra et al., 2016). Resilient to environmental conditions and nutritional quality of finger millet makes them ideal model system to study the effect of different environmental stress and crop nutrient production (Wilson and Vanburen, 2022). Millet also acts as a symbol of cultural identity (Choudhary et al., 2023). Millets are often referred as 'Yesterday coarse grains and today's Nutri-cereals' (Harish et al., 2024).

## 2. ORIGIN

Finger millet is believed to have originated in eastern Africa around Uganda or the nearby highlands of Ethiopia, where the genus *Eleusine* is quite diverse. There was confliction over whether *Eleusine coracana* originated from a hybrid of two diploid species, from *E. indica*, or from *E. africana* (Dhami et al., 2018). Finger millet [*Eleusine coracana* (L.) Gaertn.] is a tetraploid ( $2n=4x=36$  AABB) species evolved from the natural crossing of *Eleusine indica* (AA) x *Eleusine floccifolia* or *Eleusine tristachya* (BB) (Kandel et al., 2019). It is an annual hardy cereal crop grown in the tropical, subtropical areas of world and mostly producing countries were India, China, Uganda and Nepal (Kandel et al., 2019). Accordance to archaeological evidence millet was cultivated 8000 years ago in China, making it one of the oldest cultivated crops in human history (Choudhary et al., 2023).

### 2.1 Taxonomy and morphology



Figure 1 : Finger millet

**Origin:** East Africa (Ethiopia and Uganda)

### 2.2 Chromosome no.: $2n = 36$

Millets are minor cereals of the grass family, Poaceae (Shobana et al., 2013). Finger millet (*Eleusine coracana*) belongs to the family Poaceae and sub-family Chloridoideae and consists of non-shattering spikelets with brown grains. Plants are annual, tufted, erect and have culms that ascend geniculate up to 165 cm in height; they can also root from lower nodes on occasion. From the top nodes, culms frequently branch to form secondary inflorescences. Finger millets have linear to lanceolate leaf blades which ranges up to 70cm in length and width of 20 mm. It consists of digitate inflorescence which are slender to robust, up to 24 cm long (Chandrashekar, 2010). Except the terminal ones, all florets are fertile in finger millet (Sood et al., 2019). Spikelets are 6–9 mm long, overlapping, and primarily distributed in two rows along one side of the rachis

(Chandrashekar, 2010). The grain might be red, brown, black, or white (Chandrashekar, 2010). There are two subspecies of finger millet, *E. coracana* subsp. *africana* (wild form) and *E. coracana* subsp. *coracana* (cultivated form). *E. coracana* subsp. *africana* is similar to *E. indica* and is difficult to distinguish, but *E. indica* has smaller spikelets and oblong grains (Sood et al., 2019).

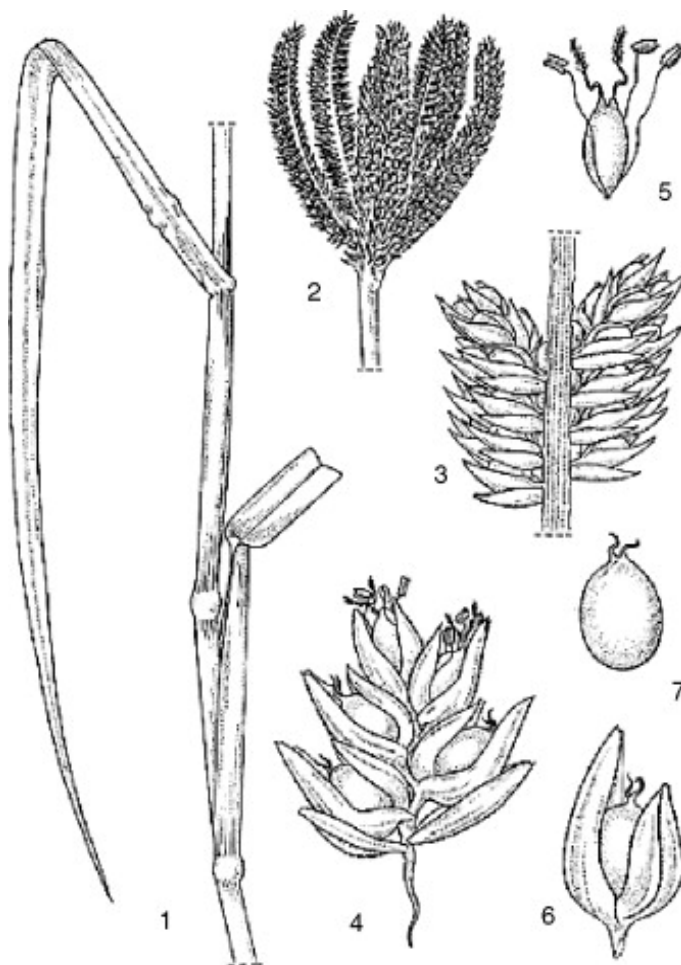


Figure 2: Stem part with leaves 2. Inflorescence 3. Part of inflorescence branch 4. Spikelet 5. Floret without lemma and palea 6. Grain within lemma and palea 7. Grain

Source : (Harish et al., 2024)

### 2.3 Why finger millets?

- Food for human: finger millets are rich in carbohydrates, proteins and minerals.
- Feed for livestock.
- Have wide range of adaptability.
- Grow well in mixed cropping.
- Have low resource requirement.
- Requires little or no synthetic fertilizers.
- Long life properties due to good storability.

(Singh E, 2016)

### 2.4 Nutritional composition of finger millet

Finger millet is often referred as 'Nutri-cereals' as it is rich in carbohydrate, protein, macro and micro-nutrients (Harish et al., 2024). Cultivars, varieties and geographical locations are the factors affecting the nutritional and phytochemical qualities of finger millet (Abioye et al., 2022). As compared to other major cereals, wheat and rice, finger millet is considerably rich in micronutrients such as vitamins and minerals. It contains 10 times greater calcium as that of wheat, maize, and rice and 3 times greater than milk (Jagati et al., 2021). Millets are considered functional and superfoods since it contains the bioactive ingredients which helps in physiological well-being (Harish et al., 2024).

## 2.5 Carbohydrate

In finger millets, the total amount of carbohydrate ranges from 72-79.5% (Gaikwad et al., 2023). Carbohydrate in finger millet contains 59.5–61.2% starch, 6.2–7.2% pentosans, 1.4–1.8% cellulose, and 0.04–0.6% lignins. (Shobana et al., 2013). As compared to other millets, finger millet consists of higher amount of dietary fibre i.e. 11.5% whereas it has low amount of amylose in their starch content (Gaikwad et al., 2023).

## 2.6 Protein

The protein content of finger millet ranges from 5-12%, depending upon its varieties (Ambre et al., 2020). Protein composition of finger millet is well balanced and as compared to other millet grains it contains higher amount of lysine, threonine and valine (Gaikwad et al., 2023).

## 2.7 Lipid

Finger millet has the low lipid content which may acts as the major factor behind long-life properties of finger millet than other varieties (Shanmugam et al., 2013). Lipids in finger millet contain 46–62% oleic acid, 8–27% linoleic acid, 20–35% palmitic acid, and traces of linolenic acid (Shobana et al., 2013).

## 2.8 Minerals

Among all cereals and millets, finger millet consists of high amount of calcium and potassium i.e. 344 mg/100g and 408 mg/100g respectively (Shanmugam et al., 2013).

## 2.9 Vitamins

Fermentation of finger millet enhances the concentration of vitamin content including riboflavin, pantothenic acid and niacin (Thapliyal and Singh, 2015).

## 2.10 Anti-nutrients

Instead of being a good source of nutrients, finger millet also consists of certain anti-nutritional factors which leads to poor digestion and low bioavailability of carbohydrates and proteins (Gaikwad et al., 2023). Tannins, polyphenols, flavonoids, HCN, phytates, oxalic acid, digestive enzyme inhibitors (amylase inhibitor function, trypsin inhibitory activity), and goitrogens are the anti-nutrients present in finger millet (Singh E, 2016).

Table 1: Nutrient composition of Finger millet	
Components	Amount
Protein	7.3%
Fat	1.3%
Starch	59.0%
Ash	3%
Crude fibre	3.6%
Total dietary Fibre	19 g/100g
Total phenol	102 mg/100g
Carbohydrates	72.6 g

Components	Amount (mg/100g)
Calcium	344
Phosphorous	283
Iron	3.9
Magnesium	137
Sodium	11
Potassium	408
Copper	0.47
Manganese	5.49
Zinc	2.3
Thiamine	0.42
Riboflavin	0.19

Source : (Chandra et al., 2016)

## 2.11 Grain of finger millet



Figure 3 : Finger millet (Manduwa) Grain

The Poaceae family contains number of small seeded species known as millets (Divya et al., 2018). Among the millet crops, finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*S. italica* (L.) P. Beauv.), kodo millet (*Paspalum scrobiculatum* L.), proso millet (*Panicum miliaceum* L.), barnyard millet (*Echinochloa* spp.), and little millet (*Panicum sumatrense* Roth) are the small millets (Rodriguez et al., 2020). The grain shape of finger millet varies from oblong to round and oval (Sood et al., 2019). Finger millet grains are globular in shape and its diameter varies from 1.0 to 1.5 mm (Siwela et al., 2007). Finger millets are available in different colour. The red coloured finger millets are grown and cultivated worldwide such as in Sri Lanka, Nepal, Madagascar, Malaysia, Uganda, Japan, different parts of Africa and India (Jagati et al., 2021). Finger millet grain consists of five layered testa which has been implicated as one of the likely reasons for the presence of high dietary fibre content in the grain (Shobana et al., 2013).

Finger millet grain consists of three layers; the epicarp (outermost layer), mesocarp (middle layer) and endocarp (inner layer) (Ramashia et al., 2018). The main botanical components of the millet kernel consist of seed coat, embryo (germ), and the endosperm (Shobana et al., 2013).

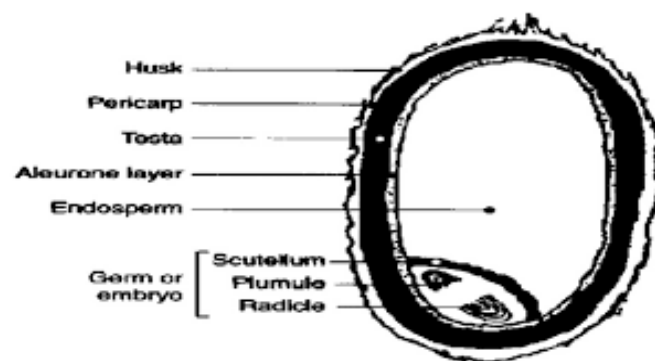


Figure 1: Structure of Finger millet grain.

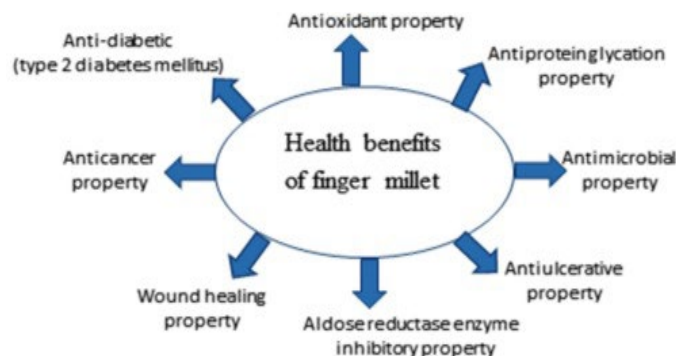
Source: (Ramashia, 2018).

## 3. HEALTH BENEFITS OF FINGER MILLET

Finger millet is one of the most nutritious food crops extensively grown in Asia and Africa (Rodriguez et al., 2020). The essential amino acids isoleucine, leucine, phenylalanine, thiamine, riboflavin, iron, and methionine are all abundant in finger millet. Because of the abundance of these phytochemicals, Finger millet becomes a powerful source of nutrients that are beneficial to health, which also increase the grain's nutraceutical abilities. It has several health benefits, including anti-diabetic (type 2 diabetes mellitus), anti-diarrheal, anti-ulcer, anti-inflammatory, anti-tumorigenic (K562 chronic myeloid leukaemia), anti-atherosclerogenic, antimicrobial, and antioxidant functions (Chandra et al., 2016 ; Thapliyal and Singh, 2015). Finger millet also has anti-tumour and anti-leukemic properties (Singh E, 2016).

Seed coat of finger millet contains tannins which has the astringent property (Shobana et al., 2013). Finger millet acts as an alternatives to wheat flour for those suffering from celiac disease (Wilson and Vanburen, 2022). Finger millet is a good source of calcium and iron which helps to maintain bone health and haemoglobin in children as well as adolescents

(Shobana et al., 2013). Finger millet is a very good source of natural iron (Fe) and its consumption helps in recovery of anaemia. The Ragi based foods are highly suited for expectant mothers and elderly due to their high Fe content. Finger millet's phytochemicals help in increasing digestion process. The study found that diet based on wholegrains of finger millet helps in controlling blood sugar level (glycaemic index) in the condition of diabetes. It has been found that finger millet-based diet helps in preventing constipation, high blood pressure and intestinal cancer as it contains higher fibre than rice and wheat.



(Chandra et al., 2016)



Figure 2: Functions of essential amino acids present in finger millet. (Dhanushkodi et al., 2023)

### 3.1 Package of practices of Finger millet

Farmers are attracted towards millet cultivation because of its wide adaptability to different soil types and climate (Dhanushkodi et al., 2023).

Components	Description
Soil requirement	Ragi can be grown under wide range of soil conditions. Well drained, fertile, humus rich, sandy loam soils is best for finger millet cultivation. Soil pH = 4.5-7.5 is suitable for finger millet cultivation. It can tolerate drought and soil salinity to some extent better than other cereals.
Climatic requirement	A short-day plant. Optimum day temperature= 30-34°C and night temperature= 20-25°C. It can grow well in areas with average rainfall of 1000mm.
Land preparation	2-3 ploughing is necessary. Perennial weeds, stones should be removed from the field.
Cultivars	VL Mandua 101, VL Mandua 204, VL 124, VL 149, VL 146, VL Mandua 315, KM-65, KMR-304, Arjuna etc.
Seed rate	Line sowing = 8-10 kg/ha. When the crop is raised by transplanting, 4-6 kg/ha is sufficient for raising nursery.
Seed treatment	Water soaking of seeds for 6 hours followed by shade drying improves the germination of seed. Treating seeds with <i>Azospirillum brasilense</i> (N fixing bacterium) and <i>Aspergillus awamori</i> (P solubilizing fungus) @25 g/kg seed is beneficial. Chemical treatment of seed involves treatment with Thiram, Captan and Carbendazim @ 2-4g/kg of seed. Chemical treatment of seed should be done prior to biological treatment if necessary.
Sowing time	In the regions of high rainfall, it can be cultivated on well-drained soil as transplanted crop. It can be grown as a rainfed crop as well as in irrigated conditions. More than 90% of finger millet area is under rainfed condition, grown during kharif season.
Sowing method	Seed can be sown by broadcasting, line sowing or drilling in rows. Seedlings should be transplanted at 25 cm × 15 cm for the early rabi and kharif seasons and at 30 cm x 10 cm for the late kharif season.
Sowing depth	Seed should be sown not less than 3-4 cm depth.
Cropping sequence	In rainfed conditions, it is generally cultivated as a mixed crop with sorghum, pearl millet, and a variety of oil seeds and pulses. Under irrigated conditions, it is grown in rotation with crops like tobacco, vegetables, linseed, mustard etc.
Nutrient management	FYM= 5-10 t/ha Under rainfed condition= 60:30:30 kg N: P205:K20/ha. Under irrigated conditions: For nursery 40:40:40kg N: P205:K20/ha and for main field=60:30:30kg N: P205:K20/ha.
Irrigation management	As it is a rainfed crop, it does not required irrigation but there must be the sufficient water at the stage of flowering and grain filling.
Weed management	The critical period of crop weed competition is 25 to 45 days after sowing (DAS). Pre-emergence herbicides like metoxuran @0.75 kg a.i./ha + one hand weeding at 35 DAS gives excellent control of weeds.
Plant protection	Protection from insects such as Armyworm, cutworm, aphids, Earhead bug, Leaf folder and disease like mosaic and blast is necessary.
Harvesting	Finger millets depending upon growing conditions and choice of cultivars generally matures at 120-135 days after sowing (DAS). Ear heads are usually harvested with sickles and after proper drying, it undergoes for threshing.
Yield	In rainfed condition = 0.7-0.8 t/ha and in irrigated condition = 3.0 to 3.5 t/ha.
Storage	For grain purpose, store them after maintaining 10% of moisture. For seed purpose, store the seeds after seed treatment (mix 100 kg of seed with 1 kilogram of activated kaolin or 5% malathion dust). Store the seeds in gunny bags or polythene-lined gunny bags.

(Soni et al., 2024)

### 3.2 Yield attributing characters of finger millet

- Plant stands per square meter
- Plant height
- Bearing head per square meter
- Number of fingers per head
- Number of grains per finger
- Thousand grain weight (Dhami et al., 2018).

### 3.3 Biotic stress

Weed (*Striga sp.*) infestation, blast disease, insects such as grasshopper, armyworms are the major constraints in finger millet cultivation (Sood et al., 2019). Finger millet shows the anti-fungal defence to *Fusarium graminearum* which is due to bacteria (*M6- Enterobacter sp.*) associated with the roots of finger millet (Sood et al., 2019). Finger millet have long storability as they are resistant to storage pests and can be stored up to 10 years (Gupta et al., 2017).

### 3.4 Abiotic Stress

Elevated temperature, unpredictable rainfall patterns, and greenhouse gas emissions (GHGs) etc., are the major impacts of climate change (Kheya et al., 2023). After domestication, millets were chosen for their ability to withstand harsh and unpredictable conditions. By cultivating these grains, dry regions can become more productive and ensure food security in the face of changing environmental conditions or climate change (Wilson and Vanburen, 2022). Millets are the climate-smart crops (Kheya et al., 2023). Due to their superior endurance to various abiotic challenges and excellent nutritional profile, minor millets are well-suited for growing on arid, salinized soils and in poor-quality water sources. Finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*), also considered as orphan crops, are highly tolerant grass crop species that grow well in marginal and degraded lands of Africa and Asia with a better nutritional profile (Rodriguez et al., 2020). Finger millet grows well in semi-arid regions since it is one of the crops with the highest nitrogen use efficiency (NUE) and low water requirements (Gupta et al., 2017). The Poaceae family is divided into two distinct clades, i.e., the BEP and PACMAD clades. The BEP clade (Bambusoideae, Ehrhartoideae, and Pooideae subfamilies) consists of cool-season C3 crops (Examples- wheat, rye, barley), whereas the PACMAD clade (Panicoideae, Arundinoideae, Chloridoideae, Micrairoideae, Aristidoideae, and Danthonioideae subfamilies) consists of C4 crops (Examples- Sorghum, maize, sugarcane, millets, etc.). C4 plants lack photorespiration and hence thrive well in environments with high light, warm temperature, and drier climate (Wilson and Vanburen, 2022).

(Wilson and Vanburen, 2020) reported that C4 plants (e.g., millet) have the following features for better adaptation to the stressful environment:

- C4 plants reduce photorespiration and have high water use efficiency.
- Leaves having high vein density and Kranz anatomy maintain the hydraulic integrity and hence have low water requirements.
- Plants with Dumb bell-shaped guard cells and amphistomatic leaves have high water use efficiency with low evapotranspiration rates.
- Deep and fibrous root systems of millets also help to increase the water availability and maintain the face with environmental changes.

Short plant height, big leaf area index with small leaf, upright leaf with high radiation use, dense root system, and thicker cell walls are the morphological and anatomical characteristics that allow finger millet to overcome abiotic stress (Kheya et al., 2023).

## 4. PROCESSING AND VALUE-ADDED PRODUCTS OF FINGER MILLET

Finger millet is processed by milling, malting, fermentation, popping and

decortication. The grain is made into a fermented drink or beer in Nepal and in many parts of African (Dhami et al., 2018). Finger millet is available in different processed value-added forms in a balanced proportion of protein contents and with enhanced activity free from gluten (Jagati et al., 2021). The effect of two major anti-nutrients i.e. phytates and tannins, can be reduced by fermentation and germination (Gaikwad et al., 2023). Chapatti (Roti), papad, alcoholic beverages, porridge, different bakery products, extruded and fermented products are the value-added products of finger (Ambre et al., 2020). Processing of finger millet consists of the following techniques:

### 4.1 Decortication

Dehulling or debranning of finger millet in centrifugal shellers is known as decortication (Ramashia et al. 2018 ; Rathore, 2016). It consists of the following steps:

Soaking, Draining, Steaming, Drying, Hydrothermally treated millet, Moist conditioning, Decortication carborundum-coated (Gaikwad et al. 2023).

### 4.2 Fermentation

Fermentation reduces the phytates and tannins more effectively than malting (Gaikwad et al., 2023). It consists of following steps:

Cleaning, Sprouting, Milling, Fermentation, Sieving, Drying, Fermented flour (Gaikwad et al., 2023)

### 4.3 Flaking

It consists of following steps:

Decortication, Moist conditioning, Steaming, Flaking, Drying, Finger millet flakes (Gaikwad et al., 2023)

### 4.4 Malting

Vitamins B are synthesized during malting process and it also helps to reduce the anti-nutritional factors (Ambre et al., 2020). It consists of following steps:

Steeping, Germination, Drying, Roasting, Grinding, Sieving, Malted flour (Gaikwad et al., 2023)

### 4.5 Milling

Milling is done to make flour which further helps to make different food products (Ambre et al., 2020). It consists of following steps:

Cleaning, Passed through abrasive or friction mill, Pulverization, Finger millet whole mill (Gaikwad et al., 2023)

### 4.6 Popping

Popping brings about several physicochemical changes in its starch and loss of birefringence (Singh E, 2016). It consists of following steps:

Moist, conditioning, Tempering, HTST Popped finger millet (Gaikwad et al., 2023)

### 4.7 Puffing

It consists of following steps:

Decortication, Conditioning, Mechanical impact in roller flaker, HTST in salt medium (hot sand puffed), Expanded finger millet (Gaikwad et al., 2023)

### 4.8 Soaking

Soaking is defined as the process where finger millet is left overnight in water at 30-60°C, and the grains are dried before making the millet flour, which helps to reduce the anti-nutrients in finger millet (Gaikwad et al., 2023). Soaking in distilled water or NaOH for 8 hours dramatically reduces the tannin and phytic acid content of finger millet (Rathore et al., 2019).

Processing Method	Purpose
Soaking or Cooking	Soaking finger millet seeds in water helps to reduce the anti-nutrient percentage in food (Jagati et al., 2021).
Fermentation	Fermentation enhances the biological value (BV), net protein utilization, Thiamine, riboflavin and niacin contents of food (Pragya Singh, 2012). It also reduces anti-nutrients, i.e. phytate and tannin in food (Gaikwad et al., 2023).
Roasting	To enhance flavour (Jagati et al., 2021). It also increases the bioavailability of minerals and increases the shelf life of foods (Thapliyal and Singh, 2015).
Decortication	Reduces polyphenolic and phytate content (Krishnan et al., 2012).
Milling and grinding	Wet milling involves overnight soaking of grains and grinding to make a paste by hand or using two stones, which also reduces the anti-nutrients in millet (Jagati et al., 2021).
Popping or puffing	Popped millets are the porous products having low bulk density with an attractive texture and distinct flavour (Jagati et al., 2021). It also deactivates some anti-nutritional factors (Mavila et al., 2000). It also enhances aroma due to Maillard's reaction (Verma and Patel, 2012).
Germination or malting	The nutritional value associated with biochemical changes is enriched by germination, and it inhibits the fungal infection of grains (Jagati et al., 2021).

### 5. PHENOTYPING (MORPHOLOGICAL AND PHYSIOLOGICAL TRAITS OF FINGER MILLET)

Phenotyping remains nonuniform, labor-intensive, and sensitive to environmental factors, in contrast to genotyping, which is today highly specialized and exact. An individual's complex set of responses to both internal and external stimuli throughout their lifetime is represented by their phenotype. Numerous high-throughput phenotyping experiments have been made possible in recent years by automation, imaging, and software technologies. A phenotyping procedure that is integrated and optimized to be as regulated and efficient as feasible is known as high-throughput phenotyping. The consistency of the data will still be impacted by biological noise, though. Furthermore, standardized methods are required for measuring the variability of traits in crops such as finger millet. Once the technology is tested in these crops, it may be possible to modify the imaging systems in these crops to accurately capture the phenotypic traits required by automation (Sood et al., 2019).

#### 5.1 Breeding activities in Finger millet

In finger millet, only a few studies on plant pigmentation, glume size, and grain colour have been carried out. Finger millet consists of different novel genes for the benefit of mankind. Interspecific hybridization between Indian and African germplasm leads to the development of finger millet with high-yielding and disease-resistant traits (Sood et al., 2019). Nutrient-rich accessions can be hybridized with agronomically superior accessions/adapted varieties, which will help in the development of nutritionally wide varieties to combat malnutrition in developing countries (Sood et al., 2019). Nutrient-rich and high-yielding varieties of finger millet, such as VL Mandua 352, local landraces, viz., Nagaland-2 and Sikkim-1, should be selected, conserved, and promoted for cultivation among the farmers to ensure food and nutritional security in the North Eastern Himalayan Region (NEHR) of India (Layek et al., 2023).

#### 5.2 Hybridization

Generally, the contact method of hybridization is followed by breeders as manual emasculation is difficult in finger millet (Sood et al., 2019). Female panicles are immersed in 48-52°C for 5 minutes for effective emasculation by the hot water emasculation method (Sood et al., 2019). An alternative technique involves covering the panicle at the appropriate stage with a 7.5 cm x 10 cm polythene bag lined with damp filter paper and plugging it with absorbent cotton wool. The anthers emerge from the florets without spilling pollen because of the extreme humidity. By tapping the bag, pollen from the male genotype is gathered and then dusted onto the emasculated panicle. Genetic male sterility (GMS) is also reported in finger millet (Sood et al., 2019).

### 5.3 Sustainable agriculture and finger millet

Sustainable agriculture has become a global imperative for food security, environmental conservation, and socio-economic well-being (Choudhary et al., 2023). Millet is important in sustainable farming because of the following reasons:

- **Climate-resilient agriculture:** Finger millet has a wide range of adaptability to changing climatic conditions.
- **Nutritional value:** Finger millets are rich in carbohydrates, proteins, and minerals.
- **Biodiversity and ecosystem services:** Finger millet helps to maintain the habitat of beneficial insects and organisms, hence helps to maintain agricultural diversity.
- **Water and resource use efficiency:** Since finger millet is a C4 plant, the water and nutrient use efficiency is better compared to other cereals.
- **Economic and social aspects:** Finger millet and its products act as a diversified income source for growers or farmers, which further helps to maintain the socio-economic well-being of growers or farmers.

### 5.4 Future Prospects of Finger Millet

- **Future scope for research:** Future innovations in crop improvement and breeding of finger millets, biotechnology and genomics, biodiversity conservation, agro-ecological approaches, climate smart agriculture etc. create a wide prospect for finger millet in future. It also creates a wide research areas to maintain agricultural diversity (Choudhary et al., 2023). Strengthened germplasm collection, maintenance breeding and seed production, improvement of promising millet cultivars, assessment of these cultivars at different agro-climatic conditions etc. are the major areas for future research in millet cultivation (Kheya et al., 2023). Because of the complex genetic basis of abiotic stress tolerance in millets, it will be challenging to replicate their broad resilience in conventional cereals. Characterization and utilization of finger millet germplasm and wild species in different breeding program, identification of novel genes for abiotic stress tolerance and nutritional traits may be future key areas of research.
- **Climate resilient crop:** Morphological, physiological, biochemical and molecular superiority of finger millets let them to withstand and resist environmental stress better as compared to other cereals. As opposed to cereal crops which takes 140-168 days to complete its lifecycle, finger millet takes only 84-98 days to complete its lifecycle (Kheya et al., 2023).
- **Wider adaptability:** Millets can be grown in marginal lands, drought prone areas, saline areas, char areas, barind tracts as well as in hilly areas (Kheya et al., 2023).
- **Scope for new agro-industries:** Finger millet processing and value-added products of finger millet creates a scope for new agro-industries.
- Government policy for crop diversification also creates a wide scope for millet cultivation in future (Kheya et al., 2023).

### 5.5 Emerging opportunities for finger millet

- Climate resilient crop: Finger millet can grow under wide range of climatic conditions.
- Nutri-cereals: Finger millet is rich in carbohydrates, proteins, micro and macronutrients.
- Gluten-free: As finger millet is gluten free, its consumption is good for the individuals with celiac disease.
- A Sustainable crop (Harish et al., 2024).
- Sustainable development goals (SDGs): The proper production and consumption of finger millet helps to attain SDG1 (no poverty), SDG2 (zero hunger), SDG3 (good health and well-being), SDG12 (sustainable consumption and production) and SDG13 (climate action) (Sahoo and Mahapatra, 2023).

### 5.6 Objectives of International Year of millet 2023

- Promoting millets as an important component of the food supply and raising public awareness of their nutritional and health benefits.
- Raising awareness of the benefits of millet on food security and its role in reducing food waste.
- Promoting the sustainable growth of millets despite challenging and shifting weather patterns and improving the quality of the grain.

- Encouraging greater use of crop rotations and increasing funding for research and development.
- Highlighting the potential for them to provide producers and consumers with new, long-term market opportunities. Increasing the output of millet can provide women and young people with respectable occupations and assist smallholder farmers maintain their families (Sahoo and Mahapatra, 2023).

### 5.7 Problems and Challenges for Finger Millet Cultivation

- Despite of agricultural potential of finger millet, seed shattering, lodging, low yield and poor agronomic practices are the major problems which hinders the globalization of finger millet (Okolo and Adejumo, 2021).
- The agricultural growth of millets in their native locations across the Global South and beyond has been hampered by inadequate funding and a lack of phenotypic, quantitative genetic, and agronomic data (Wilson and Vanburen, 2022).
- Monoculture farming of major cereals such as wheat and rice, cultural shifts towards modern grains, lack of research and investment are the major reasons behind decreasing trends of millet cultivation (Choudhary et al., 2023).
- Decline in the area of production, low productivity, high cost of production, competition with major cereals, lack of awareness, lack of government support, poor millet supply chain are the major challenges in millet cultivation (Harish et al., 2024).
- Lack of high yielding variety, decreasing cultivable land, climate change, limited research and development efforts, inadequate infrastructure and inputs, weak market linkages and demand, and insufficient awareness and knowledge about millets' nutritional and environmental benefits are the major barriers in the adoption and promotion of millet cultivation (Kheya et al., 2023).

## 6. CONCLUSION

Finger millet plays a crucial role in feeding millions, especially in Sub-Saharan Africa, where it serves as a staple food. It is highly resilient to harsh climates, rich in essential nutrients, and requires minimal inputs, making it a valuable crop for food security and sustainable agriculture. However, despite these advantages, its improvement has lagged far behind other staple crops like rice and wheat. To fully harness its potential, more attention needs to be given to research, breeding programs, and better farming practices. Supporting farmers with improved seeds, modern techniques, and market access can help boost productivity and make finger millet a key player in future food systems. Investing in this crop is not just about preserving tradition—it's about ensuring a more nutritionally secure and climate-resilient future.

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